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Dynamic responses of Indian Summer Monsoon variability during past warm intervals

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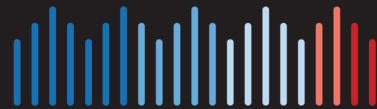
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29 August–2 September 2022

ICP14 BERGEN

14th International Conference on Paleoceanography



Book of Abstracts

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Speaker bios





Pallavi Anand

The Open University, UK

Pallavi Anand is an ocean biogeochemist and palaeoclimatologist at The Open University, UK. She obtained her MSc. (Banaras Hindu University, India) and PhD (University of Cambridge, UK), followed by post-doctoral research at University of Cambridge (UK), Vrije Universiteit (NL) and The Open University (UK). Her research focuses on the development of geochemical proxies (using biominerals) in modern environment and their applications to reconstruct past ocean and climate processes on Earth. She employs multiproxy approach to palaeoclimate reconstructions, and works with climate model experts, to understand complex Earth system interactions and responses to drivers of environmental change. She is also passionate about promoting diversity, equity and inclusion to support a more inclusive scientific community.

Nathaelle Bouttes

Laboratoire des Sciences du Climat et de l'Environnement (LSCE/IPSL), France

I use climate models to understand past carbon cycle changes through model-data comparison. I have mainly used the iLOVECLIM model, a model of intermediate complexity that includes carbon isotopes. My focus is on the Quaternary, from the Last Deglaciation to past interglacials of the last 800 000 years.

Tara Clark

Australian Research Council (ARC) Discovery Early Career Researcher Award (DECRA) Fellow/ School of Earth, Atmospheric & Life Sciences, Faculty of Science, Medicine & Health, University of Wollongong / Honorary Researcher, Radiogenic Isotope Facility, School of Earth & Environmental Sciences, The University of Queensland, Australia

Dr Tara Clark's early and current research is primarily focused on human impacts on the marine environment. During her doctoral research at The University of Queensland, Tara took a multi-disciplinary approach combining geochemistry, ecology and geochronology to investigate historical changes on inshore reef coral communities within the Great Barrier Reef prior to European settlement, with the ultimate goal of providing a baseline to assess modern day change. A highlight was the ability to help refine the uranium-series dating method of young corals (<200 yrs) to accurately determine the timing of mortality events with precisions up to ± 1 yr. Tara is continuing this research while juggling motherhood as a recently awarded ARC DECRA fellow at the University of Wollongong to investigate the timing and cause of changes observed in a collection of historical photographs of inshore reef flat environments since c.1890.

Helen Coxall

Docent Senior Lecturer in Marine Micropaleontology, and deputy Head of Dept, Department of Geological Sciences, Stockholm University, Sweden

Dr Helen Coxall is a senior lecturer at Stockholm University Department of Geological Sciences and an expert in microfossil-based paleoceanography. With a passion for planktonic foraminifera, her research involves reconstructing ocean-climate changes and pelagic biotic interactions on a variety of timescales, from past greenhouse climates and



extinctions millions of years ago, to Quaternary inter-glacials in the Arctic. Deciphering clues about ocean overturning circulation under warm climate conditions from proxies and models is an on-going focus.

Anne-Laure Daniau

Centre National de la Recherche Scientifique / Unité Mixte de Recherche Environnements et Paléoenvironnements Océaniques et Continentaux, Pessac, France

I am a paleofire scientist with a PhD in Paleoclimatology and Quaternary Geology. My research focuses on changes in wildfire activity in relation to climate change at multiple time-scales (from centennial, millennial to orbital scales). I use microscopic charcoal particles preserved in marine sediment records to understand past fire activity and its interaction with climate, vegetation and humans, with a special interest in the controls of fire in different climates in subtropical regions. I am leading a project which intends to develop a calibration model that links charcoal accumulation in core-top sediments with fire regimes on land and to progress the interpretation of charcoal in a marine depositional context. I have also been involved in understanding fires at regional and global scale through different syntheses of the PAGES Global Paleofire Working Group.

Curtis A. Deutsch

Princeton University, USA

Curtis Deutsch is an Earth Scientist at Princeton University. His research is aimed at understanding the interactions between climate and ecosystems. With his students and colleagues, he combines mathematical models of varying complexity with diverse streams of biological and physical data, to reveal how climate shapes the spatial patterns and temporal variability in ecosystems. Most of this work has focused on how the ocean transports, and transforms the nutrients and oxygen that sustain its plant, animal and microbial ecosystems, over a range of time scales from years to millennia. He also works with terrestrial ecologists to understand how climate influences the patterns of thermal fitness, and their implications for biodiversity and biogeography in a changing climate.

Mohamed Ezat

UiT The Arctic University of Norway, Norway

My research looks at quantifying the interactions between the Arctic freshwater system, ocean circulation and climate in the past, with focus on the Quaternary. I use a range of methods including stable- and radiogenic isotope and trace element analyses. I also work on proxy development for high latitude sea surface temperature, salinity, carbonate chemistry and freshwater input using culturing experiments on (sub)polar planktic foraminifera.



Sarah Fawcett

University of Cape Town, South Africa. sarah.fawcett@uct.ac.za

I am a chemical oceanographer and isotope geochemist interested in the cycling of major elements such as carbon and nitrogen in the marine environment, with a view to understanding the ocean's role in climate – past, present, and future. I have been an Assistant Professor at the University of Cape Town (UCT) since 2016 in the Department of Oceanography. I have a B.Sc. (Hons) degree in Earth and Planetary Sciences from Harvard University, and Master's and Ph.D. degrees in Geosciences from Princeton University. I am the Principal Investigator of the new Marine Biogeochemistry Lab at UCT, the focus of which is the analysis of nitrogen isotopes. My research group currently works on questions of carbon and nutrient cycling, ocean productivity, oxygen dynamics, and climate in the Southern Ocean, the Benguela upwelling system, and the subtropical South Atlantic and Indian Oceans.

Jennifer Fehrenbacher

College of Earth Ocean and Atmospheric Sciences, Oregon State University, USA

My research involves components of trace element and stable isotope geochemistry, biomineralization, and marine biology. I develop and use proxies, primarily trace elements in marine calcifiers, for reconstructing ocean circulation, temperature, and chemistry in the past.

Helena L. Filipsson

Director of Doctoral studies in Geology, Dept. of Geology, Lund University, Sweden

Professor Filipsson is a marine scientist, passionate about issues concerning the marine environment and climate changes over time scales covering approximately the last 130,000 years. A particular interest is coastal regions, prone to be subjected to low oxygen conditions. Her favorite microorganisms are benthic foraminifera and exploring them through assemblage studies, geochemistry, molecular – and tomographic analyses. The focus is both on improving the tools used to reconstruct marine environments through experimental and field studies and on paleoceanographic reconstructions.

William Gray

Laboratoire des Sciences du Climat et de l'Environnement (LSCE), France

I use the elemental and isotopic geochemistry of foraminifera to reconstruct climate and carbon cycling, with a focus on the Quaternary. Much of my research has focussed on calibrating geochemical proxies in foraminifera, as well as trying to understand their complexities and how we might account for them in the fossil record. My work also looks at how geochemical signals are incorporated during biomineralization, as well as determining the role of calcifying organisms in the calcium carbonate cycle. I am particularly interested in pairing proxy records and climate model output to understand climate and carbon cycle dynamics.



Sarah Greene

School of Geography, Earth and Environmental Sciences, University of Birmingham, UK

Sarah is a palaeoclimatologist, geobiologist, and Earth system modeller studying the biogeochemical cycling of carbon between the atmosphere, the ocean, and marine sediments. Particular research interests include rapid carbon cycle perturbations (Mesozoic mass extinctions, Palaeogene hyperthermals), protracted multi-million year carbon cycle trends (co-evolution of life and the carbon cycle), and how biogeochemical cycling within marine sediments influences palaeoclimatological and palaeoenvironmental records.

Michael Henehan

Deutsches GeoForschungsZentrum (GFZ) Potsdam, Germany

The common thread of my research is the Earth's global carbon cycle: what are the biotic and abiotic controls that shape it, how has it evolved through time, how do we best track and reconstruct this evolving carbon cycle, and how have changes in the carbon cycle been intertwined with changes in Earth's climate. I use and develop a range of geochemical and micropalaeontological tools – among them non-traditional stable isotope systems such as boron and lithium – to elucidate how processes such as chemical weathering and marine biogeochemical cycling influence atmospheric CO₂ levels and climate.

Sze Ling Ho

Institute of Oceanography, National Taiwan University, Taiwan

Dr. Ho's research focuses on reconstructing past changes of ocean temperature using multiple geochemical proxies based on biomarkers and foraminifers. Her multi-proxy approach to the study of past climates facilitates inter-proxy comparison under different climatic forcings and helps constrain the robustness of reconstructions. Her main research interests include proxy calibrations and quantifying uncertainty in sedimentary proxy records, both of which are vital for more accurate estimates of past ocean temperature.

Gordon N. Inglis

School of Ocean and Earth Sciences, University of Southampton, UK

I am a GCRF Royal Society Dorothy Hodgkin Fellow at the University of Southampton. I study climate-biogeochemistry interactions in past, present and future environments and specialise in the geochemical analysis of biomarkers ('molecular fossils'). The primary focus of my research is on past warm climates.

I have used past warm climates to: i) explore the relationship between CO₂ and temperature, ii) improve our estimates of climate sensitivity, and iii) provide new insights on key climate feedback mechanisms (e.g. methane cycling).



Malte Jansen

Dept of Geophysical Sciences, University of Chicago, USA

Malte Jansen received his PhD from MIT in 2013. After a two-year postdoctoral fellowship in Princeton, he joined the Department of the Geophysical Sciences at the University of Chicago, where he is now an associate professor. His research aims to improve our understanding of the large-scale dynamics of the oceans, atmosphere, and coupled climate system. He is particularly interested in the processes that govern the transport and storage of heat and carbon in the ocean. Understanding the mechanisms of these processes is key to deciphering the changes in the climate system during Earth's past and future.

Dan Lunt

School of Geographical Sciences, University of Bristol, UK

I carried out my undergraduate degree (MPhys) in Physics at the University of Oxford (1994-1998), followed by a PhD in Meteorology at the University of Reading (1998-2002). After a postdoc at the Laboratoire des Sciences du Climat et de l'Environnement (LSCE) in Paris, I moved to the School of Geographical Sciences at the University of Bristol in 2003. In 2014 I became Professor of Climate Science. I have been a visiting scientist at Stockholm University, and am currently an Affiliate Scientist at the National Centre for Atmospheric Research (NCAR) in Boulder, Colorado. In 2010 I was awarded the Philip Leverhulme Prize for my work on climate modelling. From 2007-2015 I was the founding and Chief Executive Editor of the journal *Geoscientific Model Development* (GMD). I lead the international DeepMIP program (www.deepmip.org), and am a Lead Author of Chapter 7 (The Earth's energy budget, climate feedbacks, and climate sensitivity) of the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6).

Rich Pancost

School of Earth Sciences at the University of Bristol, UK

Pancost is Head of the School of Earth Sciences and Professor of Biogeochemistry. He obtained his PhD from Penn State, conducted a postdoc at NIOZ, and arrived at Bristol in 2000, joining the Organic Geochemistry Unit. Using biomarker approaches and working in interdisciplinary partnerships, he studies modern and ancient climate and biogeochemical processes. He has been fortunate to work across many timescales and in diverse sedimentary contexts, but he has always been particularly interested in developing new approaches to determine the hydrological and biogeochemical responses to rapid global warming. Rich also co-created with Ujima Radio the Black and Green Ambassadors to make the environmental movement more diverse and equitable, issues that are also vital to the Palaeoceanography community.



Philip Pogge von Strandmann

Johannes Gutenberg University, Mainz, Germany

My research focuses on biogeochemical cycles, in particular silicate weathering. While weathering is a key control on the carbon cycle, and the primary long-term climate mitigator, its controlling factors and the timescales on which it operates are not clear. I examine this using non-traditional isotope techniques, primarily those of lithium, magnesium and calcium.

Patrick A. Rafter

Department of Earth System Science, UC Irvine, USA

Dr. Patrick A. Rafter is a scientist in the Department of Earth System Science at UC Irvine using his expertise in marine biogeochemistry and isotope geochemistry to tackle a variety of carbon and climate-related research questions. Some highlights of his work include: (i) A new model for N and Fe cycling in iron-limited ocean waters; (ii) Testing the long-term sensitivity of equatorial Pacific air-sea dynamics to radiative forcing; (iii) Proposing a new model for marine sedimentary carbon sources via seafloor volcanism; and (iv) An on-going survey and examination of global deep-sea $^{14}\text{C}/\text{C}$ over the past 30,000 years.

Haojia (Abby) Ren

National Taiwan University, Taiwan

Dr. Ren received her PhD in Geosciences from Princeton University, USA. Her research interests are focused on understanding the interaction between biology and the environmental conditions through the course of Earth history. In particular, she works on emerging disciplines and techniques to study the fluxes and cycles of biologically important elements, such as nitrogen and carbon, which can be then used to identify the biogeochemical processes and feedbacks that stabilizes the Earth system. She is currently working on developing planktonic foraminifera shell-bound nitrogen isotopes as a paleoceanographic tool to reconstruct past history of the marine nitrogen cycle.

Enno Schefuss

MARUM – Center for Marine Environmental Sciences, University of Bremen, Germany

I studied Marine Geology and Paleocyanography in Kiel, Germany and later learned Organic Geochemistry during my PhD at NIOZ, the Netherlands. As a senior scientist at MARUM I work inter-disciplinary with inorganic and environmental (geo-) chemists, (palaeo-) ecologists, (palaeo-) oceanographers, archaeologists, and climate modelers. My special interests are: Carbon cycling in rivers, wetlands and the atmosphere; Compound-specific isotope signals (^{13}C , H/D, ^{14}C) and their significance; Oceanic and atmospheric forcing of hydrologic changes; Impact of climate change on human-environment interactions.



Julio Sepúlveda

Geological Sciences & Institute of Arctic and Alpine Research (INSTAAR), University of Colorado Boulder, USA

As an organic biogeochemist with a multidisciplinary training, my research aims to study the interplay among microorganisms, biogeochemical processes, and climate, both today and in ancient (paleo) ecosystems across major climatic/biotic transitions in Earth history. I approach these systems with a focus on the structure, distribution, and stable isotopic composition of cell membrane lipids (biomarkers) found in the environment and preserved in depositional systems for up to billions of years. My core research program is divided into two major complementary areas: 1) Environmental lipidomics and proxy development; and 2) Paleoenvironmental sciences.

Sarah Shackleton

Princeton University, USA

I'm currently a postdoc at Princeton University working on extending atmospheric gas and ice records with blue ice archives. My research focuses on constraining physical processes of the past climate system using gas measurements in ice cores.

My research interests include the evolution of glacial cycles, ice-ocean interactions in past warm intervals, and small and largescale ice processes and their role in the interpretation of ice core records.

Sindia Sosdian

Cardiff University, UK

Sindia Sosdian is a marine biogeochemist and paleoclimatologist at Cardiff University in the School of Earth & Environmental Sciences. Her research focuses on the application of a range of geochemical techniques in marine carbonates to understand three broadly defined themes (1) the biogeochemical drivers of climate (2) understanding past major climate transitions and (3) the response of marine calcifiers in face of modern-day environmental stresses. She is currently working refining our understanding of Miocene temperature and climate patterns to identify important forcings and feedbacks at play during this past warm interval.

Andrew Thompson

Division of Geological and Planetary Sciences, California Institute of Technology, USA.

Andy Thompson is a physical oceanographer. Before coming to Caltech he spent time at Scripps Institution of Oceanography, the University of East Anglia, Cambridge University and the British Antarctic Survey. His research group uses a range of observational and numerical techniques to study ocean turbulence and its impact on the global overturning circulation. His group is particularly interested in high latitude processes, including coupled dynamics that link the ocean, atmosphere and cryosphere, and how they influence Earth's climate during periods of global change.



Diane Thompson

Director of Marine Research, Biosphere 2 & Assistant Professor, Department of Geosciences, University of Arizona, USA

Diane Thompson's research aims to improve our understanding of tropical climate change and its impact on coral-reef ecosystems, leveraging models and natural climate archives of past climate ("proxies"). There are three overarching themes of her research: (1) assessing tropical climate variability & forced change(s); (2) constraining proxy uncertainties & facilitating proxy-model comparisons, and (3) assessing the impact of warming & acidification on coral reefs. Her work spans a range of scales from local (e.g., reef-scale circulation) to global (e.g., climate change) and capitalizes on a blend of field and laboratory, observational and modeling, and experimental approaches.

Aradhna Tripathi

University of California, Los Angeles, USA

Professor Aradhna Tripathi is a geochemist and paleoceanographer. She is a faculty member at UCLA and the founding director of the Center for Diverse Leadership in Science. In partnership with her research group and collaborators, over the past 15 years her work has advanced carbonate clumped isotope geochemistry as a temperature proxy in paleoceanography and paleoclimatology. To constrain the strengths and limitations of this tool, she has studied the nature of equilibrium and kinetic isotope effects in minerals. Ultimately her goal is to advance our understanding of climate and carbon cycle dynamics during major climate transitions.

Gisela Winckler

Lamont-Doherty Earth Observatory, USA

Gisela Winckler is a Lamont Research Professor at the Lamont-Doherty Earth Observatory where she also serves as the Associate Director of the Geochemistry Division. Winckler received her Ph.D. in Physics from the University of Heidelberg in 1998. Professor Winckler is an environmental physicist and isotope geochemist interested in climate change and biogeochemical cycles. She uses elemental and isotopic analyses (noble gases, U-Th series, cosmogenic and radiogenic isotopes), to unravel processes of climate and environmental change in the oceans and on continents, on timescales ranging from decades to tens of millions of years. Her research uses climate archives such as deep-sea sediments, lake sediments and polar ice cores from Antarctica and Greenland. Gisela has sailed on 11 research cruises. In 2019, she co-led IODP Expedition 383 on the Joides Resolution to the South Pacific to study the role of the Southern Ocean and the ocean's most powerful current, the Antarctic Circumpolar Current, in the global climate system.



Masakazu Yoshimori

Division of Climate System Research, Atmosphere and Ocean Research Institute, The University of Tokyo, Japan

I have been studying physical aspects of the climate system using global climate models. My research target ranges from climate of millions of years ago to centuries ahead. The research topic of long-term engagement includes climate sensitivity and polar amplification with emphasis on the quantification of feedback processes in different climate conditions. The uniqueness may be in the approach bridging understanding of past and future climate change mechanisms as well as connecting short-and-small scale processes and long-and-large scale changes. The integrative understanding of multi-hierarchical climate system in the past, present, and future is the goal.

Jimin Yu

Pilot National Laboratory for Marine Science and Technology, Qingdao, China, and Research School of Earth Sciences, Australian National University

My research involves development and application of biogenic carbonate proxies to reconstruct past changes in marine carbon cycle, ocean circulation, atmospheric CO₂, and their intricate links to climate variability on various timescales. At present, I mainly focus on the investigation of acidity and nutrient histories in the deep ocean, the largest carbon reservoir of the ocean-land biosphere-atmosphere system. Assisted with numerical modeling, I try to identify mechanisms controlling past climate change with a hope to enhance our capability to more faithfully predict future climate in face of rapidly rising atmospheric CO₂.

Jiang Zhu

Climate & Global Dynamics Laboratory, National Center for Atmospheric Research, USA

Jiang Zhu is a Project Scientist at the US National Center for Atmospheric Research. Jiang is fascinated by the wide range of climate conditions in Earth's past such as the greenhouse and icehouse climates and their transitions. Jiang is a strong believer in the unique power of the past climate as a natural laboratory to investigate how the Earth system works. Jiang's research focuses on the climate dynamics that drive large-scale changes in climate state, variability, and sensitivity through combining information from the geological record with Earth system modeling.

Talks abstracts





Topic 1: Climate and Ocean Chemistry

Causes for millennial atmospheric CO₂ changes - A view from the deep-sea carbonate chemistry

Jimin Yu^{1, 2}

¹Pilot National Laboratory for Marine Science and Technology (Qingdao), Qingdao, China, ²Research School of Earth Sciences, The Australian National University, Canberra, Australia. gygao@qnlm.ac

Measurements of Antarctic ice cores reveal millennial-scale variations in atmospheric CO₂ during the last 800,000 years. For its large carbon inventory, the deep ocean can impose critical impacts on these variations. However, it remains elusive regarding how carbon interacted between the deep ocean and the atmospheric reservoirs due, in part, to paucity of deep-sea carbonate chemistry reconstructions. Here, we present a high-resolution deep ocean carbonate ion record over the last entire glacial cycle, based on measurements of B/Ca in benthic foraminifera from core MD95-2039 (40.6°N, 10.3°W, 3381 m) located at the Iberian Margin. The chronology of the core is constructed using planktonic foraminifera *G. bulloides* δ¹⁸O from the same core, following the established method (Shackleton et al., 2000). Our high-resolution record, combined with a robust age model, allows us to confidently define different types of relationships between deep-sea carbonate ion and atmospheric CO₂ changes on millennial timescales. Causes for these different relationships will be discussed in terms of various ocean ventilation modes involving both Southern Ocean and North Atlantic processes, with implications for millennial-scale atmospheric CO₂ changes.

Shackleton, N. J., Hall, M. A. & Vincent, E. Phase relationships between millennial-scale events 64,000-24,000 years ago. *Paleoceanogr.* 15, 565-569, doi: 10.1029/2000pa000513 (2000).

Carbon Cycling at the Dawn of the Cenozoic

Michael Henehan¹, Barnet J.², Kalderon-Asael B.³, Özen V.⁴, Rae J.², Ridgwell A.⁵, Greene S.⁶, Thomas E.^{3, 7}, Littler K.⁸, Hain M.⁹, Witts J.¹⁰, Planavsky N.³, von Blanckenburg F.¹, Hull P.³

¹GFZ Potsdam, Earth Surface Geochemistry, Potsdam, Germany, ²University of St. Andrews, Department of Earth Sciences, St. Andrews, United Kingdom, ³Yale University, Department of Earth and Planetary Sciences, New Haven, United States, ⁴Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Berlin, Germany, ⁵University of California, Riverside, Earth and Planetary Sciences, Riverside, United States, ⁶University of Birmingham, School of Geography, Earth and Environmental Sciences, Birmingham, United Kingdom, ⁷Wesleyan University, Middletown, United States, ⁸University of Exeter, Camborne School of Mines and Environment and Sustainability Institute, Penryn, United Kingdom, ⁹University of California, Santa Cruz, Earth & Planetary Sciences Department, Santa Cruz, United States, ¹⁰University of Bristol, Department of Earth Sciences, Bristol, United Kingdom. henehan@gfz-potsdam.de

The Paleocene – the first epoch of the Cenozoic (66–56 Ma) – is an intriguing, and often puzzling, time interval sandwiched between the charismatic events of the Paleocene-Eocene Thermal Maximum (PETM) and Cretaceous-Palaeogene (K-Pg) boundary. The epoch is relatively understudied, but spans numerous notable climatic and biogeochemical phenomena. In the oceans, the Paleocene saw the drawn-out recovery of calcifying plankton communities after severe extinction caused by the K-Pg impact, followed by one of the largest excursions in benthic marine carbonate δ¹³C values of the last 100 Myr¹ in the form of the Paleocene Carbon Isotope Maximum. On land, an as-yet-unexplained extreme step-change in global weathering regime is indicated by marine carbonate δ⁷Li values². More generally, despite benthic foraminiferal oxygen isotopes that suggest a greenhouse climate much warmer than today³, scant proxy estimates of atmospheric CO₂ in the Paleocene mostly indicate low CO₂ levels more similar to those seen during the relatively colder late Neogene⁴.



In this talk, I will summarise some of the recent headway we have made in understanding geochemical cycling and ocean chemistry at the dawn of the Cenozoic, immediately after the K-Pg impact. Following this, I will present new benthic and planktic foraminiferal boron and lithium isotope data that address some of the outstanding puzzles of this formative period for the Cenozoic carbon cycle. Our new, higher boron-derived atmospheric CO₂ estimates for this interval resolve some of the apparently anomalous³ behaviour of the Paleocene climate system, and in doing so provide a better understanding of the climatic baseline to the PETM.

1. Friedrich, O., Norris, R. D. & Erbacher, J. *Geology* 40, 107–110 (2012).
2. Misra, S. & Froelich, P. N. *Science* 335, 818–823 (2012).
3. Westerhold, T. et al. *Science* 369, 1383–1387 (2020).
4. Beerling, D. J. & Royer, D. L. *Nat. Geosci.* 4, 418–420 (2011).

Body size as a barometer of ocean oxygenation in Earth history

Curtis Deutsch

Princeton University, Princeton, United States. cdeutsch@princeton.edu

The fossil record of body sizes in marine species reveals numerous changes over Earth's history, but attributing their causes requires mechanistic physiological models. We present a predictive model of body size responses to temperature and oxygen (O₂), based on the thermal and geometric traits that constrain the O₂ supply and demand of diverse species from microbes to macrofauna. The model reproduces modern observations of key allometric traits and their links to intraspecific body size variability. We apply the model to the Cenozoic fossil record to glean new insights into the factors underlying previously documented body size changes under periods of both climate warming and cooling. Results imply that observed body size responses to major climate trends are too large to be explained by physiological responses to temperature alone, but are well explained by a combination of temperature and O₂. Our model highlights the potential for mechanistic organismal models to be calibrated as a paleo-barometer for the evolution of atmospheric and oceanic O₂ in Earth's history.

The marine carbonate system is the key to the past

Sarah Greene¹, Adloff M.^{1,2}, Doherty D.¹, Ridgwell A.³, Anagnostou E.⁴, Babila T.⁵, Dunkley Jones T.¹, Foster G.⁵, Greene L.⁶, Henehan M.⁷, Hoggett M.¹, Hoogakker B.⁸, Jones S.¹, Kirtland Turner S.³, Pällike H.⁹, Rae J.¹⁰, Schmidt D.¹¹, Thomas E.^{12,13}, Whiteford R.¹⁰

¹University of Birmingham, School of Geography, Earth and Environmental Sciences, Birmingham, United Kingdom, ²University of Bern, Bern, Switzerland, ³University of California Riverside, Riverside, CA, United States, ⁴GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany, ⁵University of Southampton, Southampton, United Kingdom, ⁶Duke University, Durham, NC, United States, ⁷Helmholtz GeoForschungsZentrum Potsdam, Potsdam, Germany, ⁸Heriot-Watt University, Edinburgh, United Kingdom, ⁹MARUM—Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany, ¹⁰University of St Andrews, St Andrews, United Kingdom, ¹¹University of Bristol, Bristol, United Kingdom, ¹²Yale University, New Haven, CT, United States, ¹³Wesleyan University, Middletown, CT, United States. s.e.greene@bham.ac.uk

Earth's climate state both regulates and is regulated by the global biogeochemical cycling of calcium carbonate and the marine carbonate system. The carbonate system not only buffers ocean pH, but also controls the exchange of carbon between the atmosphere, the ocean, and marine sediments. This means that proxies for the marine carbonate system, for example boron isotopes in marine carbonates or the carbonate compensation depth, are powerful constraints on past atmospheric CO₂ and global carbon



cycling, provided we have the modelling tools to interpret them.

In this talk I will summarise recent progress using Earth system modelling to reconstruct past climates and global carbon cycling from ocean carbonate chemistry proxies in the Early Cenozoic greenhouse world. Firstly, I will illustrate the counterintuitive ways in which global climate and terrestrial weathering rates are expressed in patterns of marine seafloor carbonate preservation, using the Late Paleocene-Early Eocene warming interval as a case study. Secondly, I will show how simultaneously modelling records of seafloor carbonate preservation and seawater pH provides the most robust constraints to date on atmospheric CO₂ during the peak warmth of the Early Eocene Climate Optimum. Lastly, I will show how modelling pH change across the Paleocene-Eocene Thermal Maximum, combined with independent reconstructions of large igneous province carbon emissions, can constrain global carbon cycle feedbacks to rapid atmospheric carbon injection.

A Coral Skeletal-bound Nitrogen Isotope Record of Changes in the Equatorial Pacific Mean State over the Past Century

Haojia (Abby) Ren^{1,2}, Chen W.-H.¹, Chiang J.³, Chen Y.-C.¹, Shen C.-C.^{1,2}, Taylor F. W.⁴, Sigman D.⁵

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Despite observations for decadal and long-term changes in the Equatorial Pacific Climate Mean State and El Niño Southern Oscillation (ENSO) behaviors over the past century, the drivers for these changes are debated. Recent studies suggest that the connections between the subtropics and the tropics through the western boundary route of the South Pacific likely play an important role for these changes. Using nitrogen isotopes recorded by *porites* coral skeleton obtained from the Solomon Island in the Western Equatorial South Pacific, we find that ¹⁵N/¹⁴N variabilities in the upper Solomon Sea are primarily influenced by (1) changes in the equatorial upwelling intensity; and (2) strength of the equatorward flow through the Solomon Sea. Both of these processes are closely related to changes in the Pacific Mean State. The ¹⁵N/¹⁴N decreases during basin-wide ENSO events between 1919 and 2012, consistent with reduced upwelling in the central and eastern equatorial Pacific, as well as coincidental increases in the equatorward transport of the subtropical water masses during ENSO events. The decadal variabilities in the ¹⁵N/¹⁴N are strongly correlated with Pacific Decadal Oscillation (PDO), with a clear phase shift occurred at early 1980s when ¹⁵N/¹⁴N showed a step-like decrease following the observed weakening in the trade wind and warming in the tropical Pacific. This is in line with theoretical works suggesting extratropical controls on the decadal changes in the tropical climate. Finally, the interannual and decadal changes in the ¹⁵N/¹⁴N are likely superimposed on a long-term declining trend, associated with the observed weakening of the walker circulation in the equatorial Pacific. Longer record is called for to validate this trend and evaluate whether this is related to the anthropogenic warming.



Topic 2: Ocean Circulation and its Variability

Global deep-sea radiocarbon variability over the past 25,000 years

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Using new and published marine fossil radiocarbon (¹⁴C) measurements—a tracer uniquely sensitive to circulation and air-sea gas exchange—we establish several important benchmarks for glacial Atlantic, Southern, Pacific, and Indian deep-sea circulation and ventilation since the last ice age. We find that in addition to a global slowdown in glacial deep-sea overturning, the glacial Pacific circulation was “flipped”, with the most ¹⁴C-depleted water located in Pacific bottom waters, rather than at mid-depths as in today’s ocean. This glacial overturning configuration persisted through the Last Glacial Maximum (LGM) and reorganized to present-day conditions mid-way through deglaciation. The existence of a profoundly different glacial configuration emphasizes the major role of the overturning circulation for increasing glacial deep-sea carbon storage and the concomitant drawdown of atmospheric pCO₂.

Changes of climate and carbon cycle from the LGM to the Holocene

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The Last Deglaciation is a time of large climate transition from the cold Last Glacial Maximum (LGM) with extended ice sheets at ~21 kyr BP, to the warmer Holocene with reduced ice sheets at ~9 kyr BP. Besides the notable warming, it is also a time of large atmospheric CO₂ increase, from ~190 ppm at the LGM to ~260 ppm at the beginning of the Holocene. Changes of climate, carbon cycle, as well as ocean circulation are linked, but still not fully understood. To better understand the climate and carbon cycle changes from the LGM to the Holocene, model-data comparison is key to test and evaluate different mechanisms. To facilitate climate simulation comparison and circumvent model biases, several model intercomparison protocols have been set up, such as the one for the LGM (Kageyama et al., 2018) and the Last Deglaciation (Ivanovic et al., 2016).

In these protocols, some flexibility is left as to the treatment of ice sheets and related changes, due to uncertainties in ice sheet reconstructions still remaining. The ice sheet related changes encompass orography and albedo, bathymetry and coastlines, as well as fresh water fluxes derived from ice melting. All these changes can impact climate, ocean circulation and the carbon cycle. Using different models, we evaluate the role of bathymetry on the carbon cycle and underline the importance of accurate bathymetry modifications. In addition, with the iLOVECLIM model of intermediate complexity, we have performed an in-depth study of the impact of different ice sheet related changes. We focus on the effect of the choice of ice sheet reconstructions such as ICE-6G_C or GLAC-1D, accounting for bathymetry changes and fresh water fluxes from ice sheet melting.



The Glacial Overturning Circulation: Lessons from Theory and Idealized Models

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Proxy data indicates that changes in the ocean's meridional overturning circulation may have played a major role in northern-hemisphere climate variations between glacial and interglacial climates as well as between stadials and interstadials. In this talk I will focus on the potential mechanisms behind these variations in the overturning circulation.

Using a hierarchy of models of varying complexity, we find that various inferred differences in the deep ocean circulation and stratification between glacial and interglacial climates can be explained by increased Antarctic sea-ice formation in a colder world. Increased sea ice formation and associated brine rejection around Antarctica leads to saltier and denser Antarctic Bottom Water (AABW), enhanced deep ocean stratification, a shoaling of the Atlantic Meridional Overturning Circulation (AMOC), and increased deep-ocean carbon storage. However, larger cooling of North Atlantic Deep Water (NADW) compared to AABW may counteract the effect of increased brine rejection. The competing effect of temperature and salinity changes, whose respective magnitudes are model-dependent, is likely to play an important role in explaining wide variations in the glacial AMOC across climate models.

Models of varying complexity can also reproduce oscillations that resemble Dansgaard-Oeschger events during the glacial period. We argue that these oscillations are associated with sea ice variability in the North Atlantic and a recharge-discharge mechanism of deep ocean heat content. Global atmospheric temperature affects the relative length of stadial vs. interstadial conditions, with permanent interstadial conditions in warm climates, permanent stadial conditions in cold climates, and oscillatory regimes in between. We propose a simple theoretical model that can reproduce the main characteristics of the ice core record of the last 100 kyr, prescribing only the slow variations in the global temperature.

An Arctic perspective on glacial ocean and climate changes

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Present-day water mass mixing and transformation in the Nordic Seas and the Arctic Ocean (the Arctic Mediterranean) play an important role in global ocean circulation and climate. Despite this, proxy evidence on the past evolution of key aspects of the Arctic Mediterranean circulation remains ambiguous and with large data gaps. For example, recent suggestions for the state of the late glacial deep Arctic Mediterranean range from extreme stagnancy and isolation to Holocene-like exchange rates with the Atlantic Ocean. Similarly, the relative timing of sea ice changes in the Nordic Seas across the Dansgaard-Oeschger events of the last glacial seems contradictory between different studies. By compiling and critically assessing published and new data, I will show a coherent image of regional changes in the Nordic Seas heat and carbon reservoirs, deep ocean ventilation and sea ice changes on orbital and sub-millennial time scales. Nevertheless, I argue that the potential utilization of these paleo-records (e.g., to



quantify the interactions between freshwater dynamics and ocean circulation) is hampered by the absence of robust calibrations tailored towards (sub)polar reconstructions. To this end, I will present preliminary results from ongoing proxy development efforts where (sub)polar planktic foraminifera are grown under typical environmental conditions for the Arctic i.e., temperatures 2-10°C, salinity 29-37‰, Arctic summer diurnal variations in light intensity, as well as variable element concentrations, and a wide range in carbonate chemistry. The application of these new calibrations on (sub)polar paleo-records will provide new insights on cryosphere-ocean-climate links.

Ocean overturning circulation through the early Cenozoic: a speculative history

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Warm climate intervals of the early Cenozoic offer opportunities to move outside the millennial scale-to recent climate/CO₂ boundaries and investigate meridional overturning circulation (MOC) modes very different to today. Attempts to characterize ocean overturning during these times are limited by data coverage, age models and uncertainties in the timing of oceanic gateway openings and closures. Nevertheless, a recent increase in proxy data and model simulations cast new light on this question. Here we outline a coarse picture of MOC modes in the early Cenozoic based on data from three main deep-water proxies – benthic foraminifer $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$, fish-tooth Nd isotope ratios (ξNd), and sedimentary 'drift-deposits'. We compare these data perspectives with a growing number of deep time model-model and model-data inter-comparisons, and explore commonalities and discrepancies. The collective research agrees that the Southern Ocean was a persistent source of global deep water through the Cenozoic greenhouse but we also find strong possibilities for the existence of a deep PMOC (Pacific meridional overturning circulation). There is little evidence for interhemispheric North Atlantic overturning until the middle or late Eocene 'coolhouse' 40-34 Ma. When a modern-like AMOC appears in this time window there may have been a competition between AMOC and PMOC due to salt advection feedbacks. PMOC states may have returned during the warm reversals of the middle Miocene and Pliocene. Driving forces determining the northern and southern sinking patterns, at least for the Eocene case, are linked to a very warm and wet Arctic delivering freshwater to the North Atlantic and keeping the subpolar North Atlantic stratified. Ongoing active tectonics controlling opening and closure of Arctic-Nordic ocean gateways, countered by a closed Bering Strait keeping the Arctic Ocean sealed on the Pacific side, played important roles in setting these boundary conditions.

A 20th-century reconstruction of Pacific trade-wind variability from coral Mn/Ca

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Variability in the strength of the easterly trade winds plays a critical role in regulating equatorial currents, sea-level trends, and sub-surface ocean heat uptake. In turn, short-term wind reversals known as westerly wind events are responsible for the onset and development of El Niño events in the tropical Pacific Ocean. Despite their importance in regulating climate and circulation patterns, our understanding of tropical trade-wind variations has been limited by the paucity of direct observations prior to the satellite era. We demonstrate that the Mn/Ca ratio in corals from islands with west-facing lagoons—such as Tarawa,



Butaritari, Abaiang, and Kiritimati in the Republic of Kiribati—provides a record of westerly wind anomalies over the coral's lifetime. Tracking the fate of wind-derived manganese within the sediment, pore-water, and seawater reservoirs, we provide further evidence for the accumulation of reduced manganese in the lagoonal pore waters and remobilization to seawater during westerly wind events. This remobilized manganese is incorporated into the skeleton of *Porites* spp. corals on the reef, providing a robust record of El Niño-related westerly wind events both east and west of the dateline. Nevertheless, differences in the magnitude and timing of the Mn/Ca-wind signal within and among atolls provide additional insights into the role of lagoon morphology, circulation, and El Niño diversity in the strength of the westerly wind events, remobilization and advection of Mn, and incorporation into the coral skeleton. Leveraging a network of coral cores from the Republic of Kiribati in the central-western tropical Pacific, we present a 20th-century reconstruction of trade-wind variability that significantly extends the observational wind record and provides critical insights into decadal wind variability and their role in regional oceanographic variability.

Topic 3: System interactions and Thresholds

The interaction between the climate, the continents and the oceans via changing weathering and erosion

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Long-term climate is largely controlled by the chemical weathering of silicate rocks on the continents, and the transport of their dissolved components (plus dissolved CO₂) through rivers to the oceans, where the carbon is sequestered. Chemical weathering is therefore not only a fundamental control on climate, but also on ocean chemistry. In particular, changes in aspects of the climate system (e.g. temperature, precipitation, etc.) can modify both the rate and efficiency of chemical weathering, and hence the rate and efficiency of CO₂ drawdown. However, questions still remain about the rates at which this process might both respond to, and change, parts of the climate system.

Lithium isotopes provide a tracer of silicate weathering regime, because clay formation causes isotope fractionation, meaning that residual surface waters become isotopically heavy. Clay formation can inform on CO₂ sequestration efficiency, as continental clay formation can inhibit the transport of relevant cations (Ca, Mg, Fe) to the oceans, where they would sequester CO₂. Clay transported to the oceans is also a major cause of organic carbon burial, another sequestration pathway for CO₂.

Here we will discuss, via Li isotope data, how changes in the hydrological cycle, particularly on the continents, due to rapid climate change has a direct impact on ocean chemistry, and in mitigating that climate change. We will present data from several different climate change events through Earth history.



Tropical ocean-climate-biosphere linkages

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The Earth system consists of many interlinked components which respond to changes in other parts of the system. For instance, changes in ocean circulation drive changes in sea-surface temperature distributions and hence cause atmospheric pressure anomalies which control wind directions and intensities with effects on moisture transport. Such hydro-climatic effects of amount and seasonality of rainfall influence vegetation types and, depending on the length and intensity of dry seasons, fire feedbacks on vegetation and hydro-climate. Changing vegetation cover and runoff conditions as well as biomass burning are direct feedbacks between hydro-climate and carbon cycling. The feedback between fire occurrence and vegetation types, however, depends on the hydro-climatic status. Under sustained humid conditions fire leads to diversification of ecosystems, and hence their higher resistance to disturbance, whereas under aridification fires have a destructive effect. Rivers show distinct responses to hydro-climatic changes. While increasing rainfall leads to higher erosion and faster and increased carbon export into the oceans, it may also lead to extension of river-associated wetlands and swamps with specific vegetation cover leading to carbon sequestration. Carbon cycle feedbacks of rivers systems depend on geomorphology and climate. I will present examples of ocean effects on hydro-climate, vegetation cover, fire and carbon cycling feedbacks on tropical continents.

What role does the South Pacific play in the climate evolution of the past five million years? New insights from IODP Expedition 383

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Our community's understanding of Earth's long-term climate evolution suffers a bias towards the Northern Hemisphere, where the majority of Plio-Pleistocene climate records have been developed. Although more recent efforts by the International Ocean Discovery Program (IODP) have sought to increase the number of long-term sedimentary records from the Southern Hemisphere (e.g. Expeditions 361, 374, 379, and 382), there remains an enormous gap in paleoclimate data from the South Pacific, representing the largest surface area and volume fraction of the Southern Ocean and therefore holding the largest capacity for carbon storage in the deep ocean.

Expedition 383, from May-July 2019, set out to fill this South Pacific data gap with the goal to improve our ability to understand global changes in ocean-atmosphere-ice sheet dynamics and carbon cycling during past climatic transitions.

We present early results of a suite of complementary biological and geochemical tracers to reconstruct Plio-Pleistocene changes in nutrient cycling, carbon export, dust input and dynamics of frontal positions and the Antarctic Circumpolar Current using the newly recovered DYNAPACC sediment cores from the Subantarctic Pacific from IODP Expedition 383, with a focus on the intensification of Northern Hemisphere Glaciation, the Mid-Pleistocene Transition and Glacial/Interglacial cycles.



Charcoal in deep-sea sediments: fire history and climate change

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Fire results today from interactions between climate, vegetation and human activities and occurs in most terrestrial ecosystems. It has potential feedbacks to climate, through the emission of CO₂, trace gases and aerosols that influence the global carbon cycle, the atmospheric chemistry and the radiative balance. How fire regimes (including frequency and intensity) may respond to climatic change can be explored by modelling. Empirical-based models however lack the impact of climatic change on vegetation and it is necessary to evaluate process-based models with paleofire data.

Marine sedimentary charcoal records provide the opportunity to explore drivers of fire beyond the range of recent climates at different time-scales (from centennial, millennial to orbital scales). I will focus on two subtropical regions, the southwestern Iberian Peninsula and the southern Africa where millennial- and orbital-scale fire variability was observed. Results suggest a strong orbital and millennial climate control on fires and highlight the main role of vegetation type and fuel amount in driving fires in these subtropical regions. Contrary to the conventional expectation that fire increases with higher temperatures and increased drought, fires may increase also under cooler and/or wetter climates.

Data-model comparison is still challenging as paleofire records provide charcoal measurements (abundance and morphology) not directly comparable to fire regime metrics. I will develop on calibrating charcoal in marine sediments showing recent results from the Mediterranean region and off the African continent. Results suggest the abundance and morphology of charcoal detect specific fire regimes, in particular fires of high intensity in mixed vegetation in Iberia and in graminoid-mixed ecosystems in Africa. These results might be a springboard for converting marine charcoal records into past fire regime history.

A multidisciplinary approach to understanding past and present change in coral communities

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Understanding long-term changes in coral reef ecosystems is important to provide a reliable benchmark for assessing recent and future change under a warming climate. This has become even more important with the Great Barrier Reef experiencing four mass bleaching events over the past seven years. Here I present results from uranium-thorium dating 269 dead *Acropora* spp. corals that reveal a dramatic loss in cover over a broad spatial scale on the inshore Great Barrier Reef. *Acropora* corals play an important role in many reef-scapes as key framework builders and habitat providers for numerous reef organisms, and have done so for the past two million years. Their decline warrants cause for concern. Peaks in *Acropora* mortality were found to occur in the first half of the 20th century and again between 1980-2000 in both the Palm Islands and Mackay regions. These locations are separated by a distance of ~380 km and suggest that the main driver/s behind *Acropora* decline may be acting at a regional, rather than local scale. Both periods of mortality coincide with enhanced and variable river discharge as well as anomalously warm sea surface temperatures. Mortality is also synchronous with European settlement of the Queensland coastline c.1870 and an abrupt freshening of coastal waters. Our results suggest that the combined effects of climate extremes and a decline in water quality as a result of land clearing in neighboring catchments together have created a threshold of unfavourable conditions for *Acropora* growth. Our work also highlights the need for paired long-term ecological and environmental reconstructions to be able to fully grasp the complexity surrounding recent environmental change.



Topic 4: Improving Our Understanding of a Warmer World

Clearing clouds of uncertainty with the help of paleoclimate

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Many Earth system models (ESMs) that participate in the Coupled Model Intercomparison Projects phase 6 (CMIP6) show a higher equilibrium climate sensitivity (ECS) than the previous generation of models. If those high ECS estimates are true, they imply a greater future warming than previously thought and a more severe challenge for climate adaptation and mitigation. Whether such high ECS is realistic and what causes the increase from the previous generation of models are key questions for the climate dynamics community. Such questions are difficult to address using the present-day observation, as the instrumental records usually provide limited constraints on how the Earth system responds to external forcings. In this study, we show how information from the past climates provides a straightforward means to address these questions. We perform paleoclimate simulations of the extreme cold Last Glacial Maximum and the extreme warm Early Eocene using the Community Earth System Model version 2, which is a CMIP6-class model with a high ECS ($>5^{\circ}\text{C}$). Through comparing the simulation results with the geological records, our assessment suggests that the high ECS of CESM2 is unrealistic. Making use of the paleoclimate information, we identify the physical, numerical, and parametrical inconsistencies in the cloud and convection parameterizations and develop a new CESM2 configuration to improve these inconsistencies. The new CESM2 configuration has a much lower ECS ($\sim 3^{\circ}\text{C}$) and simulates the past ice-age and hothouse climates, as well as the present-day observations. Our study stresses the importance of past climates in the assessment and development of ESMs and the projection of future climate change. We suggest that paleoclimate information should be more frequently used during the model development and evaluation.

Temperature and the hydrological cycle in high CO₂ climates

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The response of the Earth system under elevated carbon dioxide (CO₂) concentrations remains uncertain. To better constrain these climate predictions, we can examine intervals in the geological past when CO₂ levels were similar to those predicted under future scenarios. The early Eocene (56 to 47.8 million years ago) can be used to investigate how different climate processes operate under high CO₂ concentrations. A key climate metric is equilibrium climate sensitivity (i.e. the change in global temperature for a doubling in CO₂). However, this relies on accurate estimates of past global mean surface temperature (GMST). Using a multi-method experimental approach, we show that early Eocene GMST estimates are ~ 10 to 16°C higher than pre-industrial. These values are combined with existing CO₂ estimates to calculate gross estimates of the average climate sensitivity (~ 3 to 4.5°C). These values are similar to the recent IPCC report (2.3 to 4.5°C) and can be reproduced by state-of-the-art Eocene model simulations. However, the impact of higher



temperatures on other climate processes remains unclear. Of particular interest is the hydrological cycle – this is expected to intensify in response to warming, with a ‘wet-gets-wetter, dry-gets-drier’ response expected. However, evidence from past warm intervals (e.g. the Pliocene) suggests that the subtropics may get wetter (rather than drier) under warmer conditions. This has been attributed to a reduction in the latitudinal temperature gradient (LTG) and weaker Hadley circulation. Using state-of-the-art Eocene model simulations, we show that the subtropics were characterised by weaker Hadley circulation due to a reduction in the LTG. However, this was not sufficient to induce subtropical wetting. This work highlights the importance of quantifying different climate metrics in past warm climates. These metrics are also key to understanding the associated biogeochemical processes that may help to amplify or reduce global warming.

Connecting climates at different time periods through mechanism understanding

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It is often implicitly assumed that knowledge about the Earth’s history is useful for projections of future climate/environmental change: especially past warm periods. Looking the past is the only way to gain factual insight into the greater warming states than those humans have ever experienced. Paleoclimate modelling is employed not only to examine hypotheses raised to explain past climate changes but also to evaluate its performance in simulating the plausible future climate change. The important question is then how relevant the past climate change of interest is to the future. Our experience tells that a promising approach is to connect climate states at different periods through mechanism understanding on feedback and response to external forcing, rather than searching for a mirror image of the future in paleoclimate archives. Climate models are useful in that they naturally connect different time through the commonly operating physics. The task is to identify which processes dominate in feedbacks under imposed boundary conditions. In the presentation, we focus on the equilibrium climate sensitivity (ECS), defined by the surface air temperature response to the doubled atmospheric CO₂ concentration after sufficiently long time, and polar amplification (PA), a robust feature of enhanced temperature change in polar regions relative to the global average. As to ECS, we review how paleoclimate information has been used to constrain the range of ECS uncertainty with discussion on issues and perspective. Particular attention is paid to state-dependency and forcing-dependency of the sensitivity. As to PA, we will address how and why the Arctic respond similarly and differently to different external forcing. There, the importance of dynamic vegetation feedback is also addressed.

On the recovery of marine productivity across the Cretaceous-Paleogene (K/Pg) boundary

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Despite decades of research, the recovery of marine primary productivity and the biological pump in the aftermath of the Cretaceous-Paleogene mass extinction event (K/Pg; 66 million years ago) remain highly debated. As ancient plankton assemblages are primarily known from organisms with hard parts that leave a fossil record, we currently have an incomplete understanding of how the planktic ecosystem as a whole responded to the extreme environmental perturbations across the K/Pg boundary, in which fossilizing plankton experienced significant extinction. In the modern ocean, at least half of the plankton biomass is comprised of organisms which leave no physical fossil record, and they play a key role in marine food webs and in regulating the sequestration of carbon from the surface ocean to the deep sea. This talk will review the current knowledge on the recovery of marine productivity and the biological pump, and present new data of planktonic ecosystem recovery from the K/Pg Global Stratotype Section and Point area at El Kef, Tunisia. Algal biomarkers and their stable carbon isotope composition, along with records of calcareous nannoplankton, dinoflagellate cysts, benthic foraminifera, and bulk stable isotope geochemistry offer an unprecedented opportunity to explore the interplay between environmental forcing, biological resilience, and biogeochemical cycling at unparalleled high temporal resolution. Results suggest that the recovery of marine productivity and the biological pump in outer neritic-upper bathyal zones outpaced the recovery in the open ocean. This agrees with the selective extinctions among phytoplankton at the K/Pg boundary, with most survivors that would later repopulate open-ocean sites being adapted to neritic environments. We provide perspectives on future research directions for more holistic reconstructions of marine planktonic ecosystems across mass extinction events.

The Miocene Climate System – looking in the rear-view mirror with a vision to the future

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Future trajectories of the Earth System rely on our understanding of the carbon cycle and associated feedbacks on short and long-term timescales and the interaction between global climate, cryosphere, and biogeochemical conditions during warmer worlds. The Miocene Epoch (23-5 Myrs ago) is a great candidate for exploring these aspects as it has a similar continental configuration to today, a range of CO₂ levels relevant for future projections during the Miocene Climatic Optimum (MCO), and the establishment of the ‘modern’ ice house world. Over recent years, there has been a boom of Miocene paleoceanographic and modelling studies evolving and advancing our understanding of the Miocene world on broad spatial and temporal scales. In this talk, I will highlight the long-term Miocene atmospheric CO₂ reconstructions from a disparate set of proxies that are converging towards peak MCO levels similar to high emission IPCC trajectories for 2100. Further, I will explore how surface ocean temperature patterns in low latitudes cooled synchronously with the advancement of the Antarctic ice sheet, indicating an important role for carbon cycle driving glaciation and/or positive feedbacks. Lastly, I will detail how changes in carbon cycle in the Miocene operate on two timescales with the long-term changes (‘Monterey Event’) tied to changes in volcanism, global warming and rise in sea level and organic carbon burial (negative feedback) and short-term changes (‘100 kyr’) tied to marine productivity (positive feedback). Overall, ongoing Miocene community research aims to better integrate carbon cycle feedbacks into Earth System models, curate living metadata proxy temperature portal and support IODP efforts to close sediment archive gap of the early Miocene. Together, this synthesis suggests that carbon cycle feedbacks in response to C-addition are state dependent and the rear-view mirror of the past Miocene Climate system is rapidly coming into focus as visions of future climate.



Dynamic responses of Indian Summer Monsoon variability during past warm intervals

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The South Asian or Indian Summer Monsoon (ISM) is an iconic reflection of land-ocean-atmosphere interactions on Earth, affecting over a billion people. Future predictions of northern hemisphere monsoon rainfall are fraught with large uncertainties in the Intergovernmental Panel on Climate Change (IPCC) reports. To better understand monsoon rainfall pattern/behaviours in future, we need to investigate its response to climatic drivers, including past warm intervals. We present multi-proxy geochemical and vegetation records of monsoon variability from the Bay of Bengal using sediment sequences recovered during the Integrated Ocean Discovery Programme (IODP) expedition 353. We utilise these multi-proxy records to assess responses of ISM dynamics to past warming by comparing Holocene and last interglacial warm intervals at sub-millennial timescale. We integrate proxies' records and intermediate complexity climate model outputs to present evidence for heterogenous rainfall pattern across global tropical landmasses when comparing the Holocene and last interglacial warm intervals. We also find regional differences in monsoon rainfall pattern along with changing loci of the precipitation when comparing these warm intervals. Further, we will present results of seasonal rainfall variability extremes, inferred from continental and marine proxy data, covering cool and warm climate states of the late Pleistocene.

Topic 5: Innovations to Overcome Knowledge Gaps

Novel approaches to decipher past marine environments

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Three of the greatest marine environmental challenges today are warming, ocean acidification, and deoxygenation. These environmental changes have created a need for a context to understand their severity and potential outcomes and here the geological records can provide a much-needed perspective. Records of the past cannot help us to predict the future, but they can help us to understand involved processes and impacts. Using the distribution of different species has a very long tradition within palaeoceanography and later it has been complemented and to some extent subsided by geochemical methods. Microanalytical techniques such as LA-ICP-MS, ion probe, and synchrotron-based approaches μ XRF have pushed analytical resolution even further and we can now for instance analyse the calcite shell wall with respect to elemental distribution with a nanoscale resolution. Within this talk, I will give an overview of some of the synchrotron-based approaches we are using for geochemistry as well as how we are combining faunal analyses with morphometric μ CT analyses and how we can apply these techniques to further understand past marine environmental change.



Exploring the geochemistry and utility of non-spinose foraminifera using micron-scale analytical techniques

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Using samples from laboratory culture experiments, sediment traps, and plankton tows we demonstrate that magnesium, barium, manganese, and zinc are highly elevated in many non-spinose foraminifera species and often appear 'banded' (alternating high and low trace element (TE) layers). Several of these elements (i.e., Ba and Mn) are often used as diagenetic indicators in seafloor sediment samples and, if elevated, researchers often employ corrosive cleaning steps to reduce their concentration. Our results demonstrate that these TEs are incorporated during calcification and are not due to diagenesis on the seafloor. We find that non-spinose TE concentrations are higher than expected based on ambient seawater TE concentrations and incorporation mechanisms remain poorly constrained.

We hypothesize that elevated trace elements in non-spinose species are due to a particulate organic matter (POM/marine snow) microhabitat during early ontogeny. The interstitial seawater in POM can have elevated trace element composition and variable pH and oxygen concentration relative to ambient seawater. Therefore, POM is a unique habitat likely responsible for elevated TEs found within non-spinose foraminifera. We demonstrate, using culture experiments, that non-spinose species readily envelope their shells with POM or form a POM feeding cyst. While a POM microhabitat may complicate the use of non-spinose foraminifera in paleo-reconstructions, it also paves the way for new avenues of research and proxy applications. To highlight a potential new application, we show preliminary results demonstrating the utility of Ba/Ca ratios in non-spinose species for reconstructing paleoproductivity.

Direct inter-proxy comparison of upper ocean paleotemperature records reveals spatial heterogeneity in proxy agreement: Where do we go from here?

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Surface ocean temperature is a key climate variable. Past changes in this variable are routinely inferred from geochemical paleothermometers such as foraminifera-based Mg/Ca, lipid-based U^{K}_{37} and TEX_{86} . Whilst routinely used, the interpretation of proxy-based temperature estimates may be complicated by differences in habitat depth and seasonal origin of the proxy signal. Despite this, temperature estimates derived from different paleothermometers are sometimes interpreted interchangeably as sea surface temperature, for instance in global syntheses wherein a broad spatial coverage is desired. Here, we present a systematic, direct inter-proxy comparison using a regional multi-proxy dataset based on sediment cores from low-to-mid latitude Western Pacific spanning the last 30 ka. Having temperature estimates inferred from U^{K}_{37} , TEX_{86} , Mg/Ca of surface- and thermocline-dwelling foraminifera for all sites enables direct proxy comparison and the reconstruction of the thermal structure of the upper ocean since the Last Glacial Maximum. One of the most salient findings is that the temporal trends in shallow subsurface temperature records derived from TEX_{86} and Mg/Ca of thermocline-dwelling foraminifera differ at most sites. Interestingly, TEX_{86} -inferred temperature records show more structural similarities with those derived from U^{K}_{37} and Mg/Ca of surface-dwelling foraminifera, even though regional core-top TEX_{86} data correlate better with shallow subsurface temperature than sea surface temperature. Regional latitudinal temperature gradients appear to be proxy-dependent, with Mg/Ca (TEX_{86}) showing the weakest (strongest) gradients. We explore possible factors leading to the aforementioned mismatches by focusing on the ecology of the source organism and non-thermal controls on proxy. Ultimately, the spatial pattern of proxy (dis)similarity may be a useful constraint for data-model comparison and proxy comparison across sites.



Poleward shift in the Southern Hemisphere westerly winds synchronous with the deglacial rise in CO₂

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The Southern Hemisphere westerly winds influence deep ocean circulation and carbon storage. While the westerlies are hypothesised to play a key role in regulating atmospheric CO₂ over glacial-interglacial cycles, past changes in their position and strength remain poorly constrained. I will present recent work which combines a large compilation of planktic foraminiferal δ¹⁸O and 'emergent relationships' from an ensemble of climate models to reconstruct changes in the Southern Hemisphere westerlies over the last deglaciation. We find a 4.7° (2.9-6.9°, 95% confidence interval) equatorward shift and about a 25% weakening of the westerlies during the Last Glacial Maximum (about 20,000 years ago) relative to the mid-Holocene (about 6,000 years ago). Our reconstruction shows that the poleward shift in the westerlies over deglaciation closely mirrors the rise in atmospheric CO₂. We perform new experiments with a 0.25° resolution ocean-sea-ice-carbon model which demonstrate that shifting the westerlies equatorward reduces the overturning rate of the ocean deeper than 2 km, leading to a suppression of CO₂ outgassing from the Southern Ocean. Our results support a role for the westerly winds in driving the deglacial CO₂ rise, and suggest natural CO₂ outgassing from the Southern Ocean is likely to increase as the westerlies shift poleward due to anthropogenic warming.

Consistent tales of ocean warming, sea level rise, and planetary energy gain told by ice cores, corals, and marine sediments

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The last deglaciation (~18,000 – 11,000 years ago) brought about extensive changes in Earth's energy budget, with combined ocean warming and ice sheet melting dominating the deglacial global energy gain. Ocean temperature and ice sheet volume changes are recorded in the oxygen isotope composition (d¹⁸O) of benthic foraminifera in marine sediment; the separation of these two components of benthic d¹⁸O - temperature and ice volume - has been a major scientific pursuit spanning several decades. Recently, proxy development has led to independent, quantitative constraints on (a) global sea level from ancient corals (and, correspondingly, global ice volume) and (b) mean ocean temperature from inert gases preserved in ice core bubbles, with excellent age control spanning the entirety of the last glacial maximum through the present (i.e., the past ~25,000 years). At the same time, new records and advances in establishing and aligning chronologies have led to a recent compilation of benthic d¹⁸O records, providing a global volume-weighted record with radiometric age constraints for the last deglaciation. With these new records and techniques, we demonstrate the remarkable agreement between the independent estimates of the combined contributions of ocean temperature and ice volume to benthic foraminiferal d¹⁸O and the global d¹⁸O compilation. The records suggest a moderately larger contribution of ice volume over ocean temperature change in the net LGM-Holocene Δd¹⁸O and a slight lead of ocean warming over ice sheet melting across the deglaciation. The reliability of the benthic stack in recording the combined contributions of ocean warming and ice sheet melting suggests that it may serve as a unique proxy for net global energy change. We therefore propose a



new application of benthic $d^{18}O$ in constraining the global energy budget via planetary radiative imbalance reconstruction.

Frontiers of carbonate clumped isotope geochemistry as an applied tool in paleoceanography, within an inclusive science framework

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The emergence of new proxies enables us to address fundamental questions about Earth's climate evolution. A promising tool for the study of past oceanographic conditions is the carbonate clumped isotope thermometer. In principle, this technique can provide a thermodynamically-based estimate of carbonate mineral formation temperature and a relatively assumption-free calculation of the oxygen isotopic composition of seawater. Over the past fifteen years, I have worked to develop its usability for paleoceanographic and paleoclimatic reconstructions. These efforts include studying the systematics of carbonate clumped isotopes in foraminifera and coccoliths and other geological archives including coral, mollusks, and lacustrine carbonates. In this talk, I will summarize work we have done to improve measurement capabilities, advance Bayesian tools, and highlight several applications to reconstruct ocean temperatures. Our work is being done in fields that have extremely low levels of diversity, paleoceanography, paleoclimatology, and geochemistry, with negative impacts on culture, the health of the discipline for people in it, and scientific innovation, and I will describe our work to address this.

Keynote

New tools and old for exploring Earth System Processes (with a focus on terrestrial - marine interactions on a warmer planet)

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Lipid biomarkers are widely used in palaeoclimate and palaeoceanographic research, including serving as proxies for pCO_2 , sea surface temperature and salinity. Less frequently used but equally powerful are proxies for past marine ecology (sterane distributions), environmental conditions (isorenieratene-derivatives as proxies for photic zone euxinia) and biogeochemical processes (bacterial hopanoid proxies for annamox and cyanobacteria/denitrification). These proxies are largely qualitative rather than quantitative, and some have undergone recent re-interpretation, but nonetheless they have untapped potential for testing hypotheses for the biogeochemical response to climate disruption. We explore this by examining suites of plant, algal, bacterial and archaeal biomarkers from multiple Permian to Eocene putative hyperthermals. Specifically, we summarise and explore evidence that global warming caused increased erosion and weathering, which in turn increased nutrient inputs to the marine realm, enhanced productivity and caused the expansion of anoxia. Although there is consistency across these events, the magnitude of response varies. Moreover, deeper interrogation of biomarker signatures suggests that the mobilisation of organic matter from source to sink involves multiple carbon pools with varying feedback potential. We interpret our results in the context of intermediate complexity Earth System models that help extrapolate these observations, often limited in space and time, to achieve deeper understanding of biogeochemical drivers and consequences. Finally, we use these case studies to identify new opportunities and needs in our discipline, including how we examine and interpret the hydrological cycle, the next generation of organic geochemical and modelling tools, and the nature of our global collaborations and partnerships.



Perspective Lectures

The ocean's mixed layer nitrogen cycle: implications for the magnitude and composition of the export flux

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Central to the ocean's role in setting atmospheric CO₂ is the seasonal alternation between upward mixing of nutrients and their subsequent consumption by phytoplankton. The links between nutrient supply and consumption and atmospheric CO₂ have been exploited by paleoceanographers who seek to understand the drivers of glacial-interglacial CO₂ change – the idea is that the more completely phytoplankton consume the available nutrients, the stronger the biological pump (i.e., the biological removal of atmospheric CO₂). However, our recent work from the modern ocean shows that active nutrient cycling within the mixed layer, including the release of ammonium and its removal by phytoplankton and bacteria, also affects the composition of the export flux (and thus oceanic CO₂ drawdown), yet mixed layer nitrogen (N) cycling is rarely considered in reconstructions of past ocean nutrient utilization. In this talk, I will present new N cycle findings from the modern ocean that have implications for paleo-nutrient cycling and carbon export. For example, as the summer growing season progresses in the Southern Ocean, iron limitation drives phytoplankton to switch from dominant reliance on nitrate supplied from depth to ammonium recycled in the mixed layer. This switch in N source appears to be recorded in the N isotopes of modern foraminifera, the shells of which ultimately sink to the seafloor to become part of the sediment record. Additionally, while assimilation by phytoplankton is the main process acting on the Southern Ocean's mixed-layer nitrate pool in summer, nitrate production by nitrification dominates in winter, with implications for the nitrate pool available to phytoplankton in spring, and thus of the sinking organic matter. I will also discuss new modern ocean data that suggest a novel way of tracking the flow of Indian Ocean waters into the South Atlantic (i.e., Agulhas leakage), with implications for reconstructing the strength of past overturning circulation.

Back to basins: transitions in the global overturning circulation

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The ocean's global overturning circulation connects surface and abyssal waters and plays a prominent role in Earth's climate through its regulation of heat and carbon storage. The overturning circulation also exists to deliver water from regions of buoyancy gain, largely at the low latitudes, to regions of buoyancy loss in polar regions. This characteristic, combined with the geometry of the ocean basins, places important constraints on the structure of the overturning circulation for given climate and surface forcing conditions. The organization of an equilibrated overturning circulation across a range of climate states is first explored through consideration of changing pathways of heat and buoyancy transport. Next, a hierarchy of models highlight key physical mechanisms that control the transient adjustment of the ocean's overturning circulation to surface forcing perturbations over decadal to multi-millennial time scales. Across all of these scales, the evolving dynamical processes that govern exchange between Atlantic, Indo-Pacific and Southern oceans arise as important controls on global overturning transitions and oceanic tracer distributions.



Paleoclimate and paleoceanography in the 6th (and 7th!) IPCC report

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Poster abstracts



Topic 1: Climate and Ocean Chemistry

on site posters



P1-067

Glacial-interglacial carbon cycle dynamics over the past 800 kyr in an isotope-enabled Earth system Model of Intermediate Complexity

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Sediment and ice cores preserved biogeochemical evidence of carbon transfers between land, ocean, and atmosphere in connection with the temperature and sea ice fluctuations of past ice age cycles. These carbon transfers resulted from sensitivities of carbon reservoirs of the ocean, atmosphere, ocean sediments, and land to climate forcing, many of which remain poorly understood. Numerical studies proved the potential of several physical and biogeochemical processes to alter atmospheric CO₂ under steady-state glacial conditions. Yet, it is unclear how much they actually affected carbon cycling transiently during repeated glacial cycles. Addressing this uncertainty, we produced a simulation ensemble of various physical and biogeochemical carbon cycle forcings over the repeated glacial inceptions and terminations of the last 800 kyr with the Bern3D Earth system model of intermediate complexity including various biochemical tracers and carbon and neodymium isotopes. This ensemble allows assessing transient carbon cycle changes due to these different forcings and gaining a process-based understanding of the associated carbon fluxes and isotopic shifts in a repeatedly and realistically perturbed Earth system. We will present results of the simulated Earth system dynamics in the non-equilibrium glacial cycles and a comparison with multiple carbon, climate and circulation proxy time series. For example, an initial analysis shows that low glacial atmospheric CO₂ concentrations can be obtained through enhanced C storage in various reservoirs: the ocean, sediments or C burial. Yet, the associated timing of CO₂ shifts, and patterns of carbon isotope and carbonate preservation change differ and render them distinguishable in the proxy record. Our data set adds dynamic constraints which, alongside multi-proxy model-data comparisons, can contribute to understanding how glacial-interglacial Earth system changes affected the carbon cycle.



P1-072

Impacts of the Toba super-eruption on the temperature and pH of the Andaman Sea

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The Toba volcano super-eruption occurred about 74,000 years ago on the island of Sumatra, during the transition between interglacial Marine Isotope Stage (MIS) 5 and glacial MIS 4. This eruption, which led to the deposition of the so-called *Youngest Toba Tuff* (YTT), is currently described as the largest volcanic eruption of the Quaternary. However, its impact on climate is widely debated and its effects on the ocean remain poorly understood.

The aim of this work is to estimate the impact of YTT on surface and thermocline oceanic temperatures and pH of the Andaman Sea. To do so, we measured Mg/Ca (paleothermometer) and $\delta^{11}\text{B}$ (pH proxy) on monospecific samples of two planktonic foraminifera picked from core BAR94-25, located 600 km to the Toba caldera : the surface-dwelling *Globigerinoides ruber* and the thermocline-dwelling *Pulleniatina obliquiloculata*. Mg/Ca and $\delta^{11}\text{B}$ data obtained on these two species make it possible to reconstruct temperature and pH variations as well as changes in their vertical gradients in response to upper ocean dynamics and potential disturbances linked to the Toba super-eruption.

We selected the interval from 258 to 355 cm, corresponding to an age between 57 and 82 ka. In this interval, several Toba tephra/cryptotephra layers are identified, which correspond to distinct eruptive events. Our results suggest almost 2°C of abrupt sea surface cooling across the main YTT deposit, that cannot be explained by the MIS 5-4 transition alone. Thermocline seawater temperature is less impacted by the eruption than surface waters (cooling of 1°C). This cooling event correlates well with a decrease in the pH of the Andaman Sea surface, that we interpret as reflecting the acidifying impact of Toba sulfur emissions.



P1-044

A community wide approach to constrain the foraminiferal boron isotope proxy for pH/atmospheric CO₂ reconstructions

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Atmospheric carbon dioxide (CO₂) is a key environmental unknown of the geological past, and directly links to our ability to understand Earth's climate sensitivity and the future trajectory of anthropogenic climate change. The significance of paleo CO₂ reconstructions through time has been recognized by the wider climate community and now incorporated into the Intergovernmental Panel on Climate Change (IPCC) reports¹. Given the importance of the boron isotope ($\delta^{11}\text{B}$) proxy for past CO₂ reconstructions, we are leading an effort to align the international $\delta^{11}\text{B}$ community and develop consensus of best practices for analytical methods, data processing and utilization guidelines. Over the last decade, there have been several insightful publications based on $\delta^{11}\text{B}$ reconstructions of atmospheric CO₂ and seawater pH. In part motivated by the growing interest of foraminiferal $\delta^{11}\text{B}$ research, there have also been several advancements related to constraints and assumptions for calculating important supporting variables such as seawater temperature, the necessary second carbonate system parameter, how 'vital effects' are treated, seawater chemistry, and how uncertainties are propagated and presented. Given varying assumptions, the same source $\delta^{11}\text{B}$ data has yielded different atmospheric CO₂ results among even some of the newest $\delta^{11}\text{B}$ publications. Our workshops aim to support a community driven, internally self-consistent protocol for reconstructions, and produce a living dataset to yield a state-of-the-art synthesis of $\delta^{11}\text{B}$ derived, seawater pH and atmospheric CO₂ over the Phanerozoic. Here, we will present our ongoing effort, explore the limits for our reconstructions, and expand on the carbon-climate links with our evolving, and community-wide discussion of the trajectories of seawater pH and atmospheric CO₂ for the Phanerozoic from the $\delta^{11}\text{B}$ proxy. This work is supported by PAGES.

¹IPCC, 2021: *WG I, AR6*, Cambridge University Press. In Press.



P1-023

Potential causes and consequences of variability in Arctic and Labrador surface water temperature and pH during the last millennium from crustose coralline algae

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Climate over the last two millennia is full of mysteries. We have yet to fully understand the precise sequence of environmental changes and how these relate to internal natural climate variability, regional climate forcing, and feedbacks between surface climate, volcanism, biosphere, hydrosphere, and land cover¹. The Arctic Ocean and the Labrador Sea are of particular importance in this regard, because of their role in the subduction of the Atlantic Meridional Overturning Circulation (AMOC) and their proximity to ice cover which causes them to respond rapidly to changes in warming and meltwater flux². Obtaining high resolution paleoclimate records from this region is however a challenge. The coralline alga *Clathromorphum compactum*, which forms annual calcium carbonate bands and is prevalent throughout the Arctic Ocean and the Labrador Sea, is a promising archive of paleoceanographic proxies^{e.g.3}. Here, we applied these proxies within *C. compactum* collected from the Arctic Ocean and the Labrador Sea, reconstructing seawater pH and temperature from their B isotope ($\delta^{11}\text{B}$) and Mg/Li composition, respectively. We also measured $\delta^{11}\text{B}$ of river-influenced Arctic seawater, sea ice, and snow cover on the sea ice and conclude that Northern high latitude seawater $\delta^{11}\text{B}$ is dominantly within the average seawater $\delta^{11}\text{B}$ composition, ensuring the reliability of our $\delta^{11}\text{B}$ -pH proxy reconstructions. We then link our seawater pH and temperature reconstructions to the Atlantic Multidecadal Variability through wavelet analysis, and discuss how the environmental variability of the Arctic Ocean and Labrador Sea relates to changes in meltwater supply, nutrient dynamics, and surface ocean circulation. Furthermore, these high-temporal resolution paleoceanographic data provide compelling evidence for a link between Arctic warming, freshwater input, and AMOC reduction over the 20th century.

¹Newman et al., 2009 *PAGES* 17, 130

²Bamber et al. 2018 *JGR* 123, 1827

³Anagnostou et al. 2019 *GCA* 254, 142



P1-038

A multi-million year reconstruction of atmospheric CO₂ from the late Eocene “Warmhouse” to the Oligocene “Coolhouse”

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To best contextualize ongoing and future climate change, it is vital to inform climate models with atmospheric CO₂ changes that have been reconstructed from the geologic record. The boron isotope proxy for seawater pH is a tried and tested method for this purpose, as expressed in atmospheric CO₂ estimates that closely match Pleistocene ice core records and Cenozoic reconstructions that correlate with independent records of global climate changes. In particular, CO₂ estimates for the Eocene and Eocene-Oligocene Transition (EOT) indicate a CO₂ decline which matches with global cooling and continental ice growth from the Eocene “Warmhouse” to the Oligocene “Coolhouse”. These records provide valuable insights into the behavior of Earth’s climate system over multi-million-year timescales, across hyperthermal events, and under different boundary conditions from today.

One current weakness is that reconstructions older than 23 million years suffer from the absence of modern foraminifera species, and require the transfer of modern calibrations and their underlying vital effects to species that are now extinct and whose vital effects are largely unknown. In addition, atmospheric CO₂ estimates from boron isotopes are sparse for the Oligocene. We aim to fill these gaps by using a cross-calibration approach, involving analysis of overlapping species pairs from the Recent back to the Eocene in targeted sediment sequences. By pairing foraminiferal boron isotopes with C and O stable isotopes and trace element data from the same sample material, we optimize the geochemical paleoecological constraints for each species and ensure that our planktic specimens reflect surface ocean carbon chemistry. With this foundation, we present new boron-based estimates of paleo-pH and atmospheric CO₂ from the late Eocene to mid Oligocene (~37 to 27 Ma).



P1-012

Abundance and dissolution of planktic foraminifera spanning the last thousand years: a comparison between northern and southern Barents Sea

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Anthropogenic activities are causing global environmental changes, such as ocean warming and acidification. To predict the effect of these changes on marine calcifying organisms, we need to understand how their population evolved in a pre-industrial environment influenced only by natural variation. An ideal model for such investigations are the calcite shells of fossil planktic foraminifera found in sedimentary records and extensively used as climate proxies.

Using planktic foraminiferal abundances, species diversity, and size normalized shell weight coupled to scanning electron microscopy in the northern (78.7° N, 33.9° E) and southern (71.6° N, 22.9° E) Barents Sea, we aim to reconstruct the environmental changes of the surface water over the last thousand years. The study is based on two multicores sampled every 0.5 cm and for which $\delta^{13}\text{C}$, $\delta^{18}\text{O}$, total organic carbon and calcium carbonate were analyzed. The age model of both sites was build based on ²¹⁰Pb and extended with ¹⁴C dates and suggest that the post-industrial revolution (since 1850) was recorded by the upper half of both cores.

In the northern Barents Sea, low concentration of planktic foraminifera dominated by the polar species *Neogloboquadrina pachyderma* contrast with the higher foraminiferal abundances and biodiversity recorded in the South. For both sites, the abundance of foraminifera decreases towards the recent times and the preservation state of the shells degraded, notably since the start of the industrial revolution. To compare the sedimentary record to living faunas, we collected and analysed plankton tow samples at the same locations, covering the upper 300 meters of the water column.



P1-006

Establishing a geochemical daily growth rate model for fossil giant clams

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Giant clams *Tridacna* are important high resolution environmental archives in (sub)tropical marine environments. During their life span of up to 100 years they build dense aragonitic shells with lengths of over 1 m, which feature seasonal to daily growth bands. Ontogenetic ages of modern and fossil *Tridacna* can be estimated by counting macroscopically visible seasonal bands. This approach leaves some uncertainty because not every specimen shows a reliable annual banding pattern. Additionally, yearly $\delta^{18}\text{O}$ cycles are used to build internal age models, which is less applicable for equatorial areas with low seasonal SST variability and heavy seasonal precipitation influencing $\delta^{18}\text{O}$ seawater values. Another approach is to count the daily bands, which occur at intervals of several micrometres. As the daily band visibility varies throughout the shell, especially in fossil specimens, manual counting and software-based image analysis are prone to error. Using high-resolution laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to resolve daily EI/Ca cycles (Warter and Müller, 2017) represents an alternative approach. For our 250 mm large Miocene specimen, we were able to obtain sub-daily resolved EI/Ca data independent of the daily band visibility. Applying wavelet transform on the measured daily geochemical cycles allows us to quantify varying daily growth rates throughout the shell. With the analysis of seasonal growth rate variability over several decades we can reconstruct local palaeoseasonality. Furthermore, we can assess the links between measured geochemical signals, environmental parameters and the fossil clam's growth rate by comparing geochemical data to growth rate variability. Overall, combining high-resolution LA-ICP-MS with wavelet transform represents a relatively quick approach to building a robust internal age model even in large fossil giant clams.

Warter, V., Müller, W., 2017. *Palaeogeography, Palaeoclimatology, Palaeoecology* 465, 362–375.



P1-110

A high-resolution chronology of biological pump recovery following the K/Pg mass extinction

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The Cretaceous/Paleogene (K/Pg) boundary mass extinction (~66.02 million years ago; Ma) is the most recent and arguably most famous of the big 5 mass extinctions of the Phanerozoic, in part due to the demise of non-avian dinosaurs. Over 75% of plant and animal species within terrestrial and near-surface marine environments became extinct during this event, although deep-sea benthos were comparatively less affected. Such a mass extinction of calcareous plankton and phytoplankton within the surface ocean realm, and consequent reduction of organic matter export to the deep ocean, resulted in a partial collapse of the biological pump and significant perturbations to surface-to-deep pH gradients and deep-sea carbonate saturation state. However, a detailed chronology of biological pump recovery in the aftermath of the K/Pg mass extinction is still lacking. Here, we present coupled high-resolution boron isotope measurements from mixed layer-dwelling planktic foraminifera and deep-sea benthic foraminifera spanning the late Maastrichtian to early Paleocene (~66.3–62.3 Ma) from Ocean Drilling Program (ODP) Site 1262, Walvis Ridge, South Atlantic. We identify profound changes in deep-sea carbonate saturation state (“carbonate overshoot”) in the immediate aftermath of the K/Pg boundary in the South Atlantic, then document the evolution of the surface-to-deep pH gradient over the subsequent 5 million years of the early Paleocene up to ~61 Ma. Our data provide new constraints on the timescale of biological pump recovery following the most recent mass extinction of the Phanerozoic, but also yield new insights into environmental change during the superimposed but comparatively poorly studied late Maastrichtian warming event (~66.3–66.2 Ma) and Dan-C2 event (~65.8–65.7 Ma).



P1-102

Resilience of planktic foraminiferal carbonate production to PETM environmental change: a model-data analysis

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The Palaeocene-Eocene Thermal Maximum (PETM) is a large scale perturbation of the global carbon cycle. Despite decades of work assessing biographic range shifts and taxonomic turnovers, many aspects of responses such as carbonate production are not well understood. It is important we understand how planktic foraminifers respond to environmental change as they contribute significantly to open-ocean carbonate and consequently long-term CO₂ storage. Here we apply a combined data-modelling approach to investigate how PETM warming impacted foraminiferal carbonate production – namely their size, calcification (size-normalised weight) and abundance (geographic range). We quantify the change in foraminiferal test size and abundance at an Atlantic, Pacific and Southern Ocean site and upscale these data using a trait-based model for planktic foraminifers (ForamEcoGENIE). ForamEcoGENIE is an extension of the size-structured 3-D plankton ecosystem model, “EcoGENIE” that includes non-spinose planktic foraminifers as a new functional group based on the costs and benefits of key traits (e.g. growth, grazing, calcification). Our data illustrates resilience of planktic foraminifers to environmental perturbation across the PETM, with negligible change in test size and abundance. ForamEcoGENIE supports this resilience, with small reductions in size and biomass being short-lived. Despite adverse carbonate chemistry, foraminiferal calcification (size-normalised weight) remains stable in the Southern Ocean. As evidenced by the data and model, the foraminiferal response is spatially variable. This variability can be attributed to a warming induced poleward migration and differences in nutrient availability between open-ocean and shelf locations. As such, we suggest that temperature - not ocean acidification - is a key driver of foraminiferal carbonate production during the PETM, with warming having redistributed biomass to high latitudes.



P1-105

Did organic carbon export in the eastern equatorial Pacific contribute to $\delta^{13}\text{C}$ maxima (CM) events during the middle Miocene Climate Optimum?

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The middle Miocene Climate Optimum (mMCO), from ~17 to 14.7 million years ago (Ma), was an interval of significant and abrupt carbon (C) cycle variations, considered a potential paleo-analogue of near-future conditions. Expanded organic C burial on continental shelves is thought to be a key feedback during the middle Miocene warmth, expressed on orbital timescales in benthic $\delta^{13}\text{C}$ maxima or CM events. The final and highest-amplitude CM event at the middle Miocene Climate Transition (mMCT) during Antarctic ice sheet expansion was also associated with expanded organic C export within the eastern equatorial Pacific (EEP). We present a new record of organic C export in the EEP over the mMCO using marine pelagic barite extracted from International Ocean Discovery Program Site U1337 to better constrain this region's role in the marine C cycle over CM events in the mMCO.

The EEP is one of the largest regions of high primary productivity on Earth today and a large CO_2 source region because organic C export to the deep sea does not compensate the outgassing of CO_2 from upwelling. Sustained micronutrient delivery and expanded organic C export during the mMCO could have accelerated orbital feedbacks of the CM events. To reconstruct the organic C export using accumulation of barite and published XRF records at high resolution, we measured new extraterrestrial (ET) ^3He concentrations taken from the same samples within a subset of our barite record from 16.94 – 16.46 Ma over the first two CM events. Concentrations of terrestrial ^4He are also presented to test whether eolian dust delivery is associated with organic C export. Using our new ET ^3He -normalized organic C export and micronutrient delivery records, we test whether increased organic C export in the EEP occurred during earlier CM events, and whether or not these events corresponded to micronutrient delivery from eolian dust.



P1-032

Boric acid diffusion in biomineralisation: implications for B geochemical proxies.

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The abundance and isotopic content of boron in carbonate biominerals are interpreted as records of seawater carbon concentration and pH. These proxies are based on the inorganic chemistry of boron in seawater, which exists in a pH-dependent equilibrium between $B(OH)_3$ and $B(OH)_4^-$, with a B isotopic fractionation between these species. If only $B(OH)_4^-$ is incorporated into the biomineral, this provides a record of both the concentration and isotopic composition of $B(OH)_4^-$, and thus the state of ocean pH and carbon chemistry.

The theory behind this proxy is attractively simple, but the concentration and isotopic composition of B in biominerals frequently deviates from $B(OH)_4^-$ in seawater. A key assumption behind the B proxies is that the concentration and isotopic composition of B in the calcifying fluid is the same as external seawater. If this is not the case, it may explain the deviation from seawater $B(OH)_4^-$, and requires that we carefully re-evaluate our interpretation of the B proxies.

Boric acid ($B(OH)_3$) is a small, neutral molecule that can diffuse easily across biological membranes. The diffusive transfer of $B(OH)_3$ between seawater and the calcifying space provides an isotopically-distinct B-specific transport pathway between seawater and the calcifying fluid. This previously unaddressed process could alter both the concentration and isotopic composition of B in the calcifying fluid compared to seawater, violating a key assumption behind our interpretation of the B proxies. How important is this process, and how could it alter our interpretation of the B proxies?

We explore these questions using a model of B transport in biomineralisation, which includes both the transport of $B(OH)_4^-$, and the transport and passive diffusion of membrane-permeable $B(OH)_3$. This allows us to explore a comprehensive range of biomineralisation and B transport scenarios, and evaluate the potential importance of $B(OH)_3$ diffusion for the B geochemistry of biominerals and the B proxies.



P1-046

A high-resolution CO₂ record for the late Pliocene intensification of northern hemisphere glaciation

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The intensification of Northern Hemisphere Glaciation (iNHG), ~3.0-2.5 million years ago, marks the beginning of the recent massive bipolar glaciations that have characterized Quaternary climate. iNHG represents the culmination of Cenozoic cooling and is marked by the development of ice sheets in the northern hemisphere that waxed and waned with changes in insolation. Recent evidence suggests that changes in atmospheric CO₂ were the primary driver of iNHG but the precise nature of its role is unsettled. Published records are of insufficient resolution to adequately assess the relationship between changes in orbit, CO₂, and global climate cycles. The boron isotope pH proxy has shown promise when it comes to accurately estimating past absolute CO₂ concentrations and success at reconstructing the relative changes in CO₂ outside of the ice core records (Hain *et al.* 2018). Here we present a new high-resolution record of atmospheric CO₂ (1 sample per 3 kyr) change from Ocean Drilling Program Site 999 (12.74°N, -78.74 °E) spanning ~2.3-3.0 Ma based on the boron isotope ($\delta^{11}\text{B}$) composition of planktic foraminiferal calcite from *Globingerinoides ruber* (*sensu stricto*, white). We find that $\delta^{11}\text{B}$ values of *G. ruber* take a clear glacial-interglacial form and describe a substantial reduction in CO₂ ~2.7 Ma. Our new record demonstrates the importance of CO₂ in amplifying the effects of astronomical forcing on climate associated with the development in the northern hemisphere of large ice sheets that advanced into the mid-latitudes during glacials, and provides new insight into the drivers and consequences of natural CO₂ change.



P1-017

Planktic foraminifera calcification in the northwestern Mediterranean: seasonal, interannual and pre-industrial Holocene patterns

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The Mediterranean Sea is considered a sensitive region to Ocean Acidification and the response of key calcifying organisms in this part of the ocean is uncertain. Therefore, we analyzed material from both sediment traps and sediment cores coming from the Gulf of Lions in order to characterize planktic foraminifera calcification patterns on different time scales. The Gulf of Lions is located in the northwestern part of the Mediterranean Sea and is considered an exception to the general oligotrophy of the Mediterranean.

We analyzed 3 different species of planktic foraminifera according to their different ecology and life cycle: *Globigerina bulloides*, *Neogloboquadrina incompta* and *Globorotalia truncatulinoides*. A total of 4694 foraminifera specimens were picked (a mean 13 to 27 specimens per sample), cleaned by ultrasonication in methanol, weighted with a Sartorius ME5 balance and measured (area and diameter) with a Nikon SMZ18 through a DS-Fi3 camera. Sediment traps values were available from 1993 to 2005 and environmental data comes the DYFAMED site.

Results showed that Measured Based Weights (MBW) obtained were a good indicator for calcification intensity. On a seasonal scale, each species reached a calcification maximum on different moments of the year and their MBWs variations were mainly linked to Optimum Growth Conditions, temperature and carbonate system parameters. On an interannual scale, MBW values showed different trends according to the species on recent years and were mainly linked to the carbonate system values. Finally, data from sediment cores allowed a pre-industrial Holocene comparison, which showed a calcification reduction for all 3 species compared to recent data.



P1-068

Holocene humidity changes in southern Iberia inferred from the geochemical signature of marine sediments

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The Mediterranean region is particularly sensitive to global climate variability that critically reflects on its hydrological conditions. A recently published high resolution reconstruction of Holocene Sea Surface Temperature (SST) based on *Globigerina bulloides* Mg/Ca ratios, set the basis to explore, within a warm climatic period, the impact of North Atlantic oceanographic conditions shaping the properties of the inflowing waters into the Mediterranean Sea. Here we go a step further in establishing the potential links between these oceanographical changes with the hydrological conditions on the southern Iberian Peninsula.

This study combines XRF-core-scanner analyses with the radiogenic isotopes characterization (Sr, Nd and Pb) of the terrigenous fraction in core ALB-2 from the Alboran Sea. Results indicate that the most humid conditions developed during the early to middle Holocene with a transition towards drier conditions and colder SST that occurred by the late Holocene. The radiogenic Sr, Nd and Pb records do not show any covariance with the millennial scale oscillations shown in the Zr and K XRF records interpreted as humidity changes. This could suggest that inputs of African dust are not the main controlling factor in the XRF records. In contrast, the Sr isotope record shows a significant transition around the middle Holocene while SSTs show a cooling trend. For an accurate interpretation of that feature, this study also targets a novel approach by characterizing the radiogenic isotope composition of settling particles recovered by moored sediment traps under well characterized meteorological conditions.



P1-075

A multiple-proxy approach to Oxygen Minimum Zone variation and nutrient dynamics during Common Era climate shifts: Novel high resolution records from Santa Barbara Basin, California

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Santa Barbara Basin (SBB) – a partially restricted basin along the California coast – intersects the Oxygen Minimum Zone (OMZ), a region persistent of low dissolved oxygen (DO) levels in the water column (300 – 800 m). Natural OMZ variability has large implications for biogeochemical cycling of elements and species diversity, yet this variability remains poorly understood beyond the observational record. Here we explore California margin OMZ response to climate change by reconstructing DO in SBB during recent, naturally occurring climate extremes. The most significant natural climate extremes of the Common Era are the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA), the timing and expression of which are dependent on location. In Southern California, the MCA is expressed as a series of prolonged drought events associated with strong coastal upwelling from ~850 – 1180 CE. Existing records from SBB (e.g. $\delta^{15}\text{N}$ and redox-sensitive metal enrichment factors, EFs) are compared to benthic and planktic foraminifera I/Ca to better understand Southern California climate dynamics during the last 1200 years and drivers of DO/productivity variability. SBB sediments provide evidence for periods of extremely low DO levels during the MCA. Redox-sensitive metal-EF maxima supporting the presence of sulfides at 980 and 1120 CE coincide with high $\delta^{15}\text{N}$ of organic carbon (C_{org}), indicating the presence of Eastern Tropical North Pacific (ETNP) denitrified water in SBB. The lowest benthic I/Ca ratios occur between these metal-EF peaks (~1040 – 1100 CE), further supporting OMZ expansion during the MCA. During the early LIA (1250 – 1500 CE) metal-EFs decrease and benthic I/Ca increase, indicating bottom water DO recovery; however, after ~1500 CE the OMZ expands again. This occurs alongside decreasing planktic I/Ca, which tracks with C_{org} $\delta^{15}\text{N}$ in SBB, suggesting a shift in water masses entering the region.



P1-047

Deglacial Subantarctic CO₂ outgassing driven by a reduced solubility pump

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The Subantarctic Southern Ocean has been thought to be an important contributor to increases in atmospheric carbon dioxide partial pressure (pCO₂) during glacial-interglacial transitions. Extensive studies suggest that a weakened biological pump, a process associated with nutrient utilization efficiency, drove up CO₂ release from this region during these transitions. By contrast, influences of the solubility pump, a process that is mainly linked to temperature variations, have been largely overlooked. Here we evaluate the relative contributions of the biological and solubility pumps to surface-water pCO₂ variabilities in the Subantarctic Southern Ocean during the last deglaciation, based on paired reconstructions of surface-water pCO₂, temperature, and nutrient utilization efficiency. We show that compared to influences of biological processes, changes in CO₂ solubility imposed a strong impact on deglacial Subantarctic surface-water pCO₂ variabilities. Our result reveals the previously underappreciated role of the solubility pump in modulating deglacial Subantarctic CO₂ release and past atmospheric pCO₂ fluctuations.



P1-069

Reconstructing the carbon cycle in the Nordic seas over the last 30 ky using boron isotopes in *Neogloboquadrina pachyderma*

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The Nordic Seas are characterized by strong convection and deep-water formation resulting in this region being a sink of CO₂ in the modern ocean. During the last glacial period, the climate in this area witnessed significant short-term high-magnitude climate perturbations (e.g., Heinrich events (HE)) characterised by a slowdown of the meridional overturning circulation, northward penetration of warm Atlantic waters in subsurface waters and the discharge of marine based Ice sheets. Here we test the hypothesis that the release of heat to the atmosphere by warm subsurface waters at the end of HEs created ice-free conditions in the North-western Nordic Seas and CO₂ outgassing to the atmosphere^{1,2}. With this aim, we chose core CE100301, located off the Northern Greenland continental margin at 75°N to reconstruct oceanic CO₂ focussing on HE2 and HE1 using δ¹¹B measurements in the non-spinose planktonic foraminifera *Neogloboquadrina pachyderma*. The core is characterised by discrete pulses of foraminifera-rich intervals during the last glacial cycle providing evidence for ice-free conditions and allowing high resolution δ¹¹B-derived CO₂ reconstruction. Preliminary data show that for the Holocene and last glacial maximum, δ¹¹B track variations throughout the glacial cycle, showing the potential of this proxy to track changes in seawater CO₂ content.

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P1-100

North Atlantic drift sediments constrain Eocene tidal dissipation and the evolution of the Earth-Moon system.

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Cyclostratigraphy and astrochronology are now at the forefront of geologic timekeeping. While this technique heavily relies on the accuracy of astronomical calculations, the chaotic nature of the solar system limits how far back in time astronomical calculations can be performed with confidence. High-resolution paleoclimate records with high-fidelity Milankovitch imprints now allow reversing the traditional cyclostratigraphic approach: Middle Eocene drift sediments from Newfoundland Ridge (North Atlantic) are exceptionally well-suited for this purpose, thanks to high sedimentation rates and distinct lithological cycles. Per contra, the stratigraphies of Integrated Ocean Drilling Program Sites U1408-U1410 are highly complex with several hiatuses. Here, we carefully build a two-site composite and construct a conservative age-depth model to provide a reliable chronology for this rhythmic, highly-resolved (<1 kyr) sedimentary archive. Astronomical components (g-terms and precession constant) are extracted from the different proxy time-series using the numerical analysis of fundamental frequencies (NAFF). We find middle Eocene astronomical frequencies that are up to 4% lower than reported in state-of-the-art astronomical solution “La04”. This solution, however, has been smoothed over 20-Myr intervals, and our results therefore provide an order of magnitude for the variability of g-term frequencies on shorter, million-year time scales. Our precession constant estimate (51.22"/year) confirms earlier indicators of a relatively low rate of tidal dissipation in the Paleogene. Newfoundland Ridge drift sediments thus enable a reliable reconstruction of astronomical components at the limit of validity of current astronomical calculations, extracted from geologic data, providing a new target for the next generation of astronomical calculations.



P1-020

Clumped isotope analyses on biogenic aragonites and their use in paleoclimate reconstructions

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Understanding the response of Earth's climate to perturbations requires accurate and detailed reconstructions of past climate states. The clumped isotope thermometer has the potential to constrain the formation temperatures of carbonates independent from the (isotopic) composition of the precipitation fluid and regardless of the origin (e.g. taxonomy) of the carbonate producer, making it an ideal tool for paleoclimate reconstructions. Unfortunately, it is still not fully certain whether the clumped isotope composition of different carbonate minerals (e.g. calcite, aragonite, dolomite) responds similarly to changes in formation temperatures or variations in the temperature at which the acid reaction takes place during analyses. This uncertainty complicates the application of clumped isotope thermometry to biogenic aragonite shells of bivalves and gastropods, as well as to chemically precipitated travertines and speleothems.

To solve some of these issues, we present a new dataset consisting of clumped isotope measurements on aragonitic *Arctica islandica* bivalves grown at precisely controlled temperatures ($1.1 \pm 0.2^\circ\text{C}$ - $18 \pm 0.3^\circ\text{C}$). We compare our data with preexisting clumped isotope calibration datasets and models for the temperature dependence of clumped isotopes spanning a wide temperature range. Our clumped isotope data with well-defined formation temperatures allows us to constrain small but important differences between previously published calibration datasets and sheds light on the temperature dependence of clumped isotope composition of aragonites. We use these new insights into the clumped isotope thermometer at low temperatures to produce seasonally resolved paleotemperature reconstructions from excellently preserved aragonitic bivalves from the Pliocene Warm Period, a valuable analogue for future climate under intermediate greenhouse gas emission scenarios (SSP2-4.5).



P1-093

Testing the Precambrian reverse weathering hypothesis using a 1-billion-year record of marine shales

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The Precambrian Earth should have been prone to glaciation with solar luminosity 10-15% lower than the present, yet the Proterozoic sedimentary record indicates largely ice-free conditions. Elevated marine Si concentrations favoring reverse weathering during this time have recently been proposed as a mechanism helping maintain sufficiently elevated atmospheric carbon dioxide ($p\text{CO}_2$) to compensate for the reduced solar luminosity. Reverse weathering, i.e. marine authigenic clay formation, involves the consumption of alkalinity, metal ions and dissolved silica, forming clay minerals and releasing acidity. This authigenic clay formation is increasingly recognized as an important, but temporally variable, influence on $p\text{CO}_2$ and seawater composition in the Phanerozoic. However, whether this influence was magnified in the Si enriched Precambrian oceans and helped stabilize climate remains largely untested because authigenic clays cannot be readily differentiated from detrital or burial diagenetic clays using conventional mineralogical or geochemical approaches.

Here we employed a novel, scanning electron microscope based mineral mapping approach to identify and quantify the proportion of authigenic clays in twelve well preserved Proterozoic marine shales from the Vindhyan and Chhattisgarh basins of India, spanning ~ 1-billion years. We find that at least eight out of twelve formations contain unambiguous authigenic clays, with up to 45 wt% of these shales being comprised of authigenic illite, possibly formed via a smectite precursor. Ongoing work is focused on Australian Proterozoic shales to further extend this record. Our current results, while preliminary, reveal the widespread occurrence and high abundance of authigenic illite, providing strong empirical support for enhanced reverse weathering throughout much of the Proterozoic, with implications for marine geochemical cycling and the evolution of the carbon cycle.



P1-074

Redox behavior of tungsten and its isotopes in a stratified marine basin

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Tungsten (W) is increasingly considered as a promising new paleo redox proxy. A wider application, however, depends on a sound understanding of the processes influencing W behavior, which can be deduced from modern analogs. Here we present W datasets including its stable isotopic composition from the redox-stratified Landsort Deep (Baltic Sea) combining water column, porewater, and sediment records (1). Elevated levels of dissolved W in euxinic bottom waters are compatible with W inputs from redoxcline-derived Mn oxide particles and porewater reflux. Exceptionally high porewater W levels agree with the elevated solubility of thiolated tungstate species. Although short-term euxinic episodes allowed slight sedimentary W enrichments, most pronounced W enrichments appear in Mn carbonate-rich sediments formed during longer-lasting bottom water hypoxia. Variable W isotope compositions in the water column contrast to the relatively uniform open ocean and are in line with scavenging/release of light W by/from Mn oxides (2). Smooth depth trends in sedimentary $\delta^{186/184}\text{W}$ signatures mirror temporal changes between hypoxic and euxinic conditions as enhanced inflow rates of O_2 bearing seawater enhance the shuttling of Mn oxides enriched in light W (3). We thus suggest that the temporal variation in sedimentary $\delta^{186/184}\text{W}$ is linked to the extent of Mn oxide formation, which in turn depends on changing marine redox conditions. This relationship emphasizes the potential of stable W isotopes as a promising proxy for the reconstruction of redox conditions in early Earth history.

1) Dellwig et al. 2019 ESR 193, 1-23

2) Kurzweil et al. 2021 PNAS, 118, e2023544118

3) Kurzweil et al. 2022 EPSL 578, 117303



P1-059

Sea Ice in Subarctic North Pacific a Mechanism That Translates Atmospheric Phenomenon to Halocline during Deglaciation

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Recent work claims climate shifts in the Subarctic Pacific preceded changes in the North Atlantic and Southern Ocean during the deglaciation. A revised Age Model from U1340 in the Bering Sea allows for new calculations of Reservoir Ages and supports the timing of several events described in Walczack et al 2020.

Sea surface salinity (SSS) at U1340 freshens from 19.1-17.7 kya, associated with Missoula megafloods and a strong Asian Summer Monsoon. A high Benthic-Planktic 14C offset corroborates the hypothesis that deep old waters rose to intermediate (1.3 km) levels at this time (Praetorius et al 2015). SSS increases during Siku Event 1; and a large negative planktic $\delta^{13}\text{C}$ excursion occurs from 17.1-16.2 kya, suggesting the upwelling of respired carbon. Upwelling indicators %Chaetoceros and authigenic uranium also increase with this brief event. Surface Reservoir Ages then increase while B-P 14C offsets decrease, consistent with old 14C at the surface and near-homogenization of the water column to 1.3 km. B-P 14C offsets reach their lowest (350 yrs) during the Younger Dryas, while Reservoir Ages continue to rise through the PreBoreal.

An increase in planktic $\delta^{18}\text{O}$ (SSS) precedes changes in benthic $\delta^{18}\text{O}$ three times: the 17.1 kya event, Older Dryas, and late-Younger Dryas. We suggest SSS must increase before wind-driven Ekman pumping can “break through” intermediate-water stratification to pump old waters to the surface, increasing surface nutrients and sparking the productivity of the Bolling, Allerod, and PreBoreal. As the timing of this SSS is unique in each case, it may not be the sole cause. We also present diatom species indicators that suggest sea ice formation (retreat) is an important mechanism that translates atmospheric phenomenon to intermediate depths via presence (absence) of an intermediate-depth halocline. These findings support the hypothesis that these North Pacific millennial-scale climate events play active roles in CO_2 forcing and global climate change.



P1-028

Fidelity of Tropical Atlantic *Siderastrea siderea* coral in Reconstructing Sea Surface Temperature

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Sea surface temperature (SST) in the Tropical Atlantic, which includes the Caribbean Sea and the Gulf of Mexico, plays a vital role in the weather and climate of the Americas. Despite advancements in global climate models (GCMs), coupled atmosphere-ocean GCMs reveal the Tropical Atlantic has an $\sim 2^\circ\text{C}$ cold bias in SST that needs to be resolved. We are building a network of SST reconstructions using the massive coral *Siderastrea siderea* for the past ~ 200 years that will provide targets for diagnosing this cold bias. Coral skeletal Sr/Ca is a widely used SST proxy in many coral species, yet its use for absolute SST reconstructions is currently not possible due to inconsistencies in calibration equations. Recent studies have suggested other SST proxies (Li/Ca, Li/Mg, Mg/Ca, U/Ca, and Sr-U) yet these proxies have not been assessed to the same degree as coral Sr/Ca. Here we assess the reproducibility and fidelity of these coral temperature proxies for *S. siderea* from two sites in the Gulf of Mexico; Flower Garden Banks ($27^\circ 52.5' \text{N}$, $93^\circ 49' \text{W}$, one colony) and Dry Tortugas ($24^\circ 42' \text{N}$, $82^\circ 48' \text{W}$, two colonies) sampled at monthly resolution. We find discrepancies among these proxies similar to coral Sr/Ca with no other proxy outperforming Sr/Ca. We have further examined other calibration studies for this coral species from the Gulf of Mexico to Brazil and we are finding consistent transfer equations when calibrated using local SST or OISST. This consistent Sr/Ca-SST relationship will allow us to reconstruct absolute SST for past intervals as well as seasonal to decadal variability. Our absolute coral Sr/Ca-SST reconstructions back to the 18th century reveal the Gulf of Mexico has the greatest seasonality and consistent variability whereas corals from Haiti and Little Cayman have less seasonality and distinct interannual variability. This study provides us with the confidence reconstruction of absolute SST with dead and subfossil *S. siderea* with greater confidence.



P1-070

Comparison of modern and Holocene nutrient cycling in the Labrador Sea: A multiproxy application of nitrogen and silicon isotopes

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In the Labrador Sea, hydrographic and biogeochemical conditions are highly sensitive to climate variability. Accelerated warming and melting today reduce the seasonal sea ice cover and increase primary productivity. The amount of productivity is closely coupled to the delivery of nitrate and silicate. Today, high amounts of nitrate relative to silicate are delivered from the North Atlantic via the Irminger Sea. Pacific waters delivered via the Canadian Archipelago are enriched in silicate over nitrate, with isotopic compositions for both being heavier compared to Atlantic-sourced waters.

To investigate whether nitrogen isotope compositions of bulk sediments ($\delta^{15}\text{N}_{\text{bulk}}$) and silicon isotope compositions of diatoms ($\delta^{30}\text{Si}_{\text{diatom}}$) record water mass signatures or nutrient utilization, we present an extensive data set from surface sediments of the entire Labrador Sea. The $\delta^{15}\text{N}_{\text{bulk}}$ closely mirrors the water column signal, as nitrate utilization is complete, which suggests that the sediments can be used to trace changes in the source signature of nitrate and the admixture of the source waters. We apply this finding to two downcore records, one from the NE Labrador Sea located in the pathway of Atlantic waters and one from the NW Labrador Sea, where Pacific and Atlantic waters are mixed. These records show similar $\delta^{15}\text{N}_{\text{bulk}}$ values of 7 ‰ prior to 7 kyrs BP, followed by a decrease to 4.5 ‰ in the NE and a slighter decrease to 6.5 ‰ in the NW over the mid and late Holocene. $\delta^{30}\text{Si}_{\text{diatom}}$ are available from the NW record and surface sediments from the entire Labrador Shelf. There, silicate is also almost completely consumed by summer and reflects differences in the $\delta^{30}\text{Si}$ signal of source waters. However, in the record from the NW Labrador Shelf, the Holocene $\delta^{30}\text{Si}_{\text{diatom}}$ record shows variability with a 1.5 kyr cyclicity since 7 kyrs BP. This is not in line with changes in the water mass mixing but relates to changes in productivity, linked to variations in the phytoplankton community.



P1-008

The nitrogen isotopic composition of *Chaetoceros* resting spores in laboratory culture and seasonally laminated coastal marine sediments

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Diatoms play a key role in the Southern Ocean's biological pump and in modulating changes in atmospheric CO₂ across glacial/interglacial cycles, but the contribution from Antarctic coastal zones remains unconstrained. *Chaetoceros*, a diatom genus characterized by its ability to form resting spores, are particularly abundant in coastal Antarctic environments and tend to dominate sedimentary diatom fossil assemblages. *Chaetoceros* resting spores (CRS) are thought to form in response to adverse environmental conditions such as light or nutrient limitation. Paleorecords from sediment cores reveal that CRS relative abundance and the nitrogen isotopic composition of diatom frustules (as $\delta^{15}\text{N}_{\text{db}}$) increase during the last glacial period. The higher $\delta^{15}\text{N}_{\text{db}}$ values suggest a greater degree of nutrient consumption and more efficient biological pump, consistent with lower atmospheric CO₂. However, because CRS can form under nutrient-depleted conditions, and preserve well in sediments due to heavy silicification, their increased relative abundance during glacial periods may bias the $\delta^{15}\text{N}_{\text{db}}$ record towards low nutrient conditions (higher $\delta^{15}\text{N}_{\text{db}}$). We tested this with laboratory culture experiments of *C. socialis* isolated from Scotia Sea surface sediments, measuring the $\delta^{15}\text{N}_{\text{db}}$ values of both vegetative cells and low nutrient-induced CRS. The results indicate that CRS actually record lower $\delta^{15}\text{N}_{\text{db}}$ values than vegetative *Chaetoceros*. Sedimentary records from ODP Site 1098 on the western Antarctic Peninsula corroborate these results, as $\delta^{15}\text{N}_{\text{db}}$ values measured on isolated CRS are lower than $\delta^{15}\text{N}_{\text{db}}$ values from the whole diatom assemblage. Our results suggest that the observed glacial $\delta^{15}\text{N}_{\text{db}}$ increase is unlikely the product of a species-specific bias.



P1-080

Linking Antarctic temperature with Southern Ocean productivity: Diatom and geochemical proxy records from the Pacific Sector of the Antarctic Circumpolar Current

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The Antarctic Circumpolar Current (ACC) flows uninterrupted, eastward around the Antarctic continent and greatly influences formation and upwelling of water masses, therefore linking global deep ocean carbon reservoirs with atmospheric CO₂ concentrations. This study investigates paleo-productivity and efficiency of the biological pump over Quaternary glacial-interglacial cycles in the Pacific sector of the ACC. IODP Expedition 383, Site U1539 provides a high-resolution 1.4 Ma sedimentary record of this region. Initial results from diatom abundance and assemblage and biogenic Si are used as proxies for surface ocean conditions and primary productivity, in order to explore the past efficiency of the biological pump in the Southern Ocean. Shipboard color reflectance data and other proxy data sets from Site U1539 also show tight coupling with the EPICA Dome C ice core record, providing a link between East Antarctic temperature and Southern Ocean productivity over Quaternary glacial-interglacial cycles. Studying changes in the biological pump with respect to Antarctic climate over geologic timescales is essential to understanding ocean-atmosphere interactions and impact on Southern Ocean carbon sequestration.



P1-045

New constraint on atmospheric CO₂ change across the Late Miocene Carbon Isotope Shift

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The Late Miocene Carbon Isotope Shift (LMCIS, 7.7 – 6.7 Ma) is the largest carbon isotope excursion on the million-year scale observed in marine sediment records since the early Eocene. It has been hypothesised that this 0.9 ‰ decline in $\delta^{13}\text{C}$ observed globally was caused by a combination of enhanced weathering of isotopically light terrestrial carbon and the rapid expansion of plants with the C₄ photosynthetic pathway that sequester isotopically heavier carbon than their C₃ competitors. C₄ plants are known to outcompete the more dominant C₃ plants under low CO₂/high temperature conditions. Global surface temperature proxies strongly suggest that global temperatures declined toward modern across this interval. Therefore, it has been hypothesised that the C₄ expansion may have been driven by a decline in atmospheric CO₂. However, at present there is substantial uncertainty on the magnitude and timing of CO₂ variability across the LMCIS and reconstructions of CO₂ using different proxy-based methods are not in strong agreement. Without clarity on the CO₂ change, efforts to constrain the source of the global $\delta^{13}\text{C}$ shift and potential carbon cycle change remain hampered.

Here we present a new $\delta^{11}\text{B}$ -based record of surface ocean pH and atmospheric CO₂ constructed using planktic foraminifera to help further our understanding of how the carbon cycle changed across the LMCIS. This boron isotope record is supported by a series of new records of foraminifera trace element compositions from the same core that include rarely utilised elements such as S/Ca and K/Ca that may help further constrain the environmental conditions that produced one of the most significant periods carbon cycle and ecosystem change since the Paleogene.



P1-007

Applying lipid biomarkers to investigate past nitrogen dynamics in oxygen-depleted marine systems

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Nitrogen (N) is a key element in global biogeochemical cycles and is often the limiting nutrient for marine primary productivity. Currently, marine N-cycling is substantially altered through human activities and ongoing widespread deoxygenation related to climate change. As such, it is of pivotal importance to reconstruct past N-cycle changes in settings with various levels of (de)oxygenation to get a mechanistic understanding of the link between marine productivity and nutrient dynamics in a changing world. The marine N cycle is driven by microbial processes; N-fixation, nitrification, and N-loss processes through denitrification and anaerobic ammonium oxidation (anammox). The microorganisms responsible for these processes often do not leave physical fossils behind. However, their molecular fossil remnants, lipid biomarkers, can be used to identify key N processes in the past. Commonly applied lipid biomarkers include ladderane fatty acids (FAs) and a stereoisomer bacteriohopanetetrol (BHT-x) as indicators for anammox, crenarchaeol for nitrification, and heterocyst glycolipids (HGs) for N-fixation. Here, we present examples of paleo-applications of these lipid biomarkers in downcore records from two different oxygen-limited settings: the California upwelling system (ODP Site 1012) and the Eastern Mediterranean Sea (64PE406-E1). Site 1012 focuses on the last 150 kyr, while site 64PE406-E1 focuses on the last 68 kyr, which includes two episodes with transitions to lower oxygen conditions (the well-established S1 and the ambiguous S2). We present the downcore distributions of ladderane FAs, BHT-x, crenarchaeol, and HGs together with bulk sedimentary total organic and nitrogen content (wt. %) and the N isotopic signature ($\delta^{15}\text{N}_{\text{sed}}$). The overall aim of this study is to identify variations in key N processes in relation to climate dynamics in two settings that are prone to abrupt changes in future deoxygenation (i.e., restricted basins and upwelling systems).



P1-052

Investigating the driver of the long-term Cenozoic CO₂ decline using DeepCarb, a simple carbon cycle model

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The transition of Earth's climate from the greenhouse, ice-free world of the early Paleogene to the glaciated icehouse of the Pleistocene was associated with an atmospheric CO₂ decline of ~1000 ppmv. This is at odds with the notion of a strong silicate weathering feedback, which posits that on million-year timescales, CO₂ release via mantle degassing and metamorphism is balanced by CO₂ consumption during silicate weathering. Rather, the observed CO₂ change implies other factors may overwhelm any possible long-term silicate weathering responsiveness and modulate CO₂ over at least an order of magnitude on multi-million-year timescales, or that changes in silicate weathering independent of Earth's climate are a major CO₂ driver (e.g. uplift or the weatherability of ultramafic rocks within the tropics), however, the precise mechanisms remain elusive. Here, we use a simple carbon cycle box model to revisit the possible drivers of the Cenozoic CO₂ decline. The model ('DeepCarb') is designed to be sufficiently computationally efficient to be run over tens of millions of years in a Monte Carlo fashion on a normal computer, thus enabling random perturbation of key model parameterisations over an extremely wide range. We use the model to investigate a variety of possible long-term CO₂ drivers, focusing on CO₂ degassing and weathering rates as well as the changing major ion composition of seawater. Ultimately, we show that while a variety of processes can drive long-term changes in CO₂, in the set of model simulations that allow for permanent order-of-magnitude-scale variations, the concentration of calcium in seawater must have played an important role in driving changes in the seawater carbonate system and therefore atmospheric CO₂.



P1-073

Role of the deglacial buildup of the Great Barrier Reef for the global carbon cycle

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An outstanding problem in our understanding of the global carbon cycle is unravelling the processes that were responsible for the rise of atmospheric CO₂ during the last deglaciation (~19 to 11 ka). The carbon isotope ¹³C is commonly used to attribute the last deglacial atmospheric CO₂ rise to various processes. The growth of tropical coral reefs has been controversially discussed in this context. To test this, well constrained reef carbonate records that span the last deglaciation are necessary, but such records are generally not available. Here we make use of a multi-proxy coral reef record obtained at the Great Barrier Reef by IODP Expedition 325. We show that the growth of the world's largest reef system, the Great Barrier Reef, is marked by a pronounced decrease in δ¹³C in absolutely dated fossil coral skeletons between 12.8 and 11.7 ka, which coincides with a prominent minimum in atmospheric δ¹³CO₂ and the Younger Dryas cold period of the Northern Hemisphere. The event follows the flooding of a large shelf platform and initiation of an extensive barrier reef system at 13 ka. We show, by carbon cycle simulations, that the Great Barrier Reef coral δ¹³C decrease was mainly caused by the combination of isotopic fractionation during reef carbonate production and the decomposition of organic land carbon on the newly flooded shallow-water platform. The impacts of these processes on atmospheric CO₂ and δ¹³CO₂, however, are marginal. Thus, the Great Barrier Reef was not contributing to the last deglacial δ¹³CO₂ minimum at ~12.4 ka, and the world's largest reef system in existence appears to have little effect on the last deglacial atmospheric CO₂ and δ¹³CO₂ changes.



P1-077

Clumped isotope constraints on the Holocene-LGM warming in the Mediterranean

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The last glacial maximum (LGM) is the most recent time period in Earth's history with a climate that was much colder than the present, so paleoclimate data from this time period serve as important benchmarks for climate model simulations. For example, paleoclimate data from the LGM can be used to calculate the Earth's equilibrium climate sensitivity (ECS), which is needed to understand the long-term consequences of climate change. ECS can be calculated directly with paleoclimate data, or through the formal incorporation of paleoclimate data with the results of climate models (i.e., paleoclimate data assimilation). For these reasons, it is important to reduce the uncertainties of our climate proxies, and to expand the spatial coverage of our current estimates. Here, we present estimates of the magnitude of the glacial-interglacial temperature change in the western Mediterranean from the clumped isotope composition of foraminifera and coccoliths. We use clumped isotopes because our database of temperature change in the surface ocean is composed of proxies that can have important non-thermal influences (e.g., UK_{37} , TEX_{86} , Mg/Ca , $\delta^{18}O$), and we focus in the Mediterranean because SST proxies in this area show a larger magnitude of warming than some climate models (e.g., iCESM). Our motivation is to demonstrate the potential of clumped isotopes to better constrain both the Mediterranean and the global Holocene-LGM temperature change.



P1-109

Are hyperthermal events a persistent feature of greenhouse climates?

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Hyperthermal events of the early Paleogene are characterized by the release of large quantities of carbon to the ocean and atmosphere, rapid warming on a global scale, and carbonate dissolution on the sea floor. Therefore, these events indicate many key elements of the anthropogenically induced carbon release and subsequent global warming, making them a prime target when analyzing how ecosystems react to short-term but large CO₂ emissions. The precise extent of these short-term warming events and whether they are a characteristic feature of greenhouse climates or limited to the early Paleogene period, however, is still up for debate. In this study, a 1.5 Myr time interval of the Late Maastrichtian has been analyzed at a ~5 kyr-resolution to test if hyperthermal events occurred outside the early Paleogene. For two cores in the North Atlantic and tropical Pacific, XRF core scanning, wt% CaCO₃ analyses, and stable oxygen and carbon isotope records of benthic as well as planktic foraminifera were generated. Bottom-water and sea-surface temperatures were reconstructed through Mg/Ca measurements of the same foraminiferal tests. Preliminary data for both cores reveal time intervals that share features comparable to the orbitally paced hyperthermal events as they are well-known from the early Eocene greenhouse, suggesting that hyperthermal events are a much more widespread phenomenon of greenhouse climate states than previously known.



P1-095

Plio-Pleistocene CO₂ records from boron isotopes

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Atmospheric CO₂ acts as an important heat trapping gas, playing a key role in maintaining Earth's energy balanced and setting its climate state. Bubbles of ancient air trapped in Antarctic ice reveal an exquisite correlation between atmospheric CO₂ content and climate, but this picture is currently limited to the last 800 kyrs and leaves many questions unanswered. These include the nature, magnitude, and pacing of CO₂ cycles in the 41 kyr world and the role of long-term CO₂ decline in Plio-Pleistocene climate cooling. Although there is much interest in recovering older ice, there is little hope for a continuous ice core record covering the Plio-Pleistocene with adequate gas-age control. To probe the relationship between climate and CO₂ beyond the last 800 kyr we therefore need to rely on proxies for atmospheric CO₂ – and we argue that the boron isotope pH proxy has unparalleled potential in this regard.

Over the last decade, we have been striving to ground truth the boron isotope pH proxy by applying it in time intervals that overlap with the continuous ice core record, and then using it to estimate the evolution of CO₂ over the last 3.5 million years at increasingly higher temporal resolution and from multiple deep ocean sites. Here we present a summary of our progress in that endeavour along with a discussion of the relationship between climate and CO₂ that emerges.



P1-088

Mid-Pliocene Amundsen Sea Sediments Demonstrate a Direct Link Between Iceberg Melt and Diatom Productivity (IODP 379)

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Icebergs and meltwater deliver continentally sourced nutrients to the Southern Ocean. Iceberg influence on diatom productivity has been suggested, but direct seeding of the Southern Ocean during times of ice sheet collapse has never been demonstrated. We document coincident pulses of ice rafted debris (IRD) from iceberg melt and enhanced diatom production and accumulation in the outer Amundsen Sea during the mid-Pliocene. IODP Exp. 379 obtained records from the Amundsen Sea continental rise to document WAIS history in an area currently experiencing the largest ice loss in Antarctica. SEM imagery documented microstratigraphy of mid-Pliocene (3.6-4.1Ma) interglacial sediments with distinct intervals (~15 cm) of IRD-rich diatomite, lying between more dominant intervals with infrequent IRD and lower diatom abundance. We infer that these pulses of IRD likely coincide with marine ice sheet retreat and collapse, with melting icebergs primarily derived from the Thwaites and Pine Island Glaciers (particle provenance studies are in progress). Sand and granule-sized particles are seen fully encased in individual diatomite laminae. Some particles embedded in these laminae show soft-sediment micro-deformation features, further demonstrating precisely coeval IRD and diatomite accumulation. Nearly monospecific laminae of the pelagic diatom *Thalassiothrix antarctica* also include preserved plankton fecal pellets with clusters of barite grains, further indicative of high primary productivity and accumulation. The data provides evidence to support the hypothesis that during ice sheet retreat, continentally sourced nutrients seed diatom productivity in the Southern Ocean. These results may contribute to interpreting past WAIS history by providing another proxy for ice sheet models of potential collapse events, and suggest that ongoing and future ice sheet retreat may enhance Southern Ocean diatom production.



P1-033

Controls on the boron isotope paleoproxy in cultured cold-water corals and the cost of resilience to ocean acidification

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Coral skeletal composition and growth are both sensitive to environmental conditions. However, physiological processes can buffer biomineralization from these external conditions in ways that affect skeletal composition and complicate the interpretation of paleoenvironmental proxies. These same physiological processes can provide apparent resilience to environmental changes like ocean acidification. Understanding the mechanisms of coral calcification is thus crucial for accurately interpreting coral-based climate records and for predicting the vulnerability of different corals to ocean acidification. Here, using boron isotope ($\delta^{11}\text{B}$) measurements on cultured cold-water corals, we explain fundamental features of coral calcification and its sensitivity to environmental change. Boron isotopes are one of the most widely used proxies for past seawater pH, and we observe the expected sensitivity between $\delta^{11}\text{B}$ and pH. Surprisingly, we also discover that coral $\delta^{11}\text{B}$ is independently sensitive to seawater dissolved inorganic carbon (DIC). We can explain this new DIC effect if we introduce boric acid diffusion across cell membranes as a new flux within a geochemical model of biomineralization. This model independently predicts the sensitivity of the $\delta^{11}\text{B}$ -pH proxy, without being trained to these data, even though calcifying fluid pH (pHCF) is constant. Boric acid diffusion can resolve why $\delta^{11}\text{B}$ is a useful proxy across a range of calcifiers, including foraminifera, even when calcifying fluid pH differs from seawater. Our modeling shows that $\delta^{11}\text{B}$ cannot be interpreted unequivocally as a direct tracer of pHCF. Constant pHCF implies similar calcification rates as seawater pH decreases, which can explain the resilience of some corals to ocean acidification. However, we show that this resilience has a hidden energetic cost such that calcification becomes less efficient in an acidifying ocean.



P1-034

Small Signals With A Big Impact: How Marine Organisms Build Their Shells and How These Shells Record Climate

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From the pace of the ice ages to how the carbon cycle has changed through time, much of what we know about the role of the ocean in past climate is based on the chemical signatures locked within marine biominerals like foraminifera. Recorded as trace element anomalies or as isotopic shifts, these chemical signatures reflect how mass and energy move across the planet. However, skeletal composition rarely follows a simple relationship with environmental conditions. Instead, biomineralization leads to heterogeneity and biases. This biological variability can complicate the interpretation of climate records, but it also represents a rich and largely untapped signal. Major advances in our understanding of both biomineralization and paleoproxies hinge on new techniques that can isolate and explain these small signals. To probe the mechanisms controlling biomineralization and sub-micron compositional variability, we use a suite of high spatial resolution tools: NanoSIMS, ToF-SIMS, and Atom Probe Tomography (APT), together with stable isotope labels and biomineral culture. In planktonic foraminifera we conducted modified pulse chase experiments using isotope tracers to measure ion transport rates during biomineralization. By varying elemental concentrations in the surrounding seawater during these pulse chase experiments, we induced systematic shifts in the ion transport rate. The magnitude of these shifts indirectly measures the elemental composition of the calcifying microenvironment, a key and previously unmeasured parameter affecting skeletal chemistry and paleoproxy systematics. Related experiments applying APT to the organic-mineral interface in foraminifera uncovered aspects of the organic templating process during skeletal nucleation. Collectively these experiments can help explain small-scale proxy heterogeneity, upscale this variability to bulk composition, and more accurately resolve specific environmental signals from the geochemical record.



P1-014

Pore patterns of epifaunal benthic foraminifera as paleoxygenation proxy in the South-East Pacific Ocean

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Foraminiferal tests, which are made of biomineralized crystals, are more or less impermeable to small molecules. However, the living cell protected by this calcareous test needs an exchange of gasses (O_2 and CO_2) with the water. Thus, many foraminifera (planktic and benthic) have developed structures for gas exchange through the test wall, consisting of tubular holes (pores) perpendicular to the wall surface. It is generally thought that changes in benthic foraminiferal pore patterns can be explained by phenotypic or genetic adaptations to environmental parameters affecting gas exchange, including temperature, oxygen, or nitrate concentrations.

Recently, it has been proposed that the pore density and/or pore surface in some benthic foraminiferal taxa could be inversely related to oxygen concentrations in the bottom water. Therefore, foraminifera would increase total porosity for increasing oxygen uptake. The adaptative relationship between pore patterns and environmental conditions has led to propose the use of the pore surface area in fossil epifaunal benthic foraminifera as a proxy for past conditions in deep ocean oxygen and redox levels. In order to evaluate the use of this proxy for reconstructing paleoceanographic conditions in the South-East Pacific (SEP), we analyzed stained and not stained specimens of benthic foraminifera epifaunal taxa from surface sediment samples collected at water depths between 127 and 2,733 m off Peru and Chile (10-45°S). All sediments dated younger than 1,000 years (^{14}C age). We measured the number of pores, their area, percentage, and radius on the penultimate and antepenultimate chambers (ventral and dorsal sides), and on the whole test area for both sides. The establishment of the relationship between pores and bottom oxygen content is the first approach to using the pore density and surface area of epifaunal foraminifera as a calibrated proxy for changes in deep ocean oxygenation in the SEP over the geological record.



P1-112

Enhanced seasonal food supply to the seafloor at ODP Site 1085 (southeast Atlantic Ocean) during the Late Miocene Biogenic Bloom

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The Late Miocene Biogenic Bloom (LMBB) is a paleoceanographic event that has been traditionally related to increased primary productivity and associated with changes in the marine carbon cycle. Documented in the Indian, Pacific, and Atlantic Oceans, this unusual increase in primary productivity remains a mystery in the geological record because the processes and mechanisms related to this event are not yet fully understood. Different explanations have been proposed to account for persisting and anomalously high productivity conditions, from the increased delivery of nutrients to the oceans and intensification of the Late Miocene Asian monsoon, to major changes in the ocean circulation, and intensification of regional upwelling. Here we investigate the Biogenic Bloom at ODP Site 1085 (Cape Basin, southeast Atlantic Ocean), located in the outer rim of the Oranje River fan under the influence of the Angola/Namibia system, one of the largest upwelling regions in the world. We generated an integrated bio-astrochronological age model and a quantitative benthic foraminiferal record across an interval spanning from the Tortonian (Late Miocene) to the Zanclean (Early Pliocene). An increased nutrient supply to the seafloor during the Biogenic Bloom is inferred from benthic foraminiferal assemblages. The high relative abundance of phytodetritus exploiting taxa (i.e., *Alabamina weddellensis*, *Epistominella exigua*) point to an episodic food flux to the seafloor, related to seasonal phytoplankton blooms during the LMBB.

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P1-021

Can coccoliths morphological attributes be applied as past ocean carbonate chemistry proxies? - a study case from the South China Sea

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Understanding the variations in past ocean carbonate chemistry is critical in elucidating the role of the oceans in balancing the global carbon cycle. Marine calcifiers tests are widely used as past ocean carbonate chemistry proxies, however, the complexity of the carbonate system and ecological aspects limit the interpretation of these proxies. Therefore, there is a need to calibrate existing or develop new proxies to improve our past ocean chemistry changes reconstruction capacity. Here we present a new dissolution proxy based on the morphological attributes of fossil coccolithophores from surface sediments of the South China Sea (SCS). We applied morphological attributes (length, volume, thickness, and shape factor “ks”) from the Noelaerhabdaceae group (*Emiliana huxleyi* and *Gephyrocapsa* spp.) to evaluate coccolithophore calcification and preservation aspects. Surface sediments samples were retrieved along a depth gradient (629 – 3809 m) in the SCS during the R/V SO-95 cruises. The morphological attributes and environmental data, including mean annual seawater temperature, salinity, nutrients, total alkalinity and CO₂, pH, and CO₃⁻ at 50 m depth, and calcium carbonate saturation (Ω_{ca}) at bottom depth from surface samples site locations, were normalized using a box-cox transformation and combined in a redundancy analysis (RDA) to assess potential relationships. The RDA results presented samples mainly distributed along the first axis (RDA1) which explained 54.6% of the total variation in the morphological data. The RDA1 was highly correlated with the Wca at bottom depth (R=0.62). The variance of the morphological data was primarily explained by the Ω_{ca} saturation at depth. The mean Ω_{ca} was the environmental variable that explained the highest amount of variance on the ks shape factor (R²=0.47). Our results showed that the mean ks in fossil coccolithophores have the potential to be used as quantitative indicators of past carbonate dissolution changes.



P1-010

The role of benthic foraminifera in nutrient cycling and their potential to reconstruct past nutrient budgets

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Benthic foraminifera populate diverse marine habitats from saltmarsh meadows to the deepest parts of ocean. They play an important role in marine nutrient cycling, due to their metabolic adaptations to anaerobic environments and their high abundances in oxygen (O₂) depleted habitats. The ability to denitrify is widespread among foraminiferal species that inhabit anaerobic environments making them an important sink for bioavailable nitrogen. Our recent results show that intracellular phosphate storage is also common among diverse benthic species. This attribute seems to be another adaptation to O₂ depletion and likely facilitates phosphogenesis at the Peruvian oxygen minimum zone. Here we will review the influence of foraminifera on marine nutrient budgets and how we can use this knowledge to reconstruct past nutrient budgets. The porosity of the denitrifying benthic foraminifer *Bolivina spissa* is closely correlated to the nitrate availability in its habitat. The pore density increases with decreasing nitrate concentrations and thus compensate the uptake of nitrate. We present a compiled calibration of pore density vs. bottom water nitrate concentration using *B. spissa* specimens from the oxygen minimum zones off Peru and Costa Rica and from Sagami Bay, Japan. In addition, we will compare pore characteristics of *B. spissa* with the closely related species *Bolivina subadvena* and *Bolivina argentea* that often inhabit similar or even the same environments. While the pore densities of *B. spissa* and *B. subadvena* are very similar, *B. argentea* has a higher pore density and smaller pores. This indicates that *B. subadvena* might also be suitable to reconstruct past nitrate concentrations. Finally, we present a case study with a nitrate reconstruction from the Peruvian oxygen minimum zone covering the past 22,000 years.



P1-005

A quantitative, deglacial nitrate reconstruction in the intermediate Pacific using the pore density of the denitrifying benthic foraminifer *Bolivina spissa*

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Increasing anthropogenic production and the use of chemical fertilizers is altering the marine nitrogen cycle on a global scale. Nitrate (NO_3^-) is an important macronutrient limiting in some marine environments. Various box modelling studies revealed elevated NO_3^- levels during glacials due to reduced water column denitrification as compared to interglacials. Our study aims to generate a widespread, quantitative reconstruction of bottom-water NO_3^- concentrations ($[\text{NO}_3^-]_{\text{BW}}$) in the intermediate Pacific covering the last deglaciation. We utilize the pore density of the denitrifying benthic foraminifer *Bolivina spissa* as proxy for deglacial $[\text{NO}_3^-]$ at four different locations of the intermediate Pacific and its marginal side basins (i.e. Mexican & Peruvian Margin, Gulf of California & Sea of Okhotsk). *B. spissa* is abundant in oxygen-depleted environments all around the Pacific and is able to use NO_3^- as an electron acceptor instead of oxygen. Because this species increases its pore density when NO_3^- is depleted to optimize the NO_3^- uptake, there is a highly significant correlation between the pore density of *B. spissa* and $[\text{NO}_3^-]_{\text{BW}}$. A comprehensive understanding about past nutrient cycling under rapidly changing climatic conditions such as a glacial termination is one prerequisite to predict future changes in marine nutrient budgets.

Keywords: *Marine nitrogen cycle, benthic foraminifera, pore density, denitrification*



P1-116

Deoxygenation of the Pacific during the Pliocene

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The oxygen content of the world's oceans is essential for the survival of most organisms and therefore has severe economic impact when conditions deteriorate. With ongoing global climate change, the oceans are warming and therefore less oxygen can be dissolved into the sea water. In addition, increasing pollutants are flushed into the oceans such that coastal areas are also becoming starved of oxygen and thus life. To understand the impact of decreasing oxygen content on the marine ecosystem, the history of changing oxygen content can teach us what to expect in the future. Foraminifera are the ultimate tool to study these changes, as they have been shown to not only survive but also calcify, which is essential for using their geochemistry, under low-oxygen conditions. During calcification they are incorporating redox-sensitive elements like manganese indicative of the dissolved oxygen content of the water at time of calcification into their shells. Here I use foraminiferal Mn/Ca to investigate how the Pacific gained its present day state of low oxygen content during the final stages of the Pliocene. I will test the hypotheses that firstly the Pacific rapidly lost its oxygen after onset of the Northern Hemisphere Glaciation (NHG; ~2.7 Ma) due to water column stratification in the North-Pacific; secondly that short-term North Pacific stratification during Marine Isotope Stage (MIS) M2 (~3.3 Ma) decreased Pacific oxygen content; and thirdly that oxygen content in the Pacific temporarily recovered during the first warm interglacials (~2.5 Ma) after the onset of NHG. Foraminiferal Mn/Ca was analyzed on both surface and thermocline dwelling species for east-Pacific ODP sites 1236 and 1241.



P1-086

Key controls over interstitial water $\delta^{11}\text{B}$, $\delta^{30}\text{Si}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ in Southern Ocean sediments recovered during IODP Expedition 382

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During IODP Expedition 382, five sites were drilled in the Atlantic sector of the Southern Ocean (Scotia Sea). Sediments at all locations alternate between dominant terrigenous components during glacials and dominant biogenic components, carbonate at the northerly sites and opal in the southern Scotia Sea, during interglacials. We investigate the isotope geochemical environment at these sites employing the boron ($\delta^{11}\text{B}$), silicon ($\delta^{30}\text{Si}$) and $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic composition of interstitial waters alongside shipboard derived geochemical data. Our analytical approach is further substantiated by a non-steady state transport-reaction model that allows a clear diagenetic characterisation of IODP Site U1537 sediments. The model considers release of B, Si and Sr from terrigenous phases (in situ weathering), dissolution of biogenic opal, desorption/adsorption processes, as well as precipitation of authigenic phases. Advection of deep-seated fluids circulating through the sediment are also important.

Interstitial water $\delta^{11}\text{B}$ and $\delta^{30}\text{Si}$ substantially decrease in the uppermost tens of metres downcore. This process can be most accurately modelled via in situ weathering of clays preferentially releasing light isotopes to interstitial waters, although biogenic opal and desorption processes from Fe-Mn oxyhydroxides seem equally important for the $\delta^{30}\text{Si}$ budget. Both $\delta^{30}\text{Si}$ and $\delta^{11}\text{B}$ increase at deeper levels within the sediments, tracing most dominantly the increasing importance of authigenic mineral formation at every core site. Deeper interstitial waters at the southern Scotia Sea sites reveal an increasing importance of off-axis hydrothermal fluids within the basement underlying the sediments, detectable by lowest $^{87}\text{Sr}/^{86}\text{Sr}$ and strongly decreasing $\delta^{11}\text{B}$. These fluids circulating through the sedimentary column are also notably enriched in B and Sr. Our data further demonstrate why Nd isotope compositions obtained from authigenic Fe-Mn oxyhydroxides here do not reflect ambient bottom water.



P1-104

Mid Miocene seawater isotope reconstructions: comparison between foraminifera based oxygen isotopes and alkenone based hydrogen isotopes

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One of the most important oceanographic parameters that cannot be reconstructed accurately enough from sedimentary records is salinity. While we can estimate changes during the Holocene with the combination of high-resolution foraminifera records, pore water analysis and climate models, the reconstruction of older records remains a challenge.

In the last decade both culture and environmental studies have shown that the hydrogen isotopic composition of long-chain alkenones ($\delta^2\text{H}_{\text{C}_{37}}$) depends on the hydrogen isotopic composition of sea water, which correlates with salinity, and salinity itself (Schouten et al., 2006; Weiss et al., 2019; Gould et al., 2019). This observation and the fact that alkenones, produced by coccolithophores, are abundant in sediments up till ca. 40 Ma make them a potentially paleo salinity proxy.

Here, we compare foraminifera based oxygen isotope and alkenone based hydrogen isotope reconstructions of seawater from a sediment record covering the Mid-Miocene (IODP Site U1318, eastern North Atlantic Ocean, Sangiorgi et al., 2021), a time period with known changes in global ice volume. Previously published biomarker and dinoflagellate cyst proxies (Sangiorgi et al., 2021) indicate a warm and mostly stratified water column during the Miocene Climate Optimum (MCO) which cooled about 3 degrees across the Miocene Climate Transition (MCT). Additionally, 11 transient cooling events were documented using organic biomarker based (TEX_{86} and U^{K}_{37}) paleothermometers.

Remarkably, the benthic oxygen isotopes in U1318 as well as the global benthic $\delta^{18}\text{O}$ stack reveals a strong correlation with the SST proxies which indicates that the oxygen isotopes are highly temperature controlled at this site. However, the alkenone hydrogen isotope record shows different isotope excursions pointing to a decoupling in isotopic evolution between surface and bottom waters, with the former potentially affected by local changes in salinity, runoff, and precipitation.



P1-063

Paleoceanography across the Pliocene–Pleistocene transition in the southern Bering Sea: dinoflagellate cysts and acritarchs from IODP Site U1341

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The latest Pliocene–earliest Pleistocene (2.83 Ma to 2.40 Ma) interval from Integrated Ocean Drilling Program Site U1341, Bowers Ridge, southern Bering Sea, northern North Pacific has been analyzed for dinoflagellate cysts, acritarchs and other palynomorphs. Based on 86 samples, with a spacing equivalent to between 500 and 6000 years, this is the most stratigraphically detailed late Cenozoic marine palynological study yet undertaken in the Bering Sea. The dinoflagellate cyst assemblages are characterized by low taxonomic richness: round brown cysts including *Brigantedinium simplex* dominate assemblages which also include *Lejeunecysta cinctoria*, *L. fallax*, *Selenopemphix nephroides*, *Trinovantedinium variabile*, and *Trinovantedinium cf. harpagonium* (heterotrophic taxa); and *Cerebrocysta? sp.*, *Impagidinium detroitense*, *Impagidinium* spp. indet., and *Nematosphaeropsis labyrinthus* (phototrophic taxa). Marine acritarchs are represented by *Cymatiosphaera? invaginata* which is often abundant. Two informal assemblage biozones are proposed: biozone MP-A (~2.828 Ma to 2.497 Ma) and biozone MP-B (~2.477–2.401 Ma). The co-dominance of round brown cysts and the extinct high-latitude acritarch *Cymatiosphaera? invaginata* in biozone MP-A reflects predominantly cold and reduced-salinity surface waters with intermittent incursions of warm and higher salinity waters from the Alaskan Stream. The absence of pronounced changes in the dinoflagellate cyst assemblages within biozone MP-A reflects the enclosed nature of the Bering Sea and low taxonomic richness of the marine palynomorph record. However, the MP-A/ MP-B biozone boundary at 2.47 Ma marks a major change in the hydrography of the Bering Sea, as expressed by an abrupt decline in *Cymatiosphaera? invaginata* and increased proportions of terrestrial plant matter, suggesting an important increase in the influence of river discharge at Site U1341. Sporadic incursions of the Alaska Stream nonetheless continued after 2.47 Ma.



P1-057

A Pliocene-Pleistocene record of aridity/humidity variability over North Africa

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Records of North African climate are essential to get a mechanistic understanding of the link between insolation changes and global climate variability. An established way to reconstruct North African climate is by the use of the ratio of titanium to aluminum (Ti/Al) in sediment cores from the eastern Mediterranean Sea. During humid intervals these sediments contain an increased amount of aluminum-rich clays from North African rivers, while during arid intervals these sediments contain more titanium-rich dust from North African deserts. Therefore, high/low values of Ti/Al correspond to arid/humid conditions in North Africa, respectively.

Records of the Ti/Al ratio are often produced using traditional chemical techniques that give accurate results, but are time consuming and expensive. Here, we demonstrate how to obtain reliable Ti/Al data using X-Ray Fluorescence (XRF) core scanning; a method that allows rapid data generation at low expense. An essential component to obtain accurate Ti/Al data by XRF-scanning is through calibration of the raw intensity data. Our results have important implications for other elements too, as this shows that appropriate calibration can result in useful XRF-scanning data for paleoenvironmental purposes, even if the initial intensity data for elements did not correspond with accurate reference data.

Using this method, we reconstruct a long 3-Myr North African climate record from eastern Mediterranean Sea sediments (ODP Site 967). We show that (1) African environment variability was dominantly paced by low-latitude insolation alone from 3 to 1.2 million years ago, and (2) ice ages only left a notable imprint on North African aridity/humidity after the mid-Pleistocene transition (~1.2-0.7 Ma).



P1-022

Hydrographic control of carbon isotope fractionation in coccolithophores in the North Atlantic during the Mid-Pleistocene

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The carbon isotopic fractionation during photosynthesis (ϵ_p) from sedimentary alkenone biomarkers produced by coccolithophores are a widely used proxy for concentrations of past dissolved CO₂ in seawater (CO_{2(aq)}). Currently, ϵ_p records covering the last 1 Myr exist only for oligotrophic locations at low-latitudes regions. Higher latitudes are affected by more variable hydrographic conditions which are expected to produce larger changes in factors which are important for ϵ_p , such as light, temperature, CO₂ and growth rate. Understanding these processes at high latitudes is important in order to derive correct estimates of past CO₂ concentrations. Here we present a new ϵ_p records, alkenone-based temperature reconstructions and review previously published micropaleontological and geochemical records sensitive to hydrographic circulation changes, from sites across a latitudinal transect in the eastern North Atlantic (66°-37°N) for the 800-400 ka time interval. During this period, the subpolar hydrographic fronts shifted latitudinally at orbital and sub-orbital time-scales, leading to large zonal and meridional environmental gradients in the North Atlantic. We observe that ϵ_p and climate-state relationships (depicted by $\delta^{18}O_p$) are similar across different regions. ϵ_p are lower at mid-latitude regions (sites U1385 and U1313), due a higher growth rate during colder intervals. In the high-latitude sites, a longitudinal gradient is observed, with higher ϵ_p during glacial intervals eastward (Site 982) compared to interglacials, as opposite to sites located westward (sites U1314 and 984). We suggest that this is the result of the uninterrupted northward flow of warm atlantic waters through towards the east, which sustained high coccolithophore productivity and growth rate, depressing ϵ_p values at Site 982 during interglacial intervals. Combining high-latitude planktonic foraminifera species and calcium carbonate records, we reconstruct the effect of non-CO₂ factors on ϵ_p .



P1-106

Emergence of the Pacific Oxygen Minimum Zone

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The Pacific Ocean hosts the worlds largest and intense oxygen minimum zone. The emergence of this oxygen minimum zone has been linked to the closure of the Panama Isthmus between 5 and 15 million years ago, which caused dramatic changes in global ocean circulation and climate. It has been hypothesized that the Pacific basin was relatively well ventilated during the early Miocene, with inflow of North Atlantic Deep Water into the Pacific. Uplift of the sill from the mid Miocene is thought to have restricted circulation causing a reduction in deep ocean ventilation, whilst full closure of the seaway caused sluggish circulation of subsurface waters in the eastern tropical Pacific, leading to the development of an extensive OMZ in the north- and south- eastern Pacific. The timing of the emergence of the OMZ is unknown. Here we review various proxy evidence to assess when the oxygen minimum zone emerged in the Pacific Ocean. We compare this with new planktic foraminifera iodine/calcium ratios, a promising tool to reconstruct the extent of past upper ocean oxygenation, using ODP sediment samples.



P1-094

Terrestrial input changes coupled to the Panama Isthmus closing from 8 to 4 Ma

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We track changes in terrestrial input during the Isthmus closing period of 8 to 4 Ma at ODP sites 999 in the Caribbean and 1241 in the Pacific. We used a combination of plant wax *n*-alkanes and soil-derived branched-GDGTs, organic proxies and elemental ratios to 1. distinguish between different sources of terrestrial matter and 2. link changes to different triggering factors. While recent-day terrestrial input is higher in the Pacific associated to river discharge (Huguet et al. 2019), our data indicate higher values at the Caribbean site. Lower biomarker concentrations at site 1241 argues for lesser terrigenous input due to a greater distance to source(s) as the key factor. Terrestrial input at site 999 is controlled mainly by Andean tectonic uplift and inputs derived from South and Central America especially from the Magdalena River system (Mora and Martínez, 2005; Peters et al., 2000). Additionally, the uplift pulses may be coupled to increased precipitation resulting in turn in an increase of continental material being delivered to the Caribbean site. In contrast most of the terrestrial input at site 1241 was likely transported by winds and through ocean currents and thus may be linked to trade wind and ENSO dynamics during the study period. While the drift of site 1241 also needs to be considered for riverine input, the influence of the trade winds remains dominant along the trajectory of the site. A clear impact of the intensification of trade winds coupled to an increase in precipitation is observed between 8 and 6.4 Ma and 5.8 to 5.4 Ma (Hovan, 1995).

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P1-081

Oceanic regime shifts south of Iceland from Marine Isotope Stage 3

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Owing to its geographical position, Iceland's marine realm and the ecosystem it supports are affected by changes in the wider North Atlantic circulation system. Heat and salt are transported north by the North Atlantic Current, and after modification in the Nordic Seas, returned southward via the Iceland-Scotland and Denmark Strait Overflows. This unique configuration of currents is modulated by the strength of the Subpolar Gyre and thus position of the Subpolar Front. Several rapid migrations of the subpolar front occurred during the Last Interglacial (Eemian) 150 – 130 ka BP (Mokeddem et al., 2014) and more recently, exceptional warming of waters south of Iceland in the late 20th century have led to profound changes in the marine ecosystem (e.g., Spooner et al., 2020).

With a focus on past warm periods and targeting key climate transitions, we investigate a transect of three recently recovered marine sediment cores from south/southwest Iceland that lie along the main pathways of Atlantic water inflow. Chronologies, relying on a combination of radiocarbon dating and tephrochronology, indicate that these records extend back into Marine Isotope Stage 3 (MIS 3). Fossil foraminifera are used to qualitatively assess the water masses present (assemblage assessment) and quantify the properties of these water masses (e.g., temperature, salinity) back through time. We aim to characterize the impacts of global change on the Icelandic oceanographic regime and ecosystem, as well as identify any leads or lags in the response time to wider oceanic and climate variability, particularly across the transition from MIS 3 into the Last Glacial Maximum and the subsequent transition into the current interglacial.



P1-043

Carbon cycle responses to step-changes in weathering: investigating the long-term fate of CO₂ and δ¹³C

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Many changes in the carbon cycle, as documented in ice cores and marine sediments, remain unexplained to this day. On centennial to millennial timescales, variations in CO₂ and δ¹³C are often caused by reallocation of carbon between the relatively fast exchanging carbon reservoirs atmosphere, ocean, and land biosphere (AOB), while on multi-millennial and longer timescales imbalances between the weathering input from the geologic reservoir to and removal from the combined AOB reservoir back to the geologic reservoir influence CO₂ and δ¹³C and cannot be neglected.

Here, we use the Bern3D Earth system model of intermediate complexity to perform idealized, 100 and 600 kyr long simulations to systematically investigate the effect of step-changes in weathering input fluxes of alkalinity, nutrients, carbon, and carbon isotopes on carbon and δ¹³C in the atmosphere and ocean. The Bern3D includes a dynamic 3-dimensional ocean circulation-carbon cycle model coupled to an energy-moisture balance atmosphere and a sediment module. Burial fluxes of CaCO₃, organic matter, and opal are explicitly simulated.

While the carbon cycle approaches a new equilibrium with an e-folding timescale on the order of 10 kyr, equilibration of the carbon isotopic perturbation requires several 100 kyr. Small changes in the δ¹³C signature of carbon burial fluxes outweigh the effect of changes in the carbon flux. Further, distinct spatio-temporal patterns in Δδ¹³C_{DIC} evolve as the result of changes in fractionation during marine photosynthesis and subsequent remineralization of this organic matter in intermediate depth waters. A thorough understanding of the mechanisms affecting, for example, Δδ¹³C_{DIC}, will help in the interpretation of paleo-records.

Results from the experiments are used to construct an emulator to probe the response in Δδ¹³C_{DIC} and CO₂ to changing periodicity in the forcing which can be further applied in numerous ways.



P1-108

Ecological and environmental drivers of calcareous nannoplankton community change following the Cretaceous-Paleogene (K/Pg) mass extinction at a distal shelf site (El Kef, Tunisia)

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The Cretaceous-Paleogene (K/Pg) mass extinction ~66.0 Ma eliminated >75% of marine species on Earth and drove large-scale ecological reorganization. In particular, the nearly complete extinction of calcareous nannoplankton – the most dominant phytoplankton group at the end of the Cretaceous – led to a shift in community structure within marine primary producers, which likely had profound knock-on effects on trophic interactions and the marine carbon cycle.

The recovery of nannoplankton during the first ~2-4 million years of the Danian is characterized by a series of short-lived opportunistic taxa (“boom-bust” successions). These communities likely represent ecological experimentation, whereby nannoplankton rapidly evolved and adapted to gradually alleviating environmental conditions following the asteroid impact. However, the key ecological and environmental mechanisms that drove the taxonomic switchovers within boom-bust successions are still uncertain. Here, we present a new, high-resolution record of nannoplankton community change for the first ~3.5 Myr of the Paleocene in rotary-drilled cores from El Kef (Tunisia), near the stratotype section for the base of the Danian. By comparing our paleoecological record to bulk carbonate $\delta^{13}\text{C}$ data, we reveal that nannoplankton boom-bust successions are correlated to changes in marine carbon cycling. Therefore, taxonomic switchovers were likely driven by the gradual restoration of biological pump efficiency and changes in surface ocean nutrient availability following the K/Pg impact.

To better understand the global significance of boom-bust successions, we also conducted a statistical meta-analysis that incorporates nannoplankton records from 8 other K/Pg sites. We observe that the series of taxa that comprise boom-bust successions at each site differ, perhaps due to geographical differences in the timing of biological pump recovery, the depositional setting, and the influence of regional, or even local, ecological factors.



P1-025

Reconstructing the secular evolution of boron isotope composition of seawater from evaporites

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The ocean boron isotope composition is homogeneous, but varies over its residence time on time scales of approximately 10 million years. To date, however, the secular evolution of the oceanic boron isotope budget has been difficult to constrain. The lack of knowledge on past boron isotope composition of seawater ($\delta^{11}\text{B}_{\text{sw}}$) not only limits our understanding of global boron biogeochemical cycling through time, but poses the major uncertainty to reliable boron-based pH and pCO_2 reconstructions from Earth's geologic past. Evaporites, and halites in particular, present a highly appealing archive for reconstructing $\delta^{11}\text{B}_{\text{sw}}$ given their direct origin from seawater, however, the interpretation of their boron isotope signatures is not straightforward due to the possibility of fractionation during evaporation and crystallisation. We present boron isotope evolution during evaporite formation from laboratory experiments and natural modern settings. These data enable us to place constraints on boron fractionation in ancient evaporites, offering new insights into $\delta^{11}\text{B}_{\text{sw}}$ during some of the key periods of the Phanerozoic.



P1-029

Evaluation of S/Ca in planktonic foraminifera as a carbonate system proxy

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Studying the geological past with naturally varying CO₂ levels provides potential insight into global-scale consequences of the ongoing increase of atmospheric CO₂, including the slow feedbacks of different carbon reservoirs involved. However, this approach relies on the accurate reconstruction of sea water inorganic carbon chemistry. Well-known tracers for past changes in the marine inorganic carbon cycle include both organic (e.g. δ¹³C of alkenones) and inorganic (e.g. δ¹¹B of foraminifera shells) proxy signal carriers, which are rarely in complete agreement. Offsets may be caused by uncertainties in the assumptions for the underlying methods and an incomplete picture of the carbon system. Both issues motivate improving available carbonate system proxies and developing new proxies for yet unconstrained parameters. Therefore, we investigate sulfur (S) incorporation into foraminiferal shell carbonate, which has previously been suggested as a potential proxy for seawater inorganic carbon chemistry. Sulfate (SO₄²⁻) is assumed to be the dominant sulfur ion incorporated into the calcium carbonate, replacing carbonate ions and hence increasing with a decrease in the saturation state (i.e. increasing SO₄²⁻/CO₃²⁻). We analyze sulfur concentrations of various planktonic foraminifera, including *G. bulloides*, *G. ruber*, and *G. sacculifer*, in core top sediments from regions with contrasting surface water [CO₃²⁻] values. Our preliminary results indicate that 1) [CO₃²⁻] may not be the only parameter affecting the incorporation of sulfur in CaCO₃ and 2) the primary [CO₃²⁻] control may be overwritten by more than one parameter. With this field survey, we investigate the major controlling parameters on foraminiferal S/Ca by evaluating the influence of the carbonate system and covarying trace elements.



P1-064

Role of the Central American Seaway closure in developing the tropical Pacific oxygen minimum zone from model simulations

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The world's largest oxygen minimum zone (OMZ) resides in the eastern tropical Pacific where poor oceanic ventilation and high biological production are both favourable for ocean oxygen deficiency in this area. The modern continental configuration with the Panamanian isthmus prevents the Pacific-Atlantic water mass exchange, shaping the climate and marine biogeochemistry in this region. The tectonic transition from the open to closed Central American Seaway (CAS) during the mid-Miocene to mid-Pliocene (~16-3 Ma BP) can be considered as a key interval for the development of the tropical Pacific OMZ. This study aims at investigating the impact of the Pliocene CAS closure on the large-scale ocean circulation and its role for the emergence of the modern tropical Pacific OMZ. To this end, we employ the global climate model KCM in combination with the biogeochemical model PISCES.

According to our experiments, the Pliocene CAS closure has led to the termination of fresh-water supply from the Pacific to the North Atlantic and therefore to an intensification of the Atlantic Meridional Overturning Circulation. This result is supported by many previous modelling studies. It was also found that the open CAS is associated with eastward subsurface flow in the eastern tropical Pacific, thus enhancing water mass ventilation in this area. This, in turn, leads to an increase in marine oxygen concentrations in the eastern tropical Pacific during the Miocene.

Marine biological production is another important factor affecting the OMZ maintenance. We show that the CAS closure is associated with the cessation of the former export of nutrients from the Pacific towards the Atlantic. This, in turn, leads to increased net primary production (NPP) in the eastern tropical Pacific and, therefore, to higher oxygen consumption in this region. Both altered NPP and ocean ventilation contribute effectively to the OMZ development in the eastern tropical Pacific for the modern continental configuration.



P1-019

Effectiveness of glycerol dialkyl glycerol tetraethers in suspended materials in northern East China Sea as paleothermometer proxy

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The spatial and seasonal distributions of the glycerol dialkyl glycerol tetraether (GDGT) concentrations in suspended materials were investigated to check the suitability of using GDGT-based TEX₈₆ as a proxy of past sea surface temperatures in the East China Sea (ECS). Surface and subsurface seawater samples of the northern ECS were collected seasonally at three-month intervals. GDGTs in the surface seawater samples were detected consistently throughout the entire study area and seasons. However, there are large differences between TEX₈₆ temperatures and in situ temperatures of the surface seawater. Comparing in situ temperatures, TEX₈₆ temperatures were higher in winter and lower in summer. On the other hand, GDGT concentrations were high in near the bottom, with large differences between TEX₈₆ and in situ temperatures in shallow area (water depth, ~30 m). These results support the probability of sediment resuspension near the bottom in the shallow western area. It can be caused by vertical mixing by strong winds, such as those from the monsoon (winter) and typhoons (summer), and turbulences near the bottom caused by tides across all seasons in the shallow waters. Meanwhile, the maximum GDGT concentration was detected between 20 m and 50 m in all seasons in the eastern part of the study area deeper than 100 m. The TEX₈₆ temperatures of the subsurface samples were close to or warmer than in situ temperatures between 20 m and 50 m. These results indicate that the main production depth of GDGT in the deeper eastern area could be the subsurface in that depth range. Additionally, a low correlation between TEX₈₆ and non-thermal factors, such as DO, NH₄-N and NO₃-N, suggest that non-thermal factors did not directly affect TEX₈₆ in the study area. Overall results indicate that resuspension of sediment and subsurface production of GDGTs can influence significantly on the use of GDGT-based TEX₈₆ as an SST proxy in shelf area.



P1-082

Glacial carbon cycle changes by Southern Ocean processes with sedimentary amplification

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Recent paleo reconstructions suggest that increased carbon storage in the Southern Ocean during glacial periods contributed to low glacial atmospheric carbon dioxide concentration ($p\text{CO}_2$). However, quantifying its contribution in three-dimensional ocean general circulation models (OGCMs) has proven challenging. Here, we show that OGCM simulation with sedimentary process considering enhanced Southern Ocean salinity stratification and iron fertilization from glaciogenic dust during glacial periods improves model-data agreement of glacial deep water with isotopically light carbon, low oxygen, and old radiocarbon ages. The glacial simulation shows a 77-ppm reduction of atmospheric $p\text{CO}_2$, which closely matches the paleo record. The Southern Ocean salinity stratification and the iron fertilization from glaciogenic dust amplified the carbonate sedimentary feedback, which caused most of the increased carbon storage in the deep ocean and played an important role in $p\text{CO}_2$ reduction. The model-data agreement of Southern Ocean properties is crucial for simulating glacial changes in the ocean carbon cycle.



P1-096

Carbon cycle changes during the Hirnantian as inferred from calcium isotopes

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The drawdown of atmospheric CO₂ via the chemical weathering of silicate rocks is generally considered to be the primary control on the Earth's climate over geologic timescales [1]. During the Hirnantian it is thought that temperatures decreased significantly, triggering an expansion of glacial coverage [2], which may have contributed towards Earth's second largest mass extinction event. However, the main driver behind this climatic event is still uncertain.

Here we present $\delta^{44/40}\text{Ca}$ data obtained from the bulk carbonates of the Point Laframboise and Ellis Bay West sections of Anticosti Island, Canada. The intimate coupling of the calcium and carbon cycles means that calcium isotopes can be employed to constrain carbon cycle dynamics, or vice versa, and can also provide information on certain sulfur cycle dynamics.

Our $\delta^{44/40}\text{Ca}$ data exhibit a positive excursion of ~0.5 to 0.7‰, reproduced at the different sections. Alongside a previously published $\delta^7\text{Li}$ record [3], which can be used to understand changes in the ratio of primary mineral dissolution to secondary mineral formation [4], we use a biogeochemical box model to explore changes to the carbon cycle, weathering congruency, and the expansion of terrestrial vegetation during the Hirnantian.

[1] Walker *et al.* (1981) *J. Geophys. Res.* **86**, 9776-9782 [2] Elrick *et al.* (2013) *Geology*. **41**, 775-778 [3] PPvS *et al.* (2017) *Geochem. Persp. Let.* **3**, 230-237 [4] PPvS *et al.* (2020) *Elements*. **16**, 253-258



P1-037

Atmospheric CO₂ concentration based on boron isotopes versus simulations of the global carbon cycle during the Plio-Pleistocene

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Atmospheric CO₂ concentration (pCO₂) beyond ice core records is typically based on δ¹¹B derived from planktic foraminifera found in equatorial sediment cores. Here, I applied a carbon cycle model over the Plio-Pleistocene to evaluate the assumptions leading to these reconstructed CO₂ concentrations. During glacial times simulated atmospheric pCO₂ was unequilibrated with pCO₂ in the equatorial surface ocean suggesting a bias of up to 35 ppm in δ¹¹B-based CO₂ concentration. In the Pliocene, surface ocean pH calculated from δ¹¹B in published studies largely differed between equatorial Atlantic and equatorial Pacific. While this difference readily explains most of the resulting pCO₂ offsets between studies, it is not supported by models. The values of an under-constrained second variable (dissolved inorganic carbon or total alkalinity) necessary to calculate pCO₂ were according to my results partly inconsistent with chemically possible combinations of the marine carbonate system. The model results suggest an existing glacial/interglacial variability in total alkalinity of the order of 100 μmol/kg, which is rarely applied to proxy reconstructions. Simulated atmospheric CO₂ is tightly ($r^2 > 0.9$) related to equatorial surface ocean pH. This relationship can be used for consistency checks and it is found that reported atmospheric pCO₂ of 450–550 ppm at 3–3.5 Ma are likely too high by 50–100 ppm. However, long-term trends in volcanic CO₂ outgassing and the strength of the continental weathering fluxes are still unconstrained allowing for a wide range of possible atmospheric CO₂ values across the Plio-Pleistocene.



P1-091

Assemblage specific diatom-bound nitrogen isotope records in the modern and glacial Atlantic sector Antarctic Zone spanning the last 150 kyrs: The nitrate exhaustion hypothesis

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In the modern Southern Ocean's Antarctic Zone (AZ), iron, and light limit phytoplankton growth, allowing nutrients to return to the ocean interior unused and CO₂ to outgas to the atmosphere. More complete nutrient consumption by phytoplankton would stem the "leak" of CO₂ from the AZ, possibly contributing to the reduction in atmospheric CO₂ during ice ages. Diatom-bound nitrogen isotope records ($\delta^{15}\text{N}_{\text{db}}$) generated from fossil diatom opal have been used to assess past nutrient consumption changes, given that diatoms assimilate nitrate with an isotope effect, causing AZ $\delta^{15}\text{N}_{\text{db}}$ to be lower than the $\delta^{15}\text{N}$ of the nitrate supply and to increase with higher degrees of nitrate consumption. Records of $\delta^{15}\text{N}_{\text{db}}$ from the Indian and Pacific sector AZs are elevated during glacial periods relative to interglacial periods, which, when combined with evidence for lower glacial productivity, suggests reduced deep-surface exchange within the AZ. However, a similarly derived glacial-interglacial $\delta^{15}\text{N}_{\text{db}}$ record from the Atlantic sector AZ shows the opposite pattern to the Indo-Pacific. This difference has been proposed to be a consequence of glacial-interglacial changes in the relative abundances of diatom taxa in the diatom opal sample. Using updated methods to produce distinct, total, pennate and centric diatom fractions, we present a compilation of AZ core top $\delta^{15}\text{N}_{\text{db}}$ and three glacial-interglacial $\delta^{15}\text{N}_{\text{db}}$ records from the eastern Atlantic sector AZ. Our results show elevated $\delta^{15}\text{N}_{\text{db}}$ during interglacials, and reduced $\delta^{15}\text{N}_{\text{db}}$ values during glacials in all three fractions, suggesting the Atlantic sector AZ signal is not a consequence of changes in diatom taxa abundances. We hypothesize that the glacial eastern Atlantic sector AZ experienced acute, early season surface nitrate exhaustion relative to the Indo-Pacific AZ because of uniquely lower deep to surface exchange rates, with diatom growth being fueled by isotopically light recycled N forms such as ammonium.



P1-099

Enhanced biological carbon pump in response to nutrient delivering during OAE2

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The Cretaceous Oceanic Anoxic Event 2 (OAE2, 94 Ma) is one of the most extreme disruptions of carbon and oxygen cycles, leading to a strong increase of carbon burial into the sediments. High nutrient delivery has been shown to enhance marine productivity and carbon export, geological data suggesting a major role of the biology with a reorganization of ecosystems, such as an increased planktonic activity, blooms of siliceous organisms and enhanced nitrogen fixation by diazotrophs. However, productivity and carbon export increase quantifications are scarce and mainly based on nutrient-based models that don't explicitly include ecosystems. In this study, we propose to fill that gap by using the IPSL-CM5A2 Earth System Model that includes the biogeochemical component PISCES. Two sources of nutrients (continental weathering and volcanic ash) are considered in our simulations, that allow to successfully reproduce the extension of anoxia during the preOAE2 and OAE2. A non-linear biological response is simulated related to nutrient delivery, with a 70% increase of phosphorus concentration leading to a 31% increase of marine productivity and a 44% increase of export production, suggesting a more efficient carbon pump. This pattern is explained by a bigger contribution of GOC relative to POC driven by trophic amplification of zooplankton biomass at low latitudes. Diazotrophy and contribution of siliceous organisms also increase, due to iron and silica inputs from volcanism. Our study thus shows the importance of considering ecosystems and various limiting nutrients to quantify carbon cycle changes during OAEs.



P1-051

Roles of insolation forcing and CO₂ forcing on Late Pleistocene seasonal sea surface temperatures

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Disentangling the causes of Late Pleistocene climate variability requires an in-depth understanding of the seasonal and spatial variations of forcing and climate responses. This effort is complicated by the fact that many paleo-proxies exhibit seasonal sensitivities. In this work, we investigate the seasonal sensitivity of foraminiferal Mg/Ca and alkenone temperature records from the same core in the East China Sea located at the western margin of the subtropical North Pacific Ocean over the last four interglacial-glacial cycles. The Mg/Ca ratio- and alkenone-based SSTs reflect summer and annual mean temperatures, respectively. We further calculate winter temperature based on the reconstructed annual mean and summer temperatures. Comparisons of annual mean and seasonal (summer and winter) temperature variability with orbital forcing and greenhouse gas forcing indicate that changes in annual mean and seasonal temperatures differ in response to insolation and CO₂ forcing. During interglacial-glacial cycles, there are phase differences between annual mean and seasonal (summer and winter) temperatures, which relate to seasonal insolation changes. These phase differences are most evident during interglacials. During glacial terminations, temperature changes were strongly affected by CO₂. Early temperature minima, ~20,000 years before glacial terminations, except the last glacial period, coincide with the largest temperature differences between summer and winter, and with the timing of the lowest atmospheric CO₂ concentration. These findings imply the need to consider proxy seasonality and seasonal climate variability to estimate climate sensitivity.



P1-048

Warming Stadials and North Atlantic CO₂ pulses during Abrupt Climate Change

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Abrupt climate change is a prominent feature of paleoclimate records from the last glacial period. The high latitude North Atlantic, a central region for deep water formation, CO₂ uptake, and atmospheric temperature regulation played a primary role in these abrupt events. Understanding the processes at work in this critical region during such rapid climate change is of great importance in the present era of abrupt warming. Here we present new, high resolution subsurface temperature and CO₂ records from the high latitude North Atlantic which shed new light on the processes at work during the last glacial period.

We show Mg/Ca temperature reconstructions from two planktic species of foraminifera which contradict traditional abundance techniques for marine paleo-temperature reconstruction during cold stadial periods. Gradual subsurface warming of as much as 3°C over the course of a stadial indicate mild subsurface conditions during the summer growing season. Simulations suggest that this build-up of heat may be explained by a lack of winter heat loss due to the insulating effect of sea ice, which may be enhanced by continued inflow of warm Atlantic waters and rising atmospheric CO₂. The accumulation of heat at critical depths has important implications for the stability of marine terminating ice sheets and may also provide an additional source of heat for interstadial warming.

For the first time we also show that the high latitude North Atlantic may have become an intermittent source of CO₂ to the atmosphere at each major climate transition. Transient pulses of subsurface pCO₂, >70 μatm above pre-event levels follow the Heinrich stadials and correspond with peaks of atmospheric CO₂. We attribute these to the sudden onset of vigorous overturning circulation, upwelling CO₂ rich deep waters accumulated during stadials into the surface ocean. This weakened the North Atlantic CO₂ sink and likely maintained atmospheric CO₂ levels after closure of the Southern Ocean leak.



P1-035

Geochemical characterization of an event bed in the Eurasian Basin of the Arctic Ocean

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Quaternary sediment cores from the central Arctic Ocean typically are characterized by light greyish and yellowish layers of fine-grained mud with rhythmically occurring brownish, Mn-rich layers. However, intercalated in this sequence, distinct dark gray layers can often be observed. Some of these layers are local in their extent and likely represent advances of regional ice sheets, such as the Svalbard-Barents Sea Ice Sheet, while other layers have a basin wide extent and likely represent dramatic event effecting large parts of the Arctic Ocean. In this study sediment-geochemical, isotopic, and organic biomarker data are presented to demonstrate that a dark gray layer that is ubiquitously found in sediment cores from the Eurasian Basin near the boundary between Marine Isotope Stages 3 and 4 most likely originated from the catastrophic drainage of an ice dammed lake on the Siberian hinterland.



P1-065

New constraints on the deglacial temperature evolution in the West Pacific Warm Pool from a Borneo speleothem

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The tropical West Pacific hosts the warmest part of the surface oceans and has a considerable impact on the global climate system. Reconstructions of past temperatures in this region can elucidate climate connections between the tropics and poles and the sensitivity of tropical temperature to greenhouse forcing. However, influences on proxy signals lead to discrepancies between different types of proxy data and cause ambiguity in deglacial tropical climate evolution.

Here we constrain the magnitude and timing of land temperature change in the tropical West Pacific across the last deglaciation using a physical method based on speleothem fluid inclusions applied to a well-dated speleothem from Northern Borneo. This method circumvents the typical challenges of (marine) proxy methods, while at the same time yielding exceptionally precise results.

We show that the cave temperature increased by 4.4 ± 0.2 °C (2 SEM) from the Last Glacial Maximum to the Holocene, amounting to 3.6 ± 0.3 °C (2 SEM) when correcting for sea-level induced cave altitude change. The warming closely follows atmospheric CO₂ and southern hemisphere warming. Mg/Ca-based sea surface temperature (SST) records from the open tropical West Pacific and the Eastern Indian Ocean show a similar, step-like, evolution of temperature, similar to Antarctic temperature and atmospheric CO₂. In contrast, SST records from locations in the Indonesian Throughflow region, which is closer to Borneo, show a different pattern of deglacial warming with a steady increase in temperature.

The consistency between our data from Borneo with the SST records from locations in the open Pacific or Indian Ocean suggests that the step-like, SH-paced temperature evolution is representative of the whole region and that the marine SST records from within the archipelago might be impacted by additional influences, such as circulation changes due to sea level changes and/or additional influences on the proxy signal.



P1-055

Reconciling Late Holocene-Last Glacial Maximum multi-proxy estimates of upper ocean temperature off Southwest Sumatra

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Foraminiferal (Mg/Ca) and organic (U^{K}_{37} , TEX_{86}) paleotemperature proxies sometimes provide contradictory results even for the more recent geological intervals, such as the Last Glacial Maximum (LGM, 19-23 ka). This situation hinders not only the improvement of climate models but also the proper evaluation of their output scenarios. To explore the apparent temperature contrast between the surface and the thermocline (ΔT_{s-t}) as suggested by existing Mg/Ca and U^{K}_{37} - TEX_{86} records for the water column off southwest Sumatra, we used clumped isotope analysis (Δ_{47}), a recently developed paleothermometer independent of seawater chemistry. Analyses were performed on the tests of surface- (*Globigerinoides ruber*, *Trilobatus trilobus*) and thermocline- (*Neogloboquadrina dutertrei*, *Globorotalia menardii*) dwelling foraminifera from sediment core offshore southwest Sumatra. Our Δ_{47} data indicate stronger warming in the mixed layer ($\sim 6^{\circ}\text{C}$) than in the thermocline ($< 2^{\circ}\text{C}$) and an increase in ΔT_{s-t} since the LGM. The spatial pattern of modern surface sediment data off Indonesia shows that ΔT_{s-t} increases in the presence of upwelling, thus a smaller foraminiferal ΔT_{s-t} during the LGM relative to the Late Holocene might indicate a deeper thermocline off southwest Sumatra during the LGM. To further understand how changes in local hydrography affect foraminiferal ΔT_{s-t} , we also present new Mg/Ca data measured on individual tests of foraminiferal species from plankton net samples off Indonesia. Individual foraminiferal analysis indicates the range of temperatures in which foraminifera calcify, allowing for the distinction between foraminiferal ecologies in upwelling and non-upwelling conditions. Overall, our study emphasizes the importance of multiproxy analysis in reconciling temperature estimates from independent proxies and highlights the need to better understand the analogs used in paleoclimate reconstructions.



P1-092

Forams, Fronts, and Fe: Foraminifera-bound nitrogen isotope values from ODP Site 1090 and IODP Site U1475 show latitudinal migrations of the Subtropical Front and enhanced Subantarctic nutrient utilization across the Mid-Pleistocene Transition

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The emergence of 100-kyr glacial cycles (The Mid-Pleistocene Transition, MPT) is attributed in part to variations in global overturning circulation and iron stimulation of biological carbon drawdown in the Southern Ocean. Despite evidence for increased accumulation of iron and biogenic sediment in Subantarctic Zone (SAZ), no supporting nutrient utilization data exist. We present foraminifera-bound nitrogen isotope values ($\delta^{15}\text{N}_{\text{FB}}$) from IODP Site U1475, on the Agulhas Plateau, and ODP Site 1090, on the Agulhas Ridge. We observe the largest changes in the $\delta^{15}\text{N}_{\text{FB}}$ gradient between sites when the Subtropical Frontal Zone (STFZ) migrates south of Site U1475 during the “super interglacial” Marine Isotope Stage 31 (1070 ka). In glacial intervals after 900 ka, increases in biogenic sediment accumulation coincide with increased SAZ surface ocean nitrate drawdown and northward migration of the STFZ. Northward migration of the STFZ in this region may have been a precondition for prolonging glacial intervals, delivering nitrate rich surface waters closer to South African iron sources, facilitating atmospheric CO_2 drawdown.



P1-024

Organomineralization of Barium in seawater: implications for reconstructing the marine carbon cycle

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Barite formation in the ocean water column has been extensively investigated. However, the precipitation of Ba in the mesopelagic zone is not fully understood, mainly because the ocean is generally undersaturated with respect to this mineral. Recent experimental work, as well as observations from microenvironments of intense organic matter mineralization in the ocean water column, support the role of bacteria and extracellular polymeric substances (EPS) in barite formation. In general, the organomineralization processes leading to barite formation are expected to be similar to those involved in the formation of other biominerals in which bacterial cells and EPS provide charged surfaces that bind metals inducing mineralization. It has been demonstrated that EPS production plays a major role in promoting locally high concentrations of Ba leading to barite precipitation. Regarding the crystallization pathway, scanning and high-resolution transmission electron microscopy analyses of these precipitates (collected using multiple-unit large volume in-situ filtration systems) have shown the occurrence of amorphous precursor phases, which supports that phosphate groups in EPS and bacterial cells are the main sites for binding Ba. These P-rich nanometer-sized amorphous particles evolve into poorly crystallized barite and micrometer-sized barite crystals. The distribution of particulate Ba and Ba isotopes in the water column is also consistent with such precipitation mechanisms. The ubiquitous presence of bacteria in aquatic systems, and in particular in the mesopelagic zone at depths of intense organic matter mineralization, and their inherent ability to biomineralize, make them extremely important agents in driving the Ba biogeochemical cycle. Thus, further investigating microbial biomineralization in the open ocean, is essential to better understand metal cycling and Ba proxies in particular when using them for reconstructing productivity and the marine carbon cycle.



P1-083

Southern Ocean stratification in the Pacific sector of the Southern Ocean and the carbon cycle across the Mid-Pleistocene transition from IODP 383 site U1540

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During the Mid-Pleistocene transition (MPT), the periodicity of Glacial-Interglacial cycles changed from the obliquity period of 41kyr to a period of 100 ± 20 kyr period. It has been proposed that this transition is linked to a long-term decrease in atmospheric $p\text{CO}_2$ levels, with a step decrease at the MPT possibly resulting from astronomically forcing of the carbon cycle. The role of the Southern Ocean in decreasing glacial $p\text{CO}_2$ through enhanced productivity and stratification of surface waters has been highlighted based on marine sediment records from the Atlantic sector of the Southern Ocean. We present here isotopic and trace element records from the Pacific sector of the Southern Ocean, from IODP site U1540 ($55^\circ 08.5' \text{ S}$, $114^\circ 50.5' \text{ W}$, 3580 m depth), to reconstruct the stratification changes and study the link between changes in ocean carbon storage and circulation throughout the MPT. The comparison between oxygen and carbon isotopic records, along with other Pacific records, allow us to study the pacing of carbon cycle dynamics in the Southern Ocean and those of the ice sheets.



P1-031

Decoding carbonate system parameters and sea surface temperatures recorded in polar foraminifera *N. pachyderma*

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Arctic climate change has global implications because some of the most sensitive climate tipping points amplifying global climate change such as, deep-water formation, sea ice extent, and permafrost melting are intrinsic to the Arctic region. To answer important questions linked to future global warming scenarios, including changes in the uptake of atmospheric CO₂ by high latitude oceans, we need both accurate estimates of past sea surface temperatures (SST) and carbonate system parameters. Unfortunately, a key hindrance to the reconstruction of past Arctic climate change is that most climate proxies of essential climate variables particularly SST suffer from severe limitations when applied to cold temperatures that characterize Arctic environments. Here we present a new Multi-Collector Inductively Coupled Mass Spectrometry (MC-ICPMS) $\delta^{11}\text{B}$ dataset measured on live *Neogloboquadrina pachyderma* (NP) collected via plankton tows from the Labrador Sea, Baffin Bay, and Nordic Seas. We compare our results with $\delta^{11}\text{B}_{\text{borate}}$ derived from pH and Alkalinity measurements, $\delta^{13}\text{C}$ DIC seawater values, temperature and salinity collected at the time and depth the foraminifera calcified. This approach allows us to avoid typical assumptions on habitat depth or age of NP since hydrographic data at the time of collection are measured. We also quantified the influence of low carbonate ion concentration [CO_3^{2-}] on Mg/Ca derived temperatures by measuring B/Ca alongside Mg/Ca in the calibration dataset. Our results showcase a new geochemical correction scheme to isolate non-thermal controls on the Mg/Ca-temperature relationship for NP, permitting for the first time the reconstruction of carbonate system parameters and SST in Polar Oceans.



P1-101

Onset of Atlantic carbon storage at the intensification of Northern Hemisphere Glaciation (2.7 Myr)

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During the last glacial an increase in carbon storage in the Atlantic Ocean interior has been proposed as a key-mechanism to lower atmospheric carbon dioxide concentrations ($p\text{CO}_2$). As carbon storage is intrinsically linked to oxygenation, proxies for sediment oxygenation have been used to quantify changes in deep ocean carbon storage during the late Pleistocene. However, evidence for this crucial ocean carbon feedback mechanism further back in time is limited. Using three marine sediment records from the North Atlantic, we find a change in the concentration of biomarkers from anaerobic bacteria during the late Pliocene (~2.7 Myr) and subsequent glacial/interglacial cycles of the Plio/Pleistocene. We interpret these records to reflect a change in sedimentary redox conditions, which is consistent with our observation of a simultaneous increase in uranium concentrations at one of the sites. We relate this to coupled changes: (i) an increase in the volume of the Atlantic occupied by southern sourced-water, and (ii) increased concentrations of regenerated nutrients and respired CO_2 in that water. Our findings suggest that the lowering of atmospheric CO_2 by the sequestration of respired carbon in the deep ocean was essential for the development of Plio-Pleistocene ice ages.



P1-002

Reconstruction of seawater chemistry using trace element proxies in larger benthic foraminifera

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While high-quality climate reconstructions of some past warm periods in the Cenozoic era now exist, the geological processes responsible for driving the observed long-term changes in atmospheric CO₂ are not well understood¹. One way of constraining the relative importance of the various driving forces proposed so far is to better understand the degree to which ocean chemistry has changed because the geological processes that can drive atmospheric CO₂ also influence the cycling of elements in seawater which is thus an important link to understanding the global carbon cycle. Moreover, knowledge of the concentration of major elements in seawaters is crucial for the accurate application of proxies such as boron isotope (pH/CO₂ proxy). Previously reported records of seawater variation are mostly derived from the fluid inclusion measurements from marine evaporitic, but the results are sparse due to the limited availability of these deposits.

The nummulitid foraminifera were abundant during the Paleogene and thus have good potential as an archive for long-term seawater chemistry reconstructions. We have investigated K/Ca as a potential proxy for reconstructing past [Ca²⁺]_{sw} changes based on cultured *Operculina ammonoides* as well as modern *O. ammonoides* and *G. ruber* from globally distributed sites. Given that previous work has suggested that [K⁺]_{sw} has remained relatively constant throughout the Phanerozoic (9-11 mmol/kg)², calcite K/Ca may reflect the variability in [Ca²⁺]_{sw}. Ultimately, combining K/Ca with other El/Ca data (e.g., the Na/Ca proxy, which functions in a similar way³) could allow their individual concentrations to be estimated, along with factors controlling their long-term variability. Preliminary results obtained from multi-proxy trace element ratios (El/Ca) investigation in Eocene *Nummulites* collected from the Paris and Hampshire Basin will be presented.

1 Xia, Z. *et al. Chemical Geology* (2020).

2 Horita, J. *et al. GCA* (2002).

3 Hauzer, H. *et al. EPSL* (2018).



P1-041

Atmospheric CO₂ across the Mid Pleistocene Transition: early decoupling of CO₂ from insolation and temperature

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Changes in atmospheric CO₂ and global ice volume as a response to changes in insolation are one of the Earth's most important feedback mechanisms during glacial-interglacial cycles. During the obliquity paced glacial-interglacial cycles of the 41kyr world prior to 1.2 million years ago (Ma), the response between insolation and the pCO₂-ice volume feedback is relatively linear. However, during the Mid-Pleistocene transition (0.6Ma – 1.2Ma), this linear response breaks down leading to an increase in ice volume and decrease in pCO₂ during Late Pleistocene glacials. Here, we present a new atmospheric CO₂ record derived from boron isotopes measured in the planktic foraminifera *G. ruber* from ocean sediment core IODP U1476 in the western Indian Ocean. We find two pCO₂ features during the MPT, firstly an early decoupling of pCO₂ and ice volume from insolation during MIS 30 (1.05Ma), where pCO₂ stays low, despite increasing summer duration, during a prolonged glacial with high ice volume. Secondly, later, during MIS 23 (0.9Ma), pCO₂ decreases rapidly, in combination with rising global ice volume, and recovers only to lower interglacial levels in the following interglacial MIS 21. The periods of low pCO₂ and high ice volume occur in line with saltier Atlantic deep waters enriched in δ¹³C which we interpret as southern origin water masses, and increased ocean carbon storage. We therefore conclude that changes in ocean circulation may have caused an increased uptake of atmospheric carbon during these periods. In contrast, global sea surface temperatures during MIS30 follow insolation suggesting a de-coupling of the pCO₂/ice volume feedback from insolation and temperature. This likely repositioned the climate system for the significant CO₂ reduction and ice sheet expansion during and after 0.9Ma.



P1-027

Nodosariida (Foraminifera): first reports on their geochemistry and potential for paleoreconstructions

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Foraminifera from the class Nodosariida evolved calcification well before the Rotaliida and Miliolida, which is reflected by a distinct lamellar wall structure by these foraminifera. The geological longevity makes Nodosariida foraminifera potentially useful proxy-carriers to reconstruct conditions in deep time. To assess the proxy-value of these foraminifera, samples were taken from The Gulf of Mexico which is a very well-known area for studying the distribution and ecology of benthic foraminifera. Living Nodosariida were collected between 100 and 600 meters water depth. Different species were isolated and single chambers were analyzed with laser ablation-ICP-MS. The comparison of element incorporation with Rotaliida suggested less variability when incorporating elements into the shell. Only three of these species were found at the three different depths, *Dentalina sp.*, *Dentalina flintii*, and *Lenticulina calcar*. The preliminary results show higher Mg/Ca incorporation when temperature increase for the three species while Na/Ca only increase with salinity for *Dentalina sp.* and *Dentalina flintii*. These results suggest that these species could be used when reconstructing environmental conditions such as temperature or salinity.



P1-004

Synthesizing Late Pleistocene Paleo-Productivity Records from ODP Site 1240 with New Insights from U-Th-Pa Measurements

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The Eastern Equatorial Pacific (EEP) is a region of upwelling, high primary productivity, and CO₂ exchange between the ocean and the atmosphere. The EEP is also where ENSO events originate, which are the dominant source of interannual climate variability today. Although Late Pleistocene paleoceanographic reconstructions of this globally significant region are abundant, they are also conflicting. For example, the timing, drivers, and impacts of changes in primary productivity vary between study sites and proxy records. The variation can likely be attributed to the spatial heterogeneity of the region and unconstrained effects on proxies. Here we present Late Pleistocene U, Th, and Pa isotope measurements and calcium carbonate measurements from the marine sediment core at ODP Site 1240 (2921 m; 0.02°N, 86.46°W). We also synthesize previously published proxy records from ODP 1240 to better characterize paleoceanographic changes in the EEP across recent glacial cycles. Timeseries records of the ²³⁰Th-normalized mass flux, authigenic uranium, ²³¹Pa/²³⁰Th, sediment focusing factors, and ²³²Th-derived dust flux were generated. We find that ²³¹Pa/²³⁰Th was at a minimum near 140 kyr, increased through the penultimate deglaciation, and remained high through 110 kyr. The influences of primary productivity and boundary scavenging on the ²³¹Pa/²³⁰Th record are explored. ²³⁰Th-normalized fluxes of proxies for primary productivity derived from concentrations in sediments, including of calcium carbonate and organic biomarkers, were also calculated. This work demonstrates the benefits of multi-proxy reconstructions from a single core site, which eliminate age uncertainties and better characterize the production and preservation of proxies in marine sediments.



P1-013

Planktonic foraminiferal $\delta^{13}\text{C}_{\text{org}}$ as a novel proxy for carbon cycling.

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It has been hypothesized that lower atmospheric CO_2 concentrations and lower temperatures during glacial times caused the enrichment of carbon isotopes of organic material ($\delta^{13}\text{C}_{\text{org}}$) produced in the surface ocean. Some downcore measurements of organic carbon isotopes from sediment cores show such a trend, however, others do not. $\delta^{13}\text{C}_{\text{org}}$ can be affected by various factors such as diagenetic alteration, the input of allochthonous organic carbon, the nature of the organic matter, and the redeposition of sediments which likely lead to different interpretations. Foraminifera test-bound organic matter (OM) is thought to be sheltered from these potential issues and a recent pilot study has shown no appreciable fractionation between its carbon isotopic signal ($\delta^{13}\text{C}_{\text{OM}}$) and that of organic material, confirming that metabolic carbon is the main source of the OM. Here we test for the glacial organic matter enrichment hypothesis using planktic foraminifera picked from ODP Site 1088 in the Southern Ocean (*G. bulloides*, *G. truncatulinoides*, and *G. inflata*) and BOFS 14K from the North Atlantic (*G. bulloides* and *N. pachyderma*), from the last 30,000 years.



P1-015

New records of environmental change in the central and western Mediterranean Sea from organic molecular proxies

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The Mediterranean region is particularly sensitive to global climate, being considered a climate change hotspot given its recent greater warming compared to global trends. Records of changes in the Mediterranean have been widely documented through reconstructions using deep sea sediments, but there are still poorly covered regions and time periods. In this presentation we focus on two of these areas, the Strait of Sicily and the Algerian Margin. For this, we selected sediment cores LC07 (38°8.72'N, 10°4.73'E; 488 m depth) and KMDJ38 (37°8.4'N, 8°E; 7; 1057 m depth). The former provides a low-resolution record covering, for the first time in the Mediterranean Sea, more than a million years, and the latter, still work in progress, presents the last 50 kyr with higher time resolution. Organic molecular proxies are used to reconstruct past changes in sea surface temperatures (SST), continental inputs, export production and phytoplankton composition. Sicily Strait alkenone SSTs evolved following the typical glacial/interglacial oscillations, with values comparable to those reconstructed in the Alboran Sea, but with slightly higher absolute values. This would be in line with the progressive warming that surface waters experience during their transit from the Strait of Gibraltar, through the African Margin and towards the Central Mediterranean. Regarding the Algerian Margin, our preliminary data show a glacial/interglacial change of around 10°C, similar to changes reconstructed in the Alboran Sea. In the Strait of Sicily, the evolution of alkenones, brassicasterol and *n*-alcohols was not controlled by glacial/interglacial variability but displayed abrupt maxima, sometimes coeval with the deposition of the Mediterranean sapropels. At these times, an enhanced export production is suggested either by the alkenone or the brassicasterol records, but rarely by both biomarkers at the same time, indicative of a different proliferation of coccolithophores or diatoms.



P1-113

Spatial heterogeneity of the Late Miocene Biogenic Bloom

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The late Miocene and early Pliocene is marked by a major oceanographic and geological event called the Late Miocene Biogenic Bloom (LMBB). This event is characterized by high accumulation rates of opals from diatoms and high calcite accumulation rates from calcareous nannofossils and planktic foraminifera. The LMBB extends over several million years and is present in the Pacific, Atlantic and Indian Oceans. Two hypotheses have emerged from the literature to explain this event: a global increase in the supply of nutrients to ocean basins through chemical alteration of the continents and/or a major redistribution of nutrients in the oceans. The objective of this study is to provide a more comprehensive look at the temporal and geographical aspects of the LMBB. We have compiled ocean drilling data (ODP-IODP) covering the late Miocene and early Pliocene. This compilation contains sedimentation rates as well as CaCO₃ and opal accumulation rates. After a careful screening of the database, we first work on global trends of sedimentation and biogenic production before going into more details. Normalization to a post-LMBB state allows comparison of rates of increase in CaCO₃ accumulation in different geographical areas. A very strong LMBB signature is present in oceanic area bordering the western side of Australia. In the Atlantic Ocean, it is mainly present near the equator and over South Africa. The LMBB signature is less pronounced in the Indian Ocean but remains trackable near the northern coasts of the basin. Moreover, it is also heterogeneous in terms of the mineralogy produced and deposited in the deep ocean between regions. For example, in the equatorial eastern Pacific, the LMBB signature is present in the silica accumulation term but not in carbonates accumulation one. Outputs from coupled ocean/atmosphere models using late Miocene paleogeography and integrating a marine biogeochemistry module have been gathered and will be discussed in regard to our database.



P1-056

Terrestrial climate variability from South Africa's southern Cape: setting the environmental scene for early modern humans

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Blombos Cave coastal archaeological site in the southern Cape of South Africa, exhibits artifacts from the Middle Stone Age (MSA), 100-50ka BP; a time interval when human cognition and technological advances underwent rapid development. Research suggests this cognitive evolution of early modern humans was facilitated by environmental and climatic conditions in the region; particularly at the dynamic land-ocean interface influenced by the Greater Agulhas system in the southwest Indian Ocean.

We report geochemical and clay data from South African river sediments to interpret modern endmembers and identify a NE-SW decrease (increase) in kaolinite (illite). We extend these data using the geochemical proxies measured in Holocene and Last Glacial Maximum dated time-slices in marine sediment cores recovered from offshore of the Southeast African coastline to (i) decipher the provenance of sediments supplying these core sites and (ii) investigate possible sediment sorting mechanisms through targeting the $<2\mu\text{m}$, $2-10\mu\text{m}$ and $10-63\mu\text{m}$ size fractions of lithogenic sediments. Utilising this interpretive framework, we further explore temporal variability recorded in sediment core, MD20-3591 ($36^{\circ}43.707\text{S}$; $22^{\circ}9.151\text{E}$, water depth 2464m) as this site records marine hydrographic (Agulhas Current) and terrestrial hydrological variability.

Multiproxy records of bulk sediment chemistry (XRF), oxygen isotopes and grain size data from MD20-3591 likely show a strong sea level control linked to the intermittently exposed Palaeo Agulhas Plain during glacial low stands and incised with deep river valleys. These initial data will be augmented by high-resolution radiogenic isotopes to fingerprint changes in the provenance of sediment supplied to the site by the Agulhas Current or regional land-ocean interactions; to ultimately explore the variability of regional hydroclimate in relation to the early human archaeological record during the MSA interval.



P1-062

Glacial-interglacial development of the Indo-Pacific Warm Pool over the last 450 kyrs based on sea surface to intermediate-depth temperature reconstructions from IODP Site U1486

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The Indo-Pacific Warm Pool (IPWP) is a major source of heat and water vapor to the atmosphere, and its past variation is important for exploring the mechanisms of global climate change. Only few studies have yet explored the variability of the IPWP through studies of ocean temperature variability at different depth levels, due to the lack of intermediate-depth ocean temperature reconstructions. We here report on Mg/Ca and $\delta^{18}\text{O}$ from planktonic foraminiferal species with different calcification depths (*G. ruber*; *T. sacculifer*; *P. obliquiloculata*; *G. truncatulinoides*), which were selected from International Ocean Discovery Program (IODP) Site U1486 (02°22.34'S, 144°36.08'E, water depth 1332 m). The proxy data allow to reconstruct the thermal structure and the upper ocean heat content changes in the West Pacific Warm Pool over the past 450 kyrs. The reconstructed sea surface to intermediate-depth temperature records exhibit pronounced glacial-interglacial cycles. By relating our proxy records to similar datasets from the Indian Ocean and the western Pacific, we address the thermal gradients at different depth levels between Site U1486 and other regions in the IPWP area. We reveal variations in the contraction and expansion of the IPWP during glacial and interglacial stages. We also discuss the mechanism of the influence of El Niño/La Niña-Southern Oscillation (ENSO) on the upper heat content changes in the IPWP.



P1-076

Ocean circulation and biology cause bottom water oxygenation changes at the Iberian Margin during MIS 4

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The deep ocean is thought to have played a key role in modulating atmospheric CO₂ changes on millennial and astronomical timescales, including through changes in its respired carbon inventory. The amount of C_{org} in a water mass may be inferred from deep water oxygen concentration ([O₂]_{bw}) reconstructions, which ultimately may help elucidate the mechanisms of CO₂ variability. MIS 4 is a key paleoclimatic interval for the last glacial inception, which is characterized by a rapid CO₂ drop, and includes several millennial events such as Heinrich Stadial 6.

Here, we present multi-proxy [O₂]_{bw} reconstructions from a depth transect from the Iberian Margin for MIS 4. We use three independent proxies: redox-sensitive foraminiferal U/Ca; Δδ¹³C between pore and bottom waters; and benthic foraminifera assemblage based oxygenation index. The [O₂]_{bw} of a deep water mass is determined by the initial concentration at the region of sinking, the amount of oxygen consumed through respiration (hence accumulated C_{org} supply), and mixing with other water masses. Our geochemical proxies suggest a general trend of decreasing [O₂]_{bw} into MIS 4, reaching a minimum during HS 6, and a subsequent recovery at the onset of MIS 3, which highlight gradual changes in oxygen supply likely linked to ventilation changes. The benthic foraminifera oxygen index varies with Greenland ice core records and exhibits clear millennial variability; supporting the notion of increased export production during Greenland stadials 19 and 20 and the beginning of HS 6. Thus, we propose that the observed discrepancies between oxygenation proxies and CO₂ variability reflect variable sensitivities to divergent export production and ventilation influences on [O₂]_{bw} records. This is especially evident in our records during stadials and HS 6, and thus highlights the difference between mechanisms of deep water oxygen supply, versus oxygen consumption (and ultimately local C_{org} variability) on millennial versus orbital timescales.



P1-118

Deep ocean carbonate chemistry over the Cenozoic

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The Cenozoic was a time of climatic extremes: abrupt events and state-changes pepper the transition from Hothouse warmth to the Pleistocene Icehouse. These evolving climate regimes were accompanied by major changes in ocean chemistry and biota. CO₂ is thought to have played a critical role in many of these events but, despite recent progress, there is still much to learn on the Cenozoic evolution of the ocean-atmosphere CO₂ system. Here we present new records of the boron isotope and trace element composition of benthic foraminifera spanning the Late Cretaceous to Pleistocene. These are paired with cGENIE Earth system model runs to provide new constraints on the Cenozoic carbon cycle and carbonate system. We find deep ocean pH substantially lower than modern during peak Eocene warmth, consistent with high CO₂ conditions in the ocean-atmosphere system. Deep ocean pH then rose as atmospheric CO₂ fell and climate cooled, indicating a rise in the ratio of ocean alkalinity to dissolved inorganic carbon. In general, our data show close coupling between the evolution of the CO₂ system and climate, though deep ocean pH change may exert a non-negligible influence on benthic δ¹⁸O. Intervals of more dynamic change in deep ocean CO₂ chemistry include the transition into the Early Eocene Climatic Optimum, for which time we suggest a novel link between changes in ocean circulation, redox, and the sulphur and carbon cycles. Another dynamic interval was the Eocene-Oligocene transition, characterized by a step transition to a higher deep-ocean pH, associated with an increase in deep sea CaCO₃ deposition and growth of major Antarctic ice. Overall, our data demonstrate the persistence of CO₂'s control on the climate system across varying boundary conditions, and the influence of both the long-term carbon cycle and shorter-term ocean biogeochemical cycling on Earth's climate.



P1-036

Insights into Sulfate Reduction and Carbonate Diagenesis on the Southern Campbell Plateau

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Microbial sulfate reduction (MSR) has been shown to impact the fidelity of carbonate-based geochemical archives. The extent of MSR can be captured by changing sulfate concentrations and sulfate sulfur and oxygen isotopes. Sulfate was measurable in all the interstitial water samples collected, reaching a depth of 420 mbsf. The observed slow decline in sulfate concentration indicates MSR should have a minimal effect on carbonate-based geochemical proxies such as carbonate associated sulfate (CAS). However, the presence of a 26-million-year unconformity at approximately 5 mbsf suggests the current porewater chemistry and the sediment chemistry are likely out of equilibrium, potentially driving significant secondary alteration.

This study analyzed carbonate sediment and porewater samples from IODP Site 378-U1553 on the western Campbell Plateau for sulfur and oxygen isotopes in sulfate. An examination of the porewater sulfate and manganese concentrations indicates the modern redox front is approximately 20 mbsf, suggesting the potential for further carbonate alteration related to changes in the porewater redox chemistry. This suggests ongoing MSR, coupled with carbonate recrystallization, could drive further alteration of the carbonate record at IODP Site 378-U1553. Understanding how the presence of an unconformity influences sulfate reduction at IODP Site 378-U1553 will provide insight into how changing chemical equilibrium states in the subsurface can impact the preservation of carbonate-based geochemical archives.



P1-009

Evaluation of redox-sensitive trace elements as a paleoxygenation proxy: citizen science to build an understanding of seawater deoxygenation

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Studies of past variations in hypoxic zones, using marine sediment records, offer information about the mechanisms and consequences of deoxygenation in different oceanic regions.

In order to have reliable past oxygen records, it is necessary to validate and refine how oxygen-sensitive proxies such as redox-sensitive trace elements in marine sediments respond to different hydrological settings.

Here, we develop a calibration of redox-sensitive trace elements (e.g. Mn, Re, U, V, Mo, Cd, Co) as a proxy for oxygen concentrations in shelf and slope sediments from the western continental margin of South America, using the uppermost centimetre of marine sediments collected during several expeditions (12°-50°S, 71°-80°W) covering water depths between 24 and 4000 m. We map redox-sensitive trace elements concentrations within the seafloor to assess relationships between redox elements and bottom water oxygen. The dataset is complemented with measurements of other geochemical characteristics (e.g. TN, TOC, $\delta^{15}\text{N}$, TS, grain size) to evaluate their potential influence on the concentrations and geochemical behaviour of the redox-sensitive trace elements.

The study area is characterized by a complex seafloor morphology, climate regime, and land geochemistry with different lithogenic sources that need to be taken into consideration to estimate the relative proportion of lithogenic and authigenic fractions of redox-sensitive trace elements in the basin. For that, we have collected water or/and sediment samples from rivers, dunes and pampa soil from the Coastal and Andes mountains. The sampling has been carried out by local communities using citizen science and open education methodologies with the purpose of setting lithogenic reservoirs useful to standardise the geochemical data from their territories.

This work is the first collaborative effort that joins paleoceanography and citizen science in the South-East Pacific, providing a foundation for potential future outreach activities.



P1-058

Holocene Deterioration of the Rio Grande outflow into the Gulf of Mexico

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The Rio Grande is an important water source in the arid southwestern United States and Mexico and its discharge into the Gulf of Mexico has been drastically reduced by dams and irrigation over the past century. Its modern reduced flow has little influence on the overall freshwater budget in the Gulf of Mexico, but little is known about long-term changes in its natural discharge over the Holocene. A reconstruction of $\delta^{18}\text{O}_{\text{sw}}$ in the northwestern Gulf of Mexico (from paired Mg/Ca and $\delta^{18}\text{O}$ in planktic foraminifer, *Globigerinoides ruber* from the Garrison Basin) indicates a long-term increase in salinity near the Rio Grande outflow since the mid-Holocene Climatic Optimum (ca. 7,000 years BP). Sedimentary records proximal to the Mississippi River indicate a long-term freshening trend from the mid-Holocene to present, suggesting that the trend in the northwestern Gulf of Mexico is sensitive to local changes in freshwater input from the Rio Grande, rather than large-scale changes in ocean circulation. We test the hypothesis that increasing salinity in the western Gulf of Mexico over the Holocene resulted from a decrease in Rio Grande discharge by measuring the relative concentration of terrestrial plant leaf waxes (long-chain *n*-alkanes) from the Garrison Basin marine sediment core. The concentration of terrigenous *n*-alkanes shows a long-term trend in decreasing delivery of terrestrial sediment via the Rio Grande, supporting the interpretation that there has been a long-term drying of the Rio Grande Basin since the mid-Holocene. We compare this multiproxy record of marine and terrestrial hydroclimate to mid-Holocene model simulations and terrestrial paleoclimate records sensitive to rainfall in the southwestern US to explore the dynamics influencing Holocene rainfall changes in the North American Monsoon region and Rio Grande drainage basin.



P1-079

Late Eocene export productivity event in the Southern Ocean

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The Eocene-Oligocene transition (EOT), ~34 Ma, marks a tipping point in the long-term Cenozoic evolution towards a glacially-driven climate. Evidence for increased late Eocene paleoproductivity has been found in high latitudes during this time period. However, the timing, driving mechanisms and feedback remain highly unconstrained. We measure biogenic barium (bio-Ba) to investigate spatial and temporal variation in export productivity in the Southern Ocean and diatoms species-level diversity data for the same sediment samples, providing constraints on plankton-climate dynamics. Sediments are from the Atlantic (Ocean Drilling Program sites 689 and 1090) and the Indian (Ocean Drilling Program Site 748) sectors of the Southern Ocean. In all sites, we found a significant peak in bio-Ba in the late Eocene (~36.8 Ma) accompanied by a pronounced increase in diatom diversity. This peak in export productivity reflects a response of phytoplankton to ocean circulation reorganisation and increased upwelling of nutrient-rich waters. This ocean circulation reorganisation was initiated through the development of a proto-Antarctic Circumpolar Current. In contrast, during the EOT, the export productivity data show asynchronous changes in the two Atlantic sites investigated. Migration of the frontal system, particularly the proto-Antarctic Polar Front could be responsible for the regional productivity changes. Our findings suggest that phytoplankton were an important contribution as a climate driver, and likely have produced positive feedback decreasing atmospheric carbon dioxide levels and contributing to the establishment of Antarctic glaciation.



P1-001

$\delta^{11}\text{B}$ paleo-pH records in the Mediterranean Sea, with a focus on the anthropogenic ocean acidification and glacial/interglacial changes

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The Mediterranean Sea currently represents one of the most vulnerable climate change hotspots due to, among other factors, its relatively small basin size, restricted water exchange connections, and much shorter turnover time than the global oceans. These characteristics make it also especially vulnerable to ocean acidification resulting from the drastic anthropogenic increase in atmospheric CO_2 since the Industrial Revolution. Indeed, instrumental measurements confirm the seawater acidification trend in this basin, not only at surface but in the whole water column. Reconstructing paleo-pH in the Mediterranean Sea is therefore relevant to understand the evolution of the carbon system and to project future changes in ocean chemistry and climate. The boron isotopic composition ($\delta^{11}\text{B}$) of foraminiferal shells allows the reconstruction of seawater pH over time. In this work, we are carrying out $\delta^{11}\text{B}$ analysis on planktonic and benthic foraminifera from Mediterranean Sea sediment cores. Sample cleaning, preparation, chemical purification, and isotopic analyses are being performed at the University of Barcelona. For this, we have set up the methodology, including the purification of boron from the foraminifera carbonate matrix using microsublimation, as well as the $\delta^{11}\text{B}$ analysis using a Nu Plasma 3 Multi Collector Inductively Coupled Plasma Mass Spectrometer (MC-ICPMS). We are focusing on a series of sediment cores from the Strait of Sicily, which are allowing us to develop pH reconstructions over different timescales and temporal resolutions: from the last centuries to glacial/interglacial cycles. Preliminary results point towards an acidification trend during the last century, correlated with the anthropogenically induced rise in atmospheric CO_2 , and also to pH decreases associated to glacial/interglacial transitions.



P1-030

Observed differences in reconstructed sea surface temperature in *G. ruber* morphotypes: Seasonal bias or depth habitat?

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The mixed-layer dwelling foraminifer *Globigerinoides ruber* is commonly used in paleoclimate reconstructions. Analysis of the geochemistry of two common *G. ruber* morphotypic variations (*sensu stricto* (*ss*) and *sensu lato* (*sl*)) has revealed differences in properties used for paleoproxy reconstructions. Here we present evidence in *G. ruber* *ss* and *sl* morphotypes from the Eastern Equatorial Pacific (EEP) showing distinct differences in the trace elemental (Mg/Ca) ratios through the Holocene and into the Younger Dryas. We find that Mg/Ca values of the *ss* morphotype are generally higher compared to *sl*, indicative of warmer temperatures at calcification. We use a multi-proxy, multi-species approach to investigate two hypotheses that may explain this finding. We examine whether our evidence supports a hypothesized differential depth habitat between morphotypes, or whether the observed offsets reflect a seasonal bias. If the foraminifera data represents differing depth habitats, our results suggest changes in the mixed layer properties providing opportunities for more highly resolved water column reconstructions. If our foraminifera data are indicative of seasonal preferences in morphotypes, our results may help to address questions about the changes in the seasonal cycle and constrain variability reconstructions. Mg/Ca data from subsurface foraminifera and evidence from organic biomarkers are used to further evaluate these hypotheses. This additional data provides clues into possible mechanisms and context for our results.



P1-039

Impact of iron fertilisation on atmospheric CO₂ during the last glaciation

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During past glaciations, the concentration of atmospheric CO₂ decreased by 80 to 100 ppm. While a combination of processes was most likely involved in this atmospheric CO₂ decrease, a better quantification of the contribution of each of these processes is needed. For example, enhanced aeolian iron input into the ocean during glacial times has been suggested to drive a 5 to 28 ppm atmospheric CO₂ decrease by increasing Southern Ocean nutrient utilisation.

Here we constrain this contribution by performing a set of sensitivity experiments using a recently developed ecosystem model incorporated in an Earth System model of intermediate complexity. We use different aeolian iron input patterns and iron solubility factors under boundary conditions corresponding to 70 thousand years before present (70 ka BP), a time period corresponding to a significant drop in atmospheric CO₂ and the first observed peak in glacial dust flux. We show that the decrease in CO₂ as a function of Southern Ocean iron input follows a logarithmic relationship. This logarithmic relationship arises due to the saturation of the biological pump efficiency and levels out at ~19 ppm in our simulations. Using a best estimate of 1 to 10% iron solubility in the ocean, a 4 to 16 ppm decline in CO₂ is simulated. This would account for ~50% of the total decrease in atmospheric CO₂ at 70 ka B.P. We further find that 67% of the simulated pCO₂ decrease is due to iron input in the Southern Ocean (south of 40°S).



P1-042

Globally reduced sedimentary iron release compensates enhanced atmospheric deposition impact on biological carbon pump and atmospheric CO₂ drawdown during the Last Glacial Maximum

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The marine iron cycle has been suggested to significantly contribute to lower glacial atmospheric CO₂ via enhanced atmospheric iron deposition fueling a stronger biological carbon pump. However, more recently the importance of other marine iron sources (e.g. sedimentary and hydrothermal) have been found to be key contributors to the marine iron inventory, which are often neglected in iron budgets including during the Last Glacial Maximum (LGM). In this study, we use an isotope-enabled Earth System Climate Model of intermediate complexity (UVic-MOBI) to quantify the globally compensating effects of reduced sedimentary iron release and enhanced atmospheric iron deposition on the export production, ocean carbon storage, and atmospheric CO₂ drawdown during the LGM. Sedimentary iron release decreases by more than a factor of 2 in the glacial upper ocean due to lower sea level and higher upper ocean oxygen concentrations. This iron reduction overcompensates the fertilizing effect from increased atmospheric deposition in all ocean basins outside of the Southern Ocean. On the global average, reduced sedimentary inputs mitigate much of the enhanced carbon storage from increased atmospheric deposition. Our simulations suggest that reduced sedimentary iron release plays an important role shaping the marine iron distribution and must be considered when estimating the iron cycle's complete role on the biological pump and atmospheric CO₂ drawdown during the LGM.



P1-026

Resolving the Carbon Isotope Conundrum for Planktic Foraminifera Carbon Isotope Records

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Despite the collection of $\delta^{13}\text{C}$ data with each $\delta^{18}\text{O}$ measurement, few studies discuss or even include these data in publications on fossil planktonic foraminifera. In principle, the $\delta^{13}\text{C}$ of surface dwelling symbiotic species such as *Globigerinoides ruber* or *Trilobatus sacculifer* should track the $\delta^{13}\text{C}$ of dissolved inorganic carbon because $\delta^{13}\text{C}_{\text{DIC}}$ is incorporated into foraminifera shells with a 1:1 relationship. This would imply that downcore $\delta^{13}\text{C}$ records from species that inhabit the same mixed layer environment should parallel each other with offsets that can be attributed to differences in physiological vital effects such as symbiont photosynthesis. This is not what we observe when these two species records are compared. My colleagues and I have argued that non-parallel offsets in these records are due to differences in the response of these species to environmental $[\text{CO}_3^{2-}]$ change through time. Core top data for different planktic foraminifera species from the eastern equatorial Pacific and western Caribbean support this hypothesis. Utilizing experimental data from cultured foraminifera that quantifies the $\delta^{13}\text{C}/[\text{CO}_3^{2-}]$ slope of the $[\text{CO}_3^{2-}]$ effect in *G. ruber* and *T. sacculifer*, we present a simple model to deconvolve changes in $\delta^{13}\text{C}_{\text{DIC}}$ and $[\text{CO}_3^{2-}]$ from Late Quaternary $\delta^{13}\text{C}$ records from these two species. Reconstructions from a tropical Indian Ocean (ODP 714A) and Caribbean (V28-122) suggest that that glacial $[\text{CO}_3^{2-}]$ was 50-100 $\mu\text{mol/kg}$ higher during the last glacial between at these two sites. More important, rather than a whole ocean decrease in $\delta^{13}\text{C}_{\text{DIC}}$ of 0.34‰, the residual $\delta^{13}\text{C}_{\text{DIC}}$ reconstructions suggest the $\delta^{13}\text{C}_{\text{DIC}}$ in the glacial Caribbean mixed layer was $\sim 0.6\text{‰}$ more positive than the late Holocene whereas the glacial tropical Indian Ocean was $\sim 0.25\text{‰}$ enriched in ^{13}C . These results suggest reconstructions of $\delta^{13}\text{C}_{\text{DIC}}$ and $[\text{CO}_3^{2-}]$ from paired mixed layer $\delta^{13}\text{C}$ records could help resolve the long-standing carbon isotope conundrum in Paleoceanography.



P1-097

Long Eccentricity Cycles and the Ocean Chemocline Over the Past 1.5 Million Years

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An enigmatic 400 kyr cycle has been observed in records of ocean carbon chemistry from across the Cenozoic Era. These cycles have been tentatively linked to long eccentricity cycles (e400 cycles) and Southern Ocean processes, however paleoclimate evidence for such a connection remains equivocal. Here, we present a new high resolution (~1.5-kyr), 1.5-million-year record of oceanic chemocline dynamics recorded in IODP Site U1475 (41°26.61'S; 25°15.64'E; 2669 m water depth) located on the Agulhas Plateau. At this Site, the planktic foraminifera, *Globorotalia truncatulinoides*, calcifies in Subantarctic Mode Water (SAMW), whilst the epibenthic *Cibicides wuellerstorfi* is bathed in a mixture of Circumpolar Deep Water (CDW). The results show that two modes of variability operate on the $\delta^{13}\text{C}$ gradient ($\delta^{13}\text{C}_{\text{SAMW-CDW}}$) during the Mid to Late Pleistocene. Firstly, glacial-interglacial and sub-orbital variations reflect the biological export of carbon and subsequent isolation at depth associated with iron fertilization and deep circulation changes. Secondly, superimposed on these fluctuations are low frequency shifts linked to changes in upper ocean circulation and mixing. Most notably, these long-term shifts align with e400 cycles with $\delta^{13}\text{C}_{\text{SAMW-CDW}}$ maxima occurring during e400 insolation minima. We compile published records of African hydroclimate and show a coherent response in atmospheric circulation patterns to eccentricity-modulated low latitude insolation. Lower maximum insolation over the equator would weaken the Hadley Cell, drawing the Southern Ocean Subtropical Front to the north. We posit that this atmosphere-ocean response would alter the supply of nutrient-rich Southern Ocean waters to the Indian Ocean thermocline, likely driving the 400-kyr cycles in carbonate productivity and coccolithophore blooms observed in regions where the thermocline is currently ventilated by SAMW.



P1-061

A Century of Change in the California Current: Quantifying the Impact of Anthropogenic Climate Change on Ocean Acidification

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The California Current System (CCS) is an eastern boundary current off the west coast of North America that is characterized by intense upwelling of low-pH and high- $p\text{CO}_2$ waters. This shoaling of the pycnocline towards the coast provides a pathway for nutrient transport from the deep ocean and fuels one of the most economically vital and biologically productive ecosystems in the world. As a result of these low-pH upwelled waters, the CCS represents the leading edge of ocean acidification (OA) impacts while also providing a window into future ocean conditions and processes. Predicting the extent and pace of acidification in eastern boundary current upwelling systems is complicated because anthropogenic contributions to acidification are intertwined with natural sources of acidity and variability. Indeed, a central and contested question is whether acidification in coastal upwelling regions like the CCS will follow the pace of increasing atmospheric CO_2 , or if dynamical climate effects will act to either accelerate or attenuate acidification. Here, we apply boron isotope and B/Ca paleo-carbonate system proxies to cold-water corals collected since the 1890s along the west coast of the North America. We establish a historic baseline for acidification in the CCS and the Salish Sea, an associated coastal estuary. Combining these geochemical records with a regional ocean model (ROMS) of the California Current, we show that the CCS and Salish Sea have experienced accelerated acidification and increased CO_2 accumulation over the industrial era relative to the atmosphere. The CCS has acidified faster than expected over the last 130 years. We use our validated ROMS model to show that this acceleration is projected to continue into the future. Our record of accelerated acidification is important for accurately predicting the impacts of OA in eastern boundary currents and is also an indicator for climate-driven shifts in the processes that govern these productive ecosystems.



P1-066

Subsurface reflections of abrupt arctic climate change in the Fram Strait between 37 and 40ka BP

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Dansgaard-Oeschger events are a series of abrupt climate change events that punctuated the Last Glaciation. These millennial scale events are composed of cold stadials and warm interstadials, and are thought to be linked to variations in the Atlantic meridional overturning circulation (AMOC) and the sea ice cover over the Nordic Seas. Although Dansgaard-Oeschger events have been extensively studied, and the chain of events are well documented in the southern Nordic Seas, several questions remain unanswered as to how they manifest farther north. We investigate two marine sediment cores from the Fram Strait, KH14-GC02 (2300 m water depth) and MD99-2304 (1300 m water depth). Ice Rafted Debris, planktonic oxygen and carbon isotope records covering the time interval 40 to 37 ka, or Heinrich-event 4 and D-O event 8, will be presented. These proxies will be used to assess the regional subsurface water conditions, the activity of the ice sheet, the meltwater input and the water mass characteristics. Preliminary IRD results indicate intense calving during Heinrich event 4. IRD numbers are low throughout the remaining part of the investigated interval, suggesting a less active smaller ice sheet in the Svalbard-Barents Sea area.



P1-049

Revealing alkenone proxies sensitivity to light and pCO₂

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Alkenones are molecular lipid fossils from marine phytoplankton used to reconstruct climate history. They are very long ketones (C35-42) with 2 to 4 trans-unsaturated bonds produced exclusively by some haptophytes. The proportion of di- to tri-unsaturated C37 alkenones, expressed as the Uk'37 undersaturation index, has been intensively used in thousands of papers as a proxy to determine sea surface temperatures on Earth. The empirical correlations of this extra unsaturation to lower temperatures suffer from offsets depending on species, location or geological period, all of which need to be corrected. In addition, the hydrogen isotopic composition of alkenones is being studied as a proxy for paleosalinity reconstructions.

In order to constrain and develop the hydrogen isotope fractionation in alkenones, the coccolithophore *Gephyrocapsa oceanica* was cultured at different light intensities and CO₂ levels. Our culture data suggests that alkenone Uk'37 and that δ²H of alkenones are also sensitive to light and pCO₂.



P1-087

1.4 Ma. productivity reconstruction at the Pacific entrance of the Drake Passage determined from mass accumulation rates corrected for syndepositional redistribution of sediments

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Increased export production in the Subantarctic Zone of the Southern Ocean has been proposed as a key mechanism for explaining carbon drawdown during glacial times. However, syndepositional redistribution of sediments is common here due to the dynamic bottom water circulation of the Antarctic Circumpolar Current, leading to biased stratigraphy-based mass accumulation rates (BMAR). We provide an evaluation of export production linked to the Earth's fundamental climate changes over the past ~1.4 Ma. in the Subantarctic Zone, at the Pacific entrance of the Drake Passage. We base our approach on a novel combination of BMAR of biogenic barium, organic carbon, biogenic opal, calcium carbonate, and iron corrected for syndepositional redistribution from sediment core PS97/093-2 (57.5°S, 70.3°W). To do so, and given the excellent correlation between focusing factors and bottom current strengths, we use an exponential regression between the measured focusing factors and the sortable silt values of the core. Our results reveal that productivity proxies varied according to some of the Mid-Pleistocene Transition and Mid-Brunhes Event characteristic features. Whereas the highest Fe input that fostered diatom production took place at the onset of the Mid-Pleistocene Transition, the carbonate record reflects a global increase in the deep-ocean corrosivity at the mid-point of the Mid-Pleistocene Transition. The Mid-Brunhes Event imprint is present through the carbonate record that displays the highest values during MIS 11, most likely associated with the extensive propagation of the *Gephyrocapsa* coccolithophore. Our results show that the productivity response is mainly conditioned by the global pattern of glacial and interglacial strength, showing enhanced (lower) productivity during those particularly strong, such as MIS 11, and MIS 16 (weaker, e.g., MIS 14) glacials or interglacials.



P1-107

Fluctuations in ocean pH across the Ordovician-Silurian boundary

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The Ordovician and Silurian periods were times of major environmental and biological change. This includes the Great Ordovician Biodiversification Event (GOBE) and the oldest of the five greatest mass extinctions (the end-Ordovician) followed by recovery in the early Silurian. The circumstances surrounding these events remain debated. Our understanding of associated changes to the carbon cycle largely comes from stable carbon isotopes where the size of carbon isotope excursion measured is dependent on the carbon isotope composition of the source or sink driving it. Here we present the first ever ocean pH reconstruction spanning the Ordovician-Silurian boundary, generated using the boron isotope composition of well-preserved fossilised brachiopods. Our initial findings show striking concurrence between fluctuations in ocean pH and, by proxy, atmospheric CO₂, and the timing of some of largest changes in biodiversity of the Phanerozoic.



P1-085

An 8-Myr Record of Dust Deposition in the South Pacific Ocean from IODP expedition 383

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The Southern Ocean is a key player in regulating atmospheric CO₂ variations through the biological utilisation of nutrients supplied by atmospheric dust. Sediment records and model simulations show that higher mineral dust fluxes during glacial periods coincide with increased bioproductivity and lower atmospheric CO₂, which has been associated with iron fertilisation. However, direct measurements of dust deposition over the Southern Hemisphere oceans are scarce and there is a great need for an expanded geographical coverage of direct observations of dust deposition. This is particularly true for long-term Plio-Pleistocene dust records from the Southern Ocean, which are presently confined to the subantarctic South Atlantic where dust almost entirely originates from Patagonian sources. Here we present the first long records from the South Pacific dominated by Australian dust sources. Our records are based on a 145 m long sediment sequence (Site U1541) recovered during IODP expedition 383 in the central South Pacific spanning the last 8 Myr. We present grain-size data, terrestrial biomarkers and dust- and sediment fluxes and relate this to global and regional paleoclimatic trends. By using end-member modelling we aim to disentangle the dust signal from current-sorted sediments. Our final goal is to improve our understanding of dust-iron coupling from the largest Southern Ocean sector and its impact on atmospheric CO₂ and global climate.



P1-053

Earth System Model Analysis of how Astronomical Forcing is Imprinted onto the Marine Geological Record

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Astronomical cycles in marine geological records are an invaluable means of constructing age models and provide insights into Earth system dynamics. However, how various astronomical periods are filtered by the Earth system and the mechanisms by which carbon reservoirs and climate components respond, particularly in absence of dynamic ice sheets, is unclear. With an intermediate complexity Earth system model, we simulate 4-million-year-long transient astronomical forcing and its impact on key paleoceanographic proxies (temperature, DIC $\delta^{13}\text{C}$, and wt% CaCO_3). We systematically examine how inorganic and organic carbon feedbacks influence the astronomical expression in these proxies with a series of simulations of increasing complexity. The global annual mean temperature is mainly controlled by eccentricity forcing and is little influenced by the modeled feedbacks. In contrast, the cycling of nutrients and carbon within the ocean and between the atmosphere, ocean, and marine sediment reservoirs is driven mainly by precession forcing that translates into pronounced eccentricity cycles in $p\text{CO}_2$, benthic $\delta^{13}\text{C}$, and wt% CaCO_3 as a result of the lowpass filtering effect of the ocean carbon reservoir. Comparison between our model simulations and paleoclimate proxy records demonstrates that the magnitude of early Cenozoic $\delta^{13}\text{C}$ variability can be obtained by an astronomically forced imbalance between the input and removal of organic carbon from the ocean reservoir, however, it does not explain the presence of the short (100 kyr) eccentricity cycles in benthic $\delta^{13}\text{C}$ as recorded in the proxy data.



P1-111

What can belemnites tell us about Mesozoic ocean circulation patterns and temperatures?

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Belemnites are an extinct group of cephalopod molluscs which were widespread across and throughout the Jurassic and Cretaceous oceans. Their ubiquity and the high preservation potential of their calcitic rostrum makes them ideal targets for stable and clumped isotope palaeothermometry techniques, yet the signals preserved in belemnite calcite may reflect a number of different influences. Here we discuss the various factors that contributed to the preserved belemnite calcite stable isotopic signals, and how palaeoceanographic and palaeotemperature signals may be reconstructed using belemnite carbonate clumped and stable isotopes.



P1-003

Reconstructing seawater $\delta^{234}\text{U}$ to improve the accuracy of U-Th ages during the Last Interglacial

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The ratio of seawater $^{234}\text{U}/^{238}\text{U}$ ($\delta^{234}\text{U}$) is a key factor in determining the accuracy of fossil coral U-Th sea level chronologies. Seawater $\delta^{234}\text{U}$ can vary on glacial-interglacial timescales but is poorly constrained prior to the Last Glacial Maximum (~20,000 years ago). Here we address the challenge posed by the assumed seawater value that impacts age interpretation in a way that has the potential to systematically bias age accuracy. The $\delta^{234}\text{U}$ initial value should reflect the seawater $\delta^{234}\text{U}$ value at the time of the formation of the respective coral sample, yet, corals have porous, aragonitic skeletons that are susceptible to diagenesis. Currently, the back-calculated value of $\delta^{234}\text{U}$ at the time the coral grew is used to screen out altered (open-system) samples and impacts calculations for open-system modeled ages. Choosing a seawater value that is too low may bias the age interpretation towards incorrect, younger ages and vice versa. Alternatively, one could calculate a modeled open-system age, but this approach relies upon the assumed seawater $\delta^{234}\text{U}$ at the time of coral growth in a similar way.

We employ a stepwise leaching protocol to identify the seawater $\delta^{234}\text{U}$ value using Last Interglacial fossil corals, a critical period where sea level was several meters higher than present, and global mean temperature was similar to today (~129,000 years ago). This approach will be used to compare $\delta^{234}\text{U}$ initial values between well-preserved corals from different sites, between corals of differing preservation at the same site, and between well-preserved corals at a single site from the beginning to the end of the Last Interglacial sea level highstand. If we can isolate a reliable $\delta^{234}\text{U}$ seawater value for the Last Interglacial, this would enable a global recalibration of the timing of sea level changes relative to other climate drivers and responses during this past warm period.



P1-084

Surface sediment coccolith assemblages and *Emiliana huxleyi* morphotype calcification across the Drake Passage, Southern Ocean

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Physical and biogeochemical properties of the Southern Ocean are experiencing rapid and profound changes that may influence the distribution and composition of pelagic plankton communities. The most prolific carbonate-producing phytoplankton group, coccolithophores, play an important role in SO biogeochemical cycles. Although the record of (sub-)fossil coccolith assemblages constitute invaluable indicators for palaeoenvironmental reconstructions, knowledge is scarce in the SO.

This study investigated the coccolith assemblages preserved in surface sediments across the Drake Passage retrieved during R/V Polarstern expedition PS97. We focused on the coccolith response to steep environmental gradients across the frontal system of the Antarctic Circumpolar Current. We also examined the morphological diversity of *Emiliana huxleyi*, emphasizing biogeographical variability, coccolith sizes and calcite carbonate mass estimations.

North of the Polar Front the surface sediments provide suitable material to reconstruct overlying surface ocean conditions. Comparatively high coccolith abundances and species diversity occur especially south of the Polar Front. Here, further factors such as temporary thriving coccolithophore communities in the surface waters or transport of settling coccoliths via surface and bottom currents and eddies influence the (sub-)fossil coccolith assemblages. Additionally, deeper samples in the southern part of the study area are particularly affected by selective carbonate dissolution.

We identified five *E. huxleyi* morphotypes (A, A overcalcified, R, B/C and O). *E. huxleyi* morphologies reflect diverging biogeographical distributions, trending towards smaller and lighter coccoliths to the south and emphasizing the importance of documenting those morphologies in relation to changing environmental conditions to assess their response to projected environmental change in the SO.

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P1-040

Last Glacial Maximum intermediate and deep-water oxygen and preformed phosphate reconstructions and its linkage to atmospheric CO₂ drawdown

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During the Last Glacial Maximum (LGM), atmospheric CO₂ was significantly lower than the pre-industrial, potentially due to an increase in the biological pump efficiency. One way we can look at changes in the biological pump efficiency is through oxygen and preformed phosphate reconstructions. Many qualitative shallow/intermediate waters record higher O₂ during the LGM due to an increase in oxygen solubility. Contrastingly, the qualitative oxygen proxies record lower O₂ in deep waters during the LGM, potentially indicating this increased storage of respired carbon. We have updated the first quantitative oxygen proxy, $\Delta\delta^{13}\text{C} - \text{O}_2$, calibration from 6 cores to over 25 cores. Preliminary results show a similar calibration to the findings from Hoogakker et al. 2014. Using this updated calibration, we generated two oxygen depth profiles in the Indo-Pacific and Atlantic Ocean. With this, we quantify preformed PO₄ (Ppre,AOU) in five marine-sediment cores off the southern-coast of Australia using a combination of unpublished LGM bottom water O₂ reconstructions and previously published paleo-temperature and paleo-nutrient estimates. Preliminary results indicate that the majority of the Glacial-Interglacial CO₂ drawdown resulted from an increase in the biological pump efficiency. Lastly, I investigated a new potential proxy for bottom water carbon export flux.



P1-089

Stratigraphy and provenance of Ocean Drilling Program Core 693A-2R from the continental margin off Dronning Maud Land in the Weddell Sea, East Antarctica

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Sedimentary records from near the East Antarctic ice sheet (EAIS) provide important context for understanding EAIS sensitivity under different climate states. An interval of particular interest is the Mid-Pleistocene Transition (MPT), centered at ~ 800 ka, where global records of ice volume transition from a 41 kyr to a 100 kyr period. Ocean Drilling Program (ODP) Leg 113 Site 693 from the Dronning Maud Land (DML) margin, recovered a discontinuous Pleistocene to Cretaceous sedimentary sequence. Core 2 from 693A recovered the Brunhes-Matuyama (B-M) magnetic reversal at 8 mbsf (average ~1cm/kyr accumulation) and included relatively abundant foraminifera. We are undertaking an integrated chemostratigraphic (⁸⁷Sr/⁸⁶Sr, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) study of foraminifera in 693A-2R, combined with multiple other proxies such as shipboard and other non destructive physical and chemical properties, sedimentology including abundance of ice rafted detritus, grain size distribution, carbonate content and geochemical provenance, to provide a record of regional stratigraphy and insights into ice sheet dynamics. Initial ⁸⁷Sr/⁸⁶Sr results from ten foraminifera samples are consistent with the position of the B-M boundary and indicate that the core spans from 1.23 to 0.675 Ma. The GRA density profile defines four cycles above the B-M, but no distinct cycles below. The stable isotope values do not show a simple and consistent relationship with GRA. Detrital mineral provenance can help to understand and compare glacial and interglacial conditions. A preliminary observation from Ar-Ar data of hornblende is that a wide range of source ages from the Archean to Phanerozoic are found at glacial-interglacial transitions, while less variability and mostly younger ages characterize glacial conditions. We are working to refine this record and to compare it with published records around Antarctica to better understand the Antarctic ice evolution during the MPT.



P1-103

Nutrient rise drove ocean deoxygenation over the past eight million years

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The modern Pacific Ocean hosts the largest oxygen-deficient zones (ODZs), in which nitrate is used to respire organic matter. The history of the ODZs may offer key insights into ocean deoxygenation under future global warming. In a 12-million-year (Ma) record from the southeastern Pacific, we observe a >10‰ increase in foraminifera-bound nitrogen isotopes (¹⁵N/¹⁴N) since late Miocene time (8-9 Ma ago), indicating large ODZs expansion. Coinciding with this change, we find a major increase in the ocean's nutrient content, reconstructed from P and Fe measurements of hydrothermal sediments at the same site. Whereas global warming studies cast seawater O₂ concentrations as mainly dependent on climate and ocean circulation, our findings indicate that modern ODZs are underpinned by historically high concentrations of seawater phosphate.



P1-114

Sea surface temperatures in the subantarctic Eastern South Pacific since the Late Miocene (IODP Expedition 383)

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The Antarctic Circumpolar Current (ACC), the world's strongest zonal current system, is connected to all three oceans and therefore responds to and interacts with global climate changes. However, for the past climate history, information on the Cenozoic palaeoceanography is lacking for the Pacific sector of the ACC. During IODP expedition 383, a complete composite sediment record from the Late Miocene to Holocene has been recovered from the Eastern South Pacific in the northern ACC system [1]. Here, we present the first alkenone-based sea surface temperatures (SST) from drill Site U1543 located close to the South American continent and the Drake Passage at ~3850 m water depth for a better understanding of the atmosphere-ocean-cryosphere dynamics since the Late Miocene at ~8 Ma. The preliminary SST record from the 376.3 m long composite sequence reveals a distinct cooling period of about 9°C during the Late Miocene Cooling (LMC). Along with previous SST records from the Pacific covering the LMC, we demonstrate that the pole-to-equator temperature gradients gradually increased from 13°C to 18°C. A SST minimum around 6 Ma corresponds to the onset of the Patagonian Glaciation and is accompanied by a change in vegetation as suggested by long-chain *n*-alkanes. While during the onset of the Northern Hemisphere Glaciation (NHG), a northern hemisphere record from the Northeast Atlantic documents decreasing SST, the long-term pattern of the southeast Pacific SST record indicates slight warming. This difference might be associated with a dynamic West Antarctic Ice Sheet during the Pliocene affecting N-S shifts of the frontal systems and water transport through the Drake Passage [2]. On a glacial-interglacial timescale, in turn, the northern and southern hemisphere records show comparable temperature changes.

[1] Lamy et al. & Expedition 383 Scientists (2019) *Expedition 383 Preliminary Report* IODP. [2] Gohl et al. (2021) *Geophysical Research Letters*, 48, e2021GL093103.



P1-060

Stratigraphy and paleoenvironmental changes across the Eocene – Oligocene succession in the Labrador Sea (DSDP Site 112) elucidated with dinocysts

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The Oligocene epoch in the North Atlantic region is often neglected in paleoclimate and paleoceanography studies, largely due to the scarcity of complete Oligocene sedimentary archives and poor biostratigraphic control in this region. Mostly, calcareous plankton biostratigraphy is used for paleoclimatic deep-time records. A utility trade-off of these microfossils is their diminished diversity and poor preservation at higher latitudes during the Oligocene. Fortunately, organic-walled dinocysts are resistant to chemical dissolution and have a high species diversity in the Late Eocene to Oligocene. This study presents the first comprehensive analysis of dinocyst assemblages of the upper Eocene to Oligocene succession recovered in Deep Sea Drilling Program (DSDP) Site 112 in the southern Labrador Sea. Abundant and well preserved dinocysts were analysed by using high-resolution images of palynological slides digitised under the AVATARA project, a novel method in studying palynological assemblages. Five biostratigraphic events are recorded at Site 112: the first occurrence (FO) of *Chiropteridium galea/lobospinosum* complex, last occurrence (LO) of *Licracysta semicircularata*, FO *Svalbardella clausii* and LO *Enneadocysta pectiniformis*. This sequence implies a late Eocene to early Chattian age. Our new dinocyst-based paleoenvironmental reconstruction shows a change in surface ocean conditions from open marine in the late Eocene to a restricted marine setting in the Oligocene. Higher productivity is recorded in the Rupelian, possibly linked to Bell River discharge into the Labrador Sea. Surface waters cooled during the Oi-2b cooling event in the early Chattian as reflected by the appearance of *S. clausii*. These results contribute to an improved biostratigraphic framework for Site 112 and to building a more detailed picture of paleoenvironmental conditions in the high-latitude North Atlantic region during the Eocene greenhouse to Oligocene coolhouse climate and oceanic transitions.



P1-117

Reconstruction of seawater calcium/magnesium concentrations and boron isotope ratio over the last 100Myr using Gaussian Processes

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Geochemical time series can be challenging to reconstruct from data. We demonstrate the advantages of using Gaussian Processes (GP) for estimating geochemical time series by application to the calcium and magnesium concentrations of seawater, and the boron isotopic composition of seawater, over the last 100Myr. These signals are ideal test cases as existing constraints are sparsely sampled, clustered, and noisy – properties common to many geochemical time series. Additionally, these parameters are important in the determination of palaeo pH and CO₂ from boron isotopes. We are therefore able to illustrate the benefits the GP approach has in practice, including: geochemical intuition for hyperparameter choice, flexibility in the form of the reconstructed signal, and improved propagation of uncertainties.



P1-050

Response of foraminifera and plankton ecology to the closure of the Central American Seaway and atmospheric CO₂ decline during the Pliocene.

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The closure of the Central American Seaway led to a significant reconfiguration of ocean circulation alongside a concurrent drop in atmospheric CO₂ at the end of the Pliocene. A low resolution record of planktic foraminiferal size shows that during the past 4 million years, planktic foraminifers have grown to unprecedented sizes, suggesting a link between environmental changes in the Pliocene and subsequent gigantism. Here we quantify the response of foraminifera using a combined data and model approach, assessing the impact on traits, geographic distribution, and ecological functions.

We measured size in foraminiferal assemblages using automatic microscopy to assess their morphological response. The 95th percentile was calculated on the maximum diameter measurements of 1.28 million specimens. Changes in foraminifera ecological guilds were quantified across 24 globally distributed sites. Both data sets reveal unexpected stability across the seaway closure history and to oceanographic responses to the Pliocene drop in atmospheric CO₂: a decrease in size at the poles from early to late Pliocene, minimal changes in the tropics, with the cold interval marine isotope stage (MIS) M2 having little to no expression on size. Complimentary predictions of plankton size and biomass were generated by the trait-based model of plankton ecology (including foraminifera), ForamEcoGenIE, allowing the assessment of changes in underlying food web changes and of broader ecological restructuring. ForamEcoGenIE predicts the distribution of plankton community biomass and biomass-weighted mean size based on fundamental eco-physiological constraints (traits) determined by cell size. The model predicts that the mean cell size of plankton communities is relatively resilient to changes in both CO₂ and seaway closure. Combined, these results suggest that changes in foraminifera size may be evolutionary in nature rather than a response to environmental change.



P1-011

Subsurface water oxygen reconstructions from the North Pacific OMZ margin using I/Ca

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The east Pacific currently holds the largest oxygen minimum zone in the world with a significant amount of dissolved CO₂ stored in the oxygen depleted intermediate waters. The distribution and volume of low oxygen waters is thought to significantly influence glacial/interglacial atmospheric CO₂ changes. The Pacific is thought to have held less oxygen in the deep water and more oxygen in the intermediate waters during glacial times.

Here we apply the planktic foraminifera iodine/calcium proxy to assess subsurface water oxygenation along the Californian Margin (ODP Sites 1011, 1014 and 1020) and the west Pacific Ontong Java Plateau (ODP Site 806) and compare these results with previous oxygenation proxies from the Pacific. Whilst other proxy (nitrogen isotopes, benthic foraminifera assemblages, trace metals) reconstructions along the California Margin show a relative decrease of oxygenation during the deglaciation, our planktic foraminifera I/Ca show no changes between the last glacial period and the Holocene. On the other hand, ODP Site 806 from the West Pacific shows an increase in I/Ca from the glacial to Holocene, indicating either increasing interglacial subsurface oxygenation in the West Pacific, or that another process influences I/Ca in planktic foraminifera.



P1-078

The Southern Ocean's role in the global carbon cycle over the last 800 kyr constrained using reconstructions of the CO₂ system

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The critical role of the Southern Ocean in controlling the Pleistocene atmospheric CO₂ oscillations is widely acknowledged. However, hindered by sampling difficulties surrounding Antarctica, the underlying mechanism and associated pathway of ocean-atmosphere CO₂ exchange in the Antarctic zone of the Southern Ocean remains mysterious. CO₂ exchange between the ocean and atmosphere is closely coupled with the pH and partial pressure of CO₂ ($p\text{CO}_2$) of surface seawater. Here, we present a new $\delta^{11}\text{B}$ record of *Neogloboquadrina pachyderma* from sediment core PS1506 (68.73°S, 5.85°W) that tracks the pH and surface $p\text{CO}_2$ of the Antarctic zone of the Southern Ocean over the last 8 glacial cycles. These data are complemented by benthic B/Ca and carbonate preservation indices; due to the location of this core on the continental margin of the eastern Weddell Sea, these data allow us to track the source CO₂ chemistry of the dense Antarctic waters that feed the ocean's lower overturning cell. From these data, we discover a tight relationship between seawater CO₂ chemistry and atmospheric CO₂, thereby highlighting the Southern Ocean's key control on glacial-interglacial CO₂ change. Considering the changes in carbonate preservation seen at this site, we also investigate the potential influence of dissolution on the shell chemistry of *N. pachyderma*. Together, our records provide direct geochemical evidence of changes in the Air-Sea CO₂ exchange of the Antarctic Zone of the Southern Ocean over multiple glacial cycles, and also contribute insights into the applications of foraminiferal $\delta^{11}\text{B}$ in paleoceanography.



P1-016

Is coral skeletal growth the key to unlocking absolute coral SST reconstructions?

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The trace element chemistry of massive coral skeletons is widely used as a proxy for sea surface temperature (SST) with Sr/Ca ratios having been successfully applied for decades. However, the relationship between Sr/Ca and SST and thus the sensitivity of the paleo-thermometer varies from location to location and between different coral species and even colonies of the same species. One potential explanation for the variable Sr/Ca-SST sensitivities could be variable attenuation in the region of skeletal mass accumulation within the living coral tissue layer. Corals calcify throughout the tissue layer so corals with wider tissue layers should exhibit more attenuation or “bio-smoothing” than those with a relatively thin tissue layer. To test this tissue layer attenuation hypothesis, we have produced three high-resolution coral multi-element/Ca records (Li/Mg, Mg/Ca, Sr/Ca, U/Ca) from three live collected *Porites* coral cores drilled in open ocean and lagoon settings from the Chagos Archipelago, tropical Indian Ocean. These corals exhibit a large range of tissue layer thickness (from 3 to 10 mm) and the temperature history at the sampling locations is well characterised by a combination of *in-situ* temperature loggers and satellite-derived SSTs. Using a computer-operated drill to collect a constant volume of coral per sample, the Ca concentrations obtained should reflect variations in skeletal density. By obtaining this information from the same sample powders measured for multiple-element SST proxies will allow for the direct evaluation of the effect of coral skeletal growth on the sensitivity of such proxies and help to identify the underlying mechanisms and potentially to allow for growth rate correction of coral SST proxies.



P1-115 **Cancelled**

Advancing the astronomically calibrated geological time scale: New astronomical solutions for the Paleocene

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Astronomical solutions provide insight into the Solar System's dynamical evolution and are indispensable tools in cyclostratigraphy and astrochronology. Constructing an absolute, fully calibrated astronomical time scale (ATS) has hitherto been hindered beyond ~50 Ma because orbital calculations disagree before that age due to solar system chaos. We have recently developed a new approach that allowed extending the fully calibrated astronomical time scale to ~58 Ma. Here, we present geologic data and new astronomical solutions, extending our approach across the Paleocene epoch (~66 to ~56 Ma). New astronomical solutions were generated using numerical solar system integrations following our earlier work. The solutions are available to 300 Ma - we caution, however, that the time interval 300-66 Ma is unconstrained due to dynamical chaos in the solar system. We have tested the sensitivity of our new solutions to various parameters, including numerical stepsize, solar quadrupole moment, number of asteroids included, initial positions, and tidal dissipation. We demonstrate that our new solutions yield improved agreement with the geologic record across the Paleocene epoch, compared to previously available astronomical solutions for that period. Furthermore, we discuss implications of our results for solar system chaos and resonance transitions. We have also obtained K/T boundary (KTB) ages based on our new solutions, which suggest slightly younger KTB ages than the most recent radiometric ages based on Ar/Ar dating.



P1-098

Was the PETM preceded by transient carbon emissions? A Pelagic Perspective

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The Late Paleocene and Early Eocene are characterized by a series of hyperthermal events that includes the PETM. Although the primary source of C during the PETM is likely the North Atlantic Igneous Province (NAIP) volcanism-induced emissions of thermogenic methane and CO₂, orbitally driven warming has been invoked to explain the destabilization of methane hydrates for the other hyperthermals, as well as the PETM onset. Theoretically, if gradual warming driven by orbital forcing was a primary trigger/driver, increasing C cycle instability might occur prior to the main C emission event. Indeed, evidence for a transient precursor carbon release to the PETM have been observed in two sections, both with high sedimentation rates. The signal of this event or of earlier precursors, however, have yet to be set in the context of orbital variations which are best constrained in pelagic sections where expression of such a short-lived perturbation would be diluted by sediment mixing. To address this deficiency, we employ the strategy of measuring the carbon and oxygen isotopes of multiple individual foraminifera from each sample, focusing on discrete time slices of the orbitally-tuned Paleocene section of the South Atlantic Site 1262. Preliminary results show a general negative relationship between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of single planktic forams within each sample reflecting a strong environmental (depth dependent) control on foraminifera growth with relatively low $\delta^{18}\text{O}$ and high $\delta^{13}\text{C}$ values in shallow dwelling species compared to deeper dwelling species. A deviation from this pattern with a partial positive relationship of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in a small subset of shells is observed in several samples, particularly in those deposited during maxima eccentricity (~100kyr), which suggests possible short-lived C emissions driving surface warming, supporting the hypothesis of increased C cycle instability caused by warming-induced thermal dissociation of methane hydrates.

Poster abstracts



Topic 1: Climate and Ocean Chemistry

virtual posters



Pv-102 > changed to P1-115

Sedimentary sterol as a paleoclimate proxy in the central Okhotsk Sea across the Mid-Pleistocene Transition

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Mid-Pleistocene Transition (MPT, ~1.2-0.6 Ma) is a period that global glacial/interglacial periodicities turned from 41- to 100-kyr with absence of significant orbital configuration changes. In order to reconstruct subarctic NW Pacific paleoclimate changes across the MPT, here we explore the potential of sedimentary sterol as proxy in core MD01-2414 (53°11.77' N, 149°34.80' E) from the central Okhotsk Sea. We measured six sterol compounds by GC-MS (β -sitosterol, stigmasterol, campesterol, dinosterol, brassicasterol and 24-methylene cholesterol), implying sources from terrestrial higher vegetations, dinoflagellates or diatoms. Our results show that all the sterols we measured generally follow the glacial/interglacial cycles during the MPT, with higher values in interglacial and lower ones in glacial periods. The concentrations during glacial and interglacial range from 1200-100 and from 50-8 ng/g sediment, respectively. There are three high concentration periods at MISs 21, 25 and 31/32 boundary. All the six sterols show significant low values during MISs 22 to 24 which support previous studies of the failed interglacial MIS 23 at around 0.9 Ma. Our observations by using sterol records from the central Okhotsk Sea are in line with pollen record from Lake El'gygytgyn located in the Far East Arctic region which suggest substantially cooling and lower forest cover across MPT and the strong warming event during one of the super interglacial periods (MIS 31).



Pv-101

Stable oxygen isotopes in planktonic foraminifera from surface sediments in the California Current system

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Stable oxygen isotopes of *Globigerinoides ruber* and *Globogerina bulloides* have been widely used to infer the variability of the hydrographic structure of the water column over various time scales. However, the reliability of this geochemical tool requires a regional view because the inferred calcification depth and temperature of planktonic foraminifera depends on local environmental conditions. In the present study, $\delta^{18}\text{O}$ values of *G. ruber* and *G. bulloides* collected from 21 surface sediment samples were used to infer the depth of calcification of these two species in the southwestern margin of the Baja California peninsula. The $\delta^{18}\text{O}$ values of *G. ruber* were representative of oceanographic conditions of warm tropical water masses (summer-autumn) and of *G. bulloides* represented upwelling conditions and cold-water masses (winter-spring). Estimated calcification depths ranged from 0 to 30 m for both species. The isotopic difference between these species was 1.2‰ (this study) and 1.1 ‰ in Guaymas basin (sediment trap) suggests a sea temperature difference of $\sim 5^\circ\text{C}$, which is very similar to the sea temperature difference inferred from the Mg/Ca ratio for both species in the period 3 to 14 ka. This evidence indicates that *G. ruber* and *G. bulloides* have calcified over the same depth interval, but under contrasting seasonal oceanographic conditions i.e. upwelling (winter-spring) and stratified water column (summer-autumn).



Pv-104

Effect of the carbonate chemistry on trace elements in the large benthic foraminifer *Operculina ammonoides*

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In the past few years, Na/Ca in biogenic CaCO₃ was introduced as a potential proxy for past seawater Ca concentrations (references 1-5). In addition, salinity was shown to have a negligible effect on the Na/Ca in the large benthic foraminifer *O. ammonoides* (references 2-3). Following these studies, we performed a set of carbonate chemistry experiments to test its effects on Na/Ca_{shell} and other trace elements in the shells. Under constant dissolved inorganic carbon (DIC, ~2170 μmol kg⁻¹) pH was varied (7.5-8.4 NBS scale), and with constant pH (~7.9) DIC was varied (830-2470 μmol kg⁻¹). The foraminiferal growth rate, based on alkalinity depletion, correlated positively with increasing pH, DIC, and Ω calcite of the experimental seawater. At the lowest pH and DIC, population growth was very low and some of the shells partially dissolved. In the varying pH experiment specimens added 25-130% to their original weight and in the varying DIC experiment, 25-90% was added.

Na and Li in the high-Mg *O. ammonoides* (12 mole% Mg) are sensitive to seawater carbonate chemistry (CO₃²⁻ and/or Ω), while Mg and Sr are insensitive to these factors. On the other hand, based on previous experimental work on low-Mg planktic foraminifera, it seems that Na and Li are much less sensitive to changes in carbonate chemistry. We conclude that for *O. ammonoides* the effect of carbonate chemistry on Na and Li incorporation should be considered when interpreting fossil data.

¹Hauzer et al.. 2018) *EPSL*

²Hauzer et al.. 2021) *Paleo Paleo*

³Le Houedec et al.. 2021) *G³*

⁴Ram & Erez (2021) *Frontiers ES*

⁵Zhou et al.. 2021) *GCA*



Pv-106

Deglacial CO₂ release from the Southern Ocean during Termination IV

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Abrupt atmospheric CO₂ increases characterise a critical feature of deglaciations. The deglacial CO₂ rise toward Marine Isotope Stage (MIS) 9e (Termination IV) started from 197.1 ppm to 300.7 ppm at 335 ka BP, representing the highest natural atmospheric CO₂ recorded in the Antarctic ice cores over the past 800 ka. The oceanic carbon storage changes must be involved in regulating the Pleistocene atmospheric CO₂ variations. However, the mechanisms and pathways of the air-sea carbon exchanges remain elusive partly due to the lack of oceanic carbonate system proxy data with a robust age control beyond Termination I. Here, we present high-resolution carbonate system records during Termination IV from Iberian Margin and employ a newly developed process to reconstruct the air-sea exchange signatures. Our results suggested that during the deglacial CO₂ increase toward MIS9e, there was a net release of CO₂ from the Atlantic sector of the Southern Ocean. The net CO₂ release is highly likely due to the expansion and ventilation of the glacial Antarctic Bottom Water.



Pv-110

Subantarctic westerly wind dynamics inferred from high-resolution mid to late Holocene peat archive

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The Southern Hemisphere mid-latitude Westerly Winds (SWW) play a critical role in the carbon storage capacity of the Southern Ocean by influencing processes such as ocean circulation, upwelling of deep ocean waters and ocean-air gas exchange. Despite the sensitivity of these key processes to changes in the position and intensity of the SWW, Holocene SWW variability is poorly constrained due to sparse geologic records. Peat mires on oceanic islands can preserve past climate information at a high temporal resolution, including proxies that indicate wind strength and air transport patterns.

Macquarie Island is uniquely positioned in the core of the SWW at 54°S, mid-way between Tasmania and Antarctica. Extending north from the main body of the island, the North Head is directly exposed to the prevailing westerlies. Here we present a high-resolution multi-proxy reconstruction from a 3-m peat sequence extracted from near the high point of North Head.

The archive dates from c. 4550 yBP, with a temporal resolution averaging 8 years for each 5 mm section. The age-depth model, based on radiocarbon and ²¹⁰Pb analyses, indicates higher accumulation rates (0.8 mm yr⁻¹) from 2000 to 4500 years BP, lower rates from 300 to 2000 years BP (0.08 mm yr⁻¹), and higher rates during the most recent 300 years (1.25 mm yr⁻¹). Wind intensity is inferred from long-range dust flux, grain size and local wind-blown material. Exotic pollen and long-range dust provenance (determined by comparing rare earth elements and Nd isotopic composition with Southern Hemisphere dust sources) indicate air transport pathways.

For a regional overview, we compare our data with temperature and CO₂ proxies from Southern Ocean marine and ice cores. Our high-resolution reconstruction further demonstrates the contributions of remote island archives to understanding past climatic and SWW variability in the Southern Ocean and reduces uncertainties in SWW strength and position during the mid to late Holocene.



Pv-111

Investigating Pleistocene ice sheet and ocean dynamics in the Subpolar North Atlantic using cosmogenic nuclides in IRD and foraminifera-bound nitrogen isotopes

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To better understand ice sheet and ocean dynamics in the subpolar North Atlantic, we are applying two relatively novel proxies - cosmogenic nuclides (^{10}Be and ^{26}Al) in ice-rafted debris and foraminifera-bound nitrogen isotopes (FB- $\delta^{15}\text{N}$) - to North Atlantic sediment cores across the Pleistocene as well as Heinrich events during the last glacial period. Cosmogenic nuclides accumulate in land surfaces exposed to cosmic rays, but decrease in concentration when surfaces are ice covered due to radioactive decay and erosion. The faster decay of ^{26}Al compared to ^{10}Be also causes their ratio to decrease during burial, yielding information about the duration of ice cover in sediment source regions. When measured in ice-rafted debris, these isotopes reflect an integrated history of exposure and erosion along flow lines discharging icebergs to the ocean. Additionally, FB- $\delta^{15}\text{N}$ reflects the degree of surface nitrate assimilation in the subpolar North Atlantic region, which has been shown to increase in response to iceberg-associated meltwater input and ocean stratification. Together, these two proxies may better constrain the evolution and coupling of ice sheet and ocean dynamics in the Pleistocene.

We have generated preliminary records of cosmogenic nuclides spanning the last glacial period and FB- $\delta^{15}\text{N}$ spanning the last glacial period and Mid-Pleistocene. We find depressed $^{26}\text{Al}/^{10}\text{Be}$ ratios and low, declining ^{10}Be concentrations on the western side of the North Atlantic basin, which suggests a persistent Laurentide ice sheet that rarely or briefly disappeared during interglacials since the MPT. Preliminary FB- $\delta^{15}\text{N}$ results appear to show an increase from the MPT towards the present, which suggests the efficiency of the biological pump in the North Atlantic has likely increased. Our pending hypothesis - that persistent ice may be related to the inferred increase in biological pump efficiency - will be clarified by continued development of these records.



Pv-109

Hydrographic Changes: Sediment Trap Record from the Northern South China Sea

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In addition to seasonal cycles, the variation of chlorophyll-*a* concentration in the South China Sea (SCS) shows a strong response to wind speed under the influence of El Niño–Southern Oscillation (ENSO). Consequently, predators relying on phytoplankton trigger the wax and wane of growth in the water column. This study examined discrete 6-year mass fluxes and 3-year planktonic foraminiferal time series census from ten and four sets of sediment trap, respectively, moored at the South East Asia Time-series Study (SEATS) site in the northern SCS. A total of four sets of sediment trap mooring, spanning from August 2016 to August 2019 with 8-day and 16-day collecting periods, provided access to evaluate the impact of the prevailing monsoon system and interannual climatic conditions. The imprint of an ENSO cold phase (La Niña event) in 2017 was signified by 2–3-fold higher values than the 3-year average of total mass and foraminiferal shell fluxes. Instead of the common dominance of *Trilobatus sacculifer* and *Globigerinoides ruber* among species composition, *Neogloboquadrina dutertrei* was the predominant species comprising over 40–60% of total shells greater than 212 μm . Furthermore, the interval with an elevated abundance of *N. dutertrei* lasted throughout January 2018 (four collecting intervals). Foraminifera shell fluxes were the lowest during warm months (March–August) in 2019, which was coeval with the increase in proportions of *Orbulina universa* and *Globigerinella calida*. The unusual species composition might signify a weak ENSO warm phase (a weak El Niño event) between September 2018 and August 2019.



Pv-103

Distribution coefficients of major and minor elements in coral skeletons: experimental results under variable seawater Ca concentrations

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In a search for paleoceanographic proxy for Ca, under the assumption that Na did not change during the past 100 My, we cultured corals under different seawater (SW) Ca concentrations (10, 15, 20 and 25 mM). Two coral species, *Pocillopora damicornis* and *Acropora cervicornis*, were cultured for ~ 3 months, and the newly precipitated skeleton was analyzed using ICP-OES and compared to the culturing solutions (experimental details and results are available in Ram & Erez, 2021). The results show highly significant linear correlations with zero intercepts between $EI/Ca_{\text{Skeletons}}$ and EI/Ca_{SW} for the following elements: Li, Na, Mg, K, Sr and Ba, from which distribution coefficients (D_{EI}) were calculated. These D_{EI} values are similar to those of Giri et al. 2018) and are close to the inorganic D values for aragonite with slightly higher values for Na, Mg and K (elements with $D_{\text{Inorganic}} \ll 1$) and lower values for Sr and Ba ($D_{\text{Inorganic}} > 1$). The deviations from $D_{\text{Inorganic}}$ suggest a Rayleigh fractionation process in which the calcifying fluid is essentially SW. Fitting D_{Corals} into Rayleigh model, explains the differences in D_{Coral} between the two species, suggesting that *A. cervicornis* has a close calcifying reservoir that utilizes ~50% of its Ca, while *P. damicornis* has an open system utilizing ~20% of its Ca. We note that growth rates of *A. cervicornis* is ~2 times higher than that of *P. damicornis* which may be attributed to its higher ability to concentrate CO_3^{2-} in its calcifying fluid as indicated by its higher Ca utilization. These results are in good agreement with observations of DeCarlo et al. 2018). Using this information, Na/Ca maybe used as a paleo Ca proxy while other elements can be reconstructed relative to Ca with known corrections for temperature (e.g. Sr and Mg and possibly Na and Li).

Ram, S., & Erez, J. (2021) *Frontiers E S*, 9, 336;

Giri, S. J. et al. 2018), *GCA*, 222, 535-549;

DeCarlo, T. M. et al. 2018). *Proc. R. Soc. B* 285: 20180564



Pv-108

Stable isotope signatures from dextrally and sinistrally coiled *Morozovella* and *Acarinina* from the Pacific Ocean (Sites 1209-1210): insights on paleoecology across the Early Eocene Climatic Optimum, EECO

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The EECO (ca 53-49 Ma) is a crucial interval of time to explore the marine biota response to climate changes because Earth temperatures and pCO₂ reached the peak of the entire Cenozoic Era. The unicellular planktic foraminifera (PF) are a major group of open-marine calcifiers largely adopted in paleoceanographic reconstructions. At the beginning of the EECO (J event) the abundance and diversity of the symbiont-bearing genus *Morozovella* markedly and permanently decreased in the Atlantic and Pacific Oceans whereas abundance and diversity of genus *Acarinina* increased. In addition, the *Morozovella* species switched their coiling direction (ability to grow chambers in clock or counter clockwise) from dominantly dextral (DX) to dominantly sinistral (SN) within 200-400 kyr after the K/X event. The morozovellid crisis can thus be partly read as the DX morphotypes crisis. Our quantitative study on *Acarinina coalingensis* and *A. soldadoensis* (the most abundant forms at sites 1209-1210) coiling direction shows that these species, differently from *Morozovella*, retained rather equal proportion of the two morphotypes below and across the EECO. Searching for the triggering causes of the recorded foraminiferal response, we performed oxygen and carbon stable isotope analyses on DX and SN morphotypes (or cryptic species) on six *Morozovella* species, *A. coalingensis* and *A. soldadoensis*. We selected levels below and above the drop in abundance and coiling direction changes. Results record generally lower stable carbon isotope signatures for SN morozovellids, thus suggesting reduced dependence on symbiotic relationship and/or slightly deeper habitat. The recorded ecology may have enabled SN forms to sustain the EECO stressors. Conversely, acarininids display values that suggest major ecological flexibility possibly enabling them to proliferate. Our derived stable isotope paleobiology gives new insights on strategies adopted by PF under global warming conditions.



Pv-107

Mg/Ca derived paleotemperatures across the Early Eocene Climatic Optimum (Tropical Pacific Ocean Sites 1209-1210)

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Studies on modern biota reveal that the climate-induced environmental stress is affecting the stability of marine ecosystems that are suffering the consequences of anthropogenic CO₂ emissions and global warming such as ocean acidification, eutrophication and anoxia. However, the response of the biota under long-term elevated temperatures and CO₂ concentrations remains uncertain because modern studies are limited to decades/historical times. The unicellular planktic foraminifera (PF) are a major group of open-marine calcifiers largely adopted in paleoceanographic reconstructions as extremely sensitive to environmental and climatic variations. The Early Eocene Climatic Optimum EECO (ca 53-49 Ma) is a crucial interval of time to investigate as Earth temperatures and pCO₂ reached the peak of the entire Cenozoic Era. The EECO impacted the abundance and diversity of the PF symbiont-bearing genus *Morozovella* that markedly and permanently decreased in abundance and diversity in the Atlantic and Pacific Oceans whereas abundance and diversity of genus *Acarinina* increased. Even though a link with the EECO perturbation appears evident, the driving causes of the recorded changes are still unknown. We present here new Mg/Ca derived paleotemperatures through laser ablation (LA)-ICP-MS across the recorded changes.

Results show a major temperature increase for *Morozovella* with respect to *Acarinina*, suggesting that the recorded rise may have reduced the symbiotic relationship of the former. The greatest temperatures occurred in coincidence with the main morozovellid drop, recorded at the beginning of the EECO (J Event). These data agree with paleotemperature changes estimated at the Southern Atlantic Ocean Site 1263. The lower carbon stable-isotope signatures of the *Morozovella* species at the EECO, reinforce the hypothesis of reduced dependence on photosymbiotic partnerships, possibly enabling them to be resilient, though in low abundance, to the paleoceanographic stressors.



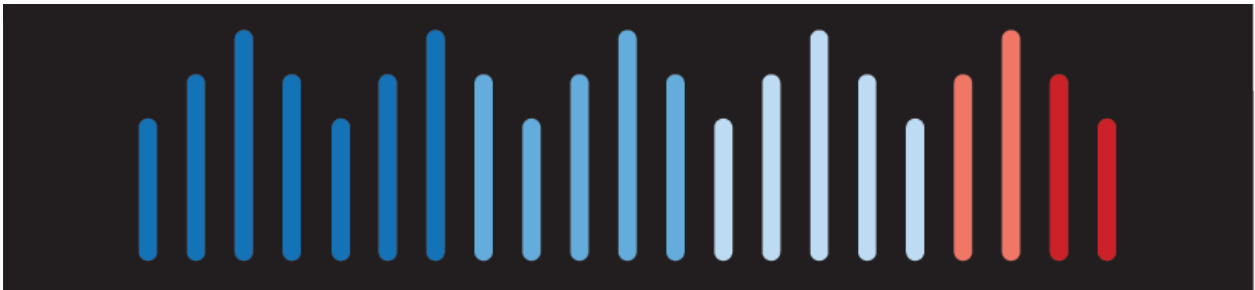
Pv-105

Can the coccolith carbon isotope fractionation solve the “Last Mile problem” from ϵ_p to CO_2 ?

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Employing the photosynthetic carbon isotopic fractionation in organic lipids, such as alkenones, is a classical method to reconstruct the atmospheric CO_2 with more than three decades history. However, recent studies show that this method would overestimate the CO_2 during the Pleistocene with ice-core CO_2 records, leading to wide queries on the usage of this method on older geological timescales. Coccoliths, the calcite carbonate shells secreted by coccolithophores, are also produced from the same groups of marine haptophytes which produced marine alkenones. It has been suggested that coccolith carbon isotope could provide another constraint on coccolithophore carbon acquisitions, which can help to improve CO_2 estimation from alkenone carbon isotope. In this work, we measured paired coccolith-alkenone carbon isotope fractionation ($\epsilon_c - \epsilon_p$) in the mid-late Pleistocene period. The new alkenone producing coccolithophore carbon isotope fractionations results show that the slope of $\epsilon_c - \epsilon_p$ varied with species. By cellular carbon isotope simulations, we suggest the slope variations could reflect differences of carbon allocations and Carbon Concentrating Mechanism (CCM) intensities among alkenone producers. Considering coccolithophores, especially alkenone producers, were rapidly evolving in geological periods, it would increase the accuracy of alkenone CO_2 -meter a lot by measuring paired coccolith carbon isotope fractionation.

Poster abstracts



Topic 2: Ocean Circulation and Its Variability

on site posters



P2-028

Widespread lithogenic overprinting of authigenic ϵ_{Nd} records?

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Neodymium isotopes (ϵ_{Nd}) recovered from foraminifera, fish teeth/debris and operationally defined authigenic phases (sediment leaches) of marine sediments are widely used as a circulation proxy in paleoceanographic reconstructions. The application of ϵ_{Nd} depends on the quasi-conservative behavior of ϵ_{Nd} in the ocean and requires that bottom water ϵ_{Nd} can be reliably recorded, and recovered, from the sediments. However, growing evidence suggests non-conservative behavior of ϵ_{Nd} in seawater, including a sedimentary source of neodymium to the ocean (benthic flux). The active cycling in the sediments required to drive this flux via the porewater demonstrates the potential for early diagenetic overprinting of the authigenic phases. Here we present a global compilation of paired authigenic and detrital neodymium records spanning 80 Ma to present from every ocean basin (n = 871) that shows a strong dependence of the authigenic isotope value on the detrital composition ($r = 0.86$). This strong correlation indicates widespread influence of early diagenetic processes on all three types of authigenic records, with the records reflecting changes in local sedimentation (provenance) rather than bottom water composition.

We demonstrate the impact of this diagenetic alteration on our interpretation of the oceanographic response to major climate upheavals of the past in two case studies: the Last Glacial and Ocean Anoxic Event 2 (OAE2). Using coupled neodymium isotopes and petrographic/mineralogical characterizations, we argue ϵ_{Nd} does not strictly act as a circulation tracer during either time period. Instead, ϵ_{Nd} responds to changes in sediment composition including those associated with glacial Heinrich Events (IODP 1308) and the deglaciation (ODP site 1063) following the Last Glacial Maximum in the North Atlantic, and widespread volcanic ash deposition across the proto-Atlantic during OAE 2 (ODP 1276, ODP 1260, and DSDP 530).



P2-100

Pliocene Variability of North Pacific Overturning Circulation: Reevaluating North Pacific Productivity and Redox Conditions from ~2.5-6 Ma

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Unlike in the high-latitude North Atlantic, no deep water is formed in the modern subarctic North Pacific (SNP). It has previously been suggested that during climate states different from today, this dichotomy did not endure, and an active Pacific meridional overturning circulation (PMOC) existed as part of the global ocean system. Specifically, the Pliocene, a period characterized by warmer-than present temperatures and atmospheric CO₂ similar to today, is one interval where North Pacific Deep Water (NPDW) formation is thought to have occurred. However, data relevant to this hypothesis is sparse. To expand our understanding of Pliocene ocean circulation, we provide a ~3.5 My record (~2.5-6 Ma) of export productivity from the central SNP. Opal and excess Ba (Ba_{xs}) fluxes, along with excess manganese (Mn_{xs}) concentrations, all point to elevated productivity during the early Pliocene. When combined with other existing productivity data and modeling results, our data provide a time series for the evolution of North Pacific Ocean dynamics from ~3-6 Ma. We not only show new data supporting the presence of an active PMOC during this time period, but provide evidence for a reduction in its intensity during the mid-Pliocene (~3.5-4 Ma) prior to its shutdown suggested at ~2.7 Ma. These findings have important ramifications for regional and global climate in the coming decades as the planet continues to warm.



P2-001

Size Distribution of Modern Planktonic Foraminifera in the tropical Indian Ocean: Environmental Controls and Paleo-reconstruction Potentials

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Palaeoceanographic studies often rely on microfossil species abundance changes, with little consideration for traits like size that could also relate to environmental changes. We hypothesize that whole-assemblage and/or species-specific planktonic foraminiferal test size could be good predictors of environmental variables, and we test this using a tropical Indian Ocean core-top dataset. We use an automated imaging and sorting system (MiSo) and a convolutional neural network model (CNN) to identify species, analyze morphology, and quantify fragmentation using machine learning techniques. A total of 311380 images were acquired at an average of 3797 images per sample. Machine model accuracy is confirmed by comparison with human classifiers (98% accuracy achieved). Data for 32 environmental parameters are extracted from modern databases and, through Exploratory Factor Analysis and regression models, we investigate the potential of using planktonic foraminiferal size to reconstruct oceanographic parameters. The size frequency distribution of most planktonic foraminifera species is unimodal and larger species show polymodal distributions. Within our tropical dataset, we find that intraspecies size response to environmental parameters is species-specific with carbonate ion concentration, temperature, and salinity identified as primary drivers. At the assemblage level, our analyses suggest that internal biogenic processes (primary) and temperature (secondary) are key drivers of morphometric changes in planktonic foraminifera. Our assessment of the potential to utilize assemblage size in reconstructing sea surface temperature in the tropical Indian Ocean showed that the reconstructed SST of the test MD90-0963 downcore site, relatively followed the delta O18 signals from previous works for the same site.



P2-041

Deglacial timing of biogeochemical changes in the Antarctic and Polar Frontal Zones: Evidence for a northward shift in wind-driven upwelling during the glacial interval

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Changes in deep water upwelling in the Southern Ocean has been proposed to explain a large portion of the changes in atmospheric CO₂ level during the glacial-interglacial cycles. The mechanism encompassing different changes in productivity in different latitudinal zones of the Southern Ocean requires a northward shift of the polar front and wind-driven upwelling during the glacial times, of which direct evidence is lacking from the Polar Frontal Zone (PFZ). We report a comparison of diatom-bound nitrogen isotope records since the Last Glacial Maximum (LGM) from two sites in the modern Antarctic Zone (AZ) (MD12-3394, Indian sector) and the northern edge of the PFZ (MD12-3396CQ, Indian sector), which show distinct differences in nutrient consumption level and productivity during the last deglaciation. We interpret these features to be the result of two opposing effects on the PFZ surface layer imposed by meridional shifts in Southern Westerly Wind (SWW)-driven upwelling and associated hydrographic fronts during different deglacial events. Our interpretation is supported by nitrogen isotopes of deep-sea coral residing at different depths within Drake Passage and simulations of a Southern Ocean multi-box biogeochemical model. Our findings argue for regionally weakened upwelling due to northward migration of the westerly winds as the proximal driver of Antarctic surface isolation under ice age conditions. Moreover, northward migration of the westerly wind-driven upwelling during glacial intervals would help to explain how Sub-Antarctic Zone (SAZ) export production was maintained during the ice ages despite sharp reductions in nutrient supply from the AZ.



P2-040

Southern Ocean upwelling, Earth's obliquity, and late Pleistocene glacial-interglacial atmospheric CO₂ change

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Previous studies suggest that, during the late Pleistocene ice ages, surface-deep exchange was somehow weakened in the Southern Ocean's Antarctic Zone, reducing the leakage of deeply sequestered CO₂ and thus contributing to the lower atmospheric CO₂ levels of the ice ages. It is our view that iron fertilization in the Sub-Antarctic Zone (SAZ) of the Southern Ocean has been established as one driver, but it can explain only a portion of the ice age CO₂ decline, and only the component occurring in the latter parts of glacial periods, requiring some additional process early in the glacial progression. The role of the Antarctic Zone (AZ) of the Southern Ocean has been a focus of attention in this regard, but with highly divergent views persisting to the current time. We show high-resolution diatom-bound nitrogen isotope data from the Antarctic Zone for the late Pleistocene glacial-interglacial cycles with improved chronology supported by TEX₈₆-paleotemperature proxy correlation with the Antarctic ice cores. Comparing the timing of nitrate consumption change in the AZ to that of other climate proxies, we identify three modes of change in Southern Westerly Wind-driven upwelling, each impacting atmospheric CO₂. Two modes, related to global climate and the "bipolar seesaw", have been proposed previously, and together with SAZ iron fertilization, they likely underlie the role of CO₂ as an important climate amplifier. The third mode, arising from the meridional temperature gradient as affected by Earth's "obliquity" (axis tilt), can explain the lag of atmospheric CO₂ behind climate during glacial inception and deglaciation, as well as the decoupling between CO₂ and global temperature during the Holocene. This obliquity mode of AZ upwelling change makes CO₂ a delayed climate amplifier, and this delaying effect is relatively more important during early glacial progression, contributing to the saw-tooth pattern of the late Pleistocene ice ages.



P2-095

Monsoonal hydrological variability and OMZ extension in the Northern Indian Ocean (Maldives Sea) during the last 1.2 Ma

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The seasonal reversing wind and precipitation patterns of the South Asian Monsoon (SAM) drive changes in sea surface circulation, primary productivity, and the oxygen minimum zone (OMZ) extension in the Northern Indian Ocean both yearly and at glacial-interglacial timescales. The Maldives Inner Sea, located in the northern Indian Ocean, is directly affected by the above-described phenomenon. Therefore, the sediments recovered during the International Ocean Discovery Program (IODP) Site U1467 (4°51.031'N, 73°17.020'E; 487 m water depth) allow us to reconstruct changes in the monsoon dynamics through time. Lipid biomarkers and ostracod assemblages have been analyzed to reconstruct sea surface temperature (SST, using the Uk'₃₇ index), past surface ocean productivity (using total alkenone concentration), and bottom water oxygenation (BWO, using a ratio between *n*-alkan-1-ols and *n*-alkanes, and ostracod assemblages). Additionally, scanning x-ray fluorescence (XRF) data from this site has been used to provide information about the winter and summer monsoon intensity.

The last ~1.2 Ma sedimentary record from IODP Site U1467 reveals two clear shifts in sea surface and bottom water conditions at the Mid-Pleistocene Transition (MPT) and the Mid-Brunhes event (MBE). Glacial SST decreased at MIS 22, and the amplitude between glacial and interglacial stages increased, particularly at the MBE. SST remained relatively warm between MIS 22 and 13, not showing significant changes between glacial and interglacial periods. Aridity and wind input show an increasing trend, especially during glacial periods and after the MBE, which points to an intensification of the winter monsoon during the last 1.2 Ma. The BWO record shows a similar pattern with increasing oxygen concentration after MIS 22 and enhanced oxygenation during the glacial periods after the MBE, which indicates a contraction of the OMZ during glacial periods and the possible influence of Antarctic Intermediate waters.



P2-110

Evolution of the Mediterranean after the Zanclean megaflood

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Collapse of the sill of Gibraltar 5.33 Ma ago, triggered the Zanclean megaflood which terminated the Messinian Salinity Crisis (MSC). The catastrophic flood may have refilled the partially desiccated Mediterranean within 2 years. Prevailing hypotheses suggest that normal marine conditions were established across the Mediterranean immediately after the catastrophic flooding. Here we use new proxy data and modelling to show that normal conditions were likely for the western Mediterranean (wMed), but that the eastern Mediterranean (eMed) became a hyper-salinity-stratified basin as a result of massive residual Messinian salt transfer from the wMed across the Sicily sill. Consequently, inhibited deep water ventilation in the eMed caused anomalously long-lasting organic-rich (sapropel) sediment deposition. We find that this organic-rich layer (named the 'mystery sapropel') is evident across the eastern Mediterranean deep sedimentary record, but absent in the wMed. Supported by proxy data, our model indicates that hyper-stratification breakdown by diapycnal diffusion required 26,000 years, releasing more than 7×10^{16} kg of excess salt into the Atlantic Ocean. We test the model for an alternative scenario on the widely disputed mode of MSC termination—reconnection of a largely refilled basin in the terminal Messinian. Our sensitivity tests reveal hyper-stratification in both the wMed and eMed, which would have left sapropels in both basins, in disagreement with observations. Our findings offer novel insight into the mechanisms involved in establishing normal marine condition following abrupt refilling of a previously desiccated ocean basin, and provide strong independent evidence for a partially desiccated Mediterranean prior to the Atlantic reconnection.



P2-054

Evaluation of the roles of surface flux changes in the Atlantic meridional overturning circulation during the last glacial maximum

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Proxy data suggest that the Atlantic Meridional Overturning Circulation (AMOC) was shallower during the Last Glacial Maximum (LGM) than at present. On the other hand, many climate models participating in the Paleoclimate Model Intercomparison Project (PMIP) show a stronger and deeper AMOC, and there are significant differences among the models. The mechanisms of how the glacial climate changes the AMOC have been studied mainly in terms of changes in wind stress and temperature, but these mechanisms have not been discussed in a comparative manner.

In this study, we conducted numerical simulations to evaluate the relative impact of changes in sea surface boundary conditions on the AMOC during the glacial period by organizing them into three categories: thermal conditions, wind stress, and freshwater fluxes. The changes in sea surface boundary conditions at the LGM were obtained from the output of various PMIP models, and the changes in thermal conditions, wind stress, and freshwater fluxes were separately applied to a ocean general circulation model to investigate how they change the AMOC. The results showed that the thermal conditions of the LGM weakened the AMOC, while wind stress and freshwater flux strengthened it. In particular, the cooling of the Southern Ocean had a significant effect on the weakening of the AMOC through the densification of Antarctic Bottom Water, and the different degrees of cooling of the Southern Ocean among the models caused a considerable variation in the strength of the AMOC.



P2-090

Intensified organic carbon burial on the Australian shelf after the Middle Pleistocene transition

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The Middle Pleistocene Transition (MPT) represents a major change in Earth's climate state, exemplified by the switch from obliquity-dominated to ~100-kyr glacial/interglacial cycles. To date, the causes of this significant change in Earth's climatic response to orbital forcing are not fully understood. Nonetheless, this transition represents an intrinsic shift in Earth's response to orbital forcing without fundamental changes in the astronomical rhythms. This study presents new high-resolution records of International Ocean Discovery Program (IODP) Site U1460 (eastern Indian Ocean, 27°S), including shallow marine productivity and organic matter flux reconstructions. The proxy series covers the interval between 1.1 and 0.6 Ma and provides insights into Pleistocene Leeuwin Current dynamics along the West Australian shelf. The large >45 m global sea level drop during the marine isotope stage (MIS) 22 – 24 is marked in our data, suggesting that the MPT led to large-scale changes in Indian Ocean circulation patterns and surface water conditions. We consider shelf exposure (and thus the “Sahul-Indian Ocean Bjerknes mechanism”) as a possible key process to increase the upwelling of nutrient-rich sub-Antarctic Mode waters through the Leeuwin Undercurrent along the Australian shelf. We conclude that the shoaling of nutrient-rich lower-thermocline waters enhanced mid-latitude productivity patterns in the eastern Indian Ocean across the 900-ka event.



P2-097

Seafloor sediment greening and redox conditions in the path of North Atlantic Deep Water across the Mid Pleistocene Transition

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Oceanic dissolved oxygen content is expected to decrease under anthropogenic climate change. In the deep ocean, the temporal and spatial variability of oxygen is associated with the interplay of three main processes: i) the strength in upper ocean productivity and associated downward fluxes of carbon, ii) subsurface oxygen consumption by biota during aerobic remineralization of organic matter and iii) changes in the ventilation of the deep ocean interior driven by the thermohaline circulation. In the subpolar North Atlantic Ocean, this supply is associated with the formation of North Atlantic Deep Water, which ventilates the global ocean with well-oxygenated waters. Understanding past changes in these processes remains an important way to gain insight into future ocean deoxygenation. Sediment color is a well-established, simple and rapid method of qualitatively appraising reduction-oxidation conditions in deep-ocean environments. Green sediments are typically associated with reduced Fe and red with oxidized Fe. We use computer vision to analyze photographic images of sediments recovered from several ocean drilling sites located in the ventilation path of NADW (IODP 1313, ODP 1090, IODP U1474) to rapidly catalog the recurrence of green layers of sediment, interpreted to reflect low oxygen deep-water conditions over the last 1.2 million years. Green layers are almost exclusively associated with glacial periods, deep-water carbon isotope minima recorded in benthic foraminifera, and found to be most abundant in-phase with insolation minima (maxima) at high latitudes in the Northern (Southern) Hemisphere. The green layers are most abundant during glacial periods prior to 600 kya, and are nearly absent from the two most recent glacial periods. Investigation into the origin, chemistry, and climate context of these green layers promises deeper insight into the structure of ocean circulation and productivity through glacial cycles and across the Mid-Pleistocene transition.



P2-104

Southern Hemisphere high-latitude processes promoting long-term AMOC circulation changes across the Mid-Brunhes Transition

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The Mid-Brunhes Transition (MBT; around 430 ka) marked changes in the climate system related to the rising amplitudes of glacial-interglacial cycles, with the post-MBT period presenting Antarctic temperatures and atmospheric CO₂ concentrations significantly higher than before. Although it has been linked to variations in the orbital parameters, changes in the Atlantic Meridional Overturning Circulation (AMOC) and deep-water formation around Antarctica have also been invoked to explain long-term disruptions of the global carbon cycle as a critical mechanism to sustain the MBT. However, the precise evaluation of the responsible internal climate processes and their expression is still elusive. Here, we present a new 770 ka benthic foraminifera (*C. wuellerstorfi*) $\delta^{13}\text{C}$ record from sediment core GL-854 retrieved from the subtropical western South Atlantic (WSA) at 2200 m water depth. We compare our record with published $\delta^{13}\text{C}$ data from the eastern South Atlantic margin to investigate the zonal variability of North Atlantic Deep Water (NADW) in the basin. NADW preferentially carries a modified signal through the deep western boundary current towards the WSA (rather than the eastern margin) after the MBT. It promotes the gradual increase of the $\delta^{13}\text{C}$ gradient record from both margins ($\Delta\delta^{13}\text{C}_{\text{w-e}}$) after a transitional period between 400 ka to 300 ka towards the Holocene. We propose that the mechanism behind the $\Delta\delta^{13}\text{C}_{\text{w-e}}$ long-term trend is driven by Antarctica sea-ice dynamics across the MBT. Post-MBT reduced sea-ice extent decreases Antarctic Bottom Water density and formation, favoring the southward penetration of isotopically heavier NADW to the WSA. Additionally, Agulhas Leakage intensification contributes to enhancing NADW production and deepening the AMOC. Our interpretation proposes a framework connecting sea-ice and ocean-atmosphere dynamics to deep-water geometry within the South Atlantic basin, which ultimately contributed to the climate change observed across the MBT.



P2-045

Deglacial changes in intermediate water ventilation off NW Africa

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A multiproxy approach using benthic foraminifera assemblages, Mg/Ca ratios and stable isotope measurements, suggests that decreased ventilation during the Heinrich Stadial 1 in times of reduced Atlantic Meridional Overturning Circulation led to a cooling of intermediate waters in the Northeastern Atlantic. The records come from site GeoB9512-5 (790 m water depth), and Mg/Ca measurements in *Uvigerina mediterranea* indicate paleotemperatures of 3.8°C for the first part of the Heinrich Stadial 1, 0.6°C lower than those observed during the Last Glacial Maximum. This was followed by a warming event (to 4.3°C) from the terminal part of the late Heinrich Stadial 1 (15.7 kyrs BP) that persisted for approximately 1.3 kyrs.

These paleotemperature changes, are related to reduced ventilation during Heinrich Stadial 1, interpreted from $\delta^{13}\text{C}$ measured in *Cibicides* spp. and associated with eutrophic conditions represented by increased abundances of infaunal foraminifera like *U. mediterranea* and *Bolivina subaenariensis*. Subsequently, bottom water temperatures drop below 3.5°C during the Younger Dryas, at the same time ventilation was shortly reduced and conditions became mesotrophic, as shown by abundant *Melonis barleeanus* and *Cibicides robertsonianus*. This cooling was followed by relative temperature stability (3.1 °C on average) over the last ~10 kyrs, when bottom water ventilation improved as Atlantic Meridional Overturning Circulation increased. These results illustrate the impact of changing Atlantic Meridional Overturning Circulation on intermediate water properties and sets an important precedent for future studies of ocean circulation - climate dynamics in the eastern North Atlantic.



P2-073

Climate induced thermocline aging and ventilation south of the Azores front over the last 32,000 years

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The radiocarbon analysis of uranium-thorium-dated cold-water corals (CWC) provides an excellent opportunity for qualitative reconstruction of past ocean circulation and water mass aging. While mid-depth water mass aging has been studied in the Atlantic Ocean, the evolution of the thermocline, which is tightly coupled to the atmosphere, is still largely unknown. Here we present a high-resolution dataset of combined ¹⁴C and U/Th data obtained from thermocline-dwelling CWCs at various sites in the Atlantic Ocean, in direct comparison with simulation results of the ¹⁴C-equipped Large Scale Geostrophic ocean general circulation model. This study fills an important data gap in the Atlantic thermocline and provides a new view of the evolution of the Atlantic Ocean upper thermocline during the last 32 ka, partially with centennial resolution. Shallow CWCs off Angola provide the link between previous records from the equatorial Atlantic and Tasmania at greater depths and open the possibility of a unified southern ¹⁴C signal in the Last Glacial Maximum (LGM). In contrast to the South Atlantic and to modeling results, North Atlantic thermocline CWCs show strong variations of a well-ventilated water mass near the modern Azores Front. During the Bølling-Allerød interstadial (B/A), our results confirm previous observations of enhanced ventilation, with both shallower and deeper water layers exhibiting the same radiocarbon signal. Our results indicate that the North and South Atlantic must be considered as separately acting reservoirs during the LGM, subsequent deglaciation and the B/A. As a direct consequence, further high-resolution CWC-based ¹⁴C records in the North Atlantic are needed to accurately reconstruct the age evolution of the reservoir since the LGM. CWC-¹⁴C records from the South Atlantic provide the opportunity to determine a consistent, high-precision calibration curve for the radiocarbon content of the thermocline.



P2-024

Multi-proxy reconstruction of deposition conditions of Holocene and Last Interglacial sapropels in the Gulf of Sirte (eastern Mediterranean Sea)

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The Mediterranean thermohaline circulation is sensitive to ongoing climate change. Projections generally indicate stagnant circulation by the end of the 21st century, although the amplitude of the changes is variable with models. To study the sensitivity of the Mediterranean circulation to distinct forcing, we reconstructed the deposition conditions of organic-rich layers “sapropels” formed during the Holocene (S1, 6.1-10.5 ka) and the Last Interglacial (S5 centred around 125 ka). The sapropel deposition was promoted by strong stratification in relation to excess freshwater flux from Nile river and deglacial meltwater inputs via the Gibraltar Strait, and consequent reduced ventilation. The paleodrainage toward the Gulf of Sirte off Libya has been proposed as an additional fresh water source but the records from this region are still scarce to define its contribution.

We applied a multi-proxy approach (bulk elemental composition by XRF scanning, planktonic foraminiferal stable isotopes, benthic foraminiferal ecological groups, and authigenic and detrital Nd isotopic composition) to core SL95 (32°46.46N, 19°11.46E; 1390 m water depth) from the eastern side of the Gulf of Sirte. Both S1 and S5 are marked by prominent Ba enrichment as well as depleted *Globigerinoides ruber* $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$, in particular for S5. Benthic foraminiferal relative abundance dropped in S1 and S5 layers. The authigenic and detrital Nd isotopic compositions increased during S1 and S5. The higher authigenic Nd isotopic ratio suggests reduced zonal water exchange and subsequent accumulation of radiogenic seawater Nd in the eastern Mediterranean basin. The increase in detrital values is a sign of more contribution of river sediment from radiogenic Nd source areas as Tibesti, thus more active paleodrainage. The changes in Nd isotopic composition are more pronounced during the S5 deposition when orbitally-driven insolation forcing was stronger.



P2-117

The Cenozoic sea surface temperature evolution offshore Tasmania

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During the Cenozoic (66–0 Ma) Tasmania been at the boundary between the cold Antarctic and the warm subtropics. It formed the final land connection between Australia and Antarctica until the mid-Eocene, and thereby a barrier for circumpolar flow. Since the Eocene, Tasmania migrated northward but was since then still partly obstructing strong throughflow of the subtropical front. The sedimentary record around Tasmania represents a perfect archive to record the oceanographic consequences of this regional tectonic change. We here present a new TEX_{86} and U^{K}_{37} -based sea surface temperature (SST) compilation from 4 sediment cores: ODP Sites 1172 (East Tasman Plateau), 1170 and 1171 (South Tasman Rise) and 1168 (western Tasman margin). Together, the ~1.000 datapoints portray the SST evolution around the island, from the time it was still connected to the Antarctic continent in the Paleocene to its near-subtropical location today. The warming due to northward tectonic migration of the island during the Cenozoic is largely compensated for by the general Cenozoic cooling trend. The mid-Paleocene is characterized by low temperatures and microplankton studies revealed that the southwest Pacific surface waters were remarkably fresh. As Tasmania migrated northward during the early Eocene, conditions warmed and salinified. Differences in SSTs on either side of the Tasmanian Gateway were small during the time intervals in which records overlap, suggesting both sides bathed in the same proto-subtropical front current. Oligocene and Neogene SST trends have subdued variability compared to those at the Antarctic margin, and is under continuous influence of the proto-subtropical front. Prominent cooling steps of the subtropical front occur in the mid-Miocene, and in the Pliocene, and SSTs show strong glacial-interglacial variability during the Pleistocene. Taken together, the sites portray a complete overview of local environmental change in a critical region of the Southern Ocean.



P2-034

Reconstructing Weddell Sea current variability since the LGM: insights from authigenic and detrital radioisotope analyses of marine sediments.

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Water-mass transformation in the Weddell Sea is responsible for the generation of 50-70% of Antarctic Bottom Water exported to the global deep ocean, with effects for the deep marine sequestration of atmospheric CO₂. Uncertainties in the dynamics of this system urgently need to be addressed to assist with modelling the carbon cycle in the southern high latitudes.

In this study, we used sequential acid-reductive leaching and total digestion to obtain neodymium (Nd), lead (Pb), and uranium (U) concentrations and isotopic compositions from both the authigenic and the detrital fractions of sediments from a suite of long-cores and surface sediments around the Weddell Sea. Paired isotope analyses were carried out to reconstruct bottom water conditions during deposition, and determine the sedimentary provenance of lithogenic detritus. The combination allows us to observe the relationship between lithogenic and authigenic phases. Authigenic Nd and Pb isotope signatures were interpreted to reflect pore-water compositions, affected by a combination of bottom-water composition, lithology, and element release from sediments into the pore-water and overlying water column. We further assess whether authigenic U may serve as a proxy for bottom-water oxygenation and ocean productivity at our Southern Scotia Sea sites, giving insight to deep-ocean ventilation and bottom-water export rates from the Weddell Sea.

Our results suggest that detrital isotopic records indicate an increase in sediment delivery from the East Antarctic to the northwestern Weddell Sea during the deglacial. We hypothesize that this was the result of a strengthening in the Weddell Gyre or Antarctic Circumpolar Current at this time. Here, we present an updated dataset of new authigenic and detrital measurements from the Weddell Sea investigating this hypothesis, and we unveil new details of the dynamic nature of Weddell Sea circulation and ice-ocean interactions over the last 30 kyr.



P2-033

Pleistocene oceanographic variability in the Ross Sea: a multiproxy approach to age model development and paleoenvironmental analyses

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Understanding how ocean circulation has varied around Antarctica in the past is vital because significant volumes of ice are grounded below sea level, and therefore ice sheet variations are strongly coupled with oceanographic variability at the continental shelf margin. This study investigates the 11.75 m sediment core RS15-LC42, retrieved from the Central Basin of the Ross Sea. A magneto-biostratigraphic age model was constructed from a magnetic reversal stratigraphy, diatom biostratigraphy, and the relative paleointensity of the geomagnetic field. The core spans the last 1.34 Myr with a mean sedimentation rate of 0.88 cm/kyr, providing insights into paleoceanographic variability in the Ross Sea throughout the Pleistocene. Winnowed deposits enriched in iceberg rafted debris were formed when the ice-sheet was not grounded in the outer Joides Trough due to a combination of enhanced glacial calving during glacial retreats, and export of Dense Shelf Water during interglacial and weak glacial periods. During periods of expanded ice sheets on the outer Ross Sea continental shelf, laminated sediments rich in reworked diatoms are interpreted to have formed due to glacial scouring on the continental shelf, transporting shelf sediments to the mouth of the Joides Trough, where slope failures and meltwater pulses remobilized this material onto the continental slope. Dense shelf water formation is inferred to be most intense during interglacial periods, with reduced export from the Joides Trough during ice-sheet advances. The study does not find any evidence for prolonged ice-sheet grounding in the outer Ross Sea since ~0.3 Ma, however, we conclude that the grounding line reached the outer shelf frequently between 0.3 and 1.2 Ma, supporting higher Antarctic ice volumes during glacial periods in this interval.



P2-094

A 1.6 Myr record of upwelling in the Indian Sector of the Southern Ocean

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We present a new orbital scale record of biogenic opal deposition from Ocean Drilling Program Site 745B in the Indian sector of the Southern Ocean between 1.2 – 1.6 Ma. High resolution age control is based on tuning minima in magnetic susceptibility to minima in the global benthic foraminiferal $\delta^{18}\text{O}$ stack (Lisiecki and Raymo, 2005). Reconstructions of opal accumulation south of the Polar Front typically show minima during glacial periods and maxima during interglacial periods, which has been interpreted to reflect increased stratification during glacial periods, limiting the upwelling of nutrient and silica-rich water and thus diatom productivity (e.g. Anderson et al., 2009); during interglacials, this pattern is reversed. Therefore, we interpret our record of opal accumulation as a record of upwelling and stratification in this climatically important region. When combined with records from Billups et al. (2018) and Kaiser et al. (2021), this new record allows us to analyze temporal patterns of inferred upwelling at this site for the past 1.6 Myr.

Consistent with the previously published data set, the new data from 1.2 – 1.6 Ma show a strong relationship between opal maxima and $\delta^{18}\text{O}$ minima, consistent with cyclicity observed using other proxies elsewhere in the Southern Ocean (e.g. Hasenfratz et al., 2019) during that same time interval. This is consistent with increased upwelling and enhanced ocean-to-atmosphere CO_2 exchange during interglacial periods, and vice versa. There is no detectable change in this pattern across the mid-Pleistocene transition. However, opal maxima are lower during this older interval than in the younger part of the record, and maxima don't increase significantly until 0.7 Ma, when opal deposition begins to show stronger power at the 100 kyr timescale (Kaiser et al., 2021).



P2-081

The temporal evolution of the Norwegian Sea subsurface radiocarbon reservoir age trough the LGM (last glacial maximum) and the deglaciation period

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Ice sheets, ocean overturning circulation and the carbon cycle underwent major changes during the last glacial maximum and the deglaciation. These changes are especially prevalent in the Nordic Seas as this is one of the main loci of the Atlantic Meridional Overturning Circulation and in the immediate proximity of several large ice sheets during the last glacial. The surface radiocarbon reservoir age (R) is affected by several ocean and carbon cycle processes and is in high latitudes likely especially sensitive to ocean stratification and sea-ice cover. Previous results from a compilation of deglacial planktonic foraminiferal ¹⁴C measurement from Norwegian Sea sediment cores (Brendryen et al., 2020, Nat. Geosci. 13, 363–368) show large variability and rapid changes in R that coincides with abrupt events in ocean circulation, ice sheet dynamics and the global carbon cycle. We have now extended this record trough the LGM showing the same large variability and with R ranging from values similar to modern in the Bølling interstadial to more than 3000 years during Heinrich Stadial 2.



P2-005

Interannual variability in the tropical Indian Ocean as simulated by the Palaeoclimate Model Intercomparison Project

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The Indian Ocean contains multiple modes of interannual climate variability, whose future behaviour is remains uncertain. Global warming induces a mean SST change reminiscent of the positive mode of the Indian Ocean Dipole (IOD), alongside a stronger Indian Monsoon and northward displacement of the Intertropical Convergence Zone. Recent analysis of glacial climates has uncovered an additional El Niño-like mode, which may come to dominate in future warm states. Here we explore changes in the tropical Indian Ocean simulated by the Palaeoclimate Model Intercomparison Project (PMIP4). These simulations are performed by an ensemble of models contributing to the Coupled Model Intercomparison Project 6, and over six coordinated experiments: four past periods and two idealised forcing scenarios.

The mid-Holocene (6ka) saw a dampening of both the dipole and basin modes in the Indian Ocean – akin to the dampened ENSO simulated in the Pacific. With the weaker strength of both modes, there appears to be some decoupling between them. Similar behaviour is seen during the last interglacial (127ka), although this is somewhat dependent on the application of calendar adjustment. Changes in the amplitude of both the dipole and basin modes are more ambiguous in experiments driven by greenhouse gas (the LGM and Pliocene) rather than orbital forcing. Finally, we compare the patterns in variability shown across various palaeoclimate experiments with those seen in idealised future warming runs.



P2-077

North Atlantic radiocarbon constraints on ocean circulation over the last deglaciation

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Paleoclimate records from the North Atlantic show some of the most iconic records of abrupt climate change during the ice ages. Here we use radiocarbon as a tracer of ocean circulation and air-sea gas exchange to investigate potential mechanisms for the abrupt climate changes seen in the North Atlantic over the last deglaciation. We have created a stack of surface radiocarbon reservoir ages over the past 20,000 years from the North Atlantic, using new synchronized age models from twenty sediment cores refined with thorium normalization between tie-points. This stack shows consistent and large reservoir age increases of more than 1000 years from the LGM into HS1, dropping abruptly back to approximately modern reservoir ages before the onset of the Bolling-Allerod. We use the intermediate complexity earth system model cGENIE to investigate the potential drivers of these reservoir age changes in order to further our understanding of the climatic changes occurring at these times and improve regional radiocarbon calibration. We find that the background state of overturning circulation influences the response of surface reservoir ages to fresh water hosing in the North Atlantic and caution against a straightforward interpretation of radiocarbon in terms of ventilation.



P2-120

Investigating the impact of the late Permian mean climate state and variability on ocean biogeochemical cycling with an Earth System Model

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The late Permian climate is the background state of the climate perturbations coinciding with the Permian-Triassic extinction event (~252 Ma). The end-Permian mass extinction is the largest of Earth's mass extinctions with an estimated 81-94% loss of marine species accompanied by large perturbations of biogeochemical cycles. Understanding late Permian climate variability will grant insights into regional environmental stresses prior to the extinction event. We simulate the late Permian climate with the Max Planck Earth System Model, composed of coupled atmosphere and ocean general circulation models, which each incorporate distinct biogeochemical cycling models for the land and ocean respectively. The simulated late Permian climate state is characterised by a 100 year global mean total precipitation pattern with an arid continental interior from ~50°N to ~50°S and a rainfall maximum of up to 6.5 mm day⁻¹ at the equatorial boundary of the Tethys and Panthalassa oceans. The 100 year global mean surface ocean of the late Permian illustrates a warm-pool across the equatorial boundary between the Tethys and Panthalassa oceans with a maximum temperature of 31.7°C decreasing to as low as -1.9°C near the poles. The simulated sea surface temperatures are found to be within the range of palaeotemperatures derived from available oxygen isotope records. Surface salinities vary broadly across the global oceans with 100 year global mean values ranging from 21.9 psu, in regions of strong freshwater input, to 49.2 psu, in low-latitude regions with restricted water exchange. Large-scale seasonal mixing below 60°S in the Panthalassa ocean dominates the global meridional overturning circulation. We will illustrate the results of our investigation into the impact of late Permian climate variability on ocean biogeochemical cycling with a focus on the carbon, oxygen and nitrogen cycles using the ocean biogeochemistry model, Hamburg Ocean Carbon Cycle with an extended nitrogen cycle.



P2-026

Deglacial and Holocene changes in Mediterranean Thermohaline Circulation: A joint perspective from Eastern and Western basins

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The dominant arid climate conditions over the Mediterranean (Med) control water properties and the formation processes of intermediate and deep water masses. Deep convection cells occur in both the E- and W-Med basins and there are interconnected through the intermediate waters mostly formed in the easternmost area of the Med. Model projections anticipate that the current situation of climate change will lead to an overall weakening of this circulation system during the current century. But the natural range of variability in the intensity of individual cells, the drivers and the inter-connection patterns between the cells is not well established. During the recent past (last deglaciation and current Holocene) both E- and W-Med had experienced periods of major disruptions in convection. The last organic layer (ORL1) formed in the W-Med during the deglacial period and later the last sapropel (S1) in the E-Med. Both enhanced productivity and weakening in convection are regarded as the causes in the two events but due to different drivers, the deglacial freshening in the case of the ORL1 and the African monsoon flooding for the S1. Here we present U/Mn ratios measured in the foraminifera diagenetic coatings from sediment cores from both E- and W-Med. The nature of this proxy, that provides information of the oxygen water content, allows its application in a wide range of oceanographical/oxygen conditions, a situation that limits other proxies whose carrier is very sensitive to oxygen content. This approach allows us, by the first time, to compare the oxygen evolution of individual basins and at different water depths by means of the same tool. The comparison with other available proxies let us to interpret the drivers of the changes and analyze the evolution of Med deep and intermediate convection along the ORL1 and S1. This new view advocates for a very close link between these two events but with very distinctive response of the individual cells to the dominant forcings.



P2-013

Current Atlantic Meridional Overturning Circulation weakest in last millennium

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The Atlantic Meridional Overturning Circulation (AMOC) redistributes heat on our planet and has a major impact on climate. We compare a variety of published proxy records to reconstruct the evolution of the AMOC since ~AD 400.

The results show a fairly consistent picture of the AMOC evolution: after a long and relatively stable period, there was an initial weakening starting in the nineteenth century, followed by a second, more rapid, decline in the mid-twentieth century, leading to the weakest state of the AMOC occurring in recent decades. Statistical analysis shows that in 9 of 11 proxy series, the most-recent 50- (30-, 100-) year mean value is significantly lower than any other before.

We further show that for the recent period since 1950 there is good agreement between different proxy data series and other reconstructions using a variety of observational data, as long as the expected leads and lags between different indicators are taken into account.

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P2-004

Monsoon-driven Kuroshio intrusions to the South China Sea since 1850 AD

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The intrusions of the Kuroshio current into the South China Sea (SCS) can modulate regional climate by redistributing heat and salt in the North Pacific, and conveying large scale climate modes to the marginal seas. However, long-term records for the Kuroshio intrusions are lacking. Kuroshio intrusions modify the thermocline water characteristics in the SCS by adding salty Kuroshio Tropical Water, which is also characterized by low $^{15}\text{N}/^{14}\text{N}$ ratio of its nitrate as a result of regional N_2 fixation. Here, we present a monthly to seasonally resolved *Porites* sp. coral skeletal-bound $^{15}\text{N}/^{14}\text{N}$ record from Xiaoliuqiu island, Taiwan, located in the northern SCS. The low $^{15}\text{N}/^{14}\text{N}$ values coincide with increase in the SCS thermocline salinity since the 1960s, suggesting that the variabilities in $^{15}\text{N}/^{14}\text{N}$ in the SCS are driven by changes in the Kuroshio intrusions. Our coral-bound $^{15}\text{N}/^{14}\text{N}$ record reveals a strong coupling between East Asian monsoon and the interdecadal variabilities of Kuroshio intrusions since the 1850s besides contributions from El Niño–Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). Prior to the 1950s, our record shows that Kuroshio intrusions occur during periods with strong winter monsoon and weak summer monsoon. After 1950s, Kuroshio intrusions are mostly regulated by winter monsoon. This occurs in parallel to a weakening of the overall monsoon system possibly due to continued warming of the Western Pacific Warm Pool. Our findings suggest that the Kuroshio intrusions are overall controlled by the basin-scale wind stress anomalies that are dominated by monsoon system and the background climate. Besides the natural forcings, the $^{15}\text{N}/^{14}\text{N}$ in our record rapidly increases since 1980s, coincidental with rise in sewage input to the coral reef and a sharp decline in coral reef coverage in Xiaoliuqiu island, suggesting an overprint by local nitrogen sources emerging from human pollutions to the reef environment.



P2-037

Weakening of the Pacific Walker Circulation Under Global Warming Supported by Coral Skeletal-bound Nitrogen Isotope Record from the Solomon Island

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Despite the importance of the Walker circulation in the tropical and global climate, models and observations do not agree on its changes associated with global warming. The Solomon Sea in the Southwest tropical Pacific is a major connection between the subtropics and the equator, thus influencing the water masses signatures and equatorial climate states. The nitrogen isotopes in the Solomon Sea thermocline is particularly sensitive to changes in the water masses and circulation. Upwelling along the equator, especially in the Eastern Equatorial Pacific, brings nitrate to the surface. Partial assimilation of the nitrate as the surface water is transported westward and off the equator elevates the $^{15}\text{N}/^{14}\text{N}$ of the residual nitrate, which is then incorporated into the suspended organic matter. The subtropical waters entering the Solomon Sea are on the other hand characterized by lower $^{15}\text{N}/^{14}\text{N}$ relative to the equatorial water due to high N_2 fixation rate in the subtropics. As a result, variabilities in the $^{15}\text{N}/^{14}\text{N}$ of the thermocline nitrate in the Solomon Sea are primarily influenced by altering the subtropical vs. equatorial water. Here we present a monthly-resolved skeletal-bound nitrogen isotopic record from 1919 to 2012 of a *Porites* coral core drilled from the western Solomon Island. Results show that the $^{15}\text{N}/^{14}\text{N}$ of the skeletal-bound organic N decreases during basin-wide El Niño events, consistent with an increase in the equatorward transport of the subtropical water through the Solomon Sea at El Niño years. The $^{15}\text{N}/^{14}\text{N}$ record also expresses a clear centennial-scale decrease of about 1.5‰ since 1919. The increase in the equatorward transport of water through the Solomon Sea, coincidental with the observed southward shift in the South Equatorial Current bifurcation latitude, as well as the decrease in the tropical Indo-Pacific sea level pressure gradient, together suggest a weakening of the Pacific Walker circulation which is likely driven by the anthropogenic warming.



P2-059

Radiocarbon profiles of the Bering Sea during the Last Glacial Maximum

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While no significant dense water formation occurs today in the Bering Sea, it has been hypothesized that a young, well-oxygenated intermediate water mass may have formed within the basin during the Last Glacial Maximum (LGM). Here we use benthic stable isotopes ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$) and benthic and planktonic radiocarbon (^{14}C) age differences along a transect from 350 to 3000 m in the central and eastern Bering Sea in order to constrain the depth range of this proposed water mass in this basin. During the LGM, shallow to intermediate waters (350 to 1000 m) were consistently 600 ± 200 ^{14}C years old, both more uniform and younger than those waters in the modern profile. Relatively low $\delta^{18}\text{O}$ corroborates that this intermediate water mass likely formed by brine rejection as a result of more expansive glacial sea ice extent. The bottom boundary of this water mass occurred around 1000 m, below which radiocarbon ages were higher, ranging from 1100 to 2000 ^{14}C years between 1000-3000 m. These ages were similar to or older than modern deep water values and consistent with data from these depths in the Okhotsk Sea and open subarctic North Pacific.



P2-043

Links of intermediate Atlantic Ocean circulation and climate from the past 35 thousand years

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Past ice-core data have shown significant changes in atmospheric CO₂ and temperature experienced during the last glacial and deglacial interval (~40 thousand to 11 thousand years ago, ka). Geochemical evidence had shown that oceanic circulation and oceanic configuration have considerably changed during these times, and that the ocean played an important role on regulating carbon and heat distribution. However, our present understanding of ocean behaviour lacks information on the intermediate depths clouding the full comprehension of the coupled ocean-climate system. Additionally, even though many efforts have been done to increase the amount of data at South Atlantic Ocean, it still remains a very understudied region. This study aims to expand the availability of well dated marine records by presenting a collection of uranium-series dated deep-sea corals from intermediate (600 m to 2500 m) South and North Atlantic. Here, we present 50 uranium-series deep-sea coral ages from Brazilian margin (20°S to 35°S) and Rio Grande Rise (32°S 35°W), and 30 coral ages from Tropic Seamount (23°N 21°W) both situated by the influence of modern Antarctic Intermediate Water (AAIW) and North Atlantic Deep Water (NADW). Using the calcium carbonate skeleton of the corals, we reconstruct the geochemical properties of the regional seawater of the past 35 ka, which allow us to examine the interactions between the ocean and climate during important climatic shifts. Finally, the comparison of our results of South and North Atlantic corals evidences a dynamic nature of intermediate ocean and suggest climate driven variability. These findings improve our current understanding of the regional and basin scale interactions between intermediate and deep oceanic layers, and points to a strong connection with the climatic system.



P2-003

Recent benthic foraminifera as tracers of water masses in the Skagerrak (North Sea): a comparative analysis of 1992/93 and 2020 surveys

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The Skagerrak acts as a major depositional basin of the North Sea thus providing a high-resolution geological record available for paleoclimate- and environmental reconstructions. Previous studies have shown that the prevailing water masses in the Skagerrak basin can be traced by using recent benthic foraminiferal fauna. Here, recent benthic foraminiferal faunal assemblages along a transect in the Skagerrak, between Norway and Denmark, have been studied to document any possible faunal changes in the last 30 years by comparing the results from surface sediments (0-3 cm) collected 1992/93 and 2020. Hydrographical data from the 2020 survey was compared to data from the period 1950 – 2020 to identify if the current hydrographic conditions stand out in a longer-term perspective. Comparison of foraminiferal assemblages identified in the total fauna of 1992/93 and 2020 surveys, defined three distinct assemblages with a spatial distribution following the different water masses in the basin. In both surveys, the *Elphidium excavatum* assemblage prevailed in the shallower areas of the Danish slope with a strong seasonal variability and strong currents; while the *Haplophragmoides bradyi* assemblage dominated the deep basin, affected by periods of relatively stagnant water and oxygen depletion. Finally, on the Norwegian slope and in the “transition zone” influenced by a continuously renewed Atlantic water, different assemblages were observed in both surveys: the *Cassidulina laevigata* assemblage in 2020 and the *Globobulimina turgida* assemblage in 1992/93. We hypothesize, that a shift to a stronger influence of Atlantic water starting in the late 1980s, concurrent with an extended period of oxygen depletion in the deep basin prior to the survey of 1992/93, could possibly explain the higher relative abundance of *Globobulimina turgida*, a foraminifer capable of denitrification, in 1992/93 as compared to the 2020 survey.



P2-069

Response of deep-sea benthic foraminifera in the subtropical NW Atlantic to past abrupt climate change events

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Paleoclimate records have revealed intervals of past abrupt climate change, which have been associated with changes in the Atlantic Meridional Overturning Circulation (AMOC). There are ongoing concerns about a current and/or future weakening of the AMOC. Previous studies suggest changes in AMOC may impact marine productivity, and paleo-data suggest that AMOC-related changes in surface circulation can impact the food supply to the deep sea and thus the benthic ecosystem. Here we investigate past benthic ecosystem responses to abrupt climate changes during the last 90,000 years at Bermuda Rise - an extensively studied site that has been used to reconstruct past abrupt climate and AMOC changes - to constrain past variability and its likely control(s).

We have generated high resolution records of benthic foraminifera species assemblage (percent and flux). We couple these faunal data with multiple new proxy records for ODP Site 1063: mean grain size of sortable silt (SS) to examine the vigour of bottom water currents at the site; planktic fragmentation percentage (PF%) as an indicator of the corrosivity of bottom waters; counts of ice rafted debris (IRD) to indicate the presence of icebergs; and quantitative and qualitative assessments of the amount of biogenic silica. These are used alongside existing published datasets of Pa/Th, eNd, opal, and benthic carbon isotopes. Our results reveal millennial-scale variability in the abundance and composition of benthic foraminifera, which are coupled to abrupt climate change events. We also identify prominent abundance peaks in the benthic foram, *Epistominella exigua* - a seasonal productivity indicator - that typically occur during Heinrich stadial periods. We interpret the results in terms of changes in subtropical surface ocean productivity during stadial intervals.



P2-060

Millennial-scale dynamics of the Kuroshio Current and East Asian Monsoon East of Taiwan during the last 26 ky.

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Currently, the Kuroshio Current (KC) flows northward along the east coast of Taiwan entering the Okinawa Through (OT) and the East China Sea through a gap separating the Ryukyu Arc from Taiwan. However, the trajectory of the KC during the Last Glacial Maximum (LGM) and the deglaciation is still subject to debate due to the different configuration of the OT in a period of lowered sea level. Moreover, the variability of East Asian Monsoon exerts a major control on productivity through aeolian inputs in the region: (i) the East Asian Summer Monsoon (EASM) presents warm and wet winds from the Indo-Pacific Warm Pool, and (ii) the East Asian Winter Monsoon (EAWM) presents cold and dry winds coming from the interior of the Asian continent. Changes in both EASM and/or EAWM influence the productivity and the capture of CO₂ in the oligotrophic KC.

Until now, the lack of well-preserved sediment cores for paleoceanographic off eastern Taiwan, south of the Ryukyu Arc, has hindered the understanding of the dynamics of the KC and of the EAWM forcing in the area.

Marine sediment core MD18-3532 has been retrieved during the EAGER cruise in 2018 east of Taiwan. Sedimentological (clays minerals and sedimentation rate) and geochemical ($\delta^{15}\text{N}_{\text{sed}}$, $\delta^{13}\text{C}_{\text{org}}$, TOC, TN and Br/Al) analysis have been carried out on this core in order to investigate (i) the on-going debate of the dynamics of the KC and (ii) the control of the EAWM variability on productivity since the LGM.

While the clay minerals indicate that Taiwan has been the main source of sediment at the site since the LGM, high sedimentation rate and low $\delta^{15}\text{N}_{\text{sed}}$ from 22.5 to 13.5 ky seems to indicate increases in nitrogen fixation caused by the KC cyanobacteria *Trichodesmium* spp. and in Taiwanese inputs. The high values of $\delta^{13}\text{C}_{\text{org}}$, TOC, TN and Br/Al during the LGM and their synchronous decrease with the decline of the EAWM during the deglaciation, seem to testify to the reduction of nutrient input from Asian loess dust during this period.



P2-088

Foraminifera-bound nitrogen isotopic constraints on Agulhas leakage

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Models suggest that increased exchange between the Indian and Atlantic Oceans (e.g. Agulhas leakage) plays a key role in reinvigorating meridional overturning circulation at glacial terminations. Traditionally, changes in the strength of this exchange have been inferred from the Atlantic abundance histories of *G. menardii*, on the premise that an increase in *G. menardii* records its 're-seeding' via Agulhas leakage. Other evidence, however, has linked *G. menardii* abundance in the Atlantic to changes in thermocline ventilation. Thus, the application of *G. menardii* zonation to Agulhas leakage is not straightforward, despite the chain of logic that connects it to Agulhas input.

Measurements of the nitrogen (N) isotopic composition of foraminiferal shell-bound organic matter (FB- $\delta^{15}\text{N}$) have the potential to provide a complementary constraint on Agulhas leakage. Agulhas leakage is supplied largely from the southwestern subtropical Indian Ocean, an area strongly influenced by N fixation. The $\delta^{15}\text{N}$ of shallow subsurface nitrate ($\delta^{15}\text{N-NO}_3^-$) supplied to the Atlantic should thus be low in $\delta^{15}\text{N}$ relative to other South Atlantic water masses that derive from the Southern Ocean. Modern seawater $\delta^{15}\text{N-NO}_3^-$, foraminiferal tissue $\delta^{15}\text{N}$, and core top FB- $\delta^{15}\text{N}$ confirm this expectation and indicate this distinction is recorded by the foraminifera deposited by Agulhas input.

Here we present measurements of FB- $\delta^{15}\text{N}$ of *G. menardii*, *O. universa*, and *G. truncatulinoides* over the last 140 kyr from a pair of sediment cores (ODP 1474/1479) located in the path of the Agulhas current and of modern Agulhas leakage into the Atlantic, respectively. We compare these records with measurements of FB- $\delta^{15}\text{N}$ across the penultimate deglaciation from a core located at the Walvis Ridge. Given that *G. menardii* and *O. universa* are commonly used in the eastern South Atlantic as indicators of Agulhas leakage, the downcore FB- $\delta^{15}\text{N}$ comparisons here provide a first test of FB- $\delta^{15}\text{N}$ as a tracer of Agulhas leakage.



P2-089

Terrigenous Sediment Geochemistry and the Agulhas Current: New Insights

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The Agulhas Current carries warm salty water south along the east coast of southern Africa. South of Africa, the current retroflects and a small but significant portion, the Agulhas Leakage, makes it around the tip of Africa and into the Atlantic Ocean. This Leakage is part of the surface return flow of the global overturning circulation. IODP 361 drilled 6 sites in the Agulhas Current region. We present data for two Sites: U1474, beneath the Agulhas Current and U1479, near the Agulhas Leakage. Terrigenous sediment geochemistry has been used as a provenance proxy to understand the Agulhas Current and its Leakage because of the distinctively older and more weathered continental sources on the eastern side of southern Africa. Published results using the <63 micron terrigenous sediment fraction from core tops and last glacial maximum (LGM) sediments around southern Africa and at site RC11-83 in the Atlantic have been used to conclude that (1) the Agulhas Current carries sediment with a very old crustal geochemical signature. 2) that signature did not change between the last LGM and the Holocene and (3) the Agulhas Leakage was weaker at the LGM compared to the Holocene. The scientists on IODP 361 agreed to use the <2-micron fractions of terrigenous sediments, and a common preparation procedure for all of the sites. New measurements on <2-micron terrigenous sediment from Sites U1474 and U1479 challenge some of the previous conclusions. Specifically, there is a precessional variation in the provenance of clays in both U1474 and U1479, and the values for U1479 in some cases show older crustal ages than the endmember as represented by U1474. We will present these results and intercomparisons of the <63 micron vs. the <2-micron sediments. They shed new light on the provenance and processes controlling sediment composition beneath the Agulhas Current and have implications for the paleoceanographic interpretation of such data.



P2-027

A sedimentological insight into the deglacial reorganization of the Mediterranean thermohaline circulation

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During the last deglaciation and early Holocene significant oceanographic changes have been observed in both western and eastern Mediterranean basins. Post glacial sea level rise strongly reduced the northwestern overturning cell from 14.5 to 9 ka BP, which favored the formation of an organic rich layer in the Alboran Sea. Increased river runoff in the east-Med enhanced water column stratification leading to the formation of Sapropel 1 between 10.8-6.1 ka BP. Although asynchronous and triggered by independent mechanisms, these basin-scale oceanographic changes had a profound impact on the water exchange between both basins and the Mediterranean thermohaline circulation, and consequently, in the amount and properties of Mediterranean waters exported to the north Atlantic region.

Our grain-size and geochemical records show coetaneous decrease/increase from cores at deep/intermediate levels of the west-Med confirming a major reduction of deep water currents in the deepest part of the basin related to the post glacial sea level rise, while increased intensity of currents at intermediate levels. These results likely suggest a significant change in the water masses properties during the deglaciation that would favored formation of intermediate water. On the other hand, the sedimentological records from an Ionian Sea sediment core show enhanced deep water currents during the first phase of the deglaciation, and a very marked reduction in the 10.8-7.5 ka time-interval, coinciding with the Sapropel 1 formation.

Our results show that intermediate levels circulation was reinforced in both eastern and western Mediterranean basins during the first phase of the deglaciation likely suggesting a major export of intermediate water masses from the eastern to the western basin. Finally, the strong stratification leading formation of the Sapropel 1 produced a major reduction of deep water ventilation in the eastern basin that could also affect westward export of intermediate waters.



P2-080

Little change in subantarctic radiocarbon reservoir ages since the last ice age determined from a new ultra high-resolution sediment sequence: implications for radiocarbon-based inferences of interior ocean ventilation.

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Radiocarbon is among the most powerful tracers of ocean ventilation and deep carbon storage, but its application over the last deglaciation in marine archives requires an assumption of high latitude surface ocean radiocarbon disequilibrium from the atmosphere--i.e. the reservoir age. High latitude reservoir ages are commonly inferred from stratigraphic reference to ice core or tephra chronologies, yet these strategies carry large uncertainties. Here we use a different approach to deduce variability in subantarctic radiocarbon reservoir ages, taking advantage of a unique high deposition rate (~1 meter per kyr) sequence in the Mozambique Channel. The modern bottom waters at IODP site U1477 (19°21.29'S; 36°54.90'E; 430 meters w.d.) fall on an isopycnal surface ($\sigma_t=37.1$) that outcrops at the surface just north of the Antarctic Polar Front, and, therefore, the benthic foraminiferal properties at the site, including radiocarbon, represent a direct reflection of the subducting subantarctic surface water. Benthic-planktonic foraminiferal radiocarbon age differences in Site U1477 are remarkably steady across the last 30 kyr, displaying near-modern values throughout this interval. On this basis, we infer a relatively constant radiocarbon reservoir age in the subantarctic surface ocean spanning the glacial-interglacial transition. This constancy stands in contrast to the benthic foraminiferal $\delta^{18}\text{O}$ in U1477, which exhibits abrupt shifts to low values (interpreted as warming of the subantarctic surface ocean) in the intervals associated with Heinrich Stadial (HS) events. The implications of these observations for Subantarctic Mode Water dynamics will be explored with simplified ocean modelling experiments. We also explore the implications of near-constant radiocarbon reservoir age for new and previously published radiocarbon observations in the deep subantarctic South Atlantic that capture the ventilation history of Circumpolar Deep Water over the last deglaciation.



P2-056

Changes in the Upper Ocean Stratification of the southeast Indian Ocean linked to Frontal Movement across the Last Deglaciation

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Latitudinal migrations of the Southern Ocean frontal system regulate the inter-basin exchange of heat and salt, wielding significant influence over large-scale ocean circulation and global climate. In the Indian basin, these fronts create distinct regimes of upper ocean stratification that can be leveraged to track their migration in the past. Here, we reconstruct deglacial changes in the vertical structure of upper ocean temperature and salinity using surface-dwelling *Globigerina bulloides*, subsurface-dwelling *Globorotalia truncatulinoides*, and benthic *Cibicides lobatulus* from an intermediate depth sediment core in the southeast Indian Ocean (TT1811-50GGC; 38.3°S, 77.7°E, 1118 m). During the last glacial period, the oxygen isotopic gradient between both the surface and subsurface ($\Delta\delta^{18}\text{O}_{\text{bull-trunc}}$) and subsurface and intermediate waters ($\Delta\delta^{18}\text{O}_{\text{trunc-lob}}$) was $\sim 0.75\text{‰}$, indicating a shallow and weakly stratified water column. This contrasts with the Holocene and late deglaciation, when a weaker $\Delta\delta^{18}\text{O}_{\text{bull-trunc}}$ ($\sim 0.4\text{‰}$) and an abrupt 1‰ increase in $\Delta\delta^{18}\text{O}_{\text{trunc-lob}}$ at ~ 16 ka suggests a deeper, sharper pycnocline separated the planktic and benthic species. Notably, this change was coincident with an abrupt freshening of ~ 2 psu in surface and subsurface waters. We suggest a northward migration of the fronts during the last glacial placed our core site beneath the weakly stratified waters of the Polar Frontal Zone before a southward shift in the early deglaciation exposed our core site to the deeper, sharper pycnocline of the Subantarctic Zone. This migration loosely corresponds with the reopening of the Agulhas Leakage, which likely freshened the south Indian Ocean by enhancing the exchange of salty subtropical waters between the Indian and Atlantic Oceans. Together, this response to glacial-interglacial climate change appears to have played an important role in the deglacial rise of atmospheric CO_2 .



P2-007

Contribution of wind-driven changes in the Southern Ocean circulation to variations of atmospheric CO₂ concentration, ¹³C and ¹⁴C over the past two millennia

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Southern hemisphere westerly winds have likely contributed to observed atmospheric CO₂ variations through their influence on the oceanic circulation. Their impact is potentially even larger for ¹³C and ¹⁴C variations. Besides, the carbon isotopes evolution provides a constraint on southern hemisphere westerly winds reconstructions. To compare contributions of wind-driven ocean changes in the Southern Ocean circulation to effects of land cover and temperature changes on the carbon cycle over the preindustrial Common Era, we perform an ensemble of sensitivity experiments with the LOVECLIM model. We show that reconstructed changes in southern hemisphere westerly winds induce slightly smaller changes in atmospheric CO₂ concentrations than those associated with land use and land surface temperature but variations in ¹³C of the same order of magnitude as the observed ones. Those wind changes also have a strong impact on the difference in ¹⁴C between the northern and southern hemisphere, presenting strong similarities with observed changes. This confirms that the southern hemisphere westerly winds must be accounted for in any quantification of past changes based on the combination of the information provided by ice core reconstructions of atmospheric CO₂ and carbon isotopes. This also provides additional evidence for large centennial variations in southern hemisphere westerly winds and of their impact on the whole Earth system over the past two millennia.



P2-098

Benthic foraminiferal $\delta^{13}\text{C}$ constraints on Pacific-Atlantic Ocean deep-water exchange over the past 1.5 million years

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Epibenthic foraminiferal stable carbon isotope records, thought to record the carbon isotopic signature of seawater dissolved inorganic carbon, have highlighted a shift of the most negative $\delta^{13}\text{C}$ signatures from the mid-depth North Pacific during interglacials to the deep South Atlantic Ocean during glacials. Although this proxy is not without caveats, e.g., $\delta^{13}\text{C}$ offsets among epibenthic foraminifera, this negative $\delta^{13}\text{C}$ shift bears witness to changes in ocean circulation and marine respired carbon storage in the Southern Ocean in the past. However, the spatial extent of this ^{13}C -depleted respired carbon pool and the mechanisms leading to its existence, in particular possible reorganizations associated with the mid-Pleistocene climate transition (MPT), remain to be resolved. Here, we compare two new *Cibicides* sp. $\delta^{13}\text{C}$ records from central South Pacific IODP Site U1541 (54.2°S, 125.4°W, 3.6 km water depth) and Southeast Atlantic ODP Site 1094 (53.2°S, 05.1°E, 2.8 km water depth) with existing data from the global ocean to reconstruct Pacific-Atlantic Ocean deep-water exchange over the past 1.5 Ma. Based on a revision of the shipboard age model using a probabilistic sequence alignment approach, we show a good agreement between lower Circumpolar Deep Water (CDW) $\delta^{13}\text{C}$ signatures in the central South Pacific (U1541) and in the Southeast Atlantic (ODP Sites 1089, 1090 and 1094), suggesting a continuous homogenization of CDW in these regions over the past 1.5 Ma. In the South Pacific Ocean, however, vertical $\delta^{13}\text{C}$ gradients with underlying and overlying southern- and northern-sourced water masses, respectively, were much larger than in the South Atlantic Ocean. This has strong implications for the locus, extent and driver of reduced (CDW) ventilation and increased respired carbon storage in the global ocean during glacials of the past 1.5 Ma, which have been considered crucial factors in understanding the atmospheric CO_2 decline and major ice sheet build-up across the MPT.



P2-119

A journey through tides: 1,750,000,000 years of tidal dynamics.

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Ocean tides impact a range of Earth system processes, including driving primary production, sustaining the climate-regulating global overturning circulation, and setting the environment for key evolution events. The dissipation of tidal energy also slows down Earth's spin and forces the moon to recede in an effort to conserve angular momentum, meaning the tides are first-order controller of daylength. Consequently, any change in the tide may have far-reaching consequences for the Earth system. Recent tidal model results show far less energetic tides in the past, interspersed by (geologically) brief tidal maxima when ocean basins have the correct size to host tidal resonances. On average, the tidal dissipation rates have been ~45% of present-day rates over the past 1500 Myr, and this signal will continue into the future as the next supercontinent forms in ~200-250 Myr. Whilst these results can be explained using fundamental physical oceanography principle, they may be poorly constrained due to a lack of easily accessible proxies for tides. Proxies of course exists in the geological record, both as direct estimates of tidal properties (e.g., tidal range or spring-neap periods) and as indirect ones (e.g., bedforms and grain sizes). We validate the tidal model results using data from tidalites collated in a proof-of-concept study, and show that there is validity in collating, developing, and using tidal proxies, and that the results obtained are robust. Consequently, present day tides, and associate tidal dissipation rates and associated vertical mixing, are a poor proxy for past and future tides, even at short geological time scales.



P2-103

Obliquity-Paced Southern Ocean Surface Temperature Variations during the Early to Mid-Pleistocene

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The mid-Pleistocene Transition (1.25–0.7 Ma) marks a major shift in the periodicity of climate cycles recorded in $\delta^{18}\text{O}$ from 41-kyr to 100-kyr pacing. This transition was accompanied by global cooling, ice growth, and changes in global carbon cycling. Because Southern Ocean processes (e.g., sea ice, stratification) influence global overturning circulation and carbon storage, it is likely that climate in the high southern latitudes played an important role in the MPT. Atmosphere-ice-ocean interactions shape physical water mass characteristics that then influence thermohaline circulation, but an understanding of such interactions during the early Pleistocene is incomplete without high resolution records of Southern Ocean sea surface temperature. Here we present orbitally-resolved TEX_{86} -derived paleotemperature records detailing early to mid-Pleistocene (1.55–0.99 Ma) surface ocean temperature variations from continuous sedimentary sequences drilled in the Scotia Sea at International Ocean Discovery Program Sites U1537 (59°6.65'S; 40°54.37'W) and U1538 (57°26.52'S; 43°21.47'W). TEX_{86} values range from 0.30 to 0.39 ± 0.01 . TEX_{86} records exhibit a warming trend between 1.55 and 1.28 Ma and significant power in the 41-kyr band, which disappears at the start of MPT (~1.25 Ma). An interval of pronounced cooling is centered at 1.25 Ma. Our record is significant because it captures a regional oceanographic transition that may be related to a reorganization of meridional overturning circulation and reduced ocean heat flux across the Antarctic shelf. Scotia Sea surface cooling at ~1.25 Ma was likely part of a longer-term cooling trend, which included mid- to high-latitude bottom water cooling, a northward shift of the Polar Front, and reduced thermohaline circulation strength. Furthermore, the observed disappearance of 41-kyr cycles implies a dampened surface ocean response to obliquity forcing after 1.25 Ma.



P2-070

ABRUPT Arctic Climate Change

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The last glacial was characterized by a series of abrupt climate shifts between cold stadials and warm interstadials (DO-events). A close link is documented between sea ice variability in the southern Nordic Seas and air temperature change over Greenland, with sea ice identified as a key determining factor for setting up these large, abrupt climate shifts. However, several unanswered questions remain unanswered regarding, e.g., 1) How did the spatial extent of sea ice in the Nordic Seas change during the transition? 2) What were the timing, duration, and rate of change in the northern relative to the southern part of the Nordic Seas? 3) What were the triggering mechanism and processes of abrupt, full basin-scale sea ice and hydrography changes?.

We will present the work plans of ABRUPT, a newly-started project in which we will reconstruct the sea ice conditions, hydrography, and climate of the Fram Strait, with an unprecedented resolution for this area, over two targeted DO-events. These reconstructions and regional data synthesis will be used in combination with multi-model output from at least three state-of-the-art General Circulation Model (GCM) glacial simulations, for an integrated analysis of the dynamics of abrupt Arctic climate change during the last glacial. Furthermore, the stadial Nordic Seas bear a strong resemblance with the present Arctic Ocean, e.g. the existence of a strong halocline stabilizing the sea ice cover and a subsurface layer of Atlantic Water that brings warm and salty water masses into an interior basin, where it recirculates under the halocline. ABRUPT will evaluate the relevance of the DO-events for ongoing Arctic climate change to unravel mechanisms important for understanding the risk of similar changes in the future Arctic.



P2-021

Synthesis of the palaeoceanographic evidence for changes in the deep branches of AMOC during the 8.2ka BP event.

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The Atlantic Meridional Overturning Circulation (AMOC) plays an important role in regulating climate via the transport of heat and salt in the North Atlantic. In recent years, concerns have arisen over the increase of freshwater input into the North Atlantic due to increased meltwater and precipitation resulting from anthropogenic warming [1]. Surface water freshening can weaken the AMOC by reducing the formation of dense water that sinks and supplies the deep pathways of the AMOC. One such period when this process may have occurred in the past is during the early Holocene, when the melting and retreat of the Laurentide Ice Sheet led to a massive discharge of freshwater into the North Atlantic, which is thought to have led to a reduction in meridional heat transport, resulting in an abrupt, century-long cooling event over the Northern Hemisphere at 8.2ka BP [2]. Understanding precisely how freshwater input altered North Atlantic circulation during this event may help inform our understanding of the potential consequences of increased surface freshening today and in the future.

Here, we present a synthesis of new and previously published sortable silt (SS) and benthic $\delta^{13}\text{C}$ data from sites throughout the North Atlantic, alongside other published paleoceanographic datasets, to examine the changes, or lack thereof, in deep ocean circulation during the 8.2ka BP abrupt climate event. Our datasets allow us to examine the different responses of the main deep branches of the AMOC to this event. Planktic data are also used to relate surface water circulation changes to changes in the deep ocean.

[1] Bakker, P., *et al.*, 2016, <https://doi.org/10.1002/2016GL070457>

[2] Matero, I.S.O., *et al.*, 2017, <https://doi.org/10.1016/j.epsl.2017.06.011>



P2-096

Changes in ocean circulation across the Mid-Pleistocene Transition from authigenic Nd isotope measurements in the Cape Basin

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The Mid-Pleistocene Transition (MPT; ~1200–700 ka) marks a pronounced shift in the frequency and amplitude of glacial-interglacial cycles from smaller 40,000-year cycles to larger 100,000-year cycles without an apparent change in external forcing. Among the many proposed explanations for the climatic shift seen at the MPT are changes in the geometry of deep ocean circulation, potentially related to changes in the strength of interocean exchange south of Africa. The Agulhas Current transports warm, salty surface water along the southeast margin of Africa, and a portion of this current “leaks” into the Atlantic Ocean as the Agulhas retroflects back to the east at the southern tip of Africa. This salt flux to the Atlantic is thought to be key to the formation of North Atlantic Deep Water (NADW), particularly at glacial terminations. NADW has a neodymium isotopic composition that is distinct from water originating in the Pacific, and mixing between these water masses in the subsurface is quasi-conservative. We present the highest resolution authigenic neodymium isotope record to date through the MPT from IODP Site U1479, located in the Cape Basin (35°03.53’S; 17°24.06’E, 2615 m water depth). In the modern ocean, this Site is bathed in remnant NADW, characterized by its salinity and temperature, as well as its ϵNd minimum. These data refine the interpretation of previous Nd isotope records, which were predominantly sampled at glacial/interglacial maxima, as the new data show temporal offsets between ϵNd signals and co-registered carbon and oxygen isotope measurements. We also find that the amplitude of Nd isotope variability did not substantially change when comparing the pre-MPT interval to the last glacial cycle, contrary to the conclusions of previous studies. There is, however, a shift in Nd isotopic composition toward more negative values between ~1100–950 ka (MIS 34–25), which could be evidence for a change in NADW endmember value during this time.



P2-114

Late Eocene to Miocene tectonic- and climate-induced changes in Southern Ocean surface oceanography

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The Oligocene record at IODP Site U1356 offshore Wilkes Land shows surprisingly warm (10–21°C) sea surface temperatures (SSTs) considering its location, in the vicinity of the (East) Antarctic Ice Sheet (AIS). To better understand whether such high latitude warmth is exceptional, and to identify potential drivers, we consider the wider Southern Ocean paleoceanographic context. We analyzed organic walled dinoflagellate cysts (dinocysts) and TEX₈₆ in sediments from Southern Ocean DSDP/ODP/IODP drill cores together spanning the Late Eocene to Miocene (37–5 Ma). We track changes in SST, sea ice, nutrient availability and salinity, and reconstruct the evolving latitudinal temperature gradients, and migrations of frontal systems. Furthermore, we compared these results to fully coupled climate, and high-resolution ocean-only model simulations to evaluate the possible role of CO₂ forcing, changes in ice volume, and general geographic boundary conditions. We find that the SST gradients between the subtropical front and the Antarctic Margin is indeed relatively small in the Oligocene, but progressively increases from ~26 Ma onwards, due to cooling at the Antarctic-proximal sites. Decreasing atmospheric CO₂ levels alone cannot explain this high latitude cooling. We therefore conclude that deepening of Drake Passage drove the cooling by strengthening of the proto-Antarctic Circumpolar Current and frontal systems after 26 Ma, enhancing Antarctic thermal isolation. By the latest Miocene high latitude SSTs and oceanography are similar to present day conditions. Currently, Southern Ocean warming poses a risk to AIS destabilization and consequential sea level rise. We here offer key new insight into Southern Ocean circulation and frontal system evolution during past warm climates, as crucial input for model projections.



P2-111

Miocene Paleooceanography of the Subantarctic

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The Neogene is a crucial epoch for the Earth's climate evolution as it went through the transition from a warm early-to-mid-Miocene (23-16 Ma) with a small Antarctic ice sheet, into the colder late Pliocene (~2.5 Ma) with a large ice Antarctic sheet. While $p\text{CO}_2$ decline has been proposed as the main driver of cooling, questions remain on the role that Southern Ocean oceanographic conditions have played in the evolution of the Antarctic ice sheet.

We here investigate the paleoceanographic conditions at the subtropical front (STF) from the mid-Miocene to the Pliocene. Our study presents a multi-proxy analysis of sediments from Ocean Drilling Program Site 1168, which is currently located at the northern boundary of the Southern Ocean and has recorded past STF development. Surface oceanographic changes were inferred from biomarker-based sea surface temperature (SST) reconstructions and dinoflagellate cyst (dinocyst) assemblages. Bottom water temperature (BWT) change was reconstructed using benthic foraminiferal clumped isotopes (Δ_{47}). Surface condition reconstructions indicate a cooling of the subantarctic region and combined with a northward STF migration. A $\sim 10^\circ\text{C}$ stepwise cooling was found from Site 1168 since the mid-Miocene despite its gradual northward tectonic drift. By comparing with equatorial and Antarctic-proximal sites, we found increased equator to mid-latitude SST gradient but a decreased gradient between Antarctica and mid-latitude. Meanwhile thermophilic dinocyst taxa were replaced by STF indicator *Nematosphaeropsis*, confirming the northward STF migration induced by the cooling of Southern Ocean. The Δ_{47} results show that BWT was stable around 7°C , except for a $\sim 3^\circ\text{C}$ cooling at 11-12 Ma. Sea water $\delta^{18}\text{O}$ calculations indicate that ice volume was stable and already close to modern from the MCO despite warm global climates. Our study demonstrates the complex interactions between Antarctic ice sheet and Southern Ocean surface and deep oceanographic changes.



P2-050

Changes in the strength of the oxygen minimum zone of the central Red Sea during the last glacial period

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The oceanography of the landlocked basin of the Red Sea is controlled by a restricted exchange of water masses with the Indian Ocean through the narrow and shallow strait of Bab al-Mandab and by high evaporation rates due to the arid to the semiarid climate of the surrounding land areas. At intermediate water depths, the strength of the oxygen minimum zone depends on the replenishment of oxygen-rich deep waters in the northern Red Sea and the local oxygen consumption due to the remineralization of organic matter. Here, we present benthic foraminiferal faunal data from a sediment core of the central Red Sea allowing for the quantification of orbital- and millennial-scale changes in oxygen concentrations during the past 200,000 years. The benthic foraminiferal fauna is relatively high-diverse (~70 species) and is dominated by the infaunal species *Bolivina subreticulata*, *Cassidulina laevigata*, *Bulimina marginata*, and *Siphouvigerina porrecta*, which represent suboxic to dysoxic environments. Our preliminary results indicate reduced deep-water ventilation during glacial boundary conditions supporting previous observations of a sensitive response of deep-water formation in the northern Red Sea to sea-level changes and Mediterranean climate variability. On millennial time scales, deep-water oxygenation reflects the influence of short-term hydrological changes, with stronger OMZ during interstadials and weaker OMZ during stadials.



P2-032

Reconstruction of ocean circulation in the high latitudes of the Southern Ocean over the past 130 ka

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Circulation of the Southern Ocean (SO) has a strong influence on the global ocean circulation, biogeochemical cycles, and the Antarctic ice sheet, and thereby exert global climate change. The investigation of the long-term change in the SO circulation in the past provides opportunities for a better understanding of the role of the SO in the climate system. However, previous studies on past SO circulation in the Southern Ocean are limited to low latitudes, and the change in high latitude regions remains uncertain. Therefore, the interaction between SO circulation and the Antarctic ice sheet and its impact on global climate is poorly understood.

In this study, we present new data on change in Circumpolar Deep Water (CDW) and Antarctic Bottom Water (AABW) over the past 130 ka at the high latitudes of SO. The CDW and AABW changes were reconstructed based on analyses of radiolarian fossil assemblages living in CDW and sortable silt mean grain size (10–63 μm) in marine sediment core GC1407, respectively.

The CDW and AABW records show large variations associated with the Glacial-Interglacial cycles, but substantial fluctuations are also recognized during the Last Interglacial (LIG: 130-115 ka). During the LIG, the weakening of AABW coincides with the strength of CDW, which may be related to the bipolar see-saw of Atlantic meridional ocean circulation. Furthermore, a comparison of AABW records and Nd isotope ratios, which indicates the change in the Antarctic ice sheet, suggests that the weakening of AABW coincides with ice sheet mass loss in the Wilkes Subglacial Basin. Our result suggests that change in the Antarctic ice sheet potentially influences global ocean circulation.



P2-018

Holocene natural variability in Atlantic Water inflow properties to the Arctic

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The Arctic is one of the most sensitive regions to climate change, and has been experiencing large changes in ocean temperatures and sea ice extent over the last decades, which are unprecedented in the instrumental records. The recent decline in Arctic sea ice extent has been linked to increased ocean heat transport with the Atlantic Water (AW) and the ongoing *Atlantification* of the Arctic Ocean. Here we evaluate how current changes compare in pattern and magnitude to the longer-term natural variability in AW properties and their relationship to sea ice through the Holocene.

We used Core KH18-10-14-GC1 (80.68°N, 28.95°E; 863 m), located on the Kvitøya Trough, off NE Svalbard, to reconstruct the properties of AW entering the Arctic via the Svalbard Branch over the last ~12 ka. Stable isotopes ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) of planktonic (*N. pachyderma*) and benthic foraminifera (*N. labradorica*, *C. lobatulus* and *C. neoteretis*) are used to monitor changes in the physical and chemical properties of the AW through the Holocene. Our *N. pachyderma* $\delta^{18}\text{O}$ values are generally higher than in regions with a strong Arctic halocline and covary with epibenthic *C. lobatulus* $\delta^{18}\text{O}$ values through the Holocene—suggesting there was always a presence of AW at the site and not a strong halocline dominance. During the early Holocene, our planktonic and benthic stable isotope records indicate a sudden warming/freshening ($\delta^{18}\text{O}$ decrease by ~1‰) in AW properties at ~9 ka BP, in phase with an increase in sea ice concentrations (SpSIC %) in the northern Barents Sea (>80°N). This indicates that natural variability in the region involved a close coupling between AW properties and sea ice extent. However, this past sea ice-AW coupling contrasts sharply to the recent changes suggesting modern changes are quite distinct from natural variability in the region, and have a potentially different (anthropogenic) origin.



P2-091

Reconstructing Pleistocene Deep Ocean Circulation Changes using Nd isotopes in the Pacific Sector of the Southern Ocean

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Alternating cold glacial and warm interglacial intervals are dominant features of Earth's climate during the Pleistocene epoch. The early Pleistocene was dominated by continental ice sheets that oscillated in their volume every ~41 kyr until the Mid-Pleistocene Transition (MPT; 1250-650 ka), when the dominant periodicity transitioned to ~100 kyr, and the ice sheets became bigger. It is hard to explain changing of ice sheet behavior through the Pleistocene by orbital forcing alone, rather a non-linear response within the climate system to modest insolation forcing cannot be ruled out. In this context, the state of deep circulation in the South Pacific is critical to developing a holistic understanding of the Pleistocene climate and carbon system.

In this study, we are generating a Nd isotope time-series from fossilized bio-phosphate in fish teeth/debris and Fe-Mn encrusted foraminifera spanning the Pleistocene from site U1540 (55°08.467'S, 114°50.515'W, 3580 m) retrieved during the International Ocean Discovery Program Expedition 383. Site U1540 is ideally located to capture changes in deep water mass geometry through time. Nd isotopes are a well-recognized water mass proxy, since, in the modern ocean, water masses below the thermocline reflect the values predicted from conservative water mass mixing of North Atlantic and Pacific endmembers. To first order, the initial ϵ_{Nd} record from U1540 exhibits systematic patterns of change that are similar to glacial-interglacial variations observed in the global benthic $\delta^{18}O$ record. The peak glacial stages for both pre and post-MPT exhibit a median ϵ_{Nd} value of ~ -7, while glacial peaks during the early MPT (1250-1100 ka) reach ϵ_{Nd} ~ -6. An MPT shift in seawater ϵ_{Nd} towards radiogenic values has been reported in the Atlantic, however, the U1540 ϵ_{Nd} shift predates the Atlantic shift by ~150 ka. This record hints at a major reorganization of Pacific deep-water masses during the MPT.



P2-044

South Pacific Antarctic Intermediate Water variability during the last deglacial atmospheric CO₂ increases

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Antarctic Intermediate Water (AAIW) forms in the Southern Ocean and is currently one of the main sinks of atmospheric CO₂. During the last deglaciation (21,000-10,000 years before present), atmospheric CO₂ levels increased significantly during two specific time periods, the Early Deglaciation (~17.5-14.7 ka BP) and the Younger Dryas (~12 ka BP). AAIW may have played an important role in these processes, but AAIW variability and properties are still unclear in the Pacific Ocean. Previous studies based on Atlantic marine sediment core data and model simulations suggest a warming of AAIW during deglaciations and that AAIW was less connected with deep Circumpolar (saline and nutrient-rich) waters during the last glacial maximum. Therefore, AAIW ability to absorb atmospheric CO₂ might have been reduced during deglaciation. Our goal is to reconstruct for the first time the evolution of AAIW characteristics (temperatures, salinities, nutrients, and flow speed) during the deglaciation in the Eastern and Western Pacific Ocean to obtain more information about its possible role in global CO₂ exchange. Our hypothesis is that the South Pacific AAIW warmed and developed a deep Circumpolar Water source (more saline/more nutrients) through deep mixing of the Southern Ocean during the Early Deglaciation and Younger Dryas which would support the observed increases in atmospheric CO₂. Here, we will show first results of our measurements of combined foraminiferal benthic Mg/Ca, stable isotopes, and grain size analyses in deep sea Ocean Drilling Program (ODP) sediment cores from the Southwest and the Southeast Pacific Ocean.



P2-002

Planktonic foraminiferal habitat depths in the western tropical Pacific: Data from Multiple Opening/Closing Net Environmental Sensing System

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Planktonic foraminifera calcites have been widely used as proxies for reconstructing past ocean conditions. In order to identify habitat depths of planktonic foraminifera in the tropical western Pacific Ocean, we investigated vertical distribution of planktonic foraminiferal abundance at three sites (12°N, 135°E, 15°N, 135°E, and 16°N, 127°E). Samples were seasonally (April, August, December) collected by using Multiple Opening/Closing Net Environmental Sensing System in the upper water column at depths from 0 to 600 m. To estimate the habitat depths of planktonic foraminifera, species-specific weighted averaged living depth were calculated from the vertical distribution of foraminiferal abundance for each season. Seasonal variations in the vertical distribution of planktonic foraminifera were investigated. Our results indicate that, for winter season, *Orbulina universa* (0-100 m), *Globigerinoides tenellus* (0-110 m), *Globigerina bullioides* (0-110 m), *Candeina nitida* (0-120 m) and *Globigerinoides sacculifer* without sac (0-100 m) are considered as the surface mixed layer dwellers. *Globigerinoides conglobatus* (0-180 m), *Globigerinella aequilateralis* (0-160 m) and *G. sacculifer* with sac (0-250 m) occurred from the surface mixed layer to upper part of thermocline. *Sphaeroideinella dehiscens* (120-220 m), *Neogloboquadrina dutertrei* (20-360 m), *Globorotalia hirsuta* (120-400 m), and *Globorotaloides hexagonus* (320-400 m) are regarded as thermocline inhabitants. Other seasonal data will be presented at this meeting. Information on these planktonic foraminiferal species and their habit depths can be used to reconstruct the vertical structure of the upper water column in the western tropical Pacific in the past.



P2-011

Holocene regime shifts in sea ice and open water productivity on the northern Labrador Shelf

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The Labrador Sea is a key area to study environmental and oceanographic changes of the recent past, as it is one of the subpolar areas where dramatic ecosystem changes are expected under continuous climate warming. Especially the changes preceding and following the final collapse and melting of the Laurentide Ice Sheet will offer insights crucial to improve climate predictions regarding expected further Greenland Ice Sheet melt and seasonal sea-ice retreat.

Here, we present reconstructions of palaeoceanographic changes over the past ~9 ka, with a focus on sea-ice distribution and phytoplankton productivity based on organic biomarker and sedimentary proxy records (e.g., IP₂₅, HBI III Z, biogenic opal, TOC) from the northern Labrador Shelf (gravity core MSM45-19-2).

Our records indicate a nearly perennial sea-ice cover along the northern Labrador Shelf prior to 8.75 ka BP. Coincident with the increasing inflow of Atlantic Water into the eastern Labrador Sea, sea-ice cover opens towards a pronounced seasonal distribution. This opening may have favoured the incursion of relatively warm Atlantic Water into Hudson Bay and could have destabilized the Hudson Bay Ice Saddle, which collapsed around 8.55 ka BP, resulting in a massive meltwater outburst (Lochte *et al.*, 2019). During the Holocene Thermal Maximum (7.6–3 ka BP) sea ice was only present seasonally while phytoplankton productivity was consistently high, most likely due to relaxed sea-ice conditions and lower meltwater perturbations. After 3 ka BP, winter sea ice was again more variable and extensive, coincident with the Neoglacial cooling in the Northern Hemisphere. Phytoplankton productivity seems to have stabilized on intermediate levels under the absence of meltwater runoff from land and probably caused by enhanced stratification of the water column in spring and summer.

Lochte et al., 2019, Labrador Sea freshening at 8.5 ka BP caused by Hudson Bay Ice Saddle collapse. Nature Communications, 10(1), 1–9



P2-076

Abrupt deglacial variations in the properties and vigor of the Atlantic Water inflow to the Arctic

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The recent precipitous warming and decline in Arctic-Barents sea-ice extents have been linked genetically to the increasing ocean heat transport by the Atlantic Water (AW) inflow. Similar increases in AW transport are often invoked to explain proxy indications of greater AW influence/temperatures in the past, including during abrupt climate variations of the last glaciation. Yet, the relationship between AW vigor, heat transport, and natural climate variability remains equivocal, as does the similarity of ongoing changes to abrupt natural variability in the past.

Here we use the sediment core KH18-10-15-GC1 (81.57°N, 31.61°E, 863 m) from beneath the Svalbard Branch of the AW inflow to the Arctic to delineate changes in flow vigor (sediment grain size, SS) and properties (planktic and benthic foraminiferal $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) of AW across the last deglaciation (19.5–7.5 ka BP). Endmember analysis was used to correct for the influence of unsorted size fractions by ice-rafting on SS. Contrary to previous inferences, we find AW warming and increased (vertical) extent of AW (planktic and benthic $\delta^{18}\text{O}$ minima) are associated with a sluggish AW inflow during Heinrich Event 1 (HE1). This disruption in bottom flow speeds occurs during HE1 despite regional evidence for a greater influence and temperature of the AW. Locally our foraminiferal $\delta^{18}\text{O}$ records are also consistent with subsurface and bottom water warming at this time. Subsequently, colder/saltier AW is associated with a strengthened inflow during the Bølling-Allerød interstadial. Although distinct from modern trends, these changes are consistent with modelling studies suggesting that ocean-atmosphere interactions and buoyancy flux changes along the horizontal Arctic-Atlantic circulation system played a crucial role in modulating the vertical (overturning) circulation during millennial-scale climate changes



P2-092

Variations in Subantarctic Pacific Surface to Intermediate Water stratification and ventilation during the Pleistocene

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Southern Ocean dynamics and their interaction with the atmosphere are key components for understanding Pleistocene climate change on orbital to millennial timescales. Glacial to interglacial variations in sea-ice cover, upper ocean stratification, biological nutrient utilization and water ventilation play a major role in natural variations of atmospheric CO₂ concentrations over the past 800 ka and beyond. The successful realisation of IODP Expedition 383 DYNAPACC to the subantarctic South Pacific closed a critical gap in available sedimentary records from the high-latitude Southern Hemisphere, in particular for the subantarctic Pacific. We use SE Pacific Site U1542 from the Southern Chilean continental margin and pelagic Central South Pacific Site U1541 from the East Pacific Rise to compare the characteristics of surface to mid-depth thermocline waters between the central and eastern South Pacific, and investigate the vertical structure and formation dynamics of Southern Ocean Intermediate Water (SOIW). We use planktic foraminiferal multi-species isotopes and element ratios comprising shallow and deep dwellers to reconstruct the paleo-physical and -chemical characteristics of surface, thermocline, and deep thermocline Southern Ocean Water masses, in order to understand their long-term dynamics, their sensitivity to – and interaction with – changing climate forcing mechanisms across major climate transitions throughout the last 1.5 Ma. In line with investigating these physical paleoceanographic changes, the carbon isotopic gradients from different planktic foraminifers are used to reconstruct the ventilation history between mid-depth and upper ocean waters.



P2-124

New evidence indicating the early periodic eastward flow over the South Tasman Saddle at ~43 Ma

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The timing of the opening of the Tasmanian Gateway is important for understanding global ocean circulation, regional climate, and tectonic evolution (e.g. Bijl et al., 2013). Here we study Paleogene sediments from four boreholes drilled offshore Tasmania by ODP Leg 189 to constrain the timing of throughflow. Evidence from biomarkers identified enhanced input of terrigenous organic material relative to marine organic matter at Site 1172 (East Tasman Plateau) starting ~43 Ma, further increasing and stabilising after ~35.5 Ma. Such variation is absent at Sites 1170 and 1171 (South Tasman Rise), which have consistently low terrigenous organic material and remain under the influence of westwards flowing proto-Antarctic Counter Current. Similar plankton biogeography and sea surface temperature shifts at ~40 Ma on the East Tasman Plateau have been attributed to the intermittent eastward flow of a warm proto-Leeuwin Current through the northern portion of the Gateway (Löhrr et al., in review). Several geochemical features including biomarkers in upper Eocene sediments from Site 1172 are similar to those at Site 1168, which is located close to the west coast of Tasmania. This further supports the transport of enhanced terrigenous input from the Australo-Antarctic Gulf to the East Tasman Plateau by an eastward throughflow from ~43 Ma. There is ongoing work including stable carbon isotopes, C/N ratios and Rock Eval pyrolysis for samples across all four sites to independently test the biomarker-based inference. Our findings suggest the early, partial opening of the Tasmanian Gateway, and show that biomarkers can be effective proxies for tracing ocean currents variations.



P2-105

A high-resolution reconstruction of SST and paleoproductivity from the Banda Sea, Indonesia across the mid-Brunhes event (last 820 kyr)

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Our understanding of the paleoclimate dynamics and their underlying mechanisms of the Indo-Pacific Warm Pool (IPWP) at long time scales are still limited by the low temporal coverage of paleoclimate records. High resolution and long duration paleo-records covering several glacial-interglacial cycles in the central IPWP would advance our understanding of IPWP dynamics. Here we present high-resolution data sets (alkenone SST, alkenone mass accumulation rate, opal wt%) from a piston core (MD01-2380) retrieved from the Banda Sea, eastern Indonesia, to track the changes in sea surface temperature, paleoproductivity and upwelling variability over the last 820,000 years. Our results show that the amplitude of variations in alkenone SST was small before the Mid-Brunhes Event (MBE) and became larger after the MBE, emphasizing glacial-interglacial changes. The paleoproductivity reconstruction shows no significant variation on glacial-interglacial timescales, but rather shows an overall increase after the MBE suggesting enhanced upwelling activity.

In addition, the mean temperature of each Marine Isotope Stage (MIS) and the peak events show that the interglacials did not change, but that the glacials became significantly colder after the MBE. and it is interesting to see a too warm MIS 6 and a surprisingly cold MIS 8.

Our study shows how the mid-Brunhes event is expressed in the Banda Sea, Indonesia by changing the character of the seasonal upwelling with regard to both productivity and SSTs. We hypothesize that the increase in upwelling across the MBE may have occurred global-wide. This would have released extra carbon dioxide from the deeper ocean into the atmosphere explaining the increase in atmospheric CO₂ as shown by ice core records. The reason why global upwelling did intensify, however, remains elusive.



P2-066

New constraints on the (de)glacial Atlantic overturning circulation from sedimentary $^{231}\text{Pa}/^{230}\text{Th}$

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Tremendous effort has been devoted to reconstruct and quantify the Atlantic Ocean circulation and its variability during the Last Glacial Maximum (LGM) and the subsequent Deglaciation. However, despite intensive research, there are still major uncertainties about the strength and geometry of the Atlantic meridional overturning circulation (AMOC) over this time period. Neither a wealth of different proxy approaches nor modeling attempts provide a single coherent picture. Within the scientific community the prevailing opinion is still shaped by the iconic $^{231}\text{Pa}/^{230}\text{Th}$ down-core records from the Bermuda Rise, which suggest a slightly weaker AMOC during the LGM, compared to the Holocene, and a nearly halted AMOC during Heinrich Stadials.

As new reconstructions become available, questions arise as to whether the Bermuda Rise is indeed a suitable representative of the entire Atlantic circulation regime. Location, water depth, regional particle dynamics, and prevailing water mass exert additional influences on individual $^{231}\text{Pa}/^{230}\text{Th}$ -signals. Not surprisingly then, new $^{231}\text{Pa}/^{230}\text{Th}$ -profiles over a wide range of water depths from the North and the South Atlantic show a complex picture, not in line with Bermuda Rise or adjacent records.

The emerging data suggest a deep North Atlantic constantly bathed by northern sourced waters from the Last Glacial Maximum to the Holocene. The deglacial period witnessed a gradual change from the LGM to the modern AMOC pattern, with variations in strength, but without the distinct millennial scale AMOC collapses that have been inferred from the Bermuda Rise $^{231}\text{Pa}/^{230}\text{Th}$ records. This gradual shift reflects the reorganization of water masses from slightly shallower Glacial North Atlantic Deep water transforming into North Atlantic Deep Water of the Holocene.



P2-051

Impact of ocean circulation and particle sinking on the glacial marine biogeochemistry in MPI-ESM

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Constraining the ocean state during the last glacial maximum (LGM) in Earth System Models (ESMs) remains challenging, given the sparseness of proxy data and model uncertainties. Previous modelling studies mostly applied additional surface fluxes (e.g., freshwater hosing, elevated iron deposition) to achieve a good comparison to proxy data. However, such an approach is not suitable for investigating the internally evolved mechanisms in comprehensive ESMs. We simulate different LGM ocean states using the model tuning and the inclusion of new processes in the Max Planck Institute Earth System Model (MPI-ESM). By tuning the vertical background mixing in the ocean, we simulated two LGM circulation states: one with a deeper boundary between NADW and AABW and a stronger NADW strength (hereafter “deep LGM AMOC”), the other with a shallower boundary and a weaker NADW (hereafter “shallow LGM AMOC”). Moreover, we compare two schemes of particle sinking in the ocean biogeochemical component. In the default scheme, the sinking velocities POC, CaCO₃ and opal are respectively prescribed. In a new Microstructure, Multiscale, Mechanistic, Marine Aggregates in the Global Ocean (M4AGO) sinking scheme, the size, microstructure, heterogeneous composition, density and porosity of marine aggregates are explicitly represented, and POC, CaCO₃ and opal fluxes are tied together. Unlike previous flux-adjustment studies, we found the best comparison to ¹³C and ¹⁴C data not always under the shallow LGM AMOC. The latter features a better ventilated LGM Pacific Ocean, which worsens the comparison to ¹⁴C and oxygen data in this basin. Different particle sinking schemes show a generally small impact on the ocean biogeochemical tracers for the deep LGM AMOC. On the contrary, for shallow LGM AMOC, the M4AGO scheme yields better agreement to data of ¹³C and CaCO₃ burial rate, suggesting the quantitative impact of particle sinking schemes strongly depends on the background LGM ocean circulation states.



P2-035

The Southern Ocean Water Mass Index using Radiolarians

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It is widely accepted that the Southern Ocean plays a key role in global climate by influencing atmospheric carbon dioxide over a glacial cycle. However, questions remain regarding the changes in productivity, upwelling, sea ice and stratification of Southern Ocean water masses. Polycystine radiolarians present an opportunity to address these questions. These siliceous organisms reside in the subsurface waters between 100 and 400 m depth and display significant diversity in the modern Southern Ocean, related to water masses and ocean circulation (Lawler et al., 2021; Lowe et al., 2022).

Here we present a new radiolarian-based Southern Ocean Water Mass (SOWM) index. The index was developed using the relative abundance data for the Southwest Pacific Sector within the Southern Ocean Radiolarian Dataset (Lawler et al., 2021). Multivariate regression tree analysis was used to identify clusters according to isopycnal depth and nutrient data. Indicator species were identified for each cluster and a ratio was developed using the species data.

We apply the SOWM Index to a transect of sediment cores through the Southwest Pacific Sector of the Southern Ocean. The cores span from the Subtropical Front to the Polar Front and represent the last glacial cycle (160,000 years). We compare the results of the SOWM Index with geochemical (stable isotopes, opal content, elemental variations) and other microfossil data (diatom assemblages), on the same cores. We investigate the changes in ocean circulation and water masses over the glacial cycle and the implications of those changes on the climate and carbon cycle.

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P2-106

Multiproxy paleoceanography from Broken Ridge pinpoints the onset of Tasman Leakage at 6.6 Ma

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Inter-basinal heat and water exchange play a prominent role in driving global climate change on astronomical timescales, as part of the global thermohaline circulation. Tasman Leakage connects the Pacific and Indian Oceans at an intermediate water depth, south of Australia. Therewith, Tasman Leakage advects heat toward the Indian Ocean, and ultimately toward the Agulhas system. Hence, Tasman Leakage constitutes a non-negligible part of the present-day thermohaline circulation. The onset of Tasman Leakage likely occurred sometime in the Late Miocene (Christensen et al., 2021), but precise geochronology for the establishment of this inter-basinal connection is still lacking. Moreover, Tasman Leakage sensitivity to astronomical forcing remains to be constrained in detail. To understand Tasman Leakage on astronomical timescales, we present a new Miocene-to-recent multi-proxy dataset from Ocean Drilling Program (ODP) Sites 752 and 754, cored on Broken Ridge (30°53.475'S), southeastern Indian Ocean.

The dataset consists of new X-ray Fluorescence (XRF) core scans that provide element contents for 18 different elements, along with benthic carbon and oxygen stable isotopic records at 4 cm resolution. The XRF-derived Ca/Fe record is paced by 405-kyr eccentricity between 22 Ma and 13 Ma (early-middle Miocene), but then becomes more sensitive to obliquity and precession forcing. The new high-resolution benthic $\delta^{13}\text{C}$ record confirms the onset of Tasman Leakage in the Late Miocene, more specifically at 6.6 Ma. This is when the Broken Ridge benthic $\delta^{13}\text{C}$ signature no longer reflects an Antarctic Intermediate Water signal. The benthic $\delta^{18}\text{O}$ record shows a strong ~ 110 -kyr eccentricity imprint, indicating that Tasman Leakage might be most sensitive to this astronomical parameter. We conclude that the Neogene nannofossil oozes, preserved on Broken Ridge, constitute an excellent paleoceanographic archive that allows us to fingerprint Tasman Leakage sensitivity to astronomical forcing.



P2-046

Benthic foraminiferal assemblages from Cape Blanc, Atlantic Ocean: horizontal and vertical zonation

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Offshore Cape Blanc is one of the most productive regions on the Earth due to the upwelling oceanic currents and the dust input from NW Africa.

The link between the vertical migration and distribution of the benthic foraminiferal taxa and the oxygen penetration depth, nitrate, and sulfate levels were observed for the first time in this area (Jorissen et al., 1998). However, this observation is based on the >150 µm fraction, thus neglecting important smaller taxa, whilst other studies (i.e., Lutze and Coulbourn, 1984) focused on the > 250 µm fraction.

To fill the gap, we conducted a high resolution (1 cm) investigation of the benthic foraminiferal assemblages (>63 µm fraction) and studied their horizontal and their vertical (in the top 10 cm) distribution in 5 MUC samples (GeoB20317, -18, -21, -22, -23), retrieved from ~500 to 3000 m water depths during the MSM48 ADOMIS cruise (Zonneveld et al., 2016).

Our data show a significant vertical and horizontal structuring of the foraminiferal assemblages: the deepest assemblages consist of *A. weddellensis*, *C. wuellerstorfi*, and *E. exigua*, while the shallower-water assemblages are dominated by *P. ariminensis*, *H. mantaensis*, *B. truncana*, and *Cassidulina* spp. Vertically a down-deep increase of low-oxygen tolerant taxa (i.e., *B. aculeata*, *B. truncana*, and *U. peregrina*) could be observed. Both, the horizontal and vertical zonation of the benthic foraminiferal taxa are related to environmental factors like temperature, food, and oxygen availability, and reflect the strong control of the oceanic currents.

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P2-072

Tropical Pacific sea surface temperature patterns during the Last Glacial Maximum

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The thermal state of the tropical Pacific Ocean exerts a strong influence over Earth's climate. The Last Glacial Maximum (LGM, 19,000-23,000 years ago) is one of Earth's most studied climate extremes, yet there is little consensus about tropical Pacific temperature patterns during that time. We reconstruct the mean state using reduced dimension analysis, whereby the full field of equatorial Pacific sea surface temperatures is estimated from spatially sparse paleotemperature (Mg/Ca and alkenone) observations. Our reconstruction yields a mean LGM cooling in the equatorial Pacific (between 16°N and S) of 2.3 ± 0.3 °C. Cooling was greatest in the eastern cold tongue south of the equator, and in the western warm pool. A region of lesser cooling extended from the central equatorial Pacific to the coast of Central America. This anomaly pattern bears some resemblance to a Central Pacific El Niño event, and may reflect a greater prevalence of such events during the LGM.



P2-109

Salt Ages: local and global consequences of Atlantic-Mediterranean gateway changes

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The influence of exchanging heat, salt and momentum through narrow, shallow straits that link the open ocean to marginal basins helps drive the global thermohaline circulation; and the opening and closure of marine gateways has a profound impact on the Earth's climate. In the Atlantic Ocean today, the dense water supplied by the Mediterranean Sea through the Gibraltar Strait is amongst the largest overflows in the global ocean. It preconditions North Atlantic Deep Water formation, makes Greenland's climate warmer and Antarctica cooler, and is a critical component of the Atlantic Meridional Overturning Circulation (AMOC). The narrow Atlantic-Mediterranean gateway at Gibraltar evolved from a wide, open seaway. African-Eurasian convergence restricted the marine connection, raising Mediterranean salinity sufficiently that more than 1 million km³ of salt precipitated in the Late Miocene. This salt giant, equivalent to ~6% of the total dissolved oceanic NaCl, is known as the Messinian Salinity Crisis.

Changes in Atlantic-Mediterranean exchange impact buoyancy budgets sufficiently to influence ocean circulation in the North Atlantic. However, identifying the extent and location of these Late Miocene impacts is challenging because we lack a process understanding of extreme fluctuations in exchange that can be tested with geological data. This project aims to determine *what* and *where* to look for broader climate impacts of the Messinian salt giant, making use of a range of numerical models and improved physical process-based understanding, to develop a problem-specific toolbox of palaeo-methods to answer *how* we can identify these locations. This knowledge will critically contribute to IMMAGE, an amphibious IODP-ICDP drilling proposal designed to recover a complete record of Atlantic-Mediterranean exchange from its Late Miocene inception to its current configuration.



P2-020

Holocene flow through uplifting Greenland-Canadian Arctic Channels

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We examined the Holocene flow and water masses, delivered through the network of Canadian Arctic channels that now feed relatively fresh Arctic water into northern Baffin Bay in a suite of 14 radiocarbon-dated marine cores. This region is significant for setting the salinity of the waters further south in the Labrador Sea, the source for Labrador Sea Water (Upper NADW). After the collapse of the glacial ice dams blocking the channels between 10.9 and 8.4 ka (BP), glacio-isostatic rebound continued to reduce their depth by a maximum of 120 m in Nares Strait, a process continuing up to the present. This has contributed to an acceleration of the shallowing flows through the channels estimated via grainsize analysis. But has there also been an increase in the flux of Arctic waters driven by oceanographic or other factors (such as changes in the discharge of rivers draining into the Arctic Ocean)? The present work builds on several previous studies which include compositional, faunal and isotopic data to which are here added data on Holocene flow strengths and modelled flows through the progressively narrowing channels. It is a paradox that, at around the mid-Holocene (8-7 ka) when it is commonly accepted that convection in the Labrador Sea commenced, Arctic fresh water began to flood the area which should have inhibited convection, unless it was spiked with higher salinity Atlantic water that had entered the Arctic Ocean via the newly invigorated Norwegian Atlantic current and its Barents Sea branch, plus salt from brine rejection in the NOW polynya in Baffin Bay.



P2-010

Millennial to seasonal scale views of El Niño-Southern Oscillation from central Pacific corals

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El Niño-Southern Oscillation (ENSO) is naturally highly variable on interannual to decadal scales making it difficult to detect a possible response to climate forcing. Despite the high variability, several lines of evidence from tropical corals, mollusc, lake sediments, and foraminifera suggest that 5,000-3,000 years ago ENSO variance was on average reduced by 60-80% compared to the present day. We investigate the seasonal-to-centennial variation in ENSO amplitude and tropical climate during this ENSO 'quiet period' 5,000-3,000 years ago using a new Sr/Ca SST record from a 175-year-long 4,300-year-old coral, and new $\delta^{18}\text{O}$ and Sr/Ca results from a similar-aged ~180-year-long *Porites* sp. coral. Both corals were discovered on Kiritimati (Christmas) Island, an optimal ENSO 'centre of action' in the central tropical Pacific. Together, these corals confirm a reduction in ENSO amplitude and that ENSO amplitude is modulated on multi-decadal scales. Composites of month-by-month changes in Sr/Ca-SST show an unprecedented view of ENSO and detail which seasonal-scale features of ENSO are an inherent part of the system and which are subject to change under altered climate states. We also investigate the millennial timescale changes in ENSO variance using combine coral oxygen isotope ($\delta^{18}\text{O}$) data from central Pacific corals and a suite of forced and unforced simulations conducted using the CSIRO Mk3L and GFDL CM2.1 climate system models. On millennial timescales, the coral data reveal a statistically significant increase in ENSO variance over the past 6,000 years. This trend is not reproduced by the unforced model simulations, but can be reproduced once orbital forcing is taken into account. Together these views of past ENSO may contribute to advances in understanding the response of ENSO to future changes in climate forcings.



P2-047

Last Glacial Maximum and Holocene oceanographic conditions at the Portuguese margin - a reconstruction using planktonic foraminifera

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Paleodata of environmental responses to climate change from the Last Glacial Maximum (LGM) and the Holocene provide a useful performance test for climate models' sensitivity, contributing to better forecasts. Temporal high resolution data for both periods is important to reduce the uncertainties of models regionally. The Portuguese margin, one of the most productive marine regions of the world and having high sedimentation rates, is considered a key area to reconstruct past climate. This high temporal resolution study contributes with planktonic foraminifera (PF) data (fauna and stable isotopes), temperature and export productivity (Pexp) at two sites under different oceanographic conditions: MD03-2699 – off Estremadura spur and Shak-03-6K - off Sines. Preliminary results show that during the LGM, the average SSTs at the Estremadura was lower than Sines (12.3 °C vs. 19.4 °C) while the Pexp was higher (86.2 gC/m²/yr vs. 60.8 gC/m²/yr). In contrast, during the Mid Holocene (MH), at both sites, the average SSTs were warmer and the Pexp was lower than during the LGM (Estremadura - 18.9 °C, 76.1 gC/m²/yr; Sines - 21.2 °C, 55.2 gC/m²/yr). Subtropical and transitional PF species are abundant during the LGM reflecting warm, stable SSTs at both locations relative to the high mid-latitude North Atlantic (NA) sites, whereas higher Pexp was possibly caused by stronger westerly winds that enhanced the upwelling. SSTs at both sites during the MH were interrupted by a cold event (starting at 5.2 ky) coincident with a decrease in Pexp at both sites. This cold event could be related to the freshwater input from the melting Laurentide ice sheet, already observed in the NA. Pexp at the Estremadura was relatively higher than off Sines (~20 gC/m²/yr difference), probably because like today this site is under a stronger influence of upwelling events and riverine nutrient input from the Tagus River.



P2-074

Evaluation of a multiproxy seawater temperature reconstruction from the (sub)tropical western South Atlantic

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The southeast Brazilian margin in the (sub)tropical western South Atlantic is under the influence of the warm Brazil Current whose southward heat transport is supposed to change according to deglacial variability in the meridional oceanic heat transport. Thus, elucidating the deglacial thermal evolution of the (sub)tropical western South Atlantic is a pivotal scientific for understanding the interhemispheric redistribution of oceanic heat during rapid climate perturbations. However, reconstructions of (sub)tropical western South Atlantic near-surface water temperatures might show proxy-specific biases which may limit the reliability of their interpretation. Here, we present multi-proxy records of deglacial sea surface and subsurface temperatures based on foraminiferal Mg/Ca, and organic biomarker-based U^k_{37} and TEX_{86} obtained from marine sediment core M125-35-3 collected at 428 m water depth off southeastern Brazil. We discuss the fidelity of these proxies in the (sub)tropical western South Atlantic, and point to a significant offset between Mg/Ca and U^k_{37} derived sea surface temperatures. This offset likely results from a combination of the seasonal occurrence of alkenone-producing haptophyte algae and lateral sediment drift. Allochthonous deposition of southerly-sourced alkenone-bearing particles likely shifts our U^k_{37} temperature record to colder temperatures. Subsurface temperatures derived from TEX_{86} reveal a correlation to hinterland weathering, which likely reflects a shift of the habitat depth of Thaumarchaeota to cooler water masses in line with increased terrestrial influx. Foraminiferal Mg/Ca-derived surface and subsurface temperatures appear to be the most faithful temperature proxy and corroborate the role of the western (sub)tropical South Atlantic as a heat reservoir associated with the Brazil Current during deglacial climate perturbations.



P2-107

Miocene-Pliocene palynological record from the Atlantic offshore of Mexico: palaeoceanographic and palaeoecological evidences related to the Central America Seaway closure

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Timing and modality of the closure of the Central America Seaway (CAS) are widely debated among geoscientists, as they triggered the instauration of modern circulation in the North Atlantic, an essential premise for the onset of Greenland glaciation.

In the frame of an integrated biostratigraphic study of several hydrocarbon exploratory wells located in the Atlantic offshore of Mexico, a reliable chronostratigraphy was built through the analysis of foraminifera, nannofossils and palynomorphs recovered from Late Miocene and Early Pliocene successions.

Despite a pragmatic industrial approach followed in this study, observed variations in abundances of some dinocysts taxa may give interesting clues into this topic.

According to the conceptual model suggested by De Schepper et al. (2013) based on palynological and geochemical records, the closure of the CAS caused by glacial expansion during Late Pliocene MIS M2 is associated to low productivity and higher SST in the Caribbean sea, while the opening and the connection with the cooler Pacific water due to deglaciation is associated to higher productivity in the upper water column. This trend seems to be reflected in our record by abundance oscillation of *Polysphaeridium zoharyi*, a species of warm water affinity, possibly corresponding to successive phases of shoaling of CAS before the final closure of the Panama Isthmus occurred approximately 2.5 Ma (Osborne et al. 2014). An increase of the same taxon observed in Zanclean sediments shows a good correlation with a change in water salinity attested in the area by several studies at 4.2 Ma.

Most of the published records dealing with this topic are from higher latitude successions, while from tropical and sub-tropical areas very few observations are available in the literature. Therefore, we consider our results of high potential for a better understanding of these dynamics.



P2-019

Multicentury shell-based proxy records from the southern Barents Sea: Insights and future work

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Few high-resolution paleoclimate records are available from high-latitude marine environments, limiting our ability to understand past marine climate variability in the northern North Atlantic. Recently developed, annually-resolved, multicentury shell-based proxy records from the southern Barents Sea have provided an exceptional opportunity to reconstruct marine paleoclimate in this region over the past five centuries. Key results from analysis of the *Arctica islandica* master shell growth chronology (1449-2014 CE; 564 years) and the $\delta^{18}\text{O}_{\text{shell}}$ -based temperature reconstruction (1539-2014; 476 years) suggest persistent multidecadal frequency characteristics in the marine environment since 1450 CE and a warming of $\sim 2^\circ\text{C}$ since 1750 CE. Here, we present the current status and prospects for future development and application of these records, including opportunities for extending the record further in time, analyzing reservoir age estimates based on radiocarbon measurements, and using a network approach to combine information contained in these records with similarly highly-resolved proxy records across the North Atlantic. Together, these opportunities provide exceptional promise for better understanding marine climate change in the context of important climate features such as the Atlantic Multidecadal Variability, Atlantic Meridional Overturning Circulation, and marine-terrestrial coupling through time.



P2-058

Oxygen isotope constraints on the circulation of the modern and Glacial North Pacific

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Changes in the circulation of the Pacific are thought to be central to the regulation of atmospheric CO₂ on glacial/interglacial timescales. However, two contrasting views exist for the Pacific modern circulation; the classical view with Pacific Deep Water upwelling to the mid-depths (Talley, 2013), and the bathymetrically constrained view which sees the mid-depths largely isolated from the global overturning circulation (de Lavergne 2017). Furthermore, despite the potential importance for climate and carbon cycling, past changes in the circulation of the Pacific under differing climate states remain poorly understood. We bring new constraints on the circulation of the modern and Glacial Pacific using oxygen isotopes in seawater and the calcite of benthic foraminifera, both of which act as conservative tracers. We analyse modern $\delta^{18}\text{O}_{\text{sw}}$ data and compile *Cibicides* and *Planulina wuellerstorfi* $\delta^{18}\text{O}$ from across the North Pacific. We find that the depths profile of modern $\delta^{18}\text{O}_{\text{sw}}$ and LGM $\delta^{18}\text{O}$ of calcite are more easily explained by the bathymetrically-induced circulation. Our results indicate a reduction in the influence of vertical mixing relative to lateral diffusion in the mid-depths during the LGM, which we interpret as a reduction in vertical mixing in the deep Glacial Pacific which would have contributed to increased oceanic carbon storage. Our results also indicate enhanced Glacial overturning in the intermediate depths from an expansion of North Pacific Intermediate Water (NPIW), providing a further mechanism to lower atmospheric CO₂ (Rae 2020).



P2-025

Role of deep-water circulation and related redox variability during sapropel deposition: new insights into marine deoxygenation dynamics

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Marine deoxygenation is considered one of the most impacting ocean stressors on marine ecosystems. At present, marine environmental problems, such as, global warming and coastal eutrophication are contributing to exacerbate oxygen loss. Sapropel deposits in the Eastern Mediterranean (EM) represent past large-scale rapid oxic-to-anoxic transitions. These paleo-records provide key insights to further understand marine deoxygenation in a long-term perspective. We studied five different sapropel events (S1, S5, S6, S7 and S8) from three EM locations (i.e., Ionian Basin, Mediterranean Ridge and Eratosthenes Seamount), representing not only a transect but also different hydrogeographic regimes. The multi-model approach elucidates the response of water-column dynamics during rapid climate change and the role of deep-water circulation on temporal redox variations in restricted marine settings. The paleoceanographic models suggest that sapropel deposition is highly influenced by particle shuttling; as occurs in modern Cariaco Basin. During S1 deposition, deep-water restriction is only evident for the Ionian Basin (deepest location). S5 and S7 resulted from stronger and shallower water-mass restriction and oxygen-depletion with low-frequency temporal redox variations, having a similar hydrographic dynamic as for the modern Black Sea or the Framvaren Fjord, respectively. S6 was deposited under very frequent deep-water renewal and associated high-frequency temporal redox variations, with a similar hydrographic regime to the modern Saanich Inlet. S8 shows weak deep-water restriction and oxygen-depletion, with similar deep-water renewal frequency to the modern Cariaco Basin. These recurring episodes of severe oxygen-depletion support the important role of deep-water circulation on temporal redox variations. Therefore, understanding of these paleoclimate records contributes to our ability to forecast deoxygenation dynamics under different climate scenarios.



P2-085

Assessing the variability of North Atlantic Deep Water during past warm climates

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Climate variability during the Holocene is remarkably muted when compared to previous interglacial periods that are characterized by high-magnitude climate events. However, the climatic boundary conditions under which such variability can occur, have not been fully described leading to uncertainties when predicting future climate change. Here we present a multi-proxy reconstruction of deep-water characteristics from the Rockall Trough in the Eastern North Atlantic to assess the variability of Nordic Seas and Labrador Sea deep-water formation during past interglacial periods for Marine Isotope Stages (MIS) 1, 5, 11, and 19. This approach allows us to evaluate the variability of North Atlantic Deepwater formation for a large range of interglacial boundary conditions and identify prerequisites for instabilities leading to climate events. To constrain the variability of deep-water formation, we performed geochemical analysis on planktic (Nd isotopes) and benthic foraminifera ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) along with sedimentological analysis for each interglacial. This methodology allows us to reconstruct paleocurrent flow strength, as well as the origin and contribution of different water masses in the Rockall Trough. Our results show that deep-water properties varied considerably during each of our chosen periods. For example, during the Holocene ϵNd variability is smaller (1.8 ‰) when compared to variability during MIS 19 (3.3 ‰), an interglacial that experienced very similar orbital boundary conditions. Our findings support that deep-water variability in the eastern North Atlantic basin was more variable during previous interglacial periods when compared to our current Holocene and provide new insight on the contribution of natural climate forcing on Nordic Seas Deep Water and Labrador Sea Water variability in the Rockall Trough.



P2-108

The impact of CO₂ and paleogeography on the ocean circulation during the high-CO₂ Miocene Climate Optimum (~17-15 Ma)

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By the end of the twenty-first century, global temperatures are expected to have risen by 1-5°C above pre-industrial levels. The ocean's Meridional Overturning Circulation (MOC) will modulate this rise, through uptake of atmospheric CO₂, redistribution of heat across the globe, and melting of sea ice. However, the future strength and stability of the overturning circulation are uncertain, in part because it adapts to climate change on timescales longer than the observational record which thus makes it difficult to study directly. Here we investigate the development of the MOC during the Miocene Climate Optimum, a period with moderately higher CO₂ (400-600ppm), which has been proposed as a reasonable analogue for end-of-century climate scenarios. Observational evidence suggests that during the Miocene, the MOC in the Atlantic transitioned from shallow hemispheric to modern inter-hemispheric deep circulation, but how and when this transition took place is still unknown. Many sensitivity studies on the role of opening and closing of straits during the Miocene have been carried out previously. However, very few modeling studies have focused on the Miocene Ocean equilibrium circulation state. We make opportunistic use of existing fully coupled model simulations and conduct a Miocene model intercomparison study of eight experiments from six different models to assess the role of paleogeography and CO₂ in the transition of the MOC to the modern state.



P2-012

Developing A Continuous Record of Labrador Sea Dynamics over The Past Centuries

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The Intergovernmental Panel on Climate Change has expressed concern over the potential reduction in the Atlantic Meridional Overturning Circulation (AMOC) in the next century, which could cause alteration in regional climate and shifts in weather hazard distributions. Considering the potential economic losses following a significant AMOC reduction, the value of information associated with a continuous observational record of the AMOC system, which enables confident prediction of future trend, has been estimated to be tens of billions of euros. While instrumental observations of the AMOC system are only available for the last decades, we must rely on proxy indicators in natural archives to capture the long-term trend of ocean circulation throughout the Industrial Age, and further back in time when there were little anthropogenic carbon emissions. Such a long-term record is particularly important for the Labrador Sea: a region of deep-water formation that constitutes a fundamental component of AMOC. This study aims to develop a comprehensive record of Labrador Sea deep water formation by compiling new proxy reconstructions (foraminiferal stable oxygen isotopes, magnesium-to-calcium ratio, and sortable silt mean grain size) with existing instrumental observations of the region's ocean temperature, salinity, and density over the past centuries. In particular, well-resolved proxy reconstructions are possible with exceptional sedimentation rates (up to $0.16 \text{ cm year}^{-1}$) found in multiple new sediment cores acquired from the Labrador Sea. Ultimately, this study will provide essential data required to establish a clear link between ocean circulation and climate change, allowing timely mitigation of potential socio-economic consequences.



P2-087

Leeuwin Current dynamics over the last 60 kyrs – relation to Australian extinction and Southern Ocean change

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The Leeuwin Current flowing southward along West Australia is an important conduit for the poleward heat transport and interocean water exchange between the tropical and the subantarctic ocean areas. Its past development, and its relationship to Southern Ocean change and to Australian ecosystem response, however is largely unknown. We here reconstruct sea surface and thermocline temperatures and salinities from foraminiferal-based Mg/Ca and oxygen isotopes from offshore southwest and southeast Australia reflecting the Leeuwin Current dynamics over the last 60 kyrs. Its variability resembles the biomass burning development in Australasia from ~60-20 ka BP implying that climate-modulated changes related to the Leeuwin Current most likely affected Australian vegetational and fire regimes. In particular during ~60-43 ka BP, warmest thermocline temperatures point to a strongly developed Leeuwin Current during Antarctic cool periods when the Antarctic Circumpolar Current weakened. The pronounced centennial-scale variations in Leeuwin Current strength appear in line with the migrations of the Southern Hemisphere frontal system and are captured by prominent changes in the Australian megafauna biomass. We argue that the concerted action of a rapidly changing Leeuwin Current, the ecosystem response in Australia, and human interference since ~50 BP enhanced the ecological stress on the Australian megafauna until a tipping point was reached at ~43 ka BP, after which faunal recuperation no longer took place. While being weakest during the last glacial maximum, the deglacial Leeuwin Current intensified at times of poleward migrations of the Subtropical Front. During the Holocene, the thermocline off South Australia was considerably shallower compared to the short-term glacial and deglacial periods of Leeuwin Current intensification.



P2-029

Reconstructing geological processes in the North Atlantic based on Pb and Nd isotopic records from marine sediments during deglaciation

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Deep sea Nd isotopes from a range of archives record anomalously low values in the North Atlantic (NA) during warming events associated with deglaciation. Several studies attribute these nonradiogenic values to the delivery of poorly weathered material produced by glacial activity from proximal continents rather than advective mixing of northern-sourced water masses. Different mechanisms have been proposed for transferring this nonradiogenic signature to seawater, including input of fresh material into the ocean and subsequent relabeling in the water column, dissolved input from the continents, or a benthic flux from porewaters. This study aims to understand the significance of the nonradiogenic ϵNd with a focus on Termination 2 (~130 ka). We analyzed elemental concentrations and Nd and Pb isotopes for leachates of grain size separates (<3 μm , 3-10 μm , 10-32 μm , 32-63 μm) and a bulk sample (<63 μm) from sediments recovered at IODP sites U1305 (3459 m water depth) and U1306 (2272 m water depth) located on Eirik Drift. Sedimentation rates are higher during interglacial intervals at U1305 and higher during glacials at U1306. To our knowledge, our approach of leaching grain-size-specific fractions has not been applied at other sites in the NA. This method allows for a more detailed understanding of Nd and Pb proxies, as well as comparison to provenance studies based on paleomagnetic data. Preliminary results show agreement between the Pb isotopic data from leachates of all grain sizes and with records from previous studies in the NA. Similarly, the leachate Nd isotopes of the <3 μm and < 63 μm (bulk) fractions agree with previously reported data from this region, but ϵNd values of the silt fractions differ by several ϵNd units. This difference between size fraction seems inconsistent with overprinting of bottom water isotopic ratios by benthic fluxes and suggests relabeling within the water column may alter Nd isotopes preserved in sedimentary archives.



P2-006

Coupled stratosphere-troposphere-Atlantic multidecadal oscillation and its importance for near-future climate projection

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Northern Hemisphere (NH) climate has experienced various coherent wintertime multidecadal fluctuations in different climate components such as stratosphere, troposphere, ocean, and cryosphere with strong implications for continental climate. However, the overall mechanistic framework for these coherent changes is not well established. The understanding of the mechanisms of the coupled atmosphere/ocean variability and the associated implications for the continental climate and sea-ice can help in interpreting paleo climate data, choosing the paleo record and projecting the reconstructed data on different climate components,

Here we show, using long-term transient forced coupled climate-simulation, that large parts of the observed coherent NH-multidecadal changes can be understood within damped coupled stratosphere/troposphere/ocean-oscillation framework. Wave-induced downward propagating positive stratosphere/troposphere-coupled Northern Annular Mode (NAM) and associated stratospheric cooling initiate delayed thermohaline strengthening of Atlantic overturning circulation and extratropical Atlantic-gyres. These increase the poleward oceanic heat-transport leading to Arctic sea-ice melting, Arctic warming amplification, and large-scale Atlantic warming, which in turn initiates wave-induced downward propagating negative NAM and stratospheric warming and therefore reverse the oscillation-phase. This coupled variability shows that the atmosphere, ocean, sea-ice and continental climate are strongly coupled in multidecadal timescale and can be better predicted, if the link between different climate component involved is considered. The coupled variability gives high flexibility in choosing the paleo record and can help understanding the associated multidecadal fluctuations.



P2-042

Milankovitch cyclostratigraphy revealed by grain size variations on the Antarctic Margin

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The Marine Isotope Stages can be clearly recognized by grain size analysis on the Sabrina Slope, off the Antarctic's Totten Glacier. Current laid sediments display higher silt to clay ratios during interglacials, indicating faster currents are typical of the warmer climates. These observations have allowed us to construct a detailed age model for a number of piston cores that have been recovered from intermediate depths on the Sabrina Slope. The cores reveal that the occurrence of foraminifera can be rare at times, particularly during the Holocene and Stage 5e when the diatom flux is high. At other time intervals, particularly during the interstadials, foraminifers can be more abundant and better preserved. During late Marine Isotope Stage 3 and the transition between Marine Isotope Stages 5a and 4, we find foraminifer abundance spikes are correlated with negative excursions of delta 18 O within the foraminifers. We interpret these negative spikes in delta 18 O as times of intense meltwater release from beneath the Totten Glacier. These meltwater events appear to persist for over a thousand years for each event.



P2-022

Investigating the response of deep-sea ecosystems in the Northeast Atlantic during the Holocene

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The 8.2 kyr event is an abrupt climate perturbation that occurred about 8200 years before the present, which interrupted the relatively stable climate of the Holocene period. The event has been associated with an episode of massive freshwater release into the North Atlantic that is proposed to have led to a slowdown of the Atlantic Meridional Overturning Circulation (AMOC) and in turn to reduction of the northward heat transport to the Atlantic Ocean and thus cooling of the Northern Hemisphere. The 8.2ky event provides a useful scenario with which to examine how marine ecosystems may respond to changes in North Atlantic circulation and possibly AMOC weakening. This is of particular value given recent concerns about ongoing changes in the North Atlantic that may be linked to a weakening AMOC, and emerging evidence for their impact of marine ecosystems.

In order to assess the deep-sea ecosystem response to oceanographic changes during the 8.2ky event, here we present a 2500-year (~6.8-9.2 ka BP), high-resolution benthic foraminiferal assemblage record, alongside planktic foraminiferal assemblages, sediment grain size (sortable silt) and benthic $\delta^{13}\text{C}$ data from North Atlantic site RAPiD-17-5P, located south of Iceland and under the main flow of Iceland-Scotland Overflow Water (ISOW). Relatively muted changes are observed across the 8.2 kyr event, which stand in contrast to the large changes reported for the recent industrial era. To enable a broader understanding on the likely controls on benthic foraminiferal changes during the 8.2 kyr event, we also present similar, new, records from other cores located at key sites throughout the subpolar North Atlantic and NW Atlantic. We compare our results to our previous work examining the industrial era and consistent with these findings, large shifts in surface ocean conditions appear to be a primary driver for benthic assemblage change.



P2-118

Modeling the Impact of Paleogeography on Cretaceous Ocean Deoxygenation

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Oceanic Anoxic Events (OAEs) were geologically short-lived events of widespread ocean deoxygenation and marine organic carbon burial and occurred mostly during the Cretaceous period. The development of OAEs is largely attributed to the impact of massive volcanism on climate and marine biogeochemistry; however, the lack of similar events during other carbon-cycle perturbations suggests additional mechanisms. We use the IPSL-CM5A2 Earth System Model to assess the role of changing paleogeography in priming the Cretaceous Ocean for large-scale decrease in intermediate and deep oxygen concentrations. We focus on three time-slices that present differences in potential gateway (e.g. the Central American Seaway) depth and basin configuration (e.g. the North Atlantic): the Cenomanian-Turonian boundary (~94 Ma), the Maastrichtian age (~70 Ma) and the Paleocene age (~60Ma). This set of simulations illustrates the impact of paleogeography on global circulation and its consequences for intermediate and deep water oxygenation. We also show the impact of different atmospheric CO₂ concentrations (2x and 4x pre-industrial) to study the additional influence of differing climatic states on oxygenation and primary productivity, and their importance relative to ocean dynamics.



P2-023

Collapse of the Mediterranean Thermohaline Circulation during the Sapropel S1: New insights from Nd isotopes

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Sapropel events, organic-rich sedimentary layers that typically appear in the E-Mediterranean, have been often attributed to a combination of enhanced biological production in the surface ocean as well as a deficit in the renewal rate of deep basin waters leading to severe anoxic conditions that helped with the preservation of organic matter in the sediment. The sapropels are intrinsically linked to changes in the Mediterranean thermohaline circulation (MedTHC), but little is known on the drivers of these changes. For example, there are no evidences on how the main intermediate and deep convection cells in the E-Med responded during sapropels. Here we present a new reconstruction of the changes of the MedTHC circulation system during Sapropel 1 using Nd isotopes (ϵNd) in the Adriatic-North Ionian Sea region. Our study core site is located at the mixing line between the formation of Adriatic Deep Waters (ADW) and the arrival of E-Med Levantine Intermediate Water (LIW). Our newly measured Nd isotope ratios thus reflect changes in the mixing proportions of these two endmembers (ADW vs. LIW), and clearly show two distinctive collapse phases during the sapropel (S1a and S1b) as a result of reduced strength in the ADW convection cell and increased presence of LIW. The two sapropel phases were interrupted but a relatively short period where ADW resumed its convection into the north Ionian Sea. Further support to this interpretation comes from U/Mn ratios measured in foraminifera as well as benthic foraminiferal fauna supporting the idea that the changes in the intensity of deep water convection preceded both the establishment of anoxic conditions at depth and the increased organic matter export to the sediments. We conclude that the collapse of ADW convection cell led the deposition of the last sapropel layer and favoured the dominance of LIW at intermediate depths in the E-Med water column.



P2-008

Tracing the last millennium cyclicity and ENSO influence of the Río de la Plata plume water over the Southwestern Atlantic Ocean

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The Río de la Plata plume water (PPW) is very significant globally in terms of water discharge and sediments to the oceans and highly modulated the productivity of the adjacent shelf, and is mainly determined by the climatic modes of variability, such as El Niño Southern Oscillation (ENSO), by modulating the discharge patterns and regional winds. Thus, the present study aims to identify the last millennium cyclicity and ENSO influence of the PPW over the northern continental shelf. To achieve that, diatom associations were analyzed from two marine sediment cores retrieved from the Uruguayan inner shelf. The cyclicity of diatom data was explored by means of time series analysis and Spearman's correlations were performed to address the correlation between diatomological data and last millennium ENSO reconstruction. Diatom associations indicated that the hydrological history of the basin (associated with the evolution of the regional climate) recorded in sediments was characterized by a lower influence of the PPW between 900-1400 CE and was climatically related to the Medieval Climate Anomaly-MCA. An Intermediate influence was inferred between 1400-1600 CE (associated with the first half of the Little Ice Age- LIA), while the highest influence of the PPW was recorded from 1600 CE to the present, climatically related to the second half of the LIA and the Current Warm Period-CWP. Such increase of the PPW influence after 1600 CE is most likely related to the onset of more humid conditions installed by the intensification of ENSO. In this sense, diatom analyses presented a significant high correlation between ENSO reconstruction of Mann et al. (2009), indicating that El Niño events are indeed associated with a greater influence of the PPW on the Southwestern Atlantic Ocean (SWAO), and vice versa for La Niña events.



P2-038

Migrations of the South Atlantic Subtropical Gyre during Heinrich Stadials

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Subtropical ocean gyres play a key role in modulating the global climate system redistributing energy between low and high latitudes. A poleward displacement of the subtropical gyres has been observed over the last decades, but the lack of long-term monitoring data hinders an in-depth understanding of their dynamics. Paleoceanographic records offer the opportunity to identify meridional changes in the subtropical gyres and investigate their consequences to the climate system. Here we present the abundance of *Globorotalia truncatulinoides* as a new proxy for the meridional displacement of the South Atlantic Subtropical Gyre (SASG) on millennial timescales. We compare the abundance of planktonic foraminiferal species *G. truncatulinodes* from a sediment core collected at the northernmost boundary of the SASG with a previously published record of the same species from the southernmost boundary of the SASG to reconstruct meridional fluctuations of the SASG over last ca. 70 kyr. Our findings indicate southward displacements of the SASG during Heinrich Stadials (HS) 6-4 and HS1, and a contraction of the SASG during HS3 and HS2. During HS6-4 and HS1, the SASG southward displacements likely boosted the transfer of heat to the Southern Ocean, ultimately strengthening deep-water upwelling and CO₂ release to the atmosphere. We hypothesize that the ongoing SASG poleward displacement may further increase oceanic CO₂.



P2-039

Environmental changes in the Kosterhavet National Park marine protected area: evidence from local sediment archives

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The Koster Trench is the deepest part of the Kosterfjord (North Sea), which stretches along the west coast of Sweden. Since 2009 Kosterfjord has been included in the MPA Kosterhavet National Park due a presence of cold water coral communities. To effectively manage national parks, long-term time series of ecological data are needed and those can be derived from local sediment archives. In this study we present multiproxy geochemical (bulk TOC, C/N and heavy metals) and micropaleontological (dinoflagellate cysts, selected palynomorphs and benthic foraminifera) data from a sediment core taken in the southern part of the Koster Trench. Radiometric dating by ²¹⁰Pb and ¹³⁷Cs places the core within 1988 - 2012. The TOC, heavy metals and foraminiferal indices indicate high to good ecological quality status (EcoQS), with moderate EcoQS for arsenic concentrations. Dinoflagellate cysts suggest a major change occurring in the upper water column around 2002. The cysts of *Pentapharsodinium dalei* show overall slightly higher relative abundances between 1988 and 2002. Increased *Biecheleria baltica* cysts are present during ~ 2002 to 2012. Also, there is a clear increase of *Alexandrium* cysts in the top of the core (~ 2008 – 2012). Benthic foraminifera show a significant increase of agglutinated species (mainly *Textularia earlandi*) from 2007 towards present day, while during 1988-2007 calcareous species dominate. This suggests an increased freshwater input or a higher river/land runoff, as supported by the observed increased precipitation, lower salinity, and an increased POC in surface waters during the 2000s. These changes, in combination with trawling activities, likely favoured dinoflagellate and foraminiferal species with mixotrophic and omnivorous feeding strategies. Similar to the dinocysts, calculated foram-AMBI and NQI_{foram} indices show a shift around 2002 suggesting that environmental changes occurring in the study area are likely linked to darkening of coastal waters.



P2-075

Converging constraints on the glacial Atlantic overturning circulation from multiple proxies

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The Atlantic overturning circulation plays a critical role in inter-hemispheric transport of heat, carbon, and nutrients, and its potential collapse under anthropogenic greenhouse gas forcing would represent a major tipping point in the climate system. Yet, despite decades of research many uncertainties remain regarding the evolution of the ocean circulation over the past 20,000 years, during which Earth's climate was propelled out of the last ice age. Here, we employed the Bern3D model, which is equipped with all major isotope-based water mass tracers ($\Delta^{14}\text{C}$, $\delta^{13}\text{C}$, $\delta^{18}\text{O}$, ϵNd , Pa/Th), to search for converging constraints on the often conflicting interpretations of paleo-reconstructions from individual proxies focusing on the Last Glacial Maximum (LGM). By varying formation rates of northern- and southern-sourced waters in a model set up with realistic glacial boundary conditions we explore a wide range of circulation states and test their ability to reproduce the spatial patterns of newly compiled proxy data of the LGM. We find that the previously opposing neodymium and stable carbon isotope-based interpretations of the glacial water mass structure can be reconciled when non-conservative effects are appropriately taken into account. Both tracers indicate a shoaling of northern-sourced water by about 1000 m. This shoaling is further corroborated by model-data constraints from radiocarbon ventilation ages that we find to trace almost exclusively water mass provenance not overturning. For the latter we rely on the Pa/Th proxy, which indicates substantially reduced Atlantic overturning during the LGM compared to the pre-industrial. Pa/Th records previously interpreted as indication for stronger glacial circulation are further consistent with such weakening in the model due to the complex behavior of Pa in the ocean. Thus, our multi-proxy analysis reveals a shoaled and weakened Atlantic overturning circulation at the LGM, reconciling apparently conflicting proxy evidence.



P2-083

Paleoceanography of the subpolar North Atlantic ODP Site 984 for the Last Interglacial (Late Pleistocene): preliminary results based on dinoflagellate cysts.

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The Last Interglacial (~129 ka) is relevant for understanding future climate but its ocean and climate dynamics are not well understood. Ocean Drilling Program Site 984, drilled in the subpolar North Atlantic just south of Iceland, is ideally located to detect past shifts in the Arctic and Subpolar fronts, and the North Atlantic Current (NAC). Here, sediments representing the Last Interglacial and its bounding glacials have high sedimentation rates and excellent temporal control based primarily on benthic foraminiferal isotopes. Of interest are climate (in)stability and the timing of inception of full interglacial conditions. Multiproxy evidence for Site 984 during this interval (Mokeddem & McManus, 2016, Paleoceanography) is detailed but incomplete. A dinoflagellate cyst study based on samples for the interval 132.45–108.9 ka (average sample spacing of 183 years) is in progress. The last interglacial is characterised by a rich association including the autotrophs *Ataxiodinium choane*, *Bitectatodinium tepikiense*, *Dalella chathamensis*, *Impagidinium* species including *I. sphaericum*, *I. paradoxum*, and *I. plicatum*, *Nematosphaeropsis labyrinthus*, *Operculodinium centrocarpum* sensu Wall and Dale, and *Spiniferites* species including *S. elongatus*, *S. mirabilis*, and *S. ramosus*; and heterotrophs including *Brigantedinium* species, *Lejeunecysta* species, *Polykrikos* sp., and *Selenopemphix quanta*. Some assemblages indicate conditions warmer than today at this subpolar site. The first signs of climatic amelioration with dominant *O. centrocarpum* at 131.7 ka, and sustained warming from 131.0 ka, indicate the active influence of the NAC at Site 984 well before the onset of full interglacial conditions in the North Atlantic at 128–129 ka.



P2-123

The evolution of ocean dynamics and the carbon cycle after a Marinoan snowball Earth

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The two large-scale glaciations of the Neoproterozoic, commonly referred to as snowball Earth events, caused extreme shifts in the climate and the geochemical state of the ocean. The conditions after a snowball Earth are responsible for the accumulation of unique geological formations like cap carbonates and potentially posed a threat for the early forms of life existing in the Neoproterozoic. To improve our understanding of the interplay between climate, ocean circulation and the carbon cycle, we simulate the aftermath of the Marinoan snowball Earth, using the coupled atmosphere-ocean general circulation model ICON, including also the ocean-biogeochemistry model HAMOCC. It is assumed that in the snowball Earth aftermath the high atmospheric CO₂ concentration responsible for the termination of the pan-glacial state causes a rapid transition into a hot supergreenhouse climate. The inflow of large amounts of freshwater into the cold and salty sub-snowball ocean would further cause a stable oceanic stratification, with consequences for climate and ocean biogeochemistry. Our simulations show, however, that the supergreenhouse climate in the snowball Earth aftermath was possibly not as extreme as previously assumed and that the oceanic freshwater stratification breaks up rapidly on a timescale of only a few thousand years. Therefore, we derive that Marinoan cap dolostones showing signs of deposition in a freshwater-influenced environment must have accumulated during the geologically short period of deglaciation. Our simulations with HAMOCC represent the first study of the snowball Earth aftermath, where the simulated climate and ocean circulation can dynamically interact with the carbon cycle and the biogeochemical state of the ocean. We show that, depending on its state at the start of the deglaciation, the ocean after a snowball Earth can be either a source or a major sink for atmospheric CO₂, thereby modulating the severity of the supergreenhouse climate.



P2-099

A multi-proxy study of changes in the Indonesian Throughflow since the Pliocene

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Today, the Indo-Pacific Warm Pool (IPWP) is the largest mass of very warm water (greater than 28 °C), and a major reservoir and source of heat and moisture to the atmosphere. As such, the evolution of the IPWP has major consequences for our understanding of tropical and global climate processes. An important component of the IPWP circulation system is the Indonesian Throughflow (ITF) which transports heat from the Pacific to the Indian Ocean, thereby affecting the heat budget of both basins.

Here, we produced paired records of clumped isotopes (Δ_{47}) and Mg/Ca measurements of mixed layer-dwelling planktonic foraminifera (*T. trilobus*) to reconstruct temperature changes in the Indonesian Throughflow (ITF) over the past ~6 million years (Myrs). We examined selected glacial/interglacial intervals spaced over 6 Myrs, as well as a continuous Mg/Ca record from ~1-5 Ma, at two sites on the NW Australian margin, IODP U1482 and IODP U1483, which together generate a single record (U1483/82). We do not detect any temporal correlation in the difference between Δ_{47} and Mg/Ca through time, suggesting that our Pliocene Mg/Ca SST estimates are not systematically biased due to changes in Mg/Ca of seawater or changes in carbonate preservation.

We observe pronounced cooling at Site U1483 after 1.4 Ma, primarily due to cooling during glacial periods. This cooling is likely linked to exposed shallow shelves around the ITF during glacial sea level lowstands, which restricted ITF outflow and contributed to decreasing the poleward heat transport carried by the Leeuwin Current (LC). In contrast, during the Pliocene, previously observed LC cooling is decoupled from surface temperature changes at Site U1482, suggesting that LC cooling was due to increased mixing with cool waters near the West Australian Margin rather than changes in the ITF.



P2-062

Control of Vertical Mixing on the Emergence of Dansgaard-Oeschger Events in Glacial Climate

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During the last glacial period the North Atlantic experienced large and abrupt fluctuations in climate, known as Dansgaard-Oeschger (D-O) events, which involved major changes in sea ice and ocean circulation. Recent studies with General Circulation Models (GCMs) have suggested that the existence of D-O events may depend on the distribution of diapycnal mixing in the glacial ocean (e.g., Peltier and Vettoretti, 2014). However, the physical mechanism linking changes in ocean vertical mixing to abrupt glacial climate change remains elusive.

In this study we use a coupled atmosphere-ocean-sea ice model (MITgcm) with idealized geometry to investigate how vertical mixing affects the sea ice cover and its interaction with the large-scale ocean circulation. The idealized setup comprises an Atlantic-like and a Pacific-like basin joined by a circumpolar Southern Ocean. Our results demonstrate that the glacial climate system is unstable and exhibits unforced and self-sustained oscillations when mixing in the thermocline is weak. The weak mixing promotes a build-up of oceanic heat beneath the ice cover in the North Atlantic, triggering rapid sea ice retreat, enhanced deep water formation, and an increase in the Atlantic Meridional Overturning Circulation (AMOC). In contrast, enhanced thermocline mixing promotes a stronger AMOC and a reduced North Atlantic sea ice cover which does not exhibit self-sustained oscillations. These findings suggest that the strength and distribution of vertical mixing in the glacial ocean may have played a role in preconditioning rapid climate changes such as the D-O events of the last glacial, and highlight the importance of interactions between the AMOC and North Atlantic sea ice.



P2-102

Millennial-scale Sea Surface Temperature variability in the Southeast Pacific over the past 0.8 Ma

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The Antarctic Circumpolar Current (ACC) is the world's strongest current connecting the three main basins, linking the deep and shallow layers of the ocean. The major constriction of the ACC is the Drake Passage (DP). The DP throughflow, also called the "Cold-Water route", exerts a strong control on the Atlantic Meridional Oceanic circulation. However, little is known concerning glacial-interglacial variations in the export of water masses in the DP. Resolving changes in the flow of circumpolar water masses through this gateway is, therefore, crucial for advancing our understanding of the Southern Ocean's role in global ocean and climate variability. To assess changes in the flow of water masses through Drake Passage, we reconstructed an unprecedented millennial scale resolution Sea Surface Temperature (SST) record over the past 800 kyr from drill Site U1542 at ~1100 m water depth. Site U1542 is in the northern ACC system close to the Chilean Margin linked to the main ACC through the Cape Horn Current into the Drake Passage. We performed alkenones-derived SST reconstructions at ~1 kyr interval during glacial period to explore in detail the climate variability in the subantarctic ACC. Alkenone-based SST changes at Site U1542 document variability about ~9 °C between glacial and interglacial periods and appear to be mainly eccentricity driven. Superimposed to this orbital variability, we observe strong amplitude SST variations (~2-3°C) at millennial scale. Additionally, synchronous variations between alkenone-derived SST and Zr/Rb ratio, suggests a tight coupling between intermediate and shallow water. This study provides insight into disentangling role of the ACC in ocean circulation at millennial scale, more precisely changes in the transfer between oceanic basins. Our next step is to explore zonal and latitudinal gradients by comparing between Site U1542 with similar time-scale record in both Pacific and Atlantic.



P2-064

Exploring the Atlantic overturning meridional circulation stability during last glacial period

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Climate variability during the last glacial period (~ 115 to 12 thousand years ago) is associated with massive reorganisations of the Atlantic Overturning Meridional Circulation (AMOC). It has been demonstrated that the AMOC may have existed in more than one stable modes, but the mechanisms leading to switches between different regimes are still misunderstood. It is also unclear how disruptions of the ocean circulation may have led to millennial-scale climate oscillations such as the one observed during Dansgaard-Oeschger events.

Most attempts at theorising glacial millennial-scale variability have involved looking at heat and salt transfers between the subtropical and subpolar gyres, often referred to as the salt oscillator mechanism, that in turn controlled the intensity of the north Atlantic current. We believe that the salt oscillator is in fact part of a larger motion combining harmonic and stochastic components and spanning through all components of the climate system. When in the right combination of boundary conditions and forcings, this motion can lead to jumps between different stable states, hence triggering abrupt climate changes.

Based on a new set of last glacial maximum (~21 thousand years ago) simulations that oscillates when forced with snapshots of the early last deglaciation meltwater history, we propose a new way to visualise the stability of the AMOC and how it can move between different regimes. We also demonstrate how the meltwater forcing creates conditions favourable to the triggering of abrupt climate transitions.



P2-116

Global deep ocean circulation through the early Eocene Climatic Optimum - a neodymium isotope perspective

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The early Eocene Climatic Optimum (EECO) (~49–53 Ma) presents an ideal test bed to explore climate interactions in a high CO₂ world (pCO₂ > 1000 ppm). Here we investigate deep ocean circulation during the EECO, employing the Nd isotope fingerprint of water masses as reconstructed using fish debris and foraminifera, at sixteen global DSDP, ODP and IODP sites. Our data reveal a distinct dichotomy between the Atlantic and the Pacific Oceans in both average $\epsilon_{Nd(t)}$ and time-dependent variability. Pacific data disclose relatively constant site-specific signatures, suggesting that the observed latitudinal trend constitutes a long-term feature of the EECO. Through comparison with existing data, we note a latitudinal gradient towards more radiogenic signatures from the south to the north ($\epsilon_{Nd(t)} = -4.6 \pm 0.3$, DSDP Site 287 24°4S and $\epsilon_{Nd(t)} = -1.9 \pm 0.4$, ODP Site 883 [1], 38°9N). Although this observation alone is inconclusive in distinguishing between North and South Pacific deep-water formation/export, the data strengthen the notion of a Pacific sector Southern Ocean deep-water source.

In contrast, Atlantic Ocean signatures display time-dependent variability throughout the EECO. South Atlantic signatures largely reflect Southern Ocean export, characterised by Nd isotope values between -10.4 ± 0.4 and -8.6 ± 0.3 in the Atlantic and Indian sector. The observed amplitude of change in South Atlantic sites, 1.2 ϵ units, is insufficient to explain large variability in Nd isotope signatures observed within the North Atlantic, 3.7 ϵ units at DSDP Site 549 between ~53.9 and 47.6 Ma. Whether transient or long-term, strengthened export of highly unradiogenic Baffin Bay outflow water offers a feasible explanation for these North Atlantic observations.

We will furthermore interrogate whether our new data support multiple, separate, Southern Ocean deep water sources during the EECO and potential export from the North Atlantic.

[1] Hague, A. *et al.* (2012) *Geology* **40** 527-530.



P2-036

Water mass provenance in the Atlantic sector of the Southern Ocean reconstructed through neodymium isotopes

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The deep Southern Ocean (SO) circulation is of major significance for the understanding of the ocean's impact on Earth's climate as uptake and release of CO₂ strongly depend on the redistribution of well and poorly ventilated water masses.

Neodymium isotopes preserved in deep sea sediment have proven useful to study the deep ocean circulation and water mass provenance thanks to basin scale isotope gradients between the Pacific and the North Atlantic.

Here we present novel Nd isotope data (ϵ_{Nd}) of two sediment cores in 2.8 and 3.6 km water depth in the Atlantic sector of the SO. The drilling sites are well situated to resolve changes in past ocean circulation and to assess the presence of old and poorly ventilated Pacific sourced Deep Water (PDW). The ϵ_{Nd} records include several glacial-interglacial cycles in high temporal resolution of up to 12 data points per 10 ka.

For the past 150 ka the sediment cores indicate dramatic temporal changes of ϵ_{Nd} , spanning a range of 7.7 ϵ -units from -1.0 to -8.3. Concentration measurements of the other leached elements including REE reveal that the ϵ_{Nd} variability of the deeper situated core is driven by glacial-interglacial changes in ocean circulation, whereas the shallower drilling site is likely influenced by a local interference of radiogenic Nd, resulting in highly variable ϵ_{Nd} values.

During peak glacial periods of MIS 2, 6 and 12 with maximum sea ice extent and a shoaled AMOC we observe radiogenic ϵ_{Nd} values of -2.5 to -3.5. This confirms a predominance of glacial PDW at depths of >3 km with proportions close to 100% and thus increasing the water volume portion with enhanced respired carbon. We further advocate for the persistent presence of PDW in the Atlantic sector of the SO even during interglacials although with a much smaller proportion.

Hence, our results enforce the leading role of the SO in storing and reinjecting respired CO₂ into the deep Atlantic Ocean and the atmosphere during glacial-interglacial terminations.



P2-101

Sea surface temperature and productivity records from the Pacific Southern Ocean spanning the last ~5 million years

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To explore the largely unknown Cenozoic paleoceanography of the Pacific Southern Ocean, we generate proxy records from Site U1541 that was drilled during IODP Expedition 383 and is located ~180 km north of the modern Subantarctic Front in the central South Pacific. We analyze alkenones and total organic carbon (TOC) content at Site U1541 and derive sea surface temperature (SST) and phytoplankton productivity records now spanning the last ~5 My. Pliocene average SST at Site U1541 were ~10°C and thus ~4°C warmer than modern and Pleistocene average values, suggesting a southward shift of the Subantarctic Front and a more extensive/warmer Pacific subtropical gyre. Our record indicates initial cooling of the subantarctic Pacific at 2.5–3 Ma, with the underlying oceanographic reorganization potentially being linked with the intensification of the cold upwelling tongue in the tropical East Pacific (1). The Pleistocene is marked by glacial/interglacial SST changes of up to 6–8°C suggesting major northward/southward shifts of the Subantarctic Front over Site U1541, which are most pronounced after the Mid-Pleistocene Transition (MPT). The alkenone and TOC concentrations indicate that the phytoplankton productivity in the subantarctic South Pacific was enhanced during glacials and reduced during interglacials, a pattern that emerged during the late MPT. This is similar to findings from the subantarctic South Atlantic and consistent with the idea that the glacial subantarctic phytoplankton productivity was stimulated by dust derived iron fertilization and contributed to lowered atmospheric CO₂ (2). Our emerging new proxy records will provide unprecedented insights into southern high-latitude ocean–atmosphere–cryosphere dynamics and their implications for regional and global climate and atmospheric CO₂ during warmer than present times and glacial/interglacial cycles.

1) Liu et al., 2019, *Sci. Adv.* 5: eaau6060

2) Martínez García et al., 2011, *Nature* 476, 312–315



P2-112

A dipole mode in the Equatorial Indian Ocean during Miocene

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Across Miocene, Earth's climate underwent a high pCO₂ change, permanent Antarctic Ice Sheet formation, and constriction of tropical passageways [1]. However, the associated response and establishment of the tropical climate system are not fully understood. Here we use combined carbonate clumped isotope and stable oxygen isotope ($\delta^{18}\text{O}$) of surface-dwelling planktonic foraminifera *Globigerinoides quadrilobatus* from Southern Bay of Bengal (SBoB) ODP site 758 to reconstruct the Sea Surface Temperature (SST) history and surface hydrology between 18Ma and 9Ma. With respect to 28°C isotherms, the SBoB record indicates ~3°C drop in SST during high pCO₂ Mid Miocene Climate Optima (MMCO). While at Mid Miocene Climate Transition (MMCT) synchronous with the advancement of the Antarctic ice sheet, SBoB SST was ~6°C warmer. The consequence of this SST variation in rainfall over the SBoB is manifested on $\delta^{18}\text{O}$ seawater, suggesting freshening during MMCO and more evaporation during MMCT. Further, we compared our record with available SST of equivalent age from the South-Eastern Arabian Sea (SEAS) [2]. Our result exhibit equatorial Indian Ocean condition analogs to positive Indian Ocean Dipole (IOD) during MMCO and Negative IOD during MMCT. Following MMCT, the constriction of the Indonesian Seaway and closure of the Tethyan seaway caused a subtle SST gradient between SBoB and SEAS and more freshwater flux, suggesting the establishment of a modern-like Indian Monsoon system. Our observation is consistent with upwelling proxies [3] and climate model simulation [4], implying that Modern Indian Monsoon evolved post-MMCT.

References:

- 1) Steinhorsdottir et al., 2021. *Paleoceanography and Paleoclimatology*, Vol. 36(4), p.e2020PA004037.
- 2) Yang et al., 2020. *Paleoceanography and Paleoclimatology*, Vol. 35(12), p.e2020PA003853.
- 3) Gupta et al., 2015. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* Vol, 438. Pg, 160-167.
- 4) Farnsworth et al., 2019. *Science Advances*. Vol. 5(10).



P2-082

Centennial-scale isotopic and radiocarbon records document variability of the Denmark Strait Overflow over peak glacial to early deglacial times

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The Denmark Strait Overflow (DSO) today compensates for the northward flowing Norwegian and Irminger branches of the shallow North Atlantic Current that drive the Nordic heat pump. During the Last Glacial Maximum (LGM), ice sheets constricted the Denmark Strait aperture in addition to ice eustatic/isostatic effects which reduced its depth (today ~630 m) by ~130 m. These factors, combined with a reduced north-south density gradient of the water-masses, are expected to have restricted or even reversed the LGM DSO intensity. Nonetheless, epibenthic $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ maxima revealed a north-south density gradient at intermediate water depths during the LGM, hence implied a peak glacial DSO that was directed to the south like today (Millo et al., 2006; Voelker, 1998). We now discuss a new multiproxy sediment record from a watchdog site near the northern entry of the Denmark Strait (Nd, Pb, and stable C and O isotopes, and ^{14}C -based ventilation ages). Our data suggest a marked short-term instability of the DSO near the end of the LGM and possibly imply a DSO reversal during Heinrich Stadial 1.

Refs.

Millo, C. et al., *Boreas* 35, 2006; Voelker, A., PhD thesis Univ. of Kiel, 1998



P2-122

Orbital-scale deoxygenation trends driven by ventilation in Cretaceous ocean

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Mechanisms driving cyclicity in the marine realm during hothouse climate periods in response to Earth's orbit variations remain debated. Orbital cycles fingerprint in the oceanographic records results from the effect of terrestrial (eg. weathering-derived nutrient supply, freshwater discharge) and oceanic (eg. productivity, oxygenation) processes, whose respective contributions remain to be defined. In this study we investigated the effect of extreme orbital configurations on oxygenation state of the ocean using ocean biogeochemistry simulations with the IPSL-CM5A2 Earth System Model under Cenomanian-Turonian boundary conditions. Our simulations show that small ocean ventilation changes triggered by orbitally-induced variations in high latitude deep water formation have strong impact on the spatial distribution of oceanic oxygen. It is particularly true for the proto-Atlantic basin which isolated from the global ocean and is poorly oxygenated basin during the CT (Laugie et al., 2021). The eight sets of orbital parameters that have been tested here produce changes in the proportion of anoxic waters in the North-Atlantic basin going from 5 to 60% of its total volume. All three parameters describing the Earth's orbit (eccentricity, precession and obliquity) show a substantial control on these fluctuations. We also note that orbital fluctuations result in important changes in continental runoff but the impact remains highly localized to coastal environments, the open ocean mainly responding to the ocean ventilation. Changes in productivity induced by the orbital parameters remain spatially heterogeneous and could be responsible for more local signal within a single basin.



P2-068

Understanding Patterns of Pa/Th in the Atlantic: a Model-Data Comparison

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The Atlantic Meridional Overturning Circulation (AMOC) is a critical constituent of the global climate system and its strength influences the climate of both hemispheres. The ratio of protactinium-231 to thorium-230 (Pa/Th hereafter) is a unique proxy to reconstruct past AMOC strength, yet secondary processes associated with selective particle scavenging are of serious concern for its applicability. There are still open questions which regions and depths sensitively record AMOC changes in Pa/Th, and in which regions the signal may be significantly biased by particle fluxes or nepheloid layers directly – or indirectly, via biases in upstream Pa/Th.

We use the Bern3D Earth system model to simulate Pa/Th in a consistent physical and biogeochemical framework with reversible scavenging of Pa and Th in the water column by different particle types: biogenic opal, CaCO₃, particulate organic matter and mineral dust. Further, the representation of bottom scavenging by benthic nepheloid layers is improved using recent global observations. In this context, we iteratively tuned the different scavenging affinities by using the latest seawater observations. We also compare our simulations with sedimentary Pa/Th from a refined late-Holocene database. Additional model experiments were performed to distinguish the circulation signal in Pa/Th from particle biases and to further disentangle biases by particle type. This disentanglement is essential for the interpretation of sedimentary Pa/Th in the past, when both particle fluxes and ocean circulation changed simultaneously, for instance during the last deglaciation. We assess extent and potential reasons for model-data discrepancies, while we yet conclude that our model results show a clear southward Pa export in the Atlantic, as also seen in former modeling approaches.



P2-052

Southern Ocean mechanisms of CO₂ draw down and release on glacial-interglacial timescales

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Vertical and lateral exchanges of heat and carbon make Southern Ocean circulation a key regulator of global climate, yet its role in future climate change remains uncertain. To address this knowledge gap, paleoceanographers study the state of the Southern Ocean under past climate states to better understand the processes governing its role in global climate. For instance, the Southern Ocean is widely thought to play a driving role in the atmospheric CO₂ fluctuations of the ice ages, ventilating carbon-rich deep waters to the atmosphere during interglacial periods and limiting this deep-surface exchange during glacial periods. However, direct evidence of these dynamics and of the Southern Ocean's overall role in glacial CO₂ draw down remains limited.

Here we present a suite of geochemical data that provides new insights into Southern Ocean circulation and carbon cycling, evincing deep-ocean carbon storage as a mechanism of atmospheric CO₂ draw down over the last glacial cycle. Trace element and stable isotope ($\delta^{13}\text{C}$, $\delta^{18}\text{O}$, $\delta^{11}\text{B}$) compositions of foraminiferal calcite from the high-latitude Indian Ocean demonstrate how carbon was sequestered in the deep ocean during glacial intensification and subsequently released to surface waters during deglaciation. These dynamics are captured by geochemical records reflecting temperature, pH, and circulation changes in the Southern Ocean over the last glacial cycle, providing key insights into the processes responsible for this carbon cycling. This observational data provides the foundation for developing a better mechanistic understanding of the Southern Ocean's role in past and future climate change, including processes such as advection and mixing, ocean-ice interactions, and productivity dynamics.



P2-079

Constraining ventilation and non-ventilation contributions to global mean ocean-atmosphere radiocarbon offsets across the last deglaciation: implications for atmospheric CO₂ and ¹⁴C budget closure

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Radiocarbon serves as a tracer that provides unique insights into the ocean's ability to sequester CO₂ from the atmosphere. By applying a Bayesian interpolation method to compiled ocean-atmosphere radiocarbon age offsets (B-Atm), we provide global data fields and mean ocean B-Atm estimates for a suite of time-slices across the last deglaciation. These reveal a stepwise and spatially heterogeneous 'rejuvenation' of the deep ocean, and confirm that carbon was incrementally released to the atmosphere through two 'swings' of a ventilation seesaw, operating between the North Atlantic and Southern Ocean/North Pacific. A suite of numerical model sensitivity tests further demonstrate that the reconstructed changes could account for two thirds of deglacial atmospheric CO₂ rise, depending on the mix of processes driving marine and atmospheric radiocarbon change. Our model sensitivity tests also serve to constrain non-ventilation biases that could affect deglacial B-Atm offsets, under the (extreme) hypothesis of a completely passive ocean response to atmospheric radiocarbon variability driven by radiocarbon production or other non-marine processes. By placing quantitative constraints on the closure of the global radiocarbon budget, our findings help to constrain the contribution of ocean ventilation to observed B-atm changes, and to atmospheric CO₂ change, and further suggest that glacial radiocarbon production levels are likely underestimated on average by existing reconstructions.



P2-093

Pleistocene variations in Antarctic Intermediate Water

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The Antarctic Intermediate Water (AAIW) forms an integral part of the global thermohaline circulation as it redistributes heat, salt, CO₂ and nutrients from the Southern Ocean to the nutrient deprived tropics. Although there is clear evidence that the transport and composition of the AAIW played a key role in the climate change of the last deglaciation, there are only a few longer records of the AAIW variability. Our goal is to produce records of the variations in AAIW water mass sourcing, nutrient content and temperature in the south Pacific and Atlantic basins spanning the last 1.2 million years. Our study is based on two intermediate water depth cores from the open ocean, far from continental sediment input to avoid sedimentary overprinting. In the South Atlantic, DSDP Site 516 on the Rio Grande rise at 1300m water depth is located in the modern-day core of the AAIW and in the South Pacific, IODP Site U1510 at 1238m water depth in the central Tasman sea is currently bathed by a mixture of Southern Ocean and Tasman AAIW. At both sites high resolution core scanning data have been used to generate a spliced record and the age model is established based on benthic foraminiferal oxygen isotopes. To constrain the AAIW composition, trace metal proxies for temperature (Mg/Ca) and nutrient content (Cd/Ca) as well as the stable carbon isotope composition of benthic foraminifera have been measured. To reconstruct the routing of AAIW during the Pleistocene we employ the neodymium (Nd) isotope composition of the authigenic coatings of mixed planktonic foraminifers supplemented with rare earth element data and the Nd isotope signatures for selected detrital silicate samples. These data allow the assessment of whether the authigenic Nd isotopes truly reflect a water mass signal or the extent of sedimentary overprinting. Finally, these data will illuminate the role of AAIW variability in glacial/interglacial climate change for key periods across the mid Pleistocene transition.



P2-115

Deep-Water Circulation in the Gulf of Mexico During the Eocene-Oligocene Transition

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The Eocene-Oligocene Transition (EOT) encompasses a series of potentially interconnected climatic, biotic, and paleoceanographic events within a longer-term Cenozoic greenhouse to icehouse climate transition. Changes in ocean circulation within the Gulf of Mexico and the evolution of western North Atlantic deep-water flow are posited to be associated with these global events, which include 1) the development of a late Eocene stable, proto-North Atlantic Deep Water (NADW) and subsequent initiation of Atlantic overturning circulation at the EOT; 2) the first major Antarctic glaciation, likely due to a significant drawdown of atmospheric CO₂; 3) a widespread extinction of benthic and planktic biota; and 4) a more complex ocean interior with increased stratification of Oligocene foraminifera relative to the Eocene. Modern Gulf of Mexico deep-water is connected to Atlantic Meridional Overturning Circulation via the Caribbean as NADW spills over the Yucatan Sill, filling the GOM with oxygen-rich deep-water. Although modern Gulf of Mexico circulation is well-studied, it is unclear how it may have recorded and possibly contributed to late Eocene development of Atlantic overturning circulation. Deep Sea Drilling Project Sites 95 and 540 are located at the mouth of the Yucatán Channel north of potential sediment drifts identified in seismic data. These sites are ideal locales for characterizing deep-water exchange between the Gulf of Mexico, Caribbean Sea, and western Atlantic. Here, we present preliminary benthic foraminiferal stable isotope data, X-ray fluorescence, and grain size analyses from Sites 95 and 540. Site 540 preliminary data indicate probable increases in deep-water current intensity in the EOT. In contrast, significant coring gaps at Site 95 limit our ability to identify any long-term trends across multiple cores analyzed. Stable isotope analysis will indicate the source of deep-water bathing the southern Gulf of Mexico in the Eocene and Oligocene.



P2-016

Correction of the IRD influence in paleo-current flow speed reconstructions in hemipelagic sediments

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Grain-size analysis of hemipelagic sediments is a useful tool to study past geostrophic current variations. The mean size of the sortable silt fraction (10-63 μm , SS) is one of the most commonly used tracer of past bottom current strength. However, this proxy may be biased in polar and subpolar environments where sediments are generally composed of a mixture between fine-grained sediments sorted by bottom currents and coarser grains transported by iceberg rafting. The influence of these ice rafted debris (IRD) in the sortable silt fraction is still under debate. Corrections previously proposed to produce a bottom current strength proxy free of any IRD influence are also debated.

In order to assess the influence of IRD on the sortable silt fraction, we have selected grain-size records from three sedimentary cores taken in environments under the influence of bottom currents. Two of them were retrieved in the subpolar North Atlantic along the eastern flank of Reykjanes Ridge and the third one in Pridz Bay on the Antarctic margin. In each core, we compare SS records to the grain-size induced elemental log-ratio Zirconium (Zr) to Rubidium (Rb), considered to be free of IRD influences. All three SS records demonstrate that silt-sized IRDs may influence the mean size and the percentage of the non-cohesive silt fraction. Therefore, we propose a user-friendly new method to correct grain size results for IRD influences using parametric End-Member Analysis. This method gives a unique opportunity to trace bottom-current strength free of IRD influences and it allows to calculate classical parameters on IRD-free grain-size distributions. Finally, we compare our method with the most used method of IRD correction (Jonkers et al., *Paleoceanography*, 2015) and discuss advantages and limitations of both methods.



P2-017

Deep North Atlantic dynamics from interglacial to glacial conditions: the glacial inception of Marine Isotope Stage 9 to 8

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Climate simulations predict a reduction of the Atlantic Meridional Overturning Circulation (AMOC) during the 21st century, but mechanisms controlling AMOC changes remain poorly understood, in particular by the lack of available observations. The Iceland-Scotland Overflow Water (ISOW), one of the two deepest branches of the AMOC, forms in the Nordic seas, flows southward of Iceland along the eastern flank of Reykjanes ridge and contributes to the North Atlantic Deep Water. Most of the reconstructions of its past activity are based on the carbon isotopic composition of benthic foraminifera that document water-mass ventilation changes. Changes in its intensity are, by contrast, very limited and mainly focused on the Holocene and the last glacial period.

The aim of this work is to evaluate the orbital and millennial-scale variability of ISOW intensity over a full glacial inception. We explore the ISOW dynamics during the progressive transition between the end of the interglacial MIS 9e climatic optimum and the establishment of pure glacial conditions during MIS 8, i.e. during a period poorly documented in the literature. To provide a robust interpretation of past ISOW intensity variations, we have selected two sedimentary cores (MD03-2679 and MD03-2673) bathed by ISOW from the eastern flank of the Reykjanes ridge, at different depths (1800 and 2800 m) on Björn and Gardar drifts, respectively. Cores are located downstream the Iceland-Scotland basaltic province considered as the dominant northern detrital source, at different distances (61°N & 56°N). To reconstruct past flow intensity, we have used a multi-proxy approach based on elemental, magnetic and grain-size properties. We will synthesize results obtained for both cores and discuss them in terms of variability of ISOW strength over the MIS 9-8 transition.



P2-071

Tropical ocean warming dictated by Antarctic pacing during the last deglaciation

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Antarctic Intermediate Water (AAIW) latitudinally exchanges dissolved carbon, nutrients, and heat in the ocean. Yet, uncertainty surrounding circulation patterns and the timing of low latitude warming during the last deglaciation mean that AAIW controls on sub-surface temperature rise remain unclear. Here we present seawater temperature records (Li/Mg) on a precise common age-scale from deep-sea corals from East Equatorial Pacific (EEP), Equatorial Atlantic, and Southern Ocean intermediate waters. We find a coeval two-stage warming in the EEP and Atlantic, during Heinrich Stadial 1 ($> +6$ °C) and the Younger Dryas ($+3$ °C) that closely resembled deglacial Antarctic temperature rise and was associated with warming of Southern Ocean ($+3$ °C). The synchronicity and magnitude of warming recorded at all three geographically separated locations suggests that heat advection via AAIW played a dominant role in this low latitude deglacial warming.



P2-121

A record of the K-Pg extinction aftermath: The Danish Cerithium Limestone

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The K–Pg mass extinction occurred 66 Ma ago and was the second largest extinction event in the history of life. The effect of this mass extinction on the evolution of many groups, as well as its effect on carbonate deposition in its direct aftermath, is still not well understood. We revisited here the famous Stevns Klint section (Denmark), where Alvarez et al. (1980) found the Iridium anomaly in the so-called “Fiskeler Member.” Stevns Klint is a 14.5 km long coastal cliff roughly N-S oriented in eastern Denmark. The Cerithium Limestone Member is a pale yellow partly cemented unit from early Danian age, overlaying directly the Fiskeler Member. A dense network of *Thalassinoides*-burrows is characteristic for this layer. It is described mainly as a mudstone and different publications state that it is either fossil-poor or fossil-rich. The depositional environment ranges from mid-neritic to a deeper milieu. We present here the first thin sections from the Cerithium Limestone Member in Stevns Klint. This member consists of three different microfacies with a varying abundance of fossils: A fossil-poor mudstone, a peloid wackestone and a fossil-rich packstone. SEM analyses show that microfacies in the matrix are different. The mudstone matrix shows small rounded, equant, not fused calcite crystals. The peloid wackestone matrix is composed of bigger crystals with both subhedral and anhedral faces. In addition to *Thalassinoides*-burrows filled by a bioclast rich packstone, we could find other types of burrows, some of them filled by the fossil poor mudstone. The deposition of the different microfacies could be explained by changes in water currents. Strong bottom currents transported bioclasts and larger grains, whereas weaker currents only transported the fine micrite. We conclude that the different descriptions of the Cerithium Limestone in the past were due to variations in sampling locality and lack the high resolution microfacies analyses carried out in our study.



P2-113

Towards the modern ocean – the modification of the deep ocean circulation in the South Pacific during the Neogene

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The Miocene and Pliocene represent the final steps in the global long-term cooling from the Early Cretaceous greenhouse to the modern icehouse climate. Presumably, the world began to reach modern conditions during this time, including the development of the present ocean circulation mode with the onset of North Atlantic Deep Water (NADW) formation between ~20 and 6 Ma. In the Pacific, evidence exists for a period of active North Pacific Deep Water (NPDW) formation around 7.4 to 4 Ma, as also reflected by radiogenic ϵ_{Nd} in the western Pacific. Yet, the exact timing and flow development of NADW and NPDW are still debated. The South Pacific should be sensitive to changes in the relative influence of NADW and NPDW due to their distinct ϵ_{Nd} signatures.

To shed light on the evolution of the deep ocean circulation in the South Pacific during the late Miocene to mid Pliocene, we investigate ϵ_{Nd} in authigenic sediment phases of IODP 383 cores 1540 and 1541 from 3577 and 3603 m water depth, respectively. Samples cover the time period from ~7.9 to 2.9 Ma. First results show a shift in ϵ_{Nd} from -4.8 ± 0.6 towards -6.6 ± 0.1 from ~7.9 to 6.3 Ma, indicating an increase in the relative proportion of NADW in the South Pacific due to either a strengthening of NADW input and/or weakening of NPDW input. The timing agrees well with benthic foraminiferal $\delta^{13}C$ records from the South Atlantic that suggest a gradual enhancement of NADW starting at ~6.6 Ma. Between 6.3 and 2.9 Ma, ϵ_{Nd} values of -6.6 ± 0.2 were still more radiogenic than present (~-7.5), which may indicate an increased influence of NPDW at this time. Increased temporal resolution of our ϵ_{Nd} records will help to further reveal if climatic changes like the late Miocene cooling (~7.2 to 5.3 Ma) and the mid Pliocene warm period (~3.2-3.0 Ma) are reflected in the Pacific deep water circulation. This will contribute to the understanding of the global ocean circulation under generally warmer than present climate conditions.



P2-031

Characteristics of Cape Darnley Bottom Water transport minerals based on grain size and mineral composition of Wild Canyon surface sediments, East Antarctica

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Antarctic Bottom Water (AABW) is a huge amount of heat and possibly CO₂ reservoir and is closely related to global climate change. Recent observations have shown that Cape Darnley has a remarkably high CO₂ absorption rate in the southwestern Indian Ocean region. It is essential to clarify the relationship between the Cape Darnley Bottom Water (CDBW) and climate change. The mineralogical composition of the Mac. Robertson shelf (inc. Prydz Bay) is significantly different from the East Antarctic continental slope, which is dominated by hornblende. Therefore, CDBW advection is possibly determined by the characteristic mineral composition. In this study, we used the Wild Canyon sediments directly advected by CDBW to examine the CDBW inflow characteristics based on grain size and mineral composition. The Wild Canyon sediments (channel: MC01, MC02, levee: WIC-6PC, CAD-4PC) were collected by R/V Hakuho-maru KH-20-1 cruise, and compared with the Mac. Robertson shelf sediments by the 61st Japanese Antarctic Research Expedition. The deep-sea camera attached to the multiple corer observed a sandy wave ripple in the downstream region (MC02), affected by bottom currents considered CDBW. Heavy minerals were dominated by garnet and sillimanite at all sites, but clay mineral composition of the Wild canyon was similar to that of the East Antarctic continental slope. These results suggest that the transported materials by CDBW from Mac. Robertson shelf to the Wild Canyon is characterized by garnet and sillimanite. The grain size distribution of the sediments affected by CDBW showed unimodal with silt or sand mode, suggesting that clay minerals from Mac. Robertson shelf were transported to more distal areas. In this study, the grain size and mineralogical characteristics of Wild Canyon sediments were newly clarified, suggesting the possibility of distinguishing between currents with different contributing sources (Antarctic Slope Current, CDBW) based on their mineral compositions.



P2-048

Mediterranean Overflow Water temperature and salinity trends over the last 50 ka

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IODP Site U1389 is located in Gulf of Cádiz on the main branch of Mediterranean Overflow Water (MOW). Its high sedimentation rate provides continuous and high-resolution records of Pleistocene-Holocene Mediterranean dynamics through the high influence of MOW, which is a mixture of the Mediterranean Outflow and the East North Atlantic Central Water. Here we used $\delta^{18}\text{O}$ and Mg/Ca data from the benthic foraminifers *Cibicides pachyderma* and *Uvigerina mediterranea* to reconstruct MOW temperature and isolate the original seawater $\delta^{18}\text{O}$ signal of MOW from calcite $\delta^{18}\text{O}$. These results were compared with proxies of MOW strength to evaluate its impact on the temperature and seawater $\delta^{18}\text{O}$ of the MOW. The Sea Bottom Temperature (SBT) record displays a progressive warming trend during the last glacial maximum following a minimum reached at 30 ka BP, instead of expected near glacial maximum. This is the same trend as observed in Greenland temperature inferred from ice cores $\delta^{18}\text{O}$ record. This synchronism between Mediterranean deep water and Greenland air temperatures can be explained by the atmospheric teleconnection between both regions. Cool air temperatures in Greenland are transferred through winter winds that caused surface water cooling and sinking to the deep Mediterranean. The temperature-corrected $\delta^{18}\text{O}_c$ record follows the global sea level trend, but once corrected for the ice-volume effect the influence of precession becomes evident, which clearly reflects precession-driven salinity and ventilation changes in the Mediterranean, even considering the low amplitude of precession variability during studied period. SBT- $\delta^{18}\text{O}_w$ and MOW strength proxies show no significant correlation, therefore we suggest that U1389 data is mainly reflecting changes in Mediterranean outflow properties instead of changes in the mixing ratio between the Mediterranean outflow and the ENACW. This makes this site very valuable to investigate past physico-chemical changes in the Mediterranean Sea.



P2-014

Multi-proxy records of Holocene Atlantic overturning and its components

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Climate models project a ~11-34% weakening of the Atlantic Meridional Overturning Circulation (AMOC), a key component of the global climate system, through the 21st century. Model simulations suggest that melting ice-sheets caused a similar magnitude AMOC weakening during the early stages of the current interglacial epoch (the Holocene; 0-11.7 thousand years before present (ka)). Records of past changes in the AMOC can be used to test the ability of models to accurately simulate AMOC changes. Here we develop 53 new paleoclimate records from 34 sites, combined with published datasets (totalling 82 records), to produce a coherent, multi-proxy based synthesis of the strength of the AMOC and its individual components throughout the Holocene. The synthesis reveals that despite enhanced meltwater flux, the AMOC was ~10% stronger than average during the early Holocene (9-11 ka), due to strong Denmark Straits Overflow Water (DSOW) and Labrador Sea Water (LSW). On millennial timescales, Holocene changes in DSOW and LSW strength appear controlled to a greater extent by atmospheric forcing. In contrast, Iceland-Scotland Overflow Water (ISOW) strength appears tightly coupled to freshwater fluxes. Increased Arctic sea-ice and freshwater fluxes to the Nordic Seas during the late Holocene have culminated in exceptionally weak ISOW during the industrial-era. In combination with a centennial-scale weakening of LSW, this has caused AMOC strength during the industrial-era to be at a Holocene minimum, 10% weaker-than-average. Overall, our study highlights the varying controls and responses of individual AMOC components to different climate forcing and the need to correctly model these behaviours to accurately simulate past and future AMOC changes.



P2-009

Reduction in ENSO variability during the mid-Holocene: a multi-model perspective

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Paleoclimatic reconstructions have suggested a reduction in ENSO variability during the mid-Holocene. Model simulations have largely failed to capture this reduction, potentially due to the inadequate representation of the Green Sahara. The presence of a vegetated Sahara has been shown to have significant impacts on both regional and remote climate, but remains inadequately addressed in Paleoclimate Modelling Intercomparison Project / Coupled Model Intercomparison Project (PMIP/CMIP) boundary conditions. Specifically, the incorporation of a Green Sahara has been shown to impact ENSO variability through modulation of the Atlantic Niño and the Walker Circulation.

In this study, we evaluate the mid-Holocene (6,000 years BP) ENSO signatures of simulations from four models, namely -- EC-Earth, iCESM, CCSM4-Toronto and GISS Model E2.1-G. Two scenarios are considered for each model -- a standard PMIP scenario simulated with the mid-Holocene orbital parameters and greenhouse gas concentrations with vegetation prescribed to pre-industrial conditions, as well as a Green Sahara scenario which additionally considers factors such as enhanced vegetation, reduced dust, presence of lakes, and land and soil feedbacks. All models show a reduction in ENSO variability due to the incorporation of Green Sahara conditions. This variability is interpreted in the context of perturbations to the Walker Circulation, triggered by the strengthening of the West African Monsoon.



P2-049

Water export changes through the Strait of Sicily during the last deglacial period

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The Mediterranean Sea is constituted by two sub-basins connected through the Sicily channel. In the western basin deep water is formed at Gulf of Lions and in the eastern basin deep water convection occurs in both the Adriatic and Aegean Sea, while intermediate water is formed in the Levantine Sea area. The intermediate and deep water convection of the Eastern Mediterranean has been proved to be highly sensitive to varying fresh water fluxes, associated with increased rainfall during the African Humid period (15-6 kyr BP). Here we investigate for the first time, changes in the export rates of eastern Mediterranean sourced water masses (EMSW) into the western basin for the last ~15 kyr BP. For this purpose, we analyze $^{143}\text{Nd}/^{144}\text{Nd}$ isotope ratios (e_{Nd}) in planktic foraminifera coatings, a quantitative tracer of water mass provenance, from a sediment core recovered at the western flank of the Sicily channel (NDT-6-2016, 1066 m depth). At present, this site is located below the hydrographic boundary layer between the eastern and western sourced water-masses. The measured e_{Nd} values were then used to elucidate changes in EMSW export rates through late deglacial and Holocene periods applying an endmember mixing model. Our results indicate that EMSW export rates were maximum during the Younger Dryas (YD) period, about three times higher than during the S1, supporting the limited formation of both intermediate and deep water masses in the eastern basin during the S1 as suggested by previous studies. We propose that the enhanced EMSW outflow into the western Mediterranean over the YD was the result of the combined effect of 1) enhanced climate-driven convection in the Aegean Sea and 2) the reduced convection of western deep water during this period, when the last Organic Rich Layer deposited in the deepest areas of the western basin.



P2-053

The role of the subantarctic zone in regulating carbon escape from the northern lip of the Southern Ocean during the last deglaciation

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The Southern Ocean is thought to play an outsized role in regulating atmospheric CO₂ and Earth's climate on millennial and centennial timescales. An abundance of evidence suggests that the mid-depth and deep ocean stored CO₂ during the Last Glacial Maximum (LGM), releasing it to the atmosphere during deglaciation. However, evidence is lacking for the mechanism and the pathway for release of stored oceanic carbon to the atmosphere. The Indian Ocean sector of the Southern Ocean has an abundance of bathymetric features that enhance eddy mixing and air sea exchange within the Antarctic Circumpolar Current making it critical to the examination of glacial scale changes in deep ocean ventilation. Here, we utilize benthic (mixed) and planktic (*Globorotalia inflata*) foraminifera ¹⁴C/¹²C ratios ($\Delta^{14}\text{C}$) from a Southern Indian Ocean core (TT1811-50GGC), to trace the pathway and escape route of sequestered carbon through the thermocline in the southern Indian Ocean. We use the placement of our core at the northern margin of the Southern Ocean today (38.344°S, 77.715°E, 1,116 m) where Antarctic Intermediate Waters (AAIW) sit in the subsurface, in conjunction with nearby published records, to monitor the effect of changing latitudinal extent of the Southern Ocean and its frontal zones on carbon sequestration and ventilation. Our results indicate that surface and AAIW reservoir ages increased to maximum values during the LGM (~22-18 ka) and rapidly diminished during Heinrich Stadial 1 (~18-16 ka), suggesting that an expanded subpolar region trapped CO₂ in the glacial Southern Ocean while deglacial expansion of the subtropical Southern Ocean then permitted ventilation of the trapped CO₂. Our results implicate Southern Ocean frontal positions as a key factor balancing CO₂ outgassing and sequestration in a region currently responsible for absorbing nearly half of anthropogenic CO₂ emissions absorbed by the global oceans.



P2-055

Millennial scale surface and deep water changes in the Benguela upwelling system during the last 45 ky

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The intensity and extension of the Benguela upwelling, along the southwestern coast of Africa, have been shown to vary on a millennial time scale during the last deglaciation. The changes in sea surface temperature in this region have been associated either with changes in the position of the ocean fronts in the SE Atlantic Ocean, themselves related to cold episodes in the North Atlantic, or to variations in the intensity of the upwelling, related to the intensity of the dominant winds.

Marine sediment cores from the Namibian margin, a region characterized by the upwelling of waters from 150-500 m depth, contain climate records showing these surface water variations. In particular, core MD08-3167, retrieved at 23°S and 1950 m of water depth on the Namibian margin during the 2008 RETRO cruise, has been shown to present high-resolution time series covering the last 40 ky. Stable isotopes ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) and Mg/Ca have been measured in the planktonic foraminifer *Globigerina bulloides*, which may be assumed to thrive in upwelled waters. The records show a very marked, rapid warming of more than 4°C at the start of the last deglaciation, coinciding with the beginning of Heinrich Stadial (HS) 1 in the North Atlantic. However, the previous three HS show a different pattern, with subdued variability and evidences of cooling and freshening during some of them. Planktic foraminiferal counts and $\delta^{18}\text{O}$ measured in the deeper-dwelling foraminifera *Globorotalia inflata* rather suggest enhanced upwelling driving augmented productivity between 28 – 19 ky BP, that may have been driven by enhanced trade winds and obscured glacial millennial scale variability.



P2-086

Hydrological variability in the Agulhas current across Terminations I and II as inferred from geochemical multi-foraminiferal species study in the Mozambique Channel

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The Mozambique Channel is an important region for ocean circulation. It is the source of the Agulhas Current contributing to the Agulhas leakage, which acts as a climate modulator by transferring warm, salty water eddies to the Atlantic and thus contributes to the efficiency of the thermohaline circulation. The Agulhas current has not always been constant over time. This work investigates the hydrological variability (spatial and temporal) at different depths in the water column of the Mozambique Channel during Terminations I and II. A multi-proxy approach (O and C stable isotopes, Mg/Ca paleothermometer, foraminiferal U/Ca, and planktic foraminiferal assemblages) was applied to two cores in order to reconstruct a latitudinal gradient and characterise the water column structure from the surface to the ocean floor. Several foraminiferal (planktic and benthic) species were selected according to calcification depths: *G. ruber s.s.*, *N. dutertrei* for surface and subsurface waters and *C. wuellerstorfi* for deep waters. The main results obtained for hydrological conditions indicate a decoupling between surface and subsurface waters, which suggests an earlier warming associated with an increase in salinity during both Terminations. The bottom water, on the other hand, shows, a decrease in ventilation synchronous with the slowing down of the thermohaline circulation at the beginning of deglaciation. These results will be discussed in the light of the latitudinal migration of the subtropical front during the last deglaciations and the related intensity/effectiveness of the “Agulhas leakage”.



P2-061

Atlantic circulation changes across a stadial-interstadial transition: a model – data study

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During the last glacial period, surface temperatures in the North Atlantic region and above Greenland shifted between cold (stadial) and warm (interstadial) phases. These rapid changes in surface climatic conditions were accompanied by rapid changes in ocean circulation characterized by reduced Atlantic Meridional Overturning Circulation (AMOC) during stadials.

The precise geometry and extent of Atlantic circulation changes are still under debate due to the scarcity and unreliable dating of the available observations.

Here we combine a new dataset of consistently dated *Cibicides* $\delta^{13}\text{C}$ records covering the entire Atlantic Ocean, with numerical simulations performed by a glacial configuration of the Norwegian Earth System Model (NorESM) with the biogeochemistry module HAMMOC, in order to investigate the large ocean circulation changes observed in *Cibicides* $\delta^{13}\text{C}$ records across Heinrich stadial 4 (HS4: 38.2 - 39.8 cal. ky BP).

We show that the marked decrease in $\delta^{13}\text{C}$ -DIC observed in *Cibicides* $\delta^{13}\text{C}$ records during HS4 below 1500 m in the North and South-West Atlantic can be explained by changes in nutrient concentrations as simulated by the model in response to a freshwater discharge to the high latitude North Atlantic, as described in Jansen et al. (2020). We further show that this nutrient signal is associated with changes in the ratio of southern-sourced versus northern-sourced water masses at the core sites.

Reference :

Jansen, E., J. H. Christensen, T. Dokken, K. H. Nisancioglu, B. M. Vinther, E. Capron, C. Guo, M. F. Jansen, P. L. Langen, and R. A. Pedersen (2020), Past perspectives on the present era of abrupt Arctic climate change, *Nature Climate Change*, 10(8), 714-721.



P2-015

Deep-water temperature changes in the northwest Atlantic over the last 1ka

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The oceans are the major sink for the excess heat resulting from global greenhouse gas emissions. Therefore, in order to better understand the ocean's role in mediating anthropogenic warming, high-quality oceanic temperature information is essential. While temperature observations and proxy reconstructions of the surface ocean are relatively plentiful, temperature estimates related to deep ocean water masses are far more limited both spatially and temporally. In particular, there is a distinct lack of temperature data from the deep northwest Atlantic, where water masses formed in the subpolar North Atlantic and Nordic Seas flow southwards as a western boundary current transporting anomalous heat originally from the surface into the deep ocean. A single model inversion of Atlantic subsurface temperature anomalies shows a cooling throughout the whole water column coincident with the Little Ice Age (LIA) followed by warming throughout the Industrial Era. Limited proxy data also exhibit similar behaviour over the last 1ka. To improve our understanding of deep ocean temperatures, this study uses two different benthic foraminiferal temperature proxies to reconstruct past deep ocean temperature changes at three intermediate depth (~2km) sites in the northwest Atlantic over the last 1ka. Multi-species benthic-Mg/Ca records show no long-term downcore trend and are relatively noisy with multi-decadal scale temperature variability in excess of $\pm 1^\circ\text{C}$. In comparison, coeval $\delta^{18}\text{O}_c$ measurements exhibit behaviour consistent with a period of cooling ($\sim 0.75^\circ\text{C}$) and subsequent warming ($\sim 0.5^\circ\text{C}$) coincident with the LIA and Industrial Era respectively. We conclude that (1) benthic-Mg/Ca does not have a signal to noise ratio capable of resolving small temperature changes of less than 1°C , and (2) the deep northwest Atlantic experienced LIA cooling and Industrial Era warming consistent with a model inversion and the available proxy data.



P2-030

Circulation history of the deep Indian sector of the Southern Ocean since MIS 6 as revealed by ϵ_{Nd}

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Southern Ocean deep circulation is thought to play a critical role in climate change on glacial-interglacial timescales in terms of both heat transport and ocean-atmosphere carbon exchange. To date, most studies investigating deep Southern Ocean paleocirculation using Nd isotope measurements (ϵ_{Nd}) have focused on the S Atlantic and SW Pacific sectors. Here, we reconstruct circulation changes within the relatively poorly studied deep (3167 m. and 2844 m.) Indian sector of the Southern Ocean using ϵ_{Nd} of uncleaned foraminifera, between the penultimate glaciation (MIS 6; 140 ka) to the late Holocene.

During glacials MIS 2-4 and MIS 6, ϵ_{Nd} values shifted to more radiogenic (positive) values than during interglacials MIS 1 and MIS 5e, suggesting a reduced presence of North Atlantic-sourced waters (NSW) and a relative increase in Pacific Deep Water (PDW) and Indian Deep Water (IDW). ϵ_{Nd} values reached more radiogenic values during the peak of the penultimate glaciation (-5.5) than during the last glaciation (-6.2), likely reflecting a lower proportion of NSW during MIS 6 than any other time during the last 140 kyr.

Very unradiogenic (negative) ϵ_{Nd} values in the penultimate interglacial, MIS5e, transition quickly to more radiogenic, glacial-like values during MIS5d, suggesting an initial reduction in Atlantic-sourced waters during the very earliest stages of the transition into the last glacial period. We hypothesize NSW within the deep Indian sector of the Southern Ocean was replaced by an expanded contribution of carbon-rich, southern-sourced water during MIS 5d, as observed during MIS 2-4 and MIS 6. These changes may account for a portion of the ~30 ppm decline in atmospheric CO₂ from MIS5e-5d. Our data implicates the high latitude Southern Ocean as a key driver of glacial inception.



P2-063

The evolution of tides and tidal dissipation over the last glacial cycle and late Pleistocene

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Simulations of the tides from the Last Glacial Maximum (26.5 – 19 kyr BP) to the present show large amplitude and dissipation changes, especially in the semi-diurnal band during the deglacial period. New reconstructions of global ice sheet history and sea levels allow us to extend the tidal simulations back to cover most of the last glacial cycle. Climate during this period was far from stable with periods of ice sheet advance and lower sea levels interspaced with ice sheet melting and sea level increases. Here, using the sea level and ice history from Gowan et al. (2021), we present simulations of tidal amplitudes and dissipation from 80 kyr BP to present using the tide model OTIS. Our results show large variations in amplitudes and dissipation over this period for the M2 tidal constituent with several tidal maxima. Due to the lower sea levels and altered bathymetry open ocean dissipation was enhanced with respect to present day levels for most of the glacial cycle. This result is important in the context of historical ocean mixing rates. For the semi-diurnal K1 tide, in contrast, changes are mainly local or regional. We further demonstrate that these tidal changes may be extrapolated back in time for the late Pleistocene suggesting that the energy available for ocean mixing from the tide was greater than at present over most of the last 400 kyrs.



P2-084

Insolation threshold triggered abrupt changes of Atlantic overturning circulation at the end of interglacials

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Paleoclimate records show that the end of interglacials of the late Pleistocene was marked by abrupt cooling events and increased millennial variability. Strong abrupt cooling occurring when climate was still in a warm interglacial condition is puzzling and its cause remains uncertain. In this study, we performed transient climate simulations for all the eleven interglacial (sub)stages of the past 800,000 years with the model LOVECLIM1.3. Our results show that there exists a threshold in the astronomically induced insolation below which abrupt changes at the end of interglacials occur. When the summer insolation in the Northern Hemisphere (NH) high latitudes decreases to a critical value, it triggers a strong, abrupt weakening of the Atlantic meridional overturning circulation (AMOC) followed by high-amplitude variations. The mechanism involves sea ice feedbacks in the Northern Nordic Sea and the Labrador Sea. The abrupt weakening of AMOC in turn lead to strong cooling in the NH and its abrupt oscillations lead to similar abrupt oscillations in the simulated temperature, precipitation and vegetation from low to high latitudes. Our simulated results are supported by observations from marine and terrestrial records. Our study shows that the astronomically-induced slow variation of insolation could trigger abrupt climate changes. The insolation threshold occurred at the end of each interglacial of the past 800,000 years, suggests its fundamental role in terminating the warm climate conditions at the end of interglacials. Our results show that the next insolation threshold will occur in 50,000 years, suggesting an exceptionally long interglacial ahead, which is in line with what has been suggested by early studies.



P2-067

Deglacial paleoceanographic changes in the Northwest Atlantic and climate implications for the Younger Dryas cold period

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There has long been debates regarding the cause and nature of the Younger Dryas (YD) cold period, which likely marked a return to near-glacial conditions in the North Atlantic during the last glacial termination. It was originally hypothesized to be triggered by a flood of freshwater discharged into the subpolar North Atlantic, which disrupted the Atlantic Meridional Overturning Circulation (AMOC), thereby greatly reducing the northward ocean heat transport. However, evidence supporting this hypothesis is equivocal; instead, there has been an emerging view that the YD was an integral part of the termination. Here we present new multi-proxy paleoceanographic records from a marine sediment core in Northwest Atlantic (KNR197-10-44GGC, 43° 21.01' N, 60° 12.48' W, 966 m water depth), which is located southwest of the Gulf of St. Lawrence, downstream of the hypothetic outlet of the eastern freshwater route. We have generated new proxy records of benthic and planktic foraminiferal Mg/Ca- $\delta^{18}\text{O}$, planktic foraminiferal assemblages, IRD abundance and sortable silt grain size data. The high temporal resolution (<centennial) and well-constrained age model enable us to compare the timing of our various proxy records to other regional climate records. We explore hypotheses and mechanisms regarding regional freshwater input and circulation change, the response of the coupled surface-deep slope-water system, and the relation of these regional changes to broader, circum-North Atlantic shifts, providing new insight into the causes and mechanisms of climate change during the YD.

Poster abstracts



Topic 2: Ocean Circulation and Its Variability

virtual posters



PV-211

Similar Atlantic Water Mass sourcing during the Last Glacial Maximum and Heinrich Stadial 1

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The oceans are a vital part of the climate system and played an integral role in modulating Quaternary glacial cycles. For an improved fundamental understanding of this role and of the ocean system it is important to get accurate information about the past sourcing of deep ocean water due to its profound impact on marine carbon storage, heat transport, and ventilation. Yet, to date deep Atlantic water mass sourcing during past glacials is still debated, and interpretations based on different proxies such as carbon and neodymium isotopes appear to be at odds.

Here, we present evidence for the existence of a Glacial North Atlantic Deep Water in the subpolar North Atlantic. We then estimate Atlantic water mass sourcing by integrating data compilations of five different proxies (stable isotopes of carbon and oxygen, neodymium isotopes, carbonate ion concentration, and radiocarbon ventilation age) from the Last Glacial Maximum and Heinrich Stadial 1 with the help of a Bayesian mixing model.

We show that a moderate expansion of southern sourced waters in combination with widespread northern sourced deep water best explain proxy observations. Changes between LGM and HS1 were dominated by changes in water mass characteristics, rather than distribution, implying that relative deep water formation intensity may not have changed drastically. These analyses offer new detailed insights into glacial deep Atlantic water mass sourcing and reconcile findings from studies using individual proxies.



Pv-205

Deglacial-Holocene Pulses of Old Carbon-Enriched Mediterranean Water Masses: Implications for Aragonite Mounds Growth and Global Carbon Cycle

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Major changes in the Mediterranean Thermohaline Circulation (MedTHC) related to deglaciation and monsoon dynamics have been documented, while in turn, Mediterranean waters have been proposed to play a role back in global climate variability, ocean circulation and carbon cycle budgets, for instance via changes in water mass residence times. The ¹⁴C offset between coeval planktonic and benthic foraminifera over time is a very useful tool to infer variations in the water column ventilation (with no biological interference) that becomes more accurate when combined with local paired ¹⁴C-U/Th analyses in cold-water corals (CWC). Here, we present a multi-proxy-archive study (i.e., estimates of reservoir ages, ϵ Nd, [CO₃²⁻], O₂ and current speed) carried out on the on-mound sediment core MD13-3452 (305 m, West Melilla, Alboran Sea, Western Mediterranean), which investigates potential deglacial changes and triggers in deep reservoir ages, as well as possible impacts on CWC aragonite mound growth and on global carbon cycle.

Our combined foraminifera-CWC radioactive isotopes results show: 1) the arrival of two pulses of aged waters at intermediate depth corresponding to the Younger Dryas (YD) and to the end of the last sapropel (S1), when low CWC mound growth rates dominated, and 2) a very well-ventilated water mass between those two events, parallel to a CWC mound flourishing stage. In combination with the other proxies, poorer ventilated water pulses seem to have had a different origin, but common higher content in respired carbon. Our results allow, for the first time, changes in ventilation rates to be shown, quantified, and timed in association with a periodical MedTHC weakening, as well as suggesting significant aragonite dissolution as a cause of decreased mound growth rate when higher CO₂ episodes. Our findings may have implications for past hydrographic interconnexions between Mediterranean basins and for global marine carbon storage and alkalinity budget in particular.



Pv-207

Paleoceanography of the NW Greenland Sea and Return Atlantic Current evolution over 35-4 kyr

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There is still relatively limited knowledge on the inflow of Atlantic Water (AW) via the Return Atlantic Current (RAC) into the NW Greenland Sea and its impact on the regional environment, especially the east Greenland Ice Sheet (GIS) during the Late Weichselian and Holocene. We have reconstructed the inflow of AW and the associated environmental changes in the NW Greenland Sea from sediment core GR02-GC retrieved from a plateau on the NE Greenland continental slope (1170 m water depth). Our results suggest an almost continuous presence of AW in the NW Greenland Sea during the last 35 kyr BP. Two distinct meltwater events associated with melting and retreat of the adjacent GIS likely induced by the warm AW were observed around 34.5 and 33 kyr BP. The GIS advanced between 32 and 29 kyr BP, and meltwater input to the NW Greenland Sea was reduced. After 29 kyr BP, increased iceberg calving and melting augmented the sediment input, most likely due to surface warming and advance of GIS to the shelf-break, which lasted until 26 kyr BP. The Last Glacial Maximum was sea ice-free, productive with the influx of warm AW. Unstable oceanographic conditions prevailed during the Bølling–Allerød (B/A) interstadials may be caused by the melting of glaciers and sea ice, a combined effect of atmospheric warming, and AW-induced melting. We propose that a permanent major inflow of warm AW via RAC from western Fram Strait to NW Greenland Sea began at ~ 13 kyr BP. However, during the Younger Dryas, the advection of AW to the NW Greenland Sea was reduced due to the weakening of the RAC. After 11.7 kyr BP, the RAC reached its modern strength, whereas, during the Holocene Thermal Maximum, it reached its maximum strength of the studied period.

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Pv-208

Glacial weathering and erosion inputs into the Labrador Sea during the last 18 kyrs.

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During the Last Glacial Maximum the Labrador Sea was surrounded by several extensive ice sheets. Their demise led to repeated meltwater and ice rafted debris discharges, and reworked sediment inputs into the Labrador basin, the effect of which on the Atlantic Meridional Overturning Circulation is still debated. In this regard, the Labrador Sea is a critical location to study the interaction of ice sheet dynamics and ocean circulation, particularly with respect to intervals of Labrador Sea Water production and to the glacial replacement of North Atlantic Deep Water by its shallower glacial analog, the Glacial North Atlantic Intermediate Water. To differentiate between changes in deep water production and water mass circulation patterns we measured the radiogenic Nd (ϵ_{Nd}) and Pb isotope signatures of bulk sediment leachates and the residual detrital silicates from sediment cores from four locations; Lancaster Sound, Nares Strait, Hudson Strait and off the coast of Nova Scotia spanning the last 18 kyrs. These data are compared with radiogenic Nd, Hf and Pb isotope compositions of detrital clays in order to infer changes in the provenance of the sediments supplied to the Labrador basin. The bulk sediment leachates from Lancaster Sound and Nares Strait have overall more radiogenic ϵ_{Nd} and Pb isotope signatures than the residual detrital silicates. In contrast, the bulk sediment leachates of Hudson strait sediments show less radiogenic ϵ_{Nd} values than the residual detrital silicates. This suggests that the authigenic signal has either been altered after deposition or controlled by preferential release of Nd into the water column from a more reactive sediment fraction. Comparison of the radiogenic Nd, Hf and Pb isotope compositions of detrital clay fraction with the residual detrital silicates will help us identify and distinguish between changes in signals of water mass circulation patterns from alterations in source provenance and erosional inputs.



Pv-202

Ocean-temperature reconstruction and marine reservoir effect calibration from pre-modern corals in the Ross Sea

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Upwelling of Circumpolar Deep Water (CDW) is currently causing sub-ice melting which is driving thinning and a lessening of the ice-shelf buttressing effect. Other than direct observations, there is a paucity of evidence indicating the pre-modern presence or absence of CDW. We will build on deep and cold-water coral studies (e.g. Hall et al., 2010; Stewart et al., 2020) to extract a CDW signal and temperature record from geochemical proxies of pre-modern scleractinian corals that were recovered from the Ross Sea continental shelf. We will generate paired radiocarbon and U-Th ages to investigate whether the corals were bathed in CDW as they grew. The disparity between the U-Th and radiocarbon ages will be used to explore whether the marine reservoir effect is spatially and temporally variable in the different sectors of the Ross Sea. Our ongoing analyses will explore the viability of Li/Mg, Sr/Ca, and Mg/Ca for temperature reconstructions. The dominant species being used in this study is *Paraconotrochus antarcticus*, a scleractinian coral commonly found in the Southern Ocean. Only one species is used to avoid any species-dependent (vital) effects. This species is unusual in that it biomineralizes both aragonite and calcite. Only the aragonitic components will be considered. This study is significant because it provides a way to reconstruct past oceanic conditions with two independent strategies and to place those constraints within a well-resolved temporal and spatial framework.



Pv-203

Reconstruction of bottom current activity north of Svalbard on orbital and millennial-scales during the last 150,000 years.

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The last glacial period was characterised by multiple, rapid climatic fluctuations on millennial-scales, known as Dansgaard-Oeschger (D/O) events. These events are closely linked to the variations in the strength of convection in the Nordic Seas. Here, we present the preliminary results from an investigation of past bottom current activity in relation to climate change and meltwater input on orbital (glacial-interglacial) and millennial (D/O event) scales from a deep-sea sediment core recovered from the northern Svalbard margin in the Fram Strait at 1031 m water depth. The Fram Strait is an important region of exchange of deep and surface water masses between the Nordic Seas and the Arctic Ocean, where Atlantic water is currently transformed from a warm surface current into a colder subsurface intermediate water current. The results are based on the records of sortable silt (10-63 μm), planktonic foraminiferal oxygen and carbon isotopes, ice-rafted debris and AMS ^{14}C dates. The outcome of the study aims to provide further insight into the causes of variations in the strength of bottom currents in relation to past climate change and the possible input of meltwater during the last interglacial-glacial-interglacial cycle.



Pv-210

The western South Atlantic circulation since the Last Glacial Maximum based on iTraCE-21ka simulations

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The South Atlantic western boundary current system is strategically embedded in the general framework of the large-scale ocean circulation. The anticyclonic South Atlantic subtropical gyre (SASG) provides the means by which the upper limb of the Atlantic Meridional Overturning Circulation (AMOC) is advected northward, up to the point where the flow at its northern boundary (represented by the southern South Equatorial Current, sSEC) meets the South American coast and is forced to bifurcate either southward — recirculating in the SASG — or northward, continuing the AMOC upper limb path. This study investigates the spatio-temporal evolution of the sSEC bifurcation and the generated north/south western boundary currents since the Last Glacial Maximum up to the Pre-industrial era, using results from the iTraCE-21ka — an isotope-enabled transient climate simulation. The goal is to use South Atlantic large-scale circulation indexes as fingerprints for low-frequency variations in the AMOC and the SASG circulation, once the bifurcation latitude is expected to shift toward the opposite direction from which the meridional flow intensifies — generally pointing to periods of stronger/weaker overturning and spinned-up/slower subtropical gyre circulation. Improved understanding of the AMOC dynamics is key to interpret recent and future climate change, while past changes in AMOC strength might have called for compensating effects involving the upstream components of its upper limb. For this reason, the western South Atlantic has the potential to express past climate transitions, providing clues on wind-driven circulation changes as well as on AMOC states and connectivity.



Pv-214

The thermal threshold of the Atlantic meridional overturning circulation as a trigger of mode shifts of the AMOC and abrupt climate changes during glacial climate

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Abrupt climate warming events, known as Dansgaard-Oeschger events, occurred frequently during glacial periods, and are thought to be linked to changes in the Atlantic meridional overturning circulation. However, the mechanism responsible is not fully understood. Here, we present numerical simulations with a sea-ice coupled ocean general circulation model that systematically investigate the thermal threshold where deep water formation, and hence the overturning circulation, shift abruptly when the sea surface cools or warms sufficiently. Specifically, in our simulations where the magnitude of the sea surface cooling is changed separately or simultaneously in the Northern and Southern Hemispheres, a prominent threshold is identified when the Southern Hemisphere is slightly warmer than during glacial maxima. Abrupt mode changes of the Atlantic Meridional Overturning Circulation, like those during Dansgaard-Oeschger events, occur past a threshold in a transient simulation where the Southern Hemisphere is gradually warmed. We propose that the Southern Ocean plays a role in controlling the thermal threshold of the Atlantic Meridional Overturning Circulation in a glacial climate and that Southern Ocean warming may have triggered Dansgaard-Oeschger events which occurred with long interval.

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Pv-213

Is past ocean circulation predictable? (no)

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The global ocean can be conceptualized as a geochemical reservoir (hence 'box models') – its principal roles being to provide a buffer to atmospheric $p\text{CO}_2$, to integrate trace-metal and isotope sources and sinks, and as a factory for producing proxies and the accumulating sediments to preserve them in. In such a view, proxy changes are primarily a consequence of biological and/or geochemical changes occurring in the ocean and require an external causative driver (changes in orbits or mantle interactions, big rocks from space, biological evolution). The other half of our brains recognizes the importance of upper-ocean dynamical responses in episodes of rapid surface warming (e.g. present-day), as well as the potential for alternative modes of circulation to occur (e.g. last glacial, future) and the importance of this to the ocean as a geochemical reservoir. How dynamic might the past ocean be, and how much of observed proxy changes could be due to changes in large-scale circulation state rather than geochemical inventory of the ocean *per se*?

Somewhat annoyingly, it seems that while deterministic, past oceans are not predictable (at least in ocean circulation model world) – aka they exhibit chaotic behavior. Rather than fundamental transitions in global ocean circulation (and e.g. oxygenation) requiring equally fundamental changes in boundary conditions (e.g. continental configuration, climate, nutrient inventory), 'tipping points' exist, with trivial changes in tectonic and/or climatic boundary conditions inducing fundamental reorganizations of large-scale circulation patterns and biogeochemical cycling. Furthermore, regimes of stable oscillations in large-scale circulation (ca. 2-20 kyr periodicity) may also exist, where there is no 'mean' (stable) state of the system, obfuscating what ocean proxies are telling us.

We illustrate our deterministic chaotic paleo ocean and its implications, in 'cGENIE-muffin' (what else?).



Pv-204

Last Interglacial paleoceanography at ODP Site 986 on the Svalbard margin, Fram Strait, based on dinoflagellate cysts

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The Last Interglacial which approximates Marine Isotope Substage 5e represents a warm interval preceding the present interglacial. The Last Interglacial has been used as an analogue to understand and predict variability for our present and future interglacial climate. The finer details of this warm episode including its timing of inception and duration remain uncertain, although the role of the North Atlantic Current in transferring heat and salinity to high northern latitudes is critical to its development. Dinoflagellate cysts recovered from Ocean Drilling Program Site 986 on the Svalbard margin of the Fram Strait are being studied to reconstruct ocean conditions through the Last Interglacial. The dinoflagellate cyst record is constrained by a high-temporal-resolution foraminiferal isotope study covering the interval 136–109 ka at Site 986 (Zhuraleva et al., 2017; *Global and Planetary Change*, 157, 232–243), allowing us to characterize the initiation and development of full interglacial conditions and assess paleoceanographic (in)stability through to its culmination. Dinoflagellate assemblages maintain relatively high diversity at high latitudes and their organic-walled cysts are resistant to dissolution unlike calcareous microfossils. They are sensitive to variations in temperature, salinity, nutrient levels, and duration of ice cover, and their cysts therefore provide a sensitive proxy for ocean currents in the high arctic. Last Interglacial dinoflagellate cyst assemblages at Site 986 are characterised by a distinctive association including *Operculodinium centrocarpum* sensu Wall and Dale, *Nematosphaeropsis labyrinthus*, *Bitectatodinium tepikiense*, *Spiniferites elongatus*, and *Spiniferites mirabilis*. This record promises to improve our understanding of ocean current dynamics during the Last Interglacial in a climatically sensitive region.



Pv-212

Modern freshening of Antarctic surface waters outside the range of natural variability during the last 5,000 years

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In recent decades meltwater discharge from the Antarctic Ice Sheets has affected the ocean around Antarctica and altered its salinity, density, and upper-ocean mixing. This in turn influences the volume of Antarctic Bottom Water, the cold salty water mass supplying the lower limb of the global overturning circulation. The instrumental record (1960 to present) shows the largest salinity changes have been observed in the Ross Sea, Antarctica's largest drainage basin. The trend has been primarily a freshening with a very recent rebound in salinity since 2014. However, it is not possible to determine whether modern variations are outside the range of natural variability with the limited instrumental record. Here, we present a 6,000 year $\delta^{18}\text{O}$ diatom record of glacial discharge from marine sediment cores located in the southwestern Ross Sea. Our records show enhanced glacial discharge between 6 and 5 ka, a period when terrestrial records of glacial lowering and marine sediment cores indicate that the Antarctic Ice Sheet underwent a rapid phase of post-LGM retreat in the Ross Embayment, and since 1950 CE. Our study establishes that modern freshening in the Ross Sea is outside the range of natural variability during the last 5,000 years and is consistent with a period of sustained ice sheet contraction.



Pv-201

A Reconstruction of Labrador Current velocities during the Holocene based on Sortable Silt

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The Labrador Sea is a climatically important area where mixing of Arctic and Atlantic water masses occurs, leading to the formation of the Labrador Current, which in turn contributes to the global overturning circulation. The Labrador Current is made up of a shallow, inner branch which runs over the shelf, and a warmer, saltier outer branch which runs along the slope. These two branches have been observed to mix around bathymetric highs. Measurements of Labrador Current velocities date back to the mid-1900s; however, this is insufficient for investigating longer term variability in the Labrador Sea. Sedimentary grain size distributions have been shown to provide estimates of current speed at the time of deposition in the North-Atlantic region and elsewhere.

Here we present estimates of bottom current velocities in the northwestern Labrador Sea during the last 9,000 years, based on grain size distributions determined in a high-resolution sediment core (MSM45-19-2) from the northernmost Labrador Shelf at 202 m depth. Today, this site lies underneath the inner arm of the Labrador Current. The grain-size distributions, specifically the sortable silt mean grain size, imply a substantial increase of the Labrador Current flow between 9 and ca. 7.5ka. A period of variability from ca. 7.5 to ca. 3 ka is followed by an overall gradual decrease in inferred bottom current velocities during the last ca. 3,000 years toward the present. This interpretation is supported by an analysis of grain sorting, which indicates that grain size distributions are reflective of sorting by currents and not by other depositional mechanisms, such as ice rafted debris. These findings will be discussed in the context of other paleoceanographic records from the Labrador Sea and the NW Atlantic. In particular, we will explore how variations in the strength of the inner Labrador Current relate to regional changes in primary productivity and ocean-cryosphere-atmosphere interaction more generally.



Pv-209

Reconstructions of the Antarctic Circumpolar Current over the past million years

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The Antarctic Circumpolar Current (ACC) is the largest oceanic current system on Earth, which thus has strong implications for the air-sea partitioning of CO₂ and thereby modulate the efficiency of the Southern Ocean to act as a carbon sink. Documenting the sensitivity of the ACC to past climate variability could provide useful constraints for better predicting the evolution of climate in the face of anthropogenic forcing. However, past changes in ACC strength remain poorly constrained both temporally and geographically. Here we reconstruct variations in the ACC strength based on terrigenous grain-size, magnetic and geochemical properties in the Indian sector of the Southern Ocean over the past million years. We find that sortable silt mean grain size (SS) and magnetic grain size show consistent patterns with coarser grains during glacial intervals and smaller sizes during interglacials, reflecting coherent glacial-interglacial changes in ACC flow speed, with a stronger abyssal circulation during glacials and weakened current strength during interglacials.

Intriguingly, X-ray fluorescence scanner-derived zirconium and rubidium (Zr/Rb) ratios reveal anti-phased patterns compared to variations of SS and magnetic grains on orbital timescales, which shows higher Zr/Rb ratios during interglacials and not as might have been expected during glacials at our study site. Zr is mainly enriched in heavy minerals, especially in zircon, which exhibits a strong resistance to chemical weathering. Rb is typically enriched in K-feldspar and micas and is much sensitive to chemical alteration and weathering. Rb may have preferentially been released from clay minerals due to intense chemical weathering and lead to high Zr/Rb ratios during interglacials. Variations of Zr/Rb ratio may thus have been primarily controlled by changes in weathering intensity rather than by the ACC. Further study related to the sedimentary clay mineralogy would advance our understanding of upstream process.



Pv-206

Thermohaline evolution of the western equatorial Pacific intermediate water during the last deglaciation

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The Pacific intermediate water is critical for worldwide ocean heat storage and transport. However, little is known about the thermohaline development of intermediate water in the equatorial Pacific Ocean over a long-time scale. In this study, we reconstructed the evolution history of the temperature and salinity variations in the intermediate water over the past 28 kyr using sediment core KX22-4 from the western equatorial Pacific, based on Mg/Ca and $\delta^{18}\text{O}$ of deep dwelling planktonic foraminifera *Globorotalia crassaformis* and *Globorotalia truncatulinoides*. In comparison with the surface and subsurface temperature and salinity variations reconstructed by the surface and upper thermocline species, the results showed that the temperature and salinity of various water layers in the western equatorial Pacific have evolved in different ways during the last deglaciation. The surface and subsurface temperatures present no high-latitude millennium-scale climatic oscillation signals, but the intermediate water temperature rapidly rose by about 6°C during Heinrich event 1, which is compatible with the temperature variation in the high latitudes. Meanwhile, the salinity of the intermediate water in the western equatorial Pacific also clearly increased, consistent with the salinity shift in the high latitude sea areas. We hypothesized that this thermohaline signal in the western equatorial Pacific intermediate water is caused by the subduction of warm and salt waters at high latitudes during the last deglacial period.

Poster abstracts



Topic 3: System Interactions and Thresholds

on site posters



P3-011

Marine eukaryote sedimentary ancient DNA (sedaDNA) reveals diatom transition in Antarctica (IODP Exp. 382)

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Recent advancements in marine sedimentary ancient DNA (*sedaDNA*) techniques now enable detection of eukaryote taxa in deep ocean sediments. To be determined, however, is how far back in time these taxa can be detected. Here, we present the first authenticated (through *sedaDNA* damage analysis) metagenomic marine eukaryote *sedaDNA* from the Scotia Sea region, with samples acquired during IODP Expedition 382 in 2019, and covering the last ~600 thousand years (ka). Our oldest identifiable diatom and chlorophyte *sedaDNA* (using taxonomic marker genes SSU, LSU, psbO) date back to ~411 ka and ~292 ka, respectively. We find evidence of warm phases being associated with high relative diatom abundance, and a marked transition from diatoms comprising <10% of all eukaryotes prior to ~14.49 ka, to ~50% after this time, i.e., following Meltwater Pulse 1A. Diatom total abundance peaked between ~14.49 - ~11.29 ka, and composition changed from sea-ice to open-ocean diatoms, including species not normally detected via fossil analyses. We demonstrate that *sedaDNA* tools can be expanded to hundreds of thousands of years and provide new insights into polar marine paleo-environmental change.



P3-005

Persistent influence of precession on northern ice sheet variability since the early Pleistocene

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Before ~1M years ago, variations in global ice volume were dominated by changes in obliquity but the role of precession remains unresolved. Using a record of North Atlantic ice rafting spanning the last 1.7Myr, we find that the onset of ice rafting within a given glacial cycle (reflecting ice sheet expansion) consistently occurred during times of decreasing obliquity, while mass ice wasting (ablation) events were consistently tied to minima in precession. Furthermore, our results suggest that the ubiquitous association between precession-driven mass wasting events and glacial termination is a unique feature of the mid/late Pleistocene. Before then increasing obliquity alone was sufficient to end a glacial cycle, before losing its dominant grip on deglaciation with the southward extension of northern hemisphere ice sheets since ~1Ma.



P3-033

Common modes of western Pacific hydroclimate variability across the last two interglacials

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The western Pacific warm pool (WPWP) is a location of deep convection and heavy rainfall, delivering vast amounts of heat and moisture to the atmosphere. The strength of convection is largely regulated by three distinct, but related mechanisms: the position of the intertropical convergence zone, the seasonal strengthening of the Asian-Australian monsoon system, and the El Niño Southern Oscillation (e.g. De Deckker, 2016). The complicated nature of their interactions, however, make it difficult to assess the controls on rainfall amount and variability and thus to simulate past and future changes in WPWP hydroclimate with confidence. Here, we present new reconstructions of runoff (XRF core scanning Fe/Ca and Ti/Ca) and surface ocean salinity (planktic foraminifer Mg/Ca & $\delta^{18}\text{O}$) spanning the last (LIG) and present interglacial periods at IODP Site U1485 recovered off the northern coast of Papua New Guinea in the heart of the WPWP. Both interglacial periods are characterized by an early period of relative dryness followed by an increase in precipitation, consistent with other near-equatorial WPWP hydroclimate records, but anti-phased with those on its northern and southern margins. A principal components analysis of regional precipitation sensitive records confirms the observed pattern, suggesting that the primary mode of variability across the Holocene is precessionally driven expansion and contraction of the tropical rain band (TRB). The second principal component yields different signs of the loadings among the sites, and is more consistent with Walker circulation strength variations through time for both the Holocene and LIG. Our results indicate that the Walker Circulation strength peaked early in the Holocene and LIG, when the TRB was expanded. Given the consistency between interglacial periods, we speculate that the strength of the Walker circulation is modulated by the width of the TRB, which is expected to contract under global warming (e.g. Zhou et al., 2019).



P3-009

Transient Arctic Meridional Overturning (ArMOC) strengthening under past abrupt warming

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According to the recent generation of global climate models, a weakening of the Atlantic Meridional Overturning Circulation (AMOC) is unequivocal in the context of global warming. However, a recent study (Bretones et al, 2022) showed that the weakening of the AMOC at the reference latitude of 26N is decorrelated from the overturning trend north of the Greenland-Scotland Ridge.

From a paleo perspective, AMOC oscillations are believed to be one of the main drivers of the Dansgaard–Oeschger events, an alternation of cold and warm periods during the last glacial period in Greenland and with global signatures. During a warming phase, the AMOC is believed to be in a strong mode compared to the cold phase, thereby with increased amount of northward heat transport, and hence increased air temperature.

In this study, we investigate the presence and evolution of the Arctic Meridional Overturning Circulation (ArMOC) during the abrupt warming transition from Heinrich event 4 (H4) to the Greenland interstadial 8 (GI8) in the NorESM climate model (Guo et al, 2019). The simulation is based on a validated GI8 simulation and freshwater hosing experiments to simulate H4 conditions. In the model, the transition of H4 to GI8 presents a warming of around 10°C within 30 years in Greenland, which is similar with what was observed in ice cores.



P3-028

SEACHANGE: Quantifying the impact of major cultural transitions on marine ecosystem functioning and biodiversity

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Change in the marine environment is, as far as human perceptions are concerned, characteristically cryptic, occurring out of sight beneath the ocean surface. Even in the present day, when we have detailed measurements of many marine properties, we are hampered in our understanding by the shifting baseline, and our lack of direct knowledge of conditions and rates of change in the past. For periods before instrumental records became available, the impact of human cultural activity on marine ecosystems is largely unknown.

The SEACHANGE project aims to tackle this knowledge gap by applying novel geochemical and genetic techniques to high resolution marine proxy archives with the aim of identifying thresholds of recognizable human impacts on marine ecosystems by focusing on five periods of major cultural transition during the Holocene:

- (a) The Mesolithic to Neolithic transition around the North Sea (~6ka BP);
- (b) The impact of aboriginal culture and the colonial transition in Australia between ~6ka BP and the present day;
- (c) The Viking settlement of Iceland in 874 CE and the phases of intensification of fishing around Iceland up to the present day;
- (d) The transition to industrial fishing in the North Sea from 1000 CE to 1800 CE;
- (e) The onset and cessation of whaling in Antarctica in the first half of the 20th century.

SEACHANGE is a transdisciplinary project which will focus on the interactions between a wide range of diverse but interconnected marine systems by exploiting expertise from disciplines including marine ecology, marine geology, geochemistry, molecular biology (metagenomics), historical ecology, archaeology and anthropology.

SEACHANGE is an ERC (European Research Council) Synergy grant which started in October 2020. Our first major sample collection cruise took place in the North Atlantic in April and May this year (2022)



P3-044

Compiled ocean-terrestrial responses to the Younger Dryas Stadial

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The Younger Dryas (YD) stadial represents one of the best-studied periods of abrupt climate change within the Quaternary Period. While model simulations are able to achieve broadly similar conditions to the proxy reconstructions for the period, unrealistic amounts of freshwater must often be invoked to obtain these conditions. Weakening of the Atlantic Meridional Overturning Circulation (AMOC) via freshwater input has been cited as the cause of the Younger Dryas but this does not capture the changing conditions seen within the stadial across the North Atlantic region. Additionally, terrestrial records of YD summer temperatures and hydroclimate reveals a complex spatial pattern of variability within the stadial itself, thought to be related to fluctuations in sea-ice extent and the associated atmospheric Polar Front (Bakke et al., 2009).

In order to test this hypothesis, a compilation of surface foraminiferal abundances and isotope records will be presented in concert with a network of high-resolution lacustrine environmental reconstructions for the YD stadial across the North Atlantic region, to explore more about the nature and magnitude of sea-surface variability and its impacts on NW Europe. Where possible, the cores are constrained chronologically using the Vedde Ash tephra, which bisects the YD. The output of this compilation will be compared with existing model simulations to examine the mechanisms of climatic change causing variation within the YD stadial.

Bakke, J., Lie, Ø., Heegaard, E., Dokken, T., Haug, G.H., Birks, H.H., Dulski, P. and Nilsen, T., 2009. Rapid oceanic and atmospheric changes during the Younger Dryas cold period. *Nature Geoscience*, 2(3), pp.202-205.



P3-016

Ocean temperature forcings for glacial-interglacial Antarctic Ice Sheet simulations

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Ice shelf basal melt accounts for about half the present-day ice loss from the Antarctic Ice Sheet, and is important for both ice sheet mass balance and as a source of fresh water into the Southern Ocean. In Antarctic Ice Sheet simulations over Quaternary glacial cycle time scales, neither basal melt rate nor its principal oceanographic controls (e.g., temperature and salinity of waters adjacent to ice shelves) can be reconstructed directly from proxy records. Strong ice-ocean-atmosphere interactions suggest a coupled modelling approach is most appropriate for calculating basal melting, but the computational demands are prohibitively expensive at long time scales. Stand-alone ice sheet simulations can cover much longer time scales at reasonable resolution, but require an ocean forcing that is parameterised indirectly from alternative proxy records, or interpolated/extrapolated between/beyond simulated ocean states. Here we compare three methods for reconstructing ocean temperature: (i) proxy reconstructions of North Atlantic or circumpolar deep water temperatures; (ii) an ice-core air temperature reconstruction, damped and lagged by a linear response function; and (iii) a glacial index interpolation between CMIP6 lig127k (interglacial) and lgm (glacial) end-member ocean states. We find considerable differences in the rates and magnitudes of the Antarctic Ice Sheet contribution to past sea-level changes when applying the three methods in ice sheet simulations over the last two glacial cycles (220 ka). Geological evidence provides some guidance on which modelling choices are most appropriate. However, the ocean temperature remains as a poorly-constrained but crucial boundary condition, whether investigating past warm climates or using long simulations as a spin-up for future projections.



P3-030

Contraction of the Intertropical Convergence Zone over the western equatorial Atlantic and northeastern South America through the Holocene

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Modern precipitation over the western equatorial (WE) Atlantic and northeastern (NE) South America is strongly controlled by the seasonal meridional migration of the Intertropical Convergence Zone (ITCZ). Ample evidence from the Northern Hemisphere suggests a mid- to late Holocene southward migration of the ITCZ. One such shift would be expected to increase precipitation over semi-arid northern NE Brazil (Southern Hemisphere). However, the most meaningful precipitation record from northern NE Brazil shows a drying trend throughout the Holocene. Here we address this issue presenting a high temporal resolution reconstruction of precipitation over northern NE Brazil based on data from a marine sediment core, together with analyses of mid- and late Holocene simulations performed with a fully coupled climate model. We reconstructed changes in precipitation through three independent approaches: (i) bulk sediment $\ln(\text{Fe}/\text{Ca})$ and $\ln(\text{Ti}/\text{Ca})$ values; (ii) mass accumulation rates of the siliciclastic fraction; and (iii) stable hydrogen isotopic composition of long-chain *n*-alkanes. A mechanistic understanding of the reconstructed changes from our core and other NE South American ITCZ-related records was attained by specific analyses performed on the climate model simulations. Both, our reconstruction and the climate model simulations show a decrease in precipitation over northern NE Brazil from the mid- to the late Holocene. The model outputs further indicate a latitudinal contraction of the seasonal migration range of the ITCZ that, together with an intensification of the regional Walker circulation, were responsible for the mid- to late Holocene changes in precipitation over the WE Atlantic and NE South America. Our results reconcile apparently conflicting precipitation records and climate mechanisms used to explain changes in precipitation over the WE Atlantic and NE South America, challenging the hypothesis of a global southward migration of the ITCZ through the Holocene.



P3-032

ENSO variability across the last millennium from Galápagos corals

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How has the strength of the El Niño/Southern Oscillation (ENSO) system changed over the past millennium? The answer to this question will help to constrain ENSO sensitivity to ongoing anthropogenic climate forcing and expand our understanding of climate change across human-relevant time scales more broadly. Proxy records from the tropical Pacific that distinguish seasonal-interannual variability remain sparse, particularly in the eastern equatorial Pacific. Here we use geochemical records from modern and fossil corals from the Galápagos archipelago to provide a suite of multidecadal SST reconstructions across the last millennium, and we compare these data with similar published records from the central Pacific Line Islands. Our approach uses both oxygen isotope and Sr/Ca measurements, from islands that span the extremes of the archipelago. We examine the uncertainties introduced a) by local variability within the Galápagos, and b) by using different proxies for SST, which introduces calibration uncertainties. Overall, our data point to intensifying interannual variability in the past few decades, relative to the pre-industrial era and the past millennium. These results suggest a stronger response at Galápagos than in the Line Islands, in agreement with trends in instrumental data. This intensification is also consistent with a hypothesized competition in the response of ENSO to anthropogenic forcing, between a dynamical thermostat response in the short-term, followed by a weaker Walker circulation pattern after several decades. Our new results are the initial findings from a larger suite of fossil Galapagos coral samples that span the past 4 millennia.



P3-037

Green Sahara Periods in a changing world: a proxy-based reconstruction of 11 Myr of African hydroclimate

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The Sahara is a vast, bare, intensely arid, dust exporting landscape today. Yet, in the early Holocene, the Sahara was green; a well-vegetated landscape crosscut by a network of rivers and lakes, populated by hippopotamuses, other megafauna and our early ancestors. Strong evidence also exists for multiple earlier Green Sahara Periods (GSPs), with their occurrence paced by variability in solar insolation. However, terrestrial climate archives used to provide direct evidence of past humid conditions are often plagued with intervals of erosion and/or non-deposition, while sapropels (organic-rich sediment layers in the Mediterranean Sea) only provide an indirect record of North African climate. Here, we explore how the expression of GSPs has changed across a range of global climate states, including warmer intervals than today, with new, detailed records of terrigenous inputs to North Atlantic deep-sea sediments situated underneath the Saharan dust plume. We document a long and sustained history of astronomically-paced oscillations between distinctly humid and arid conditions from at least 11 million years ago, with three distinct phases in the sensitivity of the relationship between astronomical forcing and African hydroclimate identified. Our data provide a new framework for assessing evolutionary outcomes on land, including implications for our hominid ancestors.



P3-023

Paleoecologic evolution of the eastern island of Rhodes (Greece)

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Along the east coast of the island of Rhodes, Late Pliocene to Middle Pleistocene marine fossiliferous sediments are exposed, representing the sedimentation and neotectonic histories of different depocenters. It has been suggested that the sediments of each depocenter represent distinctive environmental conditions with even small-scale regional differences.

Here we present new insights into the early Pleistocene paleoenvironmental evolution of two different depocenters, represented by the sediment sections of Plimiri and Agathi from the southern and middle east coast of Rhodes. For both sections, detailed benthic foraminiferal faunal data and preliminary paleo-water depth reconstructions were generated.

Although the different depocenters along the east coast of Rhodes underwent specific vertical motions of tectonic coastal uplift and subsidence, the benthic foraminiferal records also document the regional paleoceanographic evolution. While the Agathi section indicates weaker and less frequent fluctuations in water depth, mostly with amplitudes below 100 m, at Plimiri, multiple cycles of increasing and decreasing water depth can be observed with a maximum amplitude of about 400 m. Both records show a notable number of eutrophic indicator species with average percentages of 35 % for the Plimiri section and about 40 % in the Agathi section. Unlike the modern trophic conditions in the Eastern Mediterranean Sea, these results point to rather mesotrophic conditions during the early Pleistocene. The benthic foraminiferal assemblages of the records further exhibit periodic changes in the abundance of eutrophic and oligotrophic indicator species suggesting variations in oxygen and food levels at the sea floor. These cycles likely represent the impact of orbital climate changes allowing the evaluation of hydrological changes in the northeastern Mediterranean Sea.



P3-006

Sea ice-ocean coupling during Heinrich Stadials in the Nordic Seas

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Arctic warming at similar rate as present-day climate change have occurred during the abrupt millennial-scale climate oscillations during the last glacial period, when the climate jumped from cold stadials to warm interstadials. Even though variability in Arctic sea-ice is known to be a key element in causing amplification of the effect of the abrupt atmospheric warming, it is still poorly understood what drives the changes in the sea-ice cover. Sea ice acts as a lid insulating the ocean from the atmosphere, and vice versa, and it is therefore sensitive to changes both from the atmosphere and from the ocean. Here, we investigated the relationship between bottom water temperature (BWT) and sea-ice biomarker data (IP₂₅, HBI III and calculated sea-ice indicators) at millennial-timescales during Marine Isotope Stages 3 and 2 in core HH15-1252PC, retrieved from a water depth of 1,273 west of Svalbard in the northern Nordic Seas. Our findings reveal two distinct scenarios with generally open-ocean conditions during warm interstadials and extensive sea-ice cover during cold stadials. The comparison between sea-ice biomarkers and BWT during Heinrich Stadials shows a tight linkage between both variables, with rapid reductions in spring sea-ice coincident with drops in BWT. This study thus provides new insights into the close coupling between BWT and sea-ice cover in the Nordic Seas at millennial-timescales.



P3-008

Patterns and drivers of nutrient consumption in the surface subpolar North Atlantic Ocean over the last glacial cycle

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On millennial timescales, the nutrient status of the high latitude surface oceans regulates atmospheric CO₂ levels by setting the preformed nutrient content of the deep ocean. While much has been learned about the nutrient status of the Southern Ocean over the last glacial cycle (the last 150,000 years), comparatively little is known about nutrient changes in high latitude North Atlantic surface waters from which North Atlantic Deep Water is formed. Here we present planktonic foraminifera-bound organic matter nitrogen isotope (FB- $\delta^{15}\text{N}$) records from Ocean Drilling Program Site 983 (60.4°N, 23.6°W) to reconstruct the history of nitrate consumption in the subpolar North Atlantic. We employ a second FB- $\delta^{15}\text{N}$ record from the subtropical North Atlantic (MSM58-50-3; 31.7°N, 38.6°W) to delineate nitrate consumption from changes in the isotopic ratio of subsurface nitrate in the North Atlantic. Surprisingly, our results show that subpolar nutrient consumption was largely invariant across the abrupt millennial-scale climate events of the last glacial period, which are strongly imprinted in other proxies at this location¹. Instead, results show that surface nitrate consumption was substantially increased at glacial maxima (Marine Isotope Stage [MIS] 2 and 6) compared to interglacials (MIS 1 and 5). These results will be interpreted in the context of orbital-scale drivers of subpolar nutrient dynamics, including changes in the strength and geometry of North Atlantic westerly winds in response to Laurentide ice sheet extent, and changes in subsurface ocean circulation pathways that supply nutrients to the subpolar north Atlantic.

¹S. Barker *et al.*, Nature, doi:10.1038/nature14330 (2015).



P3-010

Establishing the current relation between observed oxygen conditions and oxygen proxies in western Norwegian fjords

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In recent decades, a progressive decrease in oxygen concentration is observed, e.g., in the Norwegian fjord Masfjorden. Deoxygenation in this semi-enclosed environment is caused by a lower frequency of exchange events between coastal and basin waters, with a reduced supply of oxygen-rich waters within the fjords. It is suggested that the reduced renewal frequency is a response to global warming. Here, two fjords on the west coast of Norway, Lurefjorden and Masfjorden, are studied. During a cruise on the RV Kristine Bonnevie in February 2022 we collected water and surface sediment samples from eleven stations located in these two fjords. Both the water and surface sediment samples will be analyzed for Mn/Ca and carbon isotopes. In addition, the benthic foraminiferal fauna of the surface sediment samples will be identified. The current relationship between Mn/Ca, carbon isotopes, benthic foraminiferal species indicative of changing oxygen concentrations and instrumentally recorded oxygen conditions from the same two fjords will be investigated. The stations represent different current oxygen concentrations, from well-oxygenated bottom water masses to anoxic conditions in Haugsværfjorden, in the inner part of Masfjorden. Initial results will be presented.



P3-036

Five million years of North African hydroclimate

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On orbital timescales, North African climate variability is characterised by Green Sahara Periods (GSPs) alternating with more arid periods. GSPs correspond to boreal summer insolation maxima and minima in Earth's orbital precession cycle, resulting in a more northerly and intensified African rainbelt. Reconstructing the timing and intensity of GSPs is therefore important for understanding past changes in Earth's albedo, land-vegetation feedbacks, and hominin migrations. However, there are few continuous, well-dated records of GSPs that extend beyond the Pleistocene.

Here, we present the first continuous, astronomically dated GSP record back to 5.2 Ma from Eastern Mediterranean Ocean Drilling Program (ODP) Site 967, based on Ba/Al, Ti/Al, and planktic $\delta^{18}\text{O}$. From the same site, we also present records of Saharan dust and riverine inputs, based on environmental magnetic and scanning x-ray fluorescence records, which have been converted into element concentrations by multivariate log-ratio calibration. We find that monsoon run-off intensity into the Mediterranean during GSPs was relatively constant over the last 5 Myr, whereas wind-blown dust inputs increased sharply ~1.2 Myr ago, when global ice-ages intensified. We observe that fluvial terrigenous inputs doubled abruptly 3.2 Myr ago, at the same time as a fundamental change in sapropel development. We evaluate different hypotheses (climatic vs tectonic) to explain this shift, and deduce that it likely indicates an abrupt state-transition to expanded Saharan aridity with extreme North African arid:humid variability. We further surmise that this critical North African landscape transition was in response to a global climate state-shift to icehouse conditions, as the timing closely coincides with the onset of intensified northern hemisphere glaciation.



P3-043

The Mid-Pleistocene Transition and Precession Cancellation in the Early Pleistocene

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The Quaternary is characterised by intense climate variability due to the cyclic growth and decay of ice sheets atop the northern hemisphere continents. These glacial cycles are readily attributed to changes in summer insolation intensity, due to variations in the Earth's orbital parameters. The Mid-Pleistocene Transition (MPT), however, which is recorded in the oxygen isotope composition ($\delta^{18}\text{O}$) of benthic foraminifera, represents a switch from smaller 40 kyr glacial cycles in the Early Pleistocene, to larger 100 kyr cycles in the Late Pleistocene, with no major changes in the orbital forcings. Furthermore, the lack of global ice volume variability at the precession period (~ 21 kyr) during the Early Pleistocene, as compared with the Late Pleistocene, is difficult to reconcile with the orbital theory of glaciation. Precession is a dominant control on the summer insolation intensity and theories that attempt to explain its conspicuous absence involve either an inverse relationship between insolation intensity and the length of the summer season, or out-of-phase behaviour between Antarctica and the northern hemisphere ice sheets, leading to the cancellation of $\delta^{18}\text{O}$ signals in the deep-ocean. These different theories will be incorporated into a simple climate model that simulates glacial cycles over long time periods as a response to the full seasonal cycle in insolation. A coupled ice sheet model and energy balance mode of the climate system will be constructed which aims to simulate the evolution of both a southern hemisphere and northern hemisphere ice sheet, to determine whether out-of-phase behaviour between Antarctica and northern hemisphere ice sheets can generate precession cancellation in the global ice volume record. In addition, theories for the Mid-Pleistocene Transition, including CO_2 lowering and regolith removal, will be implemented to determine their potential influence on changes in precession periodicity between the Early and Late Pleistocene.



P3-031

Interannual Southern California Hydroclimate Variability and the ENSO Teleconnection during the Holocene.

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Southern California's Mediterranean-type hydroclimate is strongly influenced by interannual climate variability such as the El Niño–Southern Oscillation (ENSO). Heavy precipitation and subsequent flooding deposit Ti-rich lithogenic sediment layers in Santa Barbara Basin (SBB), California during El Niño years, while intervening La Niña years are associated with drought. We present an interannual precipitation reconstruction from Southern California through the Holocene using scanning XRF. This sub-annually resolved, continuous Ti record reveals ENSO variability on centennial to millennial time-scales and highlights the atmospheric teleconnection between Southern California hydroclimate and the tropical Pacific and extratropical climate. Wavelet analysis of the SBB Ti record demonstrates interannual (2–7 yrs) precipitation variance was relatively weak prior to 4.4 ka. Consistent with tropical Pacific records, ENSO variability significantly increased during the late Holocene as the Intertropical Convergence Zone (ITCZ) shifted southward. Meanwhile, the ENSO teleconnection between the tropical Pacific and Southern California could have been strengthened by a deeper, eastward-shifted Aleutian Low (AL) identified as the 4.2 ka event in NW Pacific records. These teleconnections are observed at the submillennial-scale as well. During the Common Era, increased interannual precipitation variance was associated with longer periodicities (5–7 years) when the ITCZ migrated southward (1370–1540 CE) and the AL strengthened, creating a robust ENSO teleconnection. Weak interannual precipitation variance with shorter periodicity (2–3 years) was observed when the ITCZ shifted northward (700–900 CE) and/or the AL was weak (1540–1680 CE). The role of both the ITCZ and AL in hydroclimate variability in Southern California is supported by simulated climatological anomalies generated by Community Earth System Model (CESM1.2).



P3-034

Sea surface temperature evolution across the Coral Sea during the last glacial-interglacial cycle

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Sea surface temperatures (SST) within the Coral Sea interact with the larger-scale western Pacific ocean and climate system in multiple ways. For instance, surface waters transported from the Coral Sea via western boundary currents (WBCs) to both the equatorial Pacific and the high southern latitudes, equally influence the Western Pacific Warm Pool and the Australian climate. Meridional temperature gradients affect the strength of the WBCs, which in turn control the export of heat and energy. Furthermore, SSTs play an important role in regulating the regional hydroclimate. SST reconstructions from the Coral Sea are thus essential to understand the regional ocean and climate dynamics. However, the few existing Coral Sea SST records are of low temporal resolution and neither continuous, nor consistent.

Here, we present new records of SST from gravity cores GeoB22229-1/GeoB22230-1, recovered offshore northeastern Australia (145°5'E, 15°38'S). The combined records of these two cores provide a continuous time series covering the last 130 kyr at centennial-to-millennial scale resolution. Our Mg/Ca and alkenone-based SST estimates show generally consistent patterns of variability over the last glacial-interglacial cycle, albeit with different amplitudes of SST variations. However, our new records show a substantially different pattern, for instance, of the deglacial temperature rise, compared to previously published Coral Sea SST reconstructions. Based on a compilation of the new and published records covering the last glacial-interglacial cycle, we will discuss the evolution of SST across the Coral Sea and explore potential forcing factors and implications for regional ocean and climate dynamics.



P3-040

New evidence from foraminiferal ϵ Nd records of the continental chemical erosion coupled to East Asian monsoon millennial variability over the last 25 ka

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The South China Sea (SCS) is a semi-closed marginal sea connected to the western Pacific Ocean through the Luzon Strait. It receives huge volumes of suspended sediments (~700 million t/yr) from surrounding drainage basins, resulting in high sediment accumulation rates. As detrital sediments are characterized by more unradiogenic ϵ Nd (from -9 to -13) than Pacific water masses inflowing in the northern SCS (ϵ Nd around -4), the SCS is a key area to reconstruct changes in both regional Nd inputs related to continental weathering driven by the East Asian Monsoon and changes in paleo-hydrology of the Pacific deep-water.

Nd isotopic composition records obtained from mixed planktonic foraminifera of two well dated deep-sea cores collected on the northern (South Taiwan) and southern SCS (off Mekong River) have been investigated to decipher impacts of changes in hydrology and lithogenic input on seawater ϵ Nd variability of the SCS. The variability in Nd isotopes record obtained on the Northern core permits us to reconstruct mainly past changes in the intrusion of Pacific deep water to the SCS since the last glacial period with some modulation due to sediment input to Taiwan Rivers. The past seawater ϵ Nd record obtained from the southern core permits us to compare with results of the northern core to establish the lithogenic Nd input from the Mekong River. Our new results indicate that past seawater ϵ Nd off the Mekong River mouth is strongly influenced by the input of pedogenic minerals (smectite and kaolinite) resulting from higher physical erosion and/or higher chemical weathering of the plain soils induced by variations in the East Asian Summer Monsoon rainfall intensity since the last glacial period.



P3-026

Plankton biodiversity patterns question modelled glacial ocean thermal gradients

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The LGM remains a prime target to evaluate climate models outside modern boundary conditions.

However, climate reconstructions are indirect and associated with marked uncertainty, complicating model-data comparison. Here we take a different approach and use macro-ecological patterns in fossil marine zooplankton to evaluate simulations of LGM near-surface ocean temperature.

We use the distance-decay pattern in planktonic foraminifera assemblages to evaluate modelled thermal gradients. Distance decay emerges because of species-specific habitat preferences and planktonic foraminifera indeed show decreasing similarity with increasing thermal distance between assemblages. Because changes in the ecological niches of planktonic foraminifera are unlikely, the distance-decay relationship based on simulated LGM temperatures and LGM assemblages should in principle be identical to the modern pattern. Thus we can use fossil planktonic foraminifera assemblages to evaluate climate model simulations based on ecological principles.

Our analysis is based on an extended LGM planktonic foraminifera database (2,085 assemblages from 647 unique sites) and a suite of 10 simulations from state-of-the-art climate models (PMIP3 and 4). The distance-decay pattern that emerges when the LGM assemblages are combined with simulated ocean temperatures is different from the modern pattern. All simulations show large thermal gradients between regions where the planktonic foraminifera indicate no, or only weak, compositional gradients. This difference arises from a shift to polar species assemblages in the North Atlantic, where the simulations predict only moderate cooling.

Importantly, simulations with a reduced AMOC due to coastal freshwater forcing and hence lower North Atlantic temperatures, yield a distance-decay pattern that is much more similar to the modern pattern. The planktonic foraminifera assemblages thus question the view of the LGM ocean as an equilibrium response to external forcing.



P3-022

Influence of mineral dust inputs on primary productivity in the northwestern Arabian Sea since the Last Glacial Maximum

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The Arabian Sea (AS), located in the Northwestern part of the Indian Ocean, is surrounded by desertic regions (e.i., Middle East, Pakistan), and thus receives important amounts of mineral dust. It is also under the influence of the Indian monsoon system that creates a coastal upwelling off Somalia and Oman during summer and a convective mixing north of 15°N during winter. Both, mineral dust and surface ocean mixing, bring important amount of nutrients to the euphotic zone and make the AS, one of the most productive oceanic areas in the world. Previous studies of the imprint of primary productivity in the AS in the past, yielded important results on the influence of nutrient inputs from below. However, much less is known about the impact of fertilization by mineral dust. Here, based on the multi-proxy characterization of the detrital fraction of marine core MD00-2354 (61.48°E, 21.04°N; 2740 mbsl), we provide for the first time, a high-resolution (~200 yrs) aeolian signal in the Northeastern part of the AS over the past 24,000 years. This time interval encompasses a glacial-interglacial transition with rapid fluctuations of ice volume, sea level, and atmospheric CO₂ concentration and is therefore a perfect case study to explore the impact of key Earth's climate forcing mechanisms on primary productivity for both, past and future climate conditions. The combination of grain-size distribution, clay mineralogy and geochemical compositions of the detrital fraction help reconstructing mineral dust provenance as well as atmospheric circulation changes (wind direction and intensity). The comparison of the aeolian signal obtained in this study, with primary productivity and upwelling intensity records previously obtained on the same site (Zhou et al., submitted) allows us to decipher the respective influence of mineral dust *versus* water mixing on primary productivity patterns, suggesting a major role of mineral dust inputs since the Last Glacial Maximum.



P3-003

Cryosphere change and marine ecosystem dynamics in the low Arctic – a multi-proxy Holocene record from Nuup Kangerlua, SW Greenland

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The Arctic amplification of climate change is leading to a rapid decrease in sea-ice cover and increased discharge from the Greenland Ice Sheet. These rapid cryosphere changes affect the structure and functioning of marine ecosystems. At the base of the marine food web, primary producers have a key role in carbon sequestration and sustain higher trophic levels. To fully assess how ongoing cryosphere changes will impact Arctic coastal marine ecosystems, paleorecords spanning warming/cooling intervals at high-resolution are needed. We will present the first multi-proxy record of Holocene environmental changes from Nuup Kangerlua, the largest fjord system in west Greenland. In this study, we analyzed dinoflagellate cyst assemblages alongside grain-size distribution, and biogeochemical indicators (total organic carbon (TOC), nitrogen (TN), calcium carbonate (CaCO₃), stable isotopes (¹³C and ¹⁵N), and biogenic silica (BSi)). Our multiproxy record captures significant environmental changes throughout the Holocene including a period of relatively warmer sea-surface waters and higher productivity attributed to the Holocene Thermal Maximum (HTM). The uppermost part of the core records a freshening signal, as a consequence of increased glacial discharge from the Greenlandic Ice Sheet.



P3-015

Antarctica: ocean – ice sheet interactions and tipping points

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Ice loss from the Antarctic Ice Sheet is one of the major wildcards for projections of future sea level rise. During past warm periods, such as the Last Interglacial, large parts of the West Antarctic Ice Sheet collapsed, contributing to a global mean sea level rise of several meters. In a slightly-warmer-than-present climate, the Antarctic Ice Sheet is primarily vulnerable through its contact with the surrounding ocean. In contrast, atmospheric changes will bring more snowfall, and therefore a higher surface mass balance. Surface temperatures remain low enough to avoid drastically increased surface ablation.

When warmer ocean temperatures reach the Antarctic ice shelves, they will melt, thin, and lose their buttressing effect. The ice sheet can cross a tipping point, becomes unstable and retreats.

How stable is the present-day Antarctic Ice Sheet? Are there indications that tipping points are already crossed, or will be crossed soon? Have we already committed to several meters of sea level rise?

In this poster we will present the latest knowledge on these processes, interactions and tipping points under present and past climates, based on results from the EU-funded TiPACCs project (www.tipaccs.eu).



P3-025

Response of the marine carbon cycle to climate-dependent weathering fluxes along the last deglaciation

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The glacial-interglacial variations of atmospheric CO₂ concentration have been notoriously hard to simulate in models for decades. The ocean has likely played a major role for its increase from 190 at the Last Glacial Maximum to 280 ppm in pre-industrial times as well as for abrupt events along the deglaciation. Various physical and biogeochemical processes have influenced carbon sequestration in the ocean, though their exact contribution is not elucidated yet. An obstacle to a better understanding of these mechanisms is that models vary largely in their representation of the carbon cycle and consideration of boundary conditions (Lhardy et al., 2021). At this scale, it is critical to represent the marine carbon cycle as an open system, with incoming (riverine) and outgoing (sediment) fluxes.

In this study, we have implemented weathering equations (Lacroix et al., 2020; Hartmann et al., 2009, 2014; Börker et al., 2020) in MPI-ESM. This model includes the HAMOCC ocean biogeochemistry component with a sediment module (Paulsen et al., 2017; Ilyina et al., 2013). It has been developed to prescribe varying boundary conditions (Meccia and Mikolajewicz, 2018) and river routing (Riddick et al., 2018) along the deglaciation. We have extended Lacroix et al. (2020)'s work at the pre-industrial to enable first LGM and transient deglacial runs in this dynamic setup. Taking into account 10-year climatological means of temperature and runoff, weathering equations are resolved for various lithologies (including loess deposits and continental shelves) in order to compute phosphorus and alkalinity fluxes. Based on stoichiometric ratios, carbon, nutrients and alkalinity fluxes are put into the grid cell closest to each river mouth. We then investigate the response of ocean biogeochemistry to these climate-dependent and heterogeneously distributed riverine inputs, which contrast with the homogeneous fluxes prescribed at the coast to compensate for the loss to sediment in control runs.



P3-041

Making sense of sawtooth-shaped climate cycles: the bispectrum can help

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Sawtooth-shaped climate cycles, such as the ice age cycles of the Middle and Late Pleistocene, conceal a lot of information about the underlying physical processes that were important in determining past climate change. Their asymmetric geometry in the time domain results from energy transfers among periodic physical processes in the climate system. The bispectrum can unveil these hidden periodic components in time series marked by sawtooth-shaped cycles, and the energy transfers among them. We show, through a novel bispectral analysis of the “LR04” globally averaged benthic foraminiferal oxygen isotope stack, that:

- (i) precession-forced climate cycles transferred energy to the obliquity-paced climate cycles during the Middle Pleistocene, and
- (ii) precession-forced and obliquity-paced climate cycles transferred energy to eccentricity-paced climate cycles from the Mid-Pleistocene Transition (MPT) onward.

These findings constitute a further confirmation of the Milankovitch Theory for the Pleistocene—ice age cycle sawtoothness is in agreement with their astronomically forced origin. They also visualize energy transfer mechanisms within Earth’s climate-cryosphere system and show how these evolved across the MPT. Lastly, they shed light on the (non-linear) origins of climate cycles without a direct connection to astronomy, such as the ~28 kyr and ~80 kyr cycles.



P3-042

Interaction between thermocline structure and orbital forcings during the past 588-kyr in Solomon Sea, southwest equatorial Pacific

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The Solomon Sea is the main source of the equatorial undercurrent, and main crossroad of the equatorial region and South Pacific Ocean. Here we present a multi-species geochemical proxies derived vertical thermal-hydrological variabilities over the last 588,000 years for the Solomon Sea. The comparisons between oxygen isotope of *Globigerinoides ruber* (white) and *Pulleniatina obliquiloculata* ($\Delta\delta^{18}\text{O}_c$), sea surface temperature (SST) and upper thermocline temperature (UTT) gradients (ΔT), and seawater oxygen isotope gradients ($\Delta\delta^{18}\text{O}_w$) all show persistent stable gradients across the research period with an absence of clear glacial/interglacial (G/IG) cycles. Both SST and UTT records feature similar timing of warming and 2-4 kyr earlier than G/IG boundaries for the past six terminations. Both SST and UTT records of termination V (T V), different from other five terminations, feature a persistent temperature increasing of 5-7 °C for over 10-kyr. T III shows a 6-kyr earlier cooling of surface water comparing with the other four terminations. In the subsurface, a 2- to 6-kyr earlier cooling is expressed in UTT records of T II and III than these of the other three terminations. This diverse surface and subsurface thermal conditions in the southwest equatorial Pacific Ocean may play a role to interpret the long lasting super interglacial period during MIS 11. The intriguing pattern of ice volume corrected seawater oxygen isotope records suggest complex interactions between precipitation-evaporation and water masses exchange in the Solomon Sea. Finally, significant obliquity pacing observed in both SST-UTT and $\Delta\delta^{18}\text{O}_w$, suggests strong interactions between the Solomon Sea and other mid-high latitude South Pacific regions.



P3-020

Plio-Pleistocene Dust Fluxes and Productivity Reconstructions from the Subantarctic South Pacific

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Continental dust emissions provide a valuable source of the limiting micronutrient Fe to the macronutrient-rich surface waters of the Southern Ocean. Due to the extent of water mass upwelling and subduction that occurs within the Southern Ocean, nutrient delivery and utilization within the region play a critical role in setting the net efficiency of the global marine biologic carbon pump. Consequently, changing dust emissions to the Southern Ocean associated with Plio-Pleistocene climatic variability may have a significant influence on marine productivity, carbon export, and the global carbon cycle. We investigate the proposed relationships between dust-borne Fe delivery to the Southern Ocean and export production over the Plio-Pleistocene using new sedimentary records from IODP Site U1541, recovered from the subantarctic South Pacific on Expedition 383 in 2019.

We use XRF-derived concentration data for Fe, Ti, and Al, and age model-derived mass accumulation rates to estimate lithogenic dust deposition at South Pacific Site U1541 and compare these data with analogous dust deposition records from South Atlantic ODP Site 1090 over the Plio-Pleistocene. We then examine potential linkages between Southern Hemisphere dust emissions and export production in the subantarctic South Pacific over the past 5 Myr using new excess barium deposition records at IODP Site U1541. Notably, age model-derived sediment mass accumulation rate records may be influenced by lateral sediment transport processes that can inflate or deflate apparent lithogenic dust and excess barium deposition rates to the seafloor. In order to examine the magnitude of this effect in the U1541 sediment record, we also present preliminary data for constant flux proxy-derived vertical sediment accumulation rates measured in discrete U1541 samples using extraterrestrial ³He.



P3-004

The role of internal climate feedbacks on the growth of the Northern Hemisphere ice sheets towards the Last Glacial Maximum.

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Northern Hemisphere summer insolation is regarded as a main control factor of glacial-interglacial cycles. However, internal feedbacks between ice sheets and other climate components are non-negligible. For example, a reorganization of the atmospheric circulation (due to changes of ice sheet height), or changes of the Atlantic Meridional Overturning Circulation (due to changes of ice sheet height or freshwater budget), could in turn modulate the waxing and waning processes of the ice sheets. To address this complexity, we apply a state-of-the-art Earth system model (AWI-ESM) asynchronously coupled to the ice sheet model PISM. Internal climate feedbacks and associated mechanisms are investigated during the period when ice sheet grows from an intermediate state (Marine isotope stage 3, around 38 k) to a maximum ice sheet state (the Last Glacial Maximum).



P3-017

The response of the East Antarctic Ice Sheet to deglacial climate warming

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The Wilkes Land margin of East Antarctica is experiencing high rates of grounded ice mass loss, comparable to the rates experienced across West Antarctica. The Totten Glacier is the main outlet glacier, along with the Moscow University Glacier that drains the Sabrina and Aurora Subglacial Basins. These large low-lying (>1000m below sea level) subglacial basins make the ice sheet more sensitive to atmosphere and ocean warming due to marine ice sheet instability. This study investigates the timing and response of this marine-based sector of the East Antarctic Ice Sheet to climate warming over the last deglaciation, to better understand the processes governing ice sheet retreat.

Four sediment cores from the continental rise were analysed using a multi-proxy approach. The grounding line of the expanded glacial ice sheet was interpreted to be proximal to the core sites based on the characteristics of the sediment; with fine glacial clays, high coarse sand (250 mm-2mm) mass accumulation rates, and relative abundance of robust and extinct diatom species. The results reveal the initial onset of ice retreat associated with the strengthening of the slope current and increased proportion of the diatom *Chaetoceros* subg. *Hyalochaete*, a proxy for meltwater input, occurred between 22.0 ± 3.2 ka and 19.2 ± 0.6 ka. A result that is much earlier than observed in other sectors of East Antarctica, despite radiocarbon dating of the acid insoluble organic matter. Subsequently, biological productivity (% opal, diatom abundance, Si/Al, Ba/Al) gradually increased, associated with reductions in sea ice cover and the establishment of seasonally open water conditions over the continental rise, with maxima observed at the time of the Holocene Optimum (~11-6 ka). These records provide evidence for the sensitivity of East Antarctic Ice Sheet to deglacial warming of the Southern Ocean associated with a reduction in Atlantic overturning circulation.



P3-002

Cryosphere impacts on Southwest Greenland fjord productivity since the Little Ice Age

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Freshwater discharge from the Greenland Ice Sheet has increased drastically during the last decades and is expected to increase in the future (Fettweis et al. 2013). Freshwater modulates the physico-chemical properties and nutrient dynamics of the water column, and directly impacts primary production, which is essential for socio-economic activities such as fisheries (Hopwood et al. 2020). Freshwater impacts on fjord productivity have been monitored for the last few decades (Meire et al. 2017), yet long-term timeseries of primary productivity changes are needed to elucidate variability beyond the accelerated climate change and to define the natural baseline for setting the recent changes into a wider context. Here, we use a multiproxy approach, including diatom assemblages and fluxes, total organic carbon, total nitrogen, C/N-ratios, biogenic silica, $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and sediment grain size, on marine sediment cores from the Nuup Kangerlua fjord to study spatio-temporal variations in marine primary production since the Little Ice Age with emphasis on the last ca. 100 years. To evaluate the impacts of meltwater, we compare our productivity records with freshwater runoff estimates from a MAR-regional climate model output, changes in the glacier frontline position, and with historical records of air- and sea-surface temperatures. Our long-term record shows that a relatively high marine production was maintained during the LIA, but productivity was lower during the major LIA retreat events suggesting impact from the calving ice margins. Marine productivity increased for the last 100 years in Nuup Kangerlua, and is higher today than at any other time since ca. 1200 AD. Modern high productivity is in line with the highest freshwater runoff volumes observed, and the impacts of freshwater runoff were found to be most notable in the glacier-proximal area of the fjord where our record shows an abrupt increase in marine productivity in the mid-1990's.



P3-027

Holocene fish population dynamics in the eastern Mediterranean from marine fossil otoliths

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Natural climate variability and enhanced anthropogenic pressure are rapidly modifying the marine ecosystems, shifting baselines of the ocean realm. Past changes in marine food web dynamics and fish stock changes remain largely undocumented as time-series of modern scientific surveys and fishery data collection programs spans a couple of decades at maximum, while historical data is often incomplete in time and space, not allowing to study long term fish population dynamics. Here we present a fossil otolith record from a radiocarbon dated high resolution Kasten-lot core spanning the Holocene to reconstruct the natural versus anthropogenic drivers on fish abundance and composition in the Mediterranean Sea, a region presently highly impacted by anthropogenic pressure including overfishing. The core location is stationed in the Aegean Sea (eastern Mediterranean), close to the Greek coastline. This strategic site allows us to interpret our record considering not only the climatic history but also key findings and societal changes from regional archaeological sites. Our results show high variabilities in myctophid otolith deposition rates with major cultural shifts, which could be indicative of human induced changes on mesopelagic fish community, but also be caused by natural changes as a result of Holocene climate variability. Results from the high-resolution fossil otolith record may help to better understand natural versus anthropogenic driven impacts on fish communities but can also be used to define new reference points for pristine mesopelagic fish communities in the Mediterranean.



P3-045

An investigation into the cause and structure of an abrupt climate event during MIS 11c

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Marine Oxygen Isotope Stage (MIS) 11c (~ 424 – 394 ka) was: 1) an orbitally similar period to the Holocene 2) a time of significant Greenland Ice Sheet (GIS) loss. As the GIS is poised to retreat in the future, understanding the impact this could have on North Atlantic dynamics is of paramount importance. During MIS11c there was an abrupt cooling event in the North Atlantic which, via the identification by Candy *et al.* (2021) of a tephra layer in Marks Tey (MT) (Essex) and ODP 980 (Rockall Trough), can be linked to terrestrial changes during MIS 11c. The aim of this study is to make use of the MT sequence in conjunction with a series of ocean cores to investigate this MIS11c abrupt climate event (ACE). We present records of sortable silt grain size analysis, Ice Rafted Debris (IRD) and planktic foram census data at 6 North Atlantic sites: IODP U1302 and U1305 (Labrador Sea / Denmark Strait Overflow Water (DSOW)); ODP 983, 984, and IODP U1304 (Iceland Scotland Overflow Water (ISOW)), and ODP 980. High resolution isotopic analysis of the MT sediments has also been conducted.

At MT, results confirm a long-term cooling trend spanning ~1500 varve years, punctuated by repeated isotopic incursions prior to/culminating in an ecological response. Ocean data indicate a cooling event with common features at all sites: (1) it occurred during the first phase of MIS 11c (424 – 410 ka); (2) after the final cessation of IRD (~ 419 ka onwards); and (3) it was ~1500 years in duration. Despite chronological issues, it is likely these are concurrent, indicating a pan-North Atlantic cooling event with an ecological response. This is the first study to produce such a high-resolution record of a pre-Holocene ACE.



P3-035

East African monsoon evolution and its orbital forcing during the Miocene/Pliocene transition

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Hydroclimate in tropical Africa is complex, and sensitive to both regional oceanic and remote forcing. However, understanding how these connections control past East African Monsoon (EAM) variability has been hampered by a lack of continuous paleoclimate archives recording regional land-ocean interactions. A key location to obtain reliable reconstructions of EAM variability is the northern entrance of the Mozambique Channel. Here surface ocean currents exchange water masses between the Indian and Atlantic Oceans, while regional rainfall and river discharge are strongly influenced by meridional migration of the Intertropical Convergence Zone (ITCZ). We present preliminary multiproxy data providing the first continuous reconstruction of EAM variability spanning the Late Miocene to Early Pliocene (7.4-4.4 Ma). Our data are based on Ca/Ti and Si/K ratios, planktonic foraminiferal $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ (*Orbulina universa*) and grain sizes recorded in sediments from IODP Site U1476 (15°49.25'S; 41°46.12'E and 2,166 water depth). Hydrological variability is mainly caused by precession-driven changes in mean annual rainfall in east Africa and the subsequent river sediment discharge to the ocean. The large detrital supply during precession maxima, which resulted in lower Ca/Ti ratios, was linked to strong EAM and southward migrations of the ITCZ. From 6.8-5.97 Ma, when major Antarctic Ice Sheet expansion took place, the modulation of the long eccentricity cycle (435 kyr) of precession is clearly visible. The influence of precession on the Ca/Ti and Si/K records weakens from 5.97-5.3, likely associated with a decrease in the sedimentation rate and an increase in marine productivity. Because the migrations of the ITCZ and EAM had a strong impact on Mediterranean hydrology and the formation of sapropels, this record in the Indian Ocean can be accurately correlated with the Mediterranean, being the stronger EAM events linked to minimum rainfall in this eastern Mediterranean region.



P3-001

Decoupling of surface ocean hydrology and Greenland ice core records in the eastern North Atlantic during the last glacial inception

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MIS 4, a key paleoclimatic interval for the last glacial inception, is characterized by a rapid CO₂ drop and a large drop in temperature. Several millennial events occurred during MIS 4, including Heinrich Stadial 6 and DO events 16-19. MIS 4 is thus an ideal interval to study and eventually to disentangle, glacial-interglacial and millennial variability.

Here, we present high resolution planktonic foraminifera geochemical data from the Iberian Margin. Previous studies have found that planktic foraminifera isotopes and SST reconstructions from this region recorded rapid climate change expressed in Greenland ice cores, during the last glacial period. However, our results indicate a more complex scenario, where certain aspects of the surface ocean response may not always track Greenland temperature. We attribute this to major seasonality biases associated with SST reconstructions. Whilst the winter SST follows Greenland, perhaps the most striking, is the decoupling indicated by our *G. bulloides* Mg/Ca summer SST record. It only shows a strong and rapid MIS 4 cooling at the start of HS 6, and no clear millennial variability signal. Our findings are supported by SST reconstructions based on other proxies from nearby core sites.

Furthermore, local $\delta^{18}\text{O}$ seawater and salinity reconstructions imply that hydroclimate was a major control on the Iberian Margin planktic $\delta^{18}\text{O}$. Our results suggest humid early MIS 4 and dry events just before and during HS 6. These results are in good agreement with local marine and terrestrial pollen records and speleothems from the Eastern and Western Mediterranean; as well as modelling studies. We propose that the observed progression in modes of hydroclimate variability and seasonality may be linked to evolving ice sheet topography, affecting the strength and mean position of the North Atlantic jet stream and the associated westerlies, and thus affecting the seasonality of precipitation in and around the Mediterranean during early MIS 4.



P3-019

Centennial scale solar variability in the South Westerly Winds and linkages to ocean heat and carbon storage

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Though CO₂ and temperature have been shown to co-vary on millennial timescales, with increasing anthropogenic emissions in the modern, temperature has had a surprisingly muted response. This could be due to the understudied effects of decadal to multi-centennial cycles in total solar insolation (TSI) on climate. Most of what we know about sub-millennial solar modulation of climate is based on the 11-year cycle because with short periods, multiple cycles are contained within modern observational data. Centennial scale cycles have been identified in TSI records and the 200 year De Vries cycle is thought to be a dominant Holocene period (Steinhilber et al., 2013). Further, temperature predictions based on our position within these solar cycles hypothesize cooling until the end of the century followed by warming (Liu et al., 2011; Steinhilber et al., 2013). Evidence of the effects of such centennial scale cycles on specific climate modes is rarer because a record must both be high resolution and temporally extensive. Here we use core scanning X-ray fluorescence (XRF) to examine a super high resolution (4 meters/kyr) core recovered from the Chilean margin during the JR100 expedition (379T), yielding unprecedented <2 year resolution for the entire Holocene. Superimposed on the long-term decreasing trend throughout the Holocene, we detect significant centennial cycles in the AI record consistent with the Gleissberg (~90), De Vries (~200), and ~500 year solar cycles. Interpreted as reflecting centennial shifts in the SWW position, we compare the SWW cycles with similarly resolved changes in Antarctic temperature and sea ice extent and the lead/lag relationship to identify how these solar cycles manifest within the climate system. This includes changes in precipitation in Patagonia and Antarctic upwelling which determines CO₂ and heat storage (Toggweiler et al., 2006; Lamy et al., 2001) and implications of this natural variability to future climate change.



P3-047

Simulating the physical air-sea disequilibrium of the glacial ocean

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The physical processes that govern atmosphere-ocean gas exchange play a central role in modulating global climate and biogeochemistry. Physical conditions at the air-sea interface can enhance or inhibit gas exchange, inducing solubility disequilibrium. However, parameterizations of gas exchange remain poorly constrained at the stormy conditions that characterize high-latitude sites of deep-water formation (high wind speeds and associated wave breaking, rapid temperature changes, bubble injection, etc.). Recent observational advances in the high latitudes (e.g., moored sensor platforms) have shown the importance of bubble-mediated gas exchange, and high-precision measurements over the past two decades have documented widespread (i) undersaturation of the heavy noble gases and (ii) supersaturation of the light noble gases throughout the deep ocean. As these gases are inert and derived from the well-mixed atmosphere, with no sources or sinks in the ocean interior (except for hydrothermal helium sources), they provide physical constraints on the processes that prohibit complete equilibration of the surface ocean during deep-water formation.

Here, we use observations of noble gas undersaturation in the modern deep ocean to calibrate a parameterization of gas exchange in an ocean circulation model (UVic ESCM) through a suite of Transport Matrix Method (TMM) simulations of the pre-industrial (PI) era ocean. We employ this gas exchange parameterization to a series of Last Glacial Maximum (LGM) simulations that span a range of equilibrium configurations of the global overturning circulation. At ICP 2022, we will (i) share preliminary results from both PI and LGM TMM simulations. (ii) provide an overview of existing and forthcoming inert gas constraints on deep-ocean disequilibrium, and (iii) discuss implications of our deep-ocean disequilibrium estimates for the application of atmospheric noble gas ratios in ice core air bubbles to reconstruct past ocean heat content.



P3-046

A multi-model assessment of the onset of the last deglaciation and Heinrich stadial 1

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The last deglaciation, beginning ~19 thousand years ago, features multiple abrupt climate changes that have been the focus of state-of-the-art climate model simulations. Despite decades of research on these abrupt climate events, the underlying causal mechanisms remain uncertain, but are often attributed to a weakening or strengthening of the Atlantic Meridional Overturning Circulation (AMOC). In particular, Heinrich Stadial 1 (~18 – 14.7 thousand years ago), a cold period characterised by a weak-to-shutdown AMOC, remains especially enigmatic despite evidence of the event in multiple temperature proxy records such as that of the North Atlantic, tropics, Asia, as well as with opposing conditions in Antarctica. How this event is simulated and discussed is also unresolved due to the uncertainties in deglacial forcings, such as meltwater forcing scenarios, mechanisms, and dynamic feedbacks. Here we present a multi-model assessment of the onset of the last deglaciation and into Heinrich Stadial 1 comparing 8 different climate models and over 10 simulations of the last deglaciation to constrain the uncertainty and evaluate model performance. We will provide analysis and evaluation of the model results while discussing the transition from the Last Glacial Maximum (~21 thousand years ago), ice-ocean-atmosphere interactions, and similarities and differences in climate states between the model simulations. These results will provide a better understanding of abrupt climate change mechanisms, model biases, and uncertainty with respect to deglacial forcings and the observable proxy records.



P3-012

Systematic changes in the circumpolar transport of dust to the Subantarctic Pacific Ocean over the last two glacial cycles

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The input of the soluble micronutrient iron (Fe) by mineral dust stimulates the net primary productivity in the Fe-deficient Southern Ocean. This mechanism is thought to increase carbon export thus reducing atmospheric CO₂ during the Pleistocene glacial cycles [1,2]. However, relatively little is known about changes in the sources and transport pathways of Southern Hemisphere dust over whole glacial cycles. Here we use the geochemical fingerprint of the dust fraction in marine sediments from core PS75/056-1 and multi-isotope mixture modelling to quantify changes in dust provenance in the South Pacific Subantarctic Zone (SAZ) [3]. Our data show that dust from South American sources dominated the South Pacific SAZ during most of the last 260,000 years with maximum contributions of up to ~64% in the early parts of the last two glacial cycles. The enhanced dust-Fe fluxes of the later parts of the glacial cycles [2] show increased contributions from Australian and New Zealand sources, but South American dust remained the overall dominant component. The corresponding dust grain size varies systematically with the provenance changes, consistent with the circumpolar transport of dust from the terrestrial dust source regions into the South Pacific by the westerly winds. High contributions from more proximal Australian and New Zealand sources (up to ~54%) paired with finer dust grain sizes indicate a reduction in westerly wind speeds over the South Pacific SAZ during deglacial and peak interglacial intervals. Combined with existing Fe flux data for PS75/056-1, our quantitative provenance results constrain source-specific changes in magnitude and timing of dust-Fe fluxes in the South Pacific SAZ influencing the Southern Ocean dust-Fe feedback on glacial-interglacial to millennial time scales.

[1] Martínez-García, A., et al. (2011) *Nature* **476**, 312–315. [2] Lamy, F., et al. (2014) *Science* **343**, 403–407. [3] Longman, J., et al. (2022) *Paleoceanogr. Paleoclimatol.* **37**, e2021PA004356.



P3-039

New Mediterranean speleothem records for glacial Terminations IV and III

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Speleothem archives spanning the glacial terminations IV and III (TIV and TIII) are particularly scarce in the western Mediterranean region. This study presents unprecedented geochemical records measured on a speleothem from Minorca Island that grew continuously through the period from Marine Isotope Stage 11 to 7. Its U/Th chronological model provides an accurate and excellent chronology for both terminations which are recognized as intervals with slow growth rates. Hence revealing the difficulty of the speleothem to grow during these periods of rapid melting, suggesting major distortions in the hydrological conditions associated to glacial terminations. The Mg/Ca and $\delta^{13}\text{C}$ records indicate that deglaciations were characterized by rapid transitions towards more humid conditions. However, the $\delta^{18}\text{O}$ results shows a deglacial freshening that led in time the hydrological signal, with a remarkably larger time-lag at the TIV. These earlier depletions of the $\delta^{18}\text{O}$ are interpreted to mark the onset of the glacial melting, a freshening signal that propagated through the surface ocean and transferred from the rain source into the stalagmite. The co-existence of comparable deglacial $\delta^{18}\text{O}$ depleted episodes within the marine records, brings the possibility to review the marine chronologies, independently of the orbital tuning. An exercise that indicates a significant bias in the timing of the melting onset associated to TIV.



P3-007

Abrupt change of sea-ice distribution in the northern Nordic Seas between 34 and 40 ka BP

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The last glacial period was characterized by a series of abrupt climate change events between stadial and interstadial conditions, known as the Dansgaard–Oeschger (D-O) events. During the D-O events, abrupt warming took place, which was followed by gradual cooling and then abrupt cooling towards close to full glacial temperatures before another abrupt warming occurred. The Heinrich Stadial (HS) refers to a cold stadial that contains a Heinrich Event during the D-O events, when massive icebergs as well as freshwater discharged in the North Atlantic and formed an ice-rafted debris belt there. The relationship between the variability of sea-ice distribution and the D-O events has long been discussed. Currently, updated knowledge of the climate mechanisms of the D-O events emphasize the importance of sea-ice dynamics for the abruptness of the D-O events. It is shown that during the stadial-to-interstadial transition, a sea-ice retreat in the southeastern Nordic Seas preceded the main reinvigoration of the convective deep-water formation and the abrupt Greenland warming; furthermore, the sea-ice expansion in the interstadial-to-stadial transition in this region preceded the build-up of a subsurface oceanic heat reservoir. To determine how far north in the Nordic Seas the sea-ice cover broke up during the interstadials, and for how long it stayed open in the north relative to the southern Nordic seas, IP_{25} , alkenones and sterols will be analyzed at high resolution in two sediment cores retrieved from the Fram Strait, focused on the HS 4 and the following D-O 8 event. Preliminary results will be presented, and potential causes and implications of regional differences in sea-ice distribution and concomitant changes in ocean and atmospheric conditions during the stadial-interstadial transitions will be discussed.



P3-013

Enhanced glacial dust deposition and interglacial productivity in the Antarctic Zone of the Southern Ocean over the last 1.5 Ma

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The Southern Ocean paleoceanography provides key insights into how iron fertilization and oceanic productivity developed through Pleistocene ice-ages and their role in influencing the carbon cycle. We report the first high-resolution record of dust deposition and ocean productivity for the Antarctic Zone, close to the main dust source, Patagonia. Our deep-ocean records cover the last 1.5 Ma, thus doubling that from Antarctic ice-cores. We find a 5 to 15-fold increase in dust deposition during glacials and a 2 to 5-fold increase in biogenic silica deposition, reflecting higher ocean productivity during interglacials. This antiphasing persisted throughout the last 25 glacial cycles. Dust deposition became more pronounced across the Mid-Pleistocene Transition (MPT) in the Southern Hemisphere, with an abrupt shift suggesting more severe glaciations since ~0.9 Ma. Productivity was intermediate pre-MPT, lowest during the MPT and highest since 0.4 Ma. Generally, glacials experienced extended sea-ice cover, reduced bottom-water export and Weddell Gyre dynamics, which helped lower atmospheric CO₂ levels.



P3-014

Southern Ocean Antarctic Interactions within the framework of SCAR/ INSTANT

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The INSTabilities & Thresholds in ANTArctica (INSTANT; <https://www.scar-instant.org>) Scientific Research Programme provides a new, coordinating framework within the Scientific Committee on Antarctic Research (SCAR). INSTANT covers three scientific themes with ten sub-committees. The overall aim is to quantify the Antarctic ice sheet contribution to past and future sea-level change, from an improved understanding of atmosphere, ocean and solid Earth interactions and feedbacks, so that decision-makers can better anticipate and assess the risk in order to manage and adapt to sea-level rise and evaluate mitigation pathways.

Within the sub-committee Southern Ocean Antarctic Interactions (SOAS) we provide a platform to link current and upcoming paleoceanographic studies surrounding the Antarctic Ice Sheet (AIS) and paleoclimate studies on the continent to address the following questions. (1) What can we learn from new and emerging records of past AIS, Antarctic Circumpolar Current (ACC) and Southern Hemisphere Westerly Winds dynamics? (2) What is the role of changing winds, sea ice as well as surface, intermediate and deep-water circulation of the ACC on the past growth and decay of the AIS? (3) How do recent findings for the geologic past relate to future development of global mean sea level, AIS mass loss and global thermohaline circulation? (4) How can we make use of these findings in numerical modeling? (5) How do we integrate these findings with records from the Antarctic continent (e.g., shallow-marine cores, ice cores, glacial erratics) and the Southern Hemisphere mid-latitudes (Australia, New Zealand, Patagonia)? Time scales of primary interest are glacial terminations, the Last Interglacial, the Mid-Brunhes and the Mid-Pliocene.



P3-018

Weddell Sea embayment deglaciations traced by provenance of subglacial till and ice-rafted debris

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We seek to improve the understanding of the ice sheet response to warming climate in the Weddell Sea embayment of Antarctica. Recent glacial terminations provide examples of ice retreat in a warming world, and geochemical and geochronological provenance fingerprinting of glacially eroded detritus in marine sediment cores provides a novel way to reconstruct the location and relative timing of glacial retreat in the embayment during these terminations. Provenance tracers included ⁴⁰Ar/³⁹Ar hornblende and biotite thermochronology, U-Pb zircon geochronology, Nd isotopes, and clay mineralogy.

First we characterized the fingerprint of eroded detritus from the source areas using till in modern moraines at the edges of the Foundation Ice Stream, Academy Glacier, and Recovery Glacier (Agrios et al., 2021). We then analysed subglacial till and proximal glacial marine sediment from cores along the front of the Filchner and Ronne Ice Shelves to trace ice flow lines during the last glacial termination. Finally, we used these source characterizations to document stratigraphic changes in provenance of ice-rafted detritus (IRD) and glacially-eroded sediment in a deep water sediment core, PS1575-1 in the NW Weddell Sea.



P3-038

Rapid response of chemical weathering to millennial-scale climate variability revealed by Li isotopes in Brazilian speleothems

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Chemical weathering delivers nutrients to the ocean and draws down atmospheric carbon dioxide, making it a key process in the global carbon cycle. However, weathering of the Earth surface is spatially highly variable and its response to climate variability remains poorly quantified. Novel approaches to reconstruct past terrestrial weathering at a catchment scale are needed to gain a better understanding of how climate mediates chemical weathering processes.

Cave drip-water chemistry is influenced by weathering processes in the overlying soils [1], such that past weathering changes can be reconstructed using lithium (Li) isotopes in speleothems [2]. Here we present new speleothem Li isotope records from Central Eastern and Northeastern Brazil in order to explore past changes in regional weathering processes in response to late Pleistocene climate variability. Specifically, we assess the effects of precipitation changes during the deglaciation and soil erosion during the Holocene, which were independently reconstructed using other proxies [3,4].

Deglacial variability in Li isotopes was related to millennial-scale climate oscillations, while larger Li isotope changes during the Holocene period appear to have been driven by Meghalayan aridity and soil erosion. Overall, these new records indicate a rapid coupling between local climate, soil formation, and chemical weathering processes, with implications also for understanding the controls on past seawater Li isotope compositions.

1. Wilson et al. (2021), *GCA* 312, 194-216.
2. Pogge von Strandmann et al. (2017), *EPSL* 469, 64-74.
3. Strikis et al. (2018), *PNAS* 115, 3788-3793.
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P3-021

Simulating dust and its impact on the ocean throughout the whole Phanerozoic

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Dust plays a pivotal role among different components of the Earth system, and in particular when transported from land to the ocean, the nutrients dust carries can further effect the marine ecosystem. While there is relatively good knowledge of the modern global dust emission and its interactions with the ocean, it still remains unclear on geological time scales. Here we use the new series of experiments from the coupled general circulation model HadCM3 to extend paleoclimate simulations covering the entire Phanerozoic and to force an offline dust model to simulate dust emissions for each geological stage. Further studies will use dust as the input to drive a biogeochemistry model to explore the effects of dust on ancient oceans. Our preliminary results give a long-term variation record of dust emission that corresponds to the simulated experimental conditions settings. Most notable is the significant amount of dust during the mid-Triassic and the very low dust amount for the early-Carboniferous. To what extent the changes in the marine ecosystem during these periods are attributed to dust will be further investigated. This study will lead to new knowledge of dust record reconstructions and insights into the role of dust on ancient oceans on time scales of multi-million years.



P3-024

Quantifying environmental impacts on planktic foraminifer in modern and LGM oceans using the trait-based model ForamEcoGENIE

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The rich planktic foraminifer morphology traits and abundance data are the basis of studies of impacts of long-term environmental changes on biodiversity and ecosystem function. However, our current understanding of physiological processes limits our ability to assess future climate change impacts. Trait-based models allow us to directly link environmental changes with ecophysiological processes to predict biodiversity and biogeochemical dynamics in past and future climates. Here, we extend the trait-based foraminifer model ForamEcoGENIE (coupled to the EMIC cGENIE) by incorporating important traits of symbiosis and spine traits to resolve four key foraminifer functional groups. We calibrate the model based on modern foraminifer datasets and quantify the impacts of environmental changes on foraminifera diversity and biogeochemical function in the Last Glacial Maximum.

ForamEcoGENIE successfully captures the modern global distribution and seasonal variability of each functional group compared to the ForCenS core-top data, with the symbiont-obligate group dominating subtropical gyres and the symbiont-barren groups in the productive subpolar oceans. Compared to plankton net tow and sediment trap data, the model runs overestimate the global mean biomass of each group and underestimate the global mean organic carbon export by 40%. The model predicts that foraminifera contribute ~20% of the global pelagic PIC production, with 7.7% from symbiont-barren non-spinose foraminifera and 2.6% from symbiont-obligate spinose foraminifer. We apply ForamEcoGENIE to the Last Glacial Maximum and diagnose the drivers of biogeographic distribution and impacts on the strength of the carbonate pump.

Poster abstracts



Topic 3: System Interactions and Thresholds

virtual posters



Pv-301

Climate variability in the Tropical Indian Ocean during the LGM and Mid-Holocene

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The present-day tropical Indian Ocean features weaker seasonal and interannual temperature variability compared to its Pacific or Atlantic counterparts. By contrast glacial boundary conditions appear to set this sector of the global ocean for: (a) higher seasonal and interannual climate variability; (b) a Pacific-like zonal sea surface temperature (SST) gradient; (c) and the eastward shoaling of the thermocline [1]. The proxy reconstructions from the last glacial maximum (LGM) that support this picture are to date limited to continental margin settings in the easternmost tropical Indian Ocean [2]. Hence, a wider spatial coverage is needed to better characterise the regional patterns of variability and evaluate potential influences of local environmental conditions, notably at continental margins.

Here we present new results from individual planktic foraminifera $\delta^{18}\text{O}$ analysis of surface (*G. sacculifer*) and subthermocline (*N. dutertrei*) to characterize surface and subsurface ocean variability in the Indian Ocean during the LGM and Mid-Holocene (MH). Samples are from International Ocean the Discovery Program (IODP) Site U1443, an open ocean site that was drilled north of the equator in the southernmost sector of the Bay of Bengal. Up to 70 individuals of both species for LGM and MH mean climate states were analyzed to ensure a rigorous statistical analysis [3] of the data, aimed at quantifying the amplitude of variability at surface and sub-thermocline depths. Our new data document that variance at the surface was higher during the LGM and the MH than at thermocline depths, while there is virtually no changes between the two mean climate states. Results will be discussed in the context of both modern data and past reconstructions of climate variability in the Indian Ocean.

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Pv-304

Increasing variability of tropical North Queensland rainfall in a warming climate

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Floods and droughts represent hydrological extremes and impact ecosystems, agriculture, and human health. Here we develop multi-century record of tropical rainfall using multiple geochemical proxies from a Great Barrier Reef coral that extends from the mid-1700s to 1984. The final ~35 years of coral growth allow for a robust proxy calibration to reliable records of instrumental precipitation; we then apply this calibration to quantitatively estimate interannual rainfall in northern Queensland for the two centuries prior to 1950. We find that interannual variability in tropical rainfall is related to southwest Pacific Ocean temperature and hemispheric climate dynamics—including the Interdecadal Pacific Oscillation (IPO). We also find that coastal Queensland floods and droughts are 'primed' by ocean surface temperature in the South Pacific Convergence Zone, including during the period prior to reliable instrumentation.



Pv-303

Northern Hemisphere glaciation at the Oligocene-Miocene Transition?

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The major advance and retreat of the Antarctic ice sheet across the continental shelf at the Oligocene-Miocene Transition was associated with sea level changes on the order of ~50m (Mawbey and Lear, 2013). The climate transition was apparently paced by ~100kyr orbital cycles and associated with moderate variability in pCO₂ (Liebrand et al., 2017; Greenop et al 2019). Satisfying these proxy constraints is challenging for most ice-sheet model simulations. One solution may be incorporating the marine ice cliff instability mechanism into models of the Antarctic Ice Sheet (Pollard et al., 2015), which has significant implications for future sea level predictions (DeConto and Pollard, 2016). Another potential solution could be that the transient glaciation included some component of northern hemisphere ice which would lack the strong hysteresis effect that characterises the Antarctic Ice Sheet.

Here we present new and published benthic foraminiferal trace metal and stable isotope records from Newfoundland Drift IODP Site 1406, Ceara Rise ODP Sites 926 and 929, Walvis Ridge ODP Site 1264 and Agulhas Ridge ODP Site 1090. We also present new planktonic foraminiferal trace metal and stable isotope records from Ceara Rise ODP Site 926. Our records imply a major ventilation event in the north Atlantic at the onset of the Oligocene-Miocene glaciation, and a marked freshening of low latitude waters during the glacial maximum.

We use the HadCM3BL model following the same procedure as Lauretano et al. (2021) with Chattian paleogeography to generate a series of equilibrium simulations with varying pCO₂ (280ppm, 560ppm, 1120ppm) and global ice volume (ice free, East Antarctica glaciated, full Antarctic glaciation, full Antarctic glaciation plus northern hemisphere glaciation). We use these model results and our geochemical records to discuss the possibility of northern hemisphere glaciation at the Oligocene-Miocene boundary, and ice-ocean-carbon cycle feedbacks in the climate system.



Pv-302

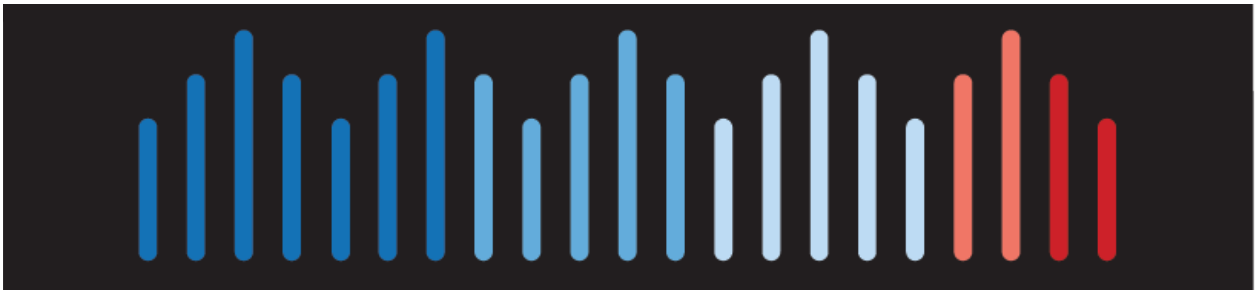
Influence of Antarctic Sea ice distribution on the Southern Ocean Overturning Circulation

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The changes invoked in the Southern Ocean physics are dynamically linked to Southern Hemisphere westerlies, ocean current, and Antarctic sea ice distribution. Therefore, it is necessary to understand the response of the Southern Ocean dynamics to the Antarctic sea ice distribution on a basin scale. This modeling study employs a fully coupled Earth system model to investigate the evolution of Southern Ocean dynamics during the last deglacial period from 19 to 9 thousand years before the present. The simulation shows that Southern Ocean surface buoyancy flux influences the Southern Ocean overturning circulation. The results indicate that the formation and melting of Antarctic sea ice feedback influenced the coverage of surface buoyancy flux. The simulated sea ice boundary (ocean surface area covered with more than a 5% sea ice fraction) overlapped with the boundary between the Southern Ocean upper and lower meridional overturning cells'. The Antarctic quasi-permanent sea ice boundary (ocean surface area covered with more than eighty percent sea ice fraction) coincides with the transition of surface buoyancy flux from positive (surface buoyancy gain) to negative (surface buoyancy loss). The negative surface buoyancy flux zone also displaced polewards during the last deglacial period. Our study found that the increase in freshwater discharge from Antarctic sea ice melt results in a steepened north-south surface salinity gradient in the Southern Ocean, which modulated the Southern Ocean overturning circulation during the last deglacial period.

Poster abstracts



Topic 4: Improving Our Understanding of a Warmer World

on site posters



P3-067

Life in a dark environment – what was the physiological and calcification response of benthic foraminifera to the environmental changes of the Paleocene–Eocene Thermal Maximum

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The Paleocene–Eocene Thermal Maximum (PETM) represents a severe disturbance of global carbon cycling and the Earth system. Responses of marine organisms included extinction, migration and evolutionary turnover, but the role of ocean acidification on deep-sea foraminiferal calcification has not yet been quantified. Using computed tomography (CT) we investigate morphological (surface area, test volume, calcite volume) and hence calcification response in two benthic foraminiferal species, at central Pacific Site 1210 (PaleoDepth 2100m), and Southern Ocean Maud Rise Site 690 (PD 1900m) and Kerguelen Plateau Site 1135 (PD ~800m). The relative warming during the event was the same at all sites, suggesting that biotic differences are not likely related to differential warming.

The environmental change led to reduction of test volume of both species, negatively impacting their potential ability to generate gametes. Epifaunal *Nuttallides truempyi* increased its surface area relative to volume in the Southern Ocean, potentially increasing its ability to forage and take up oxygen. In contrast, there is no clear pattern of change in shallow infaunal *Oridorsalis umbonatus* which, given sufficient food, can thrive at lower oxygen conditions. Calcite volume/test volume ratio decreased in both species during the PETM in the Southern Ocean, with the lack of response at upper abyssal depth in the Pacific possibly driven by severe oligotrophy even before the excursion. Therefore, changes in food supply during hyperthermals might have been less pronounced at upper abyssal depths in the Pacific than at the other two sites. These results contrast with published results from Walvis Ridge which showed an increase in calcification in small specimens of *O. umbonatus*. Food availability at the Southern Ocean sites may have supported growth as indicated by test volumes, but did not supply enough energy for calcification to mitigate against lower carbonate ion saturation during the PETM CIE.



P3-059

South Atlantic deep-sea temperatures during the late Paleocene–early Eocene hothouse based on clumped isotope thermometry

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Reconstructing deep ocean temperature is essential to infer deep water mass distribution and therefore ocean circulation in the geological past. The late Paleocene–early Eocene is known for being the warmest period of Cenozoic, characterized by high CO₂ levels and absence of polar ice sheets. Conventional δ¹⁸O records obtained from benthic foraminifera suggest relatively stable deep ocean temperatures on long time scales (>100 kyr) in this hothouse [1,2]. However, interpretations from benthic δ¹⁸O records are complicated by non-thermal influences. For instance, it requires knowledge of the isotope composition of the seawater (δ¹⁸O_{sw}). Carbonate clumped isotope thermometry (Δ₄₇) has the advantage that it is independent of non-thermal factors, including the composition of the fluid source [3–5]. Clumped isotope reconstructions of the North Atlantic have indicated surprisingly large deep-sea temperature swings under the late Paleocene–early Eocene hothouse climate state [6]. These records reveal substantial warming at the onset of the Early Eocene Climatic Optimum (EECO) [6]. To investigate the spatial extent of these temperature changes, we generated a Δ₄₇-based deep-sea temperature record spanning the same period from the South Atlantic Ocean, a region that is assumed to represent a global signal [1,2]. Intriguingly, we find similar trends and values in deep-sea temperature as those from the North Atlantic. Our reconstructions show a major rise in temperature of ~12 °C to ~20 °C across the onset of the EECO (53–51 Ma). These findings overthrow the traditional view of a gradual warming trend based on benthic δ¹⁸O records, at least for the deep Atlantic Ocean. These results raise new questions on deep water mass structure and the regions of deep water formation in the early Cenozoic hothouse.

References

- [1] Lauretano et al. (2018)
- [2] Westerhold et al. (2020)
- [3] Ghosh et al. (2006)
- [4] Tripathi et al. (2015)
- [5] Meinicke et al. (2020)
- [6] Meckler et al. (in revision)



P3-053

Enhanced ocean oxygenation during Cenozoic warm periods

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Over recent decades, the oxygen-deficient zones (ODZs) of the ocean have expanded, affecting marine ecosystems. However, their response to future global warming is poorly understood. We investigate the response of ODZs during two periods of the past characterized by prolonged warmth: the Middle Miocene and Early Eocene climate optima (MMCO and EECO). We discuss new foraminifer-bound nitrogen isotope (FB- $\delta^{15}\text{N}$) data from Pacific ODP Site 872 and Atlantic DSDP Site 516. The new FB- $\delta^{15}\text{N}$ data combined with existing data from Kast et al. (2019) are used to reconstruct the history of ODZ hosted water column denitrification across the Cenozoic. Our results show decreased water column denitrification during both the MMCO and EECO indicating that ODZs were contracted, not expanded during these two periods of prolonged warmer climate. Timing of the denitrification decrease was closely coupled to high latitude warming and reduced meridional sea surface temperature gradients indicating that climate was the main driver of the observed changes. Possible causes for the decline in denitrification and corresponding reduction in ODZs include (i) a reduction in wind-driven equatorial upwelling and primary productivity, and/or (ii) an increase in deep-ocean ventilation.

Kast, E. R., Stolper, D. A., Auderset, A., Higgins, J. A., Ren, H., Wang, X. T., Martínez-García, A., Haug, G. H., and Sigman, D. M., 2019, Nitrogen isotope evidence for expanded ocean suboxia in the early Cenozoic: Science, v. 364, no. 6438, p. 386-389.



P3-081

New high-latitude sea surface temperature records from the South Pacific Ocean across the Oligocene

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For decades, the Oligocene has been a relatively overlooked period. Nevertheless, this time span (34.5-23 Ma) is gathering increasing attention because recent estimates of CO₂ levels and the size of the Antarctic ice-sheets are comparable to their present-day values, highlighting the potential of Oligocene climate variability to better model the sensitivity of the climate system. Attempts to model Oligocene climate dynamics are currently limited by the small number of marine cores that cover this period and allow high resolution studies. Such cores are even more scarce at high latitudes, despite these are the only regions that record the role played by continental ice variations in the climate system. Here, we present two organic biomarker-based sea surface temperature (SST) records from IODP Site U1553 in the Sub-Antarctic South Pacific Ocean recovered during IODP Expedition 378. Unlike most Oligocene SST records, which derive from oxygen isotopes and Mg/Ca of calcareous microfossils and require corrections to Oligocene ocean water chemistry, organic biomarker-based records are not dependent on water chemistry corrections. Moreover, estimation of SST from two organic biomarkers (i.e., alkenones and glycerol dialkyl glycerol tetraethers (GDGTs)) provides additional control over the possible biases that specifically affect one or the other (e.g., uncertainty related to the precursor organisms or selective lipid degradation). Our records span from 34 to 26.5 Ma and have an average resolution of 40 kyr. Both SST records show comparable variability and are characterized by multimillion variability. GDGT-SST oscillates between 26-21°C on average whereas alkenone-SST varies between 23 and 18 °C. Both records show an abrupt SST drop of 10°C ca. 27 Ma. Future work will compare these records with Mg/Ca-SST records and clumped isotope paleothermometry in coccoliths.



P3-058

Improving our understanding of greenhouse period: A multiproxy approach on actual (Modern) and fossil (Paleogene) planktonic foraminifera.

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Following the IPCC AR5 RCP8.5 emission scenario, global atmospheric carbon dioxide is expected to exceed 600 ppm by 2050. Greenhouse periods in the geological past have received much attention as indicators of the response of the Earth to elevated atmospheric CO₂. Among them, the PETM (55 Ma), the EECO (51-53 Ma), the MECO (40 Ma) are considered as period of interest with high and varying atmospheric pCO₂ and global temperature. Hence, it becomes critical today to improve paleoclimate proxies and climate models under greenhouse conditions, in order to predict future warmer world. In order to improve multi proxies' calibration of temperature estimates, δ¹⁸O, Mg/Ca & Sr/Ca and porosity were applied to the modern planktonic foraminifera *Trilobatus sacculifer*, collected along a North-South transect of the Atlantic Ocean, while seawater T°C, ALK, DIC salinity, and δ¹⁸O were recorded. This method allowed us to calibrate the impact of salinity and carbonate chemistry variations on temperature reconstructions, and to establish the first porosity-T°C calibration.

The same four proxies were applied on the subsurface planktonic foraminifera *Subbotina linaperta*, sampled every 2 Ma over the Paleogene, on four different sites following a latitudinal gradient (DSDP 549/43°N, DSDP 401/47°N, ODP 689/690 /68°S, ODP 865/18°N).

For the first time, estimated temperature patterns issued of the three proxies are consistent with each other and highlight both a latitudinal gradient over the Paleogene and the intense warming episodes. The inclusion of Sr/Ca in the equation of T-Mg/Ca improves drastically temperature reconstructions over long time-scale by limiting biases related to other environmental parameters. In parallel, the porosity appears to be a valuable complementary tool at low latitudes, where pristine geochemical properties are often obliterated by diagenetic processes.



P3-079

Oligocene climate and Antarctic ice-sheet instability: evidence from clumped-isotope thermometry

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Reconstructions derived from deep-sea oxygen isotope records suggest large fluctuations in East Antarctic ice-volume between 29 to 26 million years ago (Ma), in the middle Oligocene. According to these reconstructions, changes in ice-volume were primarily paced by 100-kyr eccentricity cycles. The largest fluctuations involved complete melting of a modern-sized East Antarctic ice-sheet, while smaller fluctuations suggest reductions to one third to one half of that size. While sea-level reconstructions support large variations in ice-volume in the middle Oligocene, cyclical large-scale fluctuations are difficult to reconcile with our understanding of ice-sheet dynamics. Even when ice-sheet models are forced with large changes in atmospheric CO₂ (>500 ppm), a full melting of a modern-sized ice-sheet is not reached due to strong hysteresis.

A major limitation of oxygen isotope-based ice-volume reconstructions is that the oxygen isotope signal in calcite is also controlled by seawater temperature. To address the behavior of the Antarctic ice-sheet between 27 and 28 Ma, we are measuring clumped isotope (Δ_{47}) temperatures on benthic foraminifera at ODP Site 699, in the Atlantic sector of the Southern Ocean, at a 30 thousand year (kyr) resolution. Clumped isotope thermometry is independent from the oxygen isotope composition of seawater, hence the temperature component in the foraminiferal $\delta^{18}\text{O}$ signal can be isolated. With our new record, we aim to track 100 kyr-eccentricity cycles and test whether deep ocean temperature could explain the large fluctuations in $\delta^{18}\text{O}$ observed in the middle Oligocene, which would eliminate the need for continental-scale waxing and waning of the East Antarctic ice-sheet.



P3-107

Limited Exchange Between the Deep Pacific and Atlantic Oceans During the Warm Mid-Pliocene and MIS M2 “Glaciation”

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As the most recent interval in Earth’s history of sustained global warmth, the mid-Piacenzian Warm Period (mPWP: 3.3–3.0 Ma) has long been cited as a useful point of comparison for future, warmer-than-present climates. Considerable efforts have been made to characterize and understand climate dynamics of the mid-Pliocene over the past few decades, but deep-sea temperature records for the mPWP are sparse and often contradictory.

Here we present new benthic foraminiferal Mg/Ca and Δ_{47} (“clumped isotope”) temperatures from the Pacific (ODP Site 849, water depth: 3851 m) and North Atlantic (IODP Site U1308, water depth: 3871 m) oceans. Our new records cover the warmest and coldest intervals of the mPWP, allowing us to assess mean deep-sea temperatures as well as variability over key warming and cooling stages.

Our results show that the deep North Atlantic Ocean was considerably warmer than at present, with both proxy records agreeing on average temperatures of ~ 7 °C across the studied interval. In contrast, our Pacific data indicates average temperatures that were much colder (~ 3 °C, only slightly warmer than today) A cooling of 3–4 °C associated with the enigmatic Marine Isotope Stage (MIS) M2 event is evident at both sites.

We interpret our results to indicate that the deep Pacific and North Atlantic oceans were bathed by different water masses during the mPWP, and that only limited heat exchange occurred between the two basins at this time. Despite similar benthic foraminiferal $\delta^{18}\text{O}$ at both sites, temperatures and seawater $\delta^{18}\text{O}$ were markedly different, the latter likely reflecting differences in salinity. This points to a fundamentally different mode of ocean circulation or mixing compared to the present. The amplitude of cooling observed at both sites during MIS M2 suggests that the positive oxygen isotope excursion associated with this event is largely reflective of global-scale cooling in the deep ocean rather than a substantial increase in ice volume on land.



P3-130

Exploring the distribution and diversity of planktonic foraminifers under multiple climatic stressors: FORCIS database

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Planktonic foraminifers are a good paleo-environmental indicator due to their excellent fossil preservation in deep-sea sediments. Their distribution and diversity are affected by different environmental stressors such as the anthropogenically forced ocean and climate change. Up to now, historical changes in distribution of planktonic foraminifer species have not yet been assessed at the global scale.

The FORCIS (FORaminifera Response to Climatic Stressors) project aims to collect information from published and unpublished data since 1910 to today regarding the planktonic foraminifer diversity and distribution from the global ocean and compile a comprehensive database. The FORCIS database is composed of more than 180,000 samples, including ~157,000 Continuous Plankton Recorder (CPR), ~16,500 net tow, and ~7,000 sediment trap samples.

Our database provides a first insight in the distribution patterns of planktonic foraminifers in the global ocean at different scales over the past decades. The relationships between the abundance of the modern planktonic Foraminifera species and the different size classes and water depth ranges have been assessed, and facilitates modelling of the total abundance starting from the test size fraction larger than 100 μm . While total abundances decrease with depth, and standing stocks span a large range of magnitudes at the regional scale, historical changes in the distribution pattern indicate a poleward increase of foraminifer abundances during the past 30 years. An increasing number of warm water species were recorded at higher latitudes, and the abundance of some tropical species was decreasing at lower latitudes. The latitudinal diversity gradient of modern assemblages, comparing 10°-latitudinal bands, shows the same trends as in the surface seafloor sediments (ForCenS dataset, Siccha and Kucera, 2017, Scientific Data).



P3-092

Marine primary productivity and nutrient utilization during the Miocene Climatic Optimum in the Ross Sea, Antarctica

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The Cenozoic variability of the West Antarctic Ice Sheet (WAIS) has been well documented, however limited ice-proximal records of the of ice sheet-ocean dynamics exist. The Miocene was a period of significant climatic variability, including both the Miocene Climatic Optimum (MCO; 17-14.5 Ma) and an interval of Antarctic ice expansion during the Miocene Climatic Transition (MCT; 14 Ma). Low-latitude marine records (i.e., benthic foraminifera) indicate that the onset of the MCO is marked by global warming and/or ice volume decrease accompanied by carbon cycle perturbation. Changes in marine primary productivity in an ice proximal environment can be used to explore ocean-ice sheet dynamics and investigate the role of biological productivity in regulating atmospheric CO₂.

IODP Site U1521 was drilled in the Pennell Basin on the outer continental shelf of the Ross Sea and document a transition from glaciomarine to open marine sediments during the early – middle Miocene. Recently published geochemical and petrographic data document expansion of the WAIS during the early Miocene (~17.8 – 17.4 Ma). Following this period, there is a return to open marine conditions with high biogenic opal (bSi) content (20 – 60- wt. %) indicating increased marine primary productivity from 17.2-15.8 Ma. Silicon isotope ($\delta^{30}\text{Si}$) in diatom frustules vary (1.2-1.8 ‰) over this interval suggesting a change in 1) the source of dissolved silica (DSi) and/or 2) nutrient utilization patterns. We interpret $\delta^{30}\text{Si}$ variability as a change in the source of nutrients with low values representing meltwater pulses associated with lower DSi $\delta^{30}\text{Si}$ values and high $\delta^{30}\text{Si}$ values as a result of limited supply of DSi due to a well stratified ocean. The coupled bSi diatom $\delta^{30}\text{Si}$ variability provide important constraints in bSi production and nutrient utilization in the Ross Sea during the MCO and allow us to explore the link between a highly dynamic Antarctic ice sheet, biologic productivity, and global climate.



P3-073

Exploring the CO₂ record of the early to middle Eocene using LA-MC-ICPMS δ¹¹B of large benthic foraminifera

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Constraining Earth's climate sensitivity using past climate reconstructions is one of the key contributions of palaeoclimate data to preparing for ongoing anthropogenic climate change. Precisely determining atmospheric CO₂ concentrations during past warm intervals such as the early-middle Eocene is an ideal target in this respect. Of the available palaeo-CO₂ proxies beyond direct ice core measurements, the boron isotopic composition of marine carbonates is the most reliable method of producing quantitative pH/CO₂ reconstructions. However data are lacking, or available at low resolution only for parts of the Eocene.

We use our recently-established boron isotopes empirical calibration (Coenen *et al.* in prep.) of the extant shallow-dwelling large benthic foraminifera *Operculina ammonoides* to reconstruct pH/CO₂ in the early-middle Eocene. The advantage of this genus is that it extends back to the early Paleogene and is also closely related to the abundant and widespread Eocene *Nummulites*. This calibration allows the conversion of the measured boron isotopic composition of the foraminifera test into a seawater pH estimate, that in turn can be converted into an Eocene atmospheric pCO₂ estimate.

We use a collection of fossil *Nummulites* samples of the Paris Basin, from both modern and museum collections sampling, and the Hampshire basin to reconstruct early and mid-Eocene pCO₂. Sample preservation was assessed by SEM to diagnose possible recrystallisation and LA-ICPMS to evaluate chemical preservation. For instance, lowering of the normally high Mg/Ca and Sr/Ca, characteristic of the large benthic foraminifera, was associated with diagenetic recrystallisation. The more pristine samples were then analysed with LA-MC-ICPMS to determine their boron isotopic composition; corresponding results will be presented. The use of laser ablation for spatially resolved δ¹¹B measurements and the extant *Operculina* genus aims to improve palaeo-pH/pCO₂ reconstructions of the early Paleogene.



P3-115

Nordic Sea Deep-Water susceptible to enhanced freshwater export to the subpolar North Atlantic during peak MIS 11

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Recent investigations into Marine Isotope Stage (MIS) 11 (424-403 ka) a long and unusually warm interglacial of the Quaternary Period have found that the Atlantic Meridional Overturning Circulation remained strong while background melting of the Greenland Ice Sheet (GIS) was high and resulted in a fresh and cold surface ocean in the Nordic Seas. These investigations support the hypothesis that deep-water formation may not be as susceptible to future melting of the GIS as previously thought. Here we test this hypothesis and present a palaeoceanographic investigation of a freshwater related abrupt climate event recorded in the eastern North Atlantic during peak interglacial conditions, when the GIS was smaller than today. Using sediment core DSDP-610B recovered from the Western Rockall Trough; Feni Drift, we reconstruct the evolution of Nordic Seas Deep-Water (NSDW) by means of grain size analysis and endmember modelling. Further, a combination of planktonic foraminiferal assemblage census and Ice-Rafted Debris (IRD) counts allow us to reconstruct surface water properties: temperature and the movement of oceanic fronts throughout this event. Our results show a reduction of NSDW concurrent with a sudden release of fresh and cold surface waters from the Nordic Seas into the subpolar North Atlantic. Placing our results in the palaeogeographical context of the North Atlantic Region we tentatively propose that the ocean-atmosphere climate dynamics linking the Nordic Seas with the subpolar North Atlantic will play a crucial role for the stability of NSDW formation in the future considering the enhanced hydrological cycle at high Northern latitudes predicted for future climate scenarios.



P3-066

Evidence of enhanced silica weathering after the Palaeocene-Eocene Thermal Maximum

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The Palaeocene Eocene Thermal Maximum (PETM) was a hyperthermal event about 56 Ma ago when the global temperature rapidly increased due to massive carbon release into the atmosphere. During the recovery phase of the PETM, the global temperature returned to the pre-PETM level, due to the enhanced removal of carbon from the atmosphere and the ocean. The mechanism of the recovery phase has been under debate, but the strengthened silica weathering has been thought to be a likely contributor to the carbon removal. Here, we present new silicon isotope records in marine silica (radiolarian and sponge spicules) to reconstruct changes in the marine silica cycle during the PETM. Our reconstructions show that despite no increase in silica concentration can be detected, a negative shift in the silicon isotope of the silica in the surface ocean on timescales of hundreds of thousand years indicates enhanced silica weathering that contributed to carbon removal from the ocean.



P3-111

South Atlantic deep-sea temperature evolution across the Pliocene-Pleistocene transition from clumped isotope thermometry

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The reconstruction of deep-ocean temperatures is key in the study of the different climate states in the geological past. Reconstructions covering the Pliocene-Pleistocene transition shed light on the global climatic change that followed the mid-Pliocene warm period and culminated in full glaciation of the Northern Hemisphere.

Global $\delta^{18}\text{O}$ records measured on seafloor dwelling foraminifera constitute the backbone of our understanding of the climatic trends and transitions of the last 65 million years [1,2]. Over the glacial intensification of the last 3 Ma, these records have been translated into ice volume and temperature components. However, such interpretation of carbonate $\delta^{18}\text{O}$ data is built upon uncertain assumptions regarding the isotopic composition of ancient seawater.

Carbonate clumped thermometry ($\Delta 47$) is based on thermodynamic principles that govern the abundance of ^{13}C - ^{18}O bonds within the crystal lattice, therefore granting it independence from estimations surrounding the composition of the precipitating fluid [3]. $\Delta 47$ thermometry has revealed warmer deep oceans for the Eocene, as well as for the Miocene, in comparison with traditional stable oxygen isotope records [4, 5].

Here we present $\Delta 47$ -based deep-sea temperature constraints across the Pliocene-Pleistocene transition obtained from benthic foraminifera of ODP Site 1264 in the South Atlantic Ocean. We furthermore show that the change of benthic $\delta^{18}\text{O}$ across the Northern Hemisphere Glaciation is indicative of a decrease in global temperatures, but does not appear to contain a signal for ice volume.

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P3-126

Drivers of margin hypoxia in the late Pleistocene-Holocene North Pacific

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Expansion of mid-depth oxygen minimum zones (OMZs), potentially related to global climate change, can have dramatic consequences along upwelling continental margins. In the Pacific Northwest (PNW), prolonged seasonal upwelling of increasingly oxygen-poor, nutrient-rich waters from the OMZ is disrupting ecosystems, biogeochemical cycles, and fisheries. Mechanisms driving hypoxia in these upwelling waters may include: reduced oxygen solubility from warming; reduced downward mixing of surface oxygen due to stronger vertical stratification; heightened respiration and oxygen demand driven by increased export productivity; and slowed subsurface ocean circulation allowing time for oxygen utilization. Hypoxic events occurred in upper continental slope environments during late glacial and early Holocene warm intervals. However, precise mechanisms driving hypoxia in this region remain obscure.

Our research aims to better constrain hypoxia linked to ice sheet dynamics and climate by using a suite of marine sediment cores collected during the Cascadia H.O.P.S. Cruises in 2017 and 2020 from the continental slope of northern Oregon to northern Washington. Initial core observations and computed tomography (CT) scans show preservation of finely laminated lithofacies in upper slope sediments deposited during the late Pleistocene/early Holocene (~640m – 900m water depth). Preliminary radiocarbon-based age models indicate sediment accumulation rates in the early Holocene were similar to overlying sediments with strong bioturbation. Faunal analyses reflect the prevalence of low-oxygen tolerant benthic foraminifera, and XRF data supports enrichment of redox sensitive elements. We will further explore the origins, expression, and duration of these events across the depth transect using stable isotope and trace element geochemistry, foraminiferal faunal analyses and μ CT-scans, and high-resolution radiocarbon geochronology.



P3-085

Insight into Late Miocene ice volume variability from a global benthic foraminiferal isotope compilation (8.0-5.0 Ma)

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Benthic foraminiferal stable isotope stratigraphies track changes in past deep-sea temperatures, global ice volume and the carbon cycle in response to astronomical forcing. Our understanding of Plio-Pleistocene climate has improved through the study of global (LR04; Lisiecki & Raymo, 2005) and regional benthic foraminiferal $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ compilations (Ceara Rise; Wilkens et al., 2017). Here we present the first global Late Miocene benthic foraminiferal $\delta^{18}\text{O}$ stack spanning 8.0-5.0 Ma. We use six high-resolution, continuous benthic stable isotope stratigraphies to compile a "Base Stack", with data from the Atlantic (ODP Sites 982 (N), 926 (E) and 1264 (S)), Indian (IODP Site U1443) and Pacific Oceans (IODP Sites U1337 and U1338 (E), ODP Site 1146 (W)). Where needed, we verified the stratigraphy and established independent astrochronologies to avoid miscorrelation of individual excursions. To complement the "Base Stack", we also compile a "Global Stack", which incorporates all available high-resolution single-hole benthic $\delta^{18}\text{O}$ stratigraphies to optimise global coverage.

This new global Late Miocene benthic $\delta^{18}\text{O}$ stack represents a reference section back to 8.0 Ma, which is tied to the Geomagnetic Polarity Time Scale from Chrons C3r to C4n.2n using the Site U1337 magnetostratigraphy. We recognise new Marine Isotope Stages in the $\delta^{18}\text{O}$ stack between 7.7 and 6.5 Ma. An exceptional global response, with 40-kyr cyclicity, is imprinted on all sites from 7.7-6.9 and 6.4-5.4 Ma. This response is dampened between 6.9-6.4 Ma, when sites display regional differences to astronomical forcing. The influence of deep-sea temperature and ice volume on benthic $\delta^{18}\text{O}$ is explored at Site U1337 using Mg/Ca data combined with cycle shape analysis. The 40-kyr driven $\delta^{18}\text{O}$ cycles are asymmetric, suggesting dynamic ice volume control. The asymmetry is especially distinct from 7.7-6.9, prior to the late Miocene cooling and the growing influence of high-latitude processes in the Northern Hemisphere.



P3-091

Micropaleontological reconstruction of Miocene Ross Sea (Southern Ocean) paleoenvironmental conditions

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IODP Exp. 374 drilled five sites from the outer continental shelf to the rise in the eastern Ross Sea to resolve the relationship between climatic and oceanic change and West Antarctic Ice Sheet (WAIS) evolution through the Neogene and Quaternary. WAIS collapse events during warmer-than-present climates may be the consequence of intensified ocean-cryosphere interactions. Interactions between the wind-driven upwelling of warm Circumpolar Deep Water (CDW) and the ice shelves that buttress the WAIS appear to play a significant role in modern ice mass loss and ice sheet instability. It needs to be proven whether changes in either the formation of Antarctic Shelf Water and Antarctic Bottom Water or the vigor of the wind-driven Antarctic Shelf Current control incursions of CDW onto the shelf and the resultant retreat of the WAIS. Stratigraphic records from **Exp. 374** will allow us to address this issue by assessing changes in past water temperature and ice sheet extent.

This study aims to gain insight into the paleoenvironmental development of the inner Ross Sea and the adjacent WAIS with emphasis on the Miocene Climatic Optimum and subsequent cooling during the Miocene Climate Transition. To address changes in productivity, sea surface temperatures and sea ice extent, diatom analysis was applied to selected sediment samples. The analyzed section of inner-shelf Site **U1521** displays a 200-meter-thick sequence of diatomite and diatom-rich mudstone, deposited between 16.4 and 16.0 Ma, stratigraphically constrained by the *Denticulopsis maccollumii* Zone at the top of the Lower Miocene. The sequence is characterized by varying diatom preservation, from poor at the bottom of the sequence to good in the upper part. The analyzed section of outer-shelf Site **U1522** comprises a 200-meter-thick sequence of Upper Miocene diatom-bearing sandy diamictite. Here, the preservation of the diatoms is rather poor across the whole section, but still allows some assumptions on environmental changes.



P3-071

High-frequency orbital cyclicity in Arctic seawater temperatures during Eocene Thermal Maximum 2

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Our understanding of early Eocene climate remains flawed by its enigmatic low meridional temperature gradients. To further understand the related climate dynamics (e.g., poleward heat/moisture transport and seasonality) there is a general need for more marine temperature proxy reconstructions from polar regions. Furthermore, the resolution of the few existing polar data is generally insufficient to assess orbitally driven climate fluctuations, leaving the effect of high-frequency climate variability and the relation of extreme warm climates unresolved.

The Arctic Coring Expedition (ACEX) recovered a Paleocene to lower Eocene sequence comprised of organic-rich siliciclastic mudstone barren of carbonates from Lomonosov Ridge. Previous sea surface temperature (SST) reconstructions of the early Eocene interval based on organic biomarker proxy TEX_{86} depicted an exceptional warm Arctic Ocean, with values exceeding 20 °C and reaching as high as 26 °C and 27 °C during Paleocene Eocene Thermal Maximum (PETM) and Eocene Thermal Maximum 2 (ETM-2). Decimeter scale variations in color and iron content surrounding ETM-2 have earlier been suggested to be related to orbital cyclicity, particularly obliquity. Here we assess if this cyclicity is associated with temperature and hydrological variability. We apply TEX_{86} to reconstruct Arctic temperatures and BIT index values to assess the supply of terrestrial biomarkers at a 1-cm (2-ky) resolution on a ~4 m interval surrounding ETM-2. This allows analysis of the effect of high frequency orbital cyclicity (precession and obliquity) on the local hydroclimate and its relation to global change.



P3-128

Nitrogen isotope constraints on southwestern Indian Ocean variability in the late 20th century

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Tropical variability in the Indian Ocean impacts both regional and global climate via atmospheric teleconnections. The ocean–atmosphere dynamics in the tropics are extremely sensitive to perturbations associated with natural and anthropogenic climate change, and respond to these changes on multiple (seasonal, interannual, and multi-decadal) time scales. Despite their importance in informing our understanding of past and future climate, however, observational data of Indian Ocean variability is sparse over the 20th century, and little consensus exists as to the response of the Indian Ocean to long term anthropogenically-forced climate change.

One particularly under-sampled region is the Southwestern Indian Ocean, which plays a significant role in the regional climate of the Indian Ocean on seasonal and interannual timescales. Here we present monthly-resolved coral skeleton-bound nitrogen isotope (CS- $\delta^{15}\text{N}$) data from a pair of *Porites* coral cores collected at St. Joseph Atoll, in the Seychelles Archipelago. This data, which spans the time period between 1915-2021, shows distinct seasonal variations in CS- $\delta^{15}\text{N}$ that correlate with monsoonal-driven upwelling. In addition, the CS- $\delta^{15}\text{N}$ record varies on decadal timescales. We compare these variations with changes in $\delta^{18}\text{O}$ (itself sensitive to changes in temperature and salinity) in order to distinguish the drivers of the observed decadal-scale variability in CS- $\delta^{15}\text{N}$ (for example, fluctuations in the influence of the Indonesian Throughflow). Taken together, these records allow us to better characterize the variability of the southwestern Indian Ocean during a period in which observational data for the region is scarce, and in doing so better understand the regional impacts of anthropogenic climate change.



P3-099

Orbital scale variability and evolution of the Indian Monsoon during the Pliocene: new data from the Andaman Sea

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The Indian summer monsoon (ISM) is a critical component of the overarching Asian monsoon system, which dominates seasonal rainfall patterns over the region. The underlying mechanisms controlling monsoon variability include internal forcings (e.g., ice volume, ocean circulation) and external forcings (e.g., solar insolation), operating over a range of time scales from tectonic to decadal. While there is now considerable data from regions dominated by the SE Asian monsoon, there remains a significant data gap for the regions affected by the Indian monsoon, particularly prior to the late Pleistocene. Many unknowns remain regarding the response of ISM to past changes in global climate, such as during the intensification of Northern Hemisphere glaciation in the late Pliocene (~2.5–3.5 Ma). Key questions centre on the role of external vs. internal forcing at controlling both long-term and orbital-scale monsoon variability, and whether wind and rainfall responses were coupled during these transitions.

Here, we present a high resolution (~4 kyr), benthic oxygen isotope age model spanning from ~2.4 to 4.0 Ma for IODP Site U1448 in the Andaman Sea. This record allows us to interrogate (X-ray fluorescence) bulk elemental data from the same core to reconstruct past ISM behaviour across this enigmatic interval. Trends in elemental ratios representing terrestrial runoff and marine productivity (linked to ISM strength) show both long-term evolution in response to changing boundary conditions, and the influence of orbital forcing. Additionally, high resolution benthic carbon isotope data allows us to track changes in both water mass and marine productivity associated with orbital-scale variability in this region. Comparison of this data with comparable data from IODP Site U1445 in the NW Bay of Bengal allow us to examine spatial and temporal trends in ISM strength during the Pliocene, and identify changing loci of dominant precipitation across this region with time.



P3-102

Constraining the amplitude of Antarctic Ice Sheet change during warm intervals of the Pliocene

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Despite a major effort to constrain peak sea level during the mid-Pliocene warm period, uncertainties remain large. This interval is of interest because of the analogous CO₂ concentration to present day and because of the potential retreat of a large portion of the Antarctic Ice Sheet. The usefulness of this period to constrain ice sheet model physics is limited by these large uncertainties on peak sea level. Here we discuss efforts to produce a new record of the amplitude of sea level change from interglacial to glacial periods during the early and mid-Pliocene, which have lower uncertainties than peak sea level. We combine this effort with new climate and ice sheet model simulations of the glacial to interglacial cycle for ice sheets in both hemispheres. We discuss how this work will constrain the magnitude of Antarctic Ice Sheet retreat during warm intervals of the mid-Pliocene and how we use these constraints to discriminate between different ice sheet model physics.



P3-076

Antarctica in the early Eocene: Interpreting results from the DeepMIP simulations.

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The warmth of the early Eocene climate as seen in proxy temperature reconstructions has long proved challenging to reconcile with the output of coupled ocean-atmosphere climate models. This model-data mismatch is most pronounced at the high latitudes and for the Southern Ocean and Antarctica in particular. Following an informal intercomparison of climate models of the early Eocene (EoMIP), in which different groups had used different boundary conditions (paleogeography, atmospheric greenhouse gas concentrations) in their simulations, a formal intercomparison project with prescribed boundary conditions was recently established. In the framework of the Deep Time Climate Model Intercomparison project (DeepMIP), 36 early Eocene simulations from 8 different groups have been performed. Here we focus on the climate state of the Antarctic continent within these simulations and compare these results with proxy reconstructions.



P3-070

The relationship between the global mean deep-sea and surface temperature during the Early Eocene

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Our current understanding of global mean (land and sea) surface air temperature (GMSAT) during the Cenozoic era relies on paleo-proxy estimates of local deep-sea temperature combined with assumed relationships between global mean deep-sea temperature (GMDST), global mean sea-surface temperature (GMSST), and GMSAT. The validity of these assumptions is essential in our understanding of past and future climate states under hothouse conditions. We analyse the relationship between these global temperature indicators in 25 different millennia-long model simulations of the Early Eocene Climate Optimum (EECO, 56–48 Ma) climate under varying CO₂ levels, performed as part of the Deep-Time Model Intercomparison Project (DeepMIP). The model simulations show limited spatial variability in DST, indicating that local DST estimates can be regarded representative of GMDST. Linear regression analysis indicates that GMDST and GMSAT respond more strongly to changes in atmospheric CO₂ than GMSST by factors 1.18 and 1.17, respectively. Consequently, the responses of GMDST and GMSAT to atmospheric CO₂ changes are similar in magnitude. The best fit with paleoceanographic proxies of GMDST, GMSST, and GMSAT during EECO is found in the model simulations with atmospheric CO₂ level of 1,680 ppm. This CO₂ concentration matches with paleo proxies of atmospheric CO₂ during EECO. This model-based analysis validates the assumption that changes in GMDST can be used to estimate changes in GMSAT during the EECO. Similar analyses of other climate states should reveal whether these results are robust throughout the Cenozoic and provide essential insight into future climate under various shared socioeconomic pathways.



P3-065

Exploring approaches to extinct planktic foraminifera $\delta^{11}\text{B}$ vital effects: Implications for Paleocene-Eocene Thermal Maximum and Eocene Thermal Maximum 2 $p\text{CO}_2$ reconstructions

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Despite observations that boron incorporation into planktic foraminifera tests is largely drawn from dissolved borate ions, species-specific vital effects cause small deviations from the stable boron isotopic compositions ($\delta^{11}\text{B}$) of seawater borate¹. Vital effects complicate paleo-reconstructions from this proxy, particularly in extinct species, where the vital effect must be estimated through a modern analogue. The choice of analogue represents one of the largest sources of uncertainty in $p\text{CO}_2$ reconstructions. For instance, calibration uncertainties are pronounced across early Eocene hyperthermal events, when 1000s of Gt C were released to the atmosphere, but our ability to accurately quantify the carbon cycle perturbation is limited. Records spanning these events use different extinct foraminifera species, further complicating direct comparison. A study of the Paleocene-Eocene Thermal Maximum (PETM) analyzed several foraminifer species to estimate relative differences between extinct species' vital effects². While results were reasonable for the core site analyzed in that study, the applied vital effects result in inverted pH depth profiles or water column anoxia when applied to other early Eocene multi-species records³, which is unexpected given modern observations.

Using published hyperthermal $\delta^{11}\text{B}$ records, we revisit approaches to estimate vital effects of extinct species, and systematically explore implications for early Eocene pH profiles. Our results suggest two extant species, *T. sacculifer* and *G. ruber*, may be useful analogues as relative differences in vital effects match two PETM species, reaching a consensus between profile constraints and time series comparison. We explore the implications of our strategy on PETM and Eocene Thermal Maximum 2 (ETM-2) $p\text{CO}_2$ reconstructions using a forward boron proxy model and Bayesian statistics.

¹Hönisch et al., 2021. *Paleocean. Paleocl.*; ²Harper et al., 2020. *Paleocean. Paleocl.*; ³Anagnostou et al., 2016. *Nature*.



P3-088

Collapse of the eastern tropical North Pacific oxygen deficient zone during the Mid-Miocene Climatic Optimum: Evidence from I/Ca and nitrogen isotopes in foraminifera

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Since the mid-20th Century, the oceans have lost >2% of their oxygen, leading to expansion of the oxygen deficient zones (ODZs) and raising concerns about their response to future warming. There is debate, however, about the direction and magnitude of change going forward. This study investigates the response of the eastern tropical North Pacific (ETNP) ODZ, the ocean's most expansive ODZ, to Middle Miocene climate change. We focus on the Mid-Miocene climatic optimum (MMCO; 17-14.8 Ma), an analog for future climate with temperatures ~8°C above preindustrial levels, and the Mid-Miocene climatic transition (MMCT; 14.8-12.8 Ma), the global cooling that followed it. Based on I/Ca and FB- $\delta^{15}\text{N}$ measured in planktonic foraminifera from the heart of the ETNP ODZ (ODP Site 845), we show that the ETNP ODZ was substantially contracted or absent during the MMCO, with the ODZ developing or expanding during MMCT cooling. I/Ca values decline sharply at 15.1-14.8 Ma, near the onset of the MMCT, reflecting a rise in the reduction of iodate in the regional thermocline during the MMCT. We use a new calibration to quantify the change in the water column's minimum oxygen concentration from the MMCO to the MMCT. FB- $\delta^{15}\text{N}$ supports this interpretation, showing lower than present values during the MMCO, indicating relatively little water column denitrification, and a sharp rise during the MMCT, indicating increasing water column denitrification and intensification of the ODZ during cooling. The N isotope change occurs later than the I/Ca change, consistent with the different oxygen sensitivities of the two proxies. The reconstructed diminishment of the ETNP ODZ during the warm climate of the MMCO occurred despite the lower solubility of oxygen in warmer temperatures. We turn to other data, including Mg/Ca-based temperature reconstructions, in an effort to identify the ocean changes that led to the observed coupling between warm conditions and a contracted ETNP ODZ.



P3-119

East Antarctic warming triggered by West Antarctic ice loss during the Last Interglacial

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During the Last Interglacial (129-116 thousand years before present), global sea level was 1 to 9 m above pre-industrial levels, of which 1 to 7 m sea level is attributed to Antarctic ice sheet melting. Coupled climate model simulations of the Last Interglacial typically use prescribed ice sheets based on the present day, and lack dynamic feedbacks associated with melting of the Antarctic ice sheet. Here, we assess the impact of a partial melting of the West Antarctic ice sheet in a coupled climate model of the Last Interglacial, both from removing parts of the ice sheet, and from enhanced meltwater input around the Antarctic coast. We find that partial ice sheet removal induces a surface warming over East Antarctica of 2 to 4 °C in agreement with proxy estimates, as well as a summer sea surface temperature increase in the Weddell and Ross Seas by up to 2 °C. The meltwater perturbation causes a high latitude surface cooling, but also leads to a subsurface (100-500 m) ocean temperature increase by up to 2 °C in the Ross Sea. Our results suggest that the combination of a partial removal of the West Antarctic ice sheet and enhanced meltwater input could further destabilise the Antarctic ice sheet through an increase in surface air and subsurface ocean temperatures.



P3-127

Antarctic Peninsula Ice Sheet instability during the mid to late Holocene

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The Antarctic Peninsula (AP) is one of the fastest-warming regions on Earth, and ice sheet melting over the past 50 years has been enhanced. However, these satellite records are limited to the past half-century, so the actual climate change and ice sheet melting on a long timescale have not been elucidated. Here we show direct evidence for the linkage between ice sheet melting and low-latitude climate change by reconstructing the paleoenvironment of the northwestern AP over the past 5,000 years. During the middle Holocene warm period from 5000 to 3200 years ago, multiple events with abundant iceberg rafted debris (IBRD) and fossil chrysophyte cysts were found, and compound-specific hydrogen isotopes of fatty acid biomarkers also showed an increased glacial meltwater input in this area. These findings suggest that the Antarctic Peninsula ice sheet (APIS) significantly melted during the mid-Holocene. Based on organic carbon and Br content, and diatom abundance, there was also a significant increase in biological production in this area. During this period, a La Niña mode developed in the tropics, the Amundsen Sea Low was enhanced, and the Southern Annular Mode (SAM) showed positive anomalies, indicating that the teleconnection with SAM+ may have accelerated APIS melting by amplifying local meridional wind anomalies around the AP, which enhanced warm air advection from lower latitudes to the AP. On the other hand, after about 3200 years ago, the IBRD decreased and biological production declined, suggesting that ice sheet melting decreased with the development of the El Niño mode.



P3-080

Paleoceanographic conditions of the Oligocene Eastern Equatorial Atlantic

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The Oligocene (33.9 – 23.03 Ma ago) experienced large climate and ice sheet fluctuations in a unipolar icehouse, with glaciation limited to the Southern Hemisphere. This time interval provides a useful test case for studying polar amplification patterns under atmospheric greenhouse gas concentrations similar to those projected for the future. Large-amplitude climate variability has been recorded close to Antarctica, but climatic and environmental conditions and variability in the tropical band are poorly known. Reconstructing Oligocene paleoceanographic conditions and absolute sea surface temperatures (SSTs) will deliver an insight into the climate variability and sensitivity of the lower latitudes under the unipolar conditions.

Here we present SSTs reconstructions for the Oligocene equatorial Atlantic based on lipid biomarkers (TEX₈₆) at Ocean Drilling Program Site 959, offshore Ghana. In addition, variations in the depositional environment and surface oceanographic conditions were reconstructed using bulk carbonate stable isotope ratios ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$), weight% carbonate, magnetic susceptibility and dinoflagellate cyst assemblages. Lastly, atmospheric CO₂ concentrations based on stable carbon isotopic fractionation of marine organic carbon and alkenones suggest that $p\text{CO}_2$ remained stable (300-800ppm) between ~23 – 33 Ma.

Our TEX₈₆ record shows that the prevailing SSTs during the Oligocene was ~27°C, which is ~1 – 4°C colder than at the west Equatorial Atlantic (e.g. ODP Site 929, Ceara Rise). Dinoflagellate cyst assemblages indicate upwelling alternating with strong stratification on ~50 to 100 kyr timescale. Hence, monsoonal upwelling could explain the lower SSTs at Site 959, consistent with modern east-west gradients. Subsequent comparison of our equatorial SSTs record with general circulation modelling studies and SSTs records from high latitudes should reveal the polar amplification of warming and climate sensitivity on long and short (orbital) timescales.



P3-125

Constraining the timing, rates, and mechanisms forcing retreat of a large East Antarctic outlet glacier during the last deglaciation

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Understanding the timing, rates, and mechanisms of Antarctic ice retreat is necessary to predict ice sheet response to future warming. Observations indicate that the West Antarctic Ice Sheet (WAIS) is losing mass as atmospheric and ice-proximal oceanic temperatures warm. The Totten Glacier in East Antarctica drains the marine-based Aurora Subglacial Basin and is presently one of the most rapidly thinning glaciers in Antarctica. This glacial system is also influenced by warm ocean waters and contains 5.13m sea level equivalent ice, comparable to the entire WAIS (5.28m). Here we use marine sediments from the Sabrina Coast continental shelf, seaward of the Totten Glacier system, to establish the timing and rates of ice stream retreat during the last deglaciation (23-11 ka). Previous studies indicate that ice retreated from the middle shelf, off axis of the cross-shelf trough, by 16.5 ka, but it is possible that an ice stream retreated within the trough before that time. Here, we establish both the timing and rate of deglacial ice retreat from the middle to inner shelf using a transect of five marine sediment cores collected within the trough. To establish deglaciation age, we radiocarbon dated sediments above and below the contact between glacial diamict and open-marine diatom-rich mud. Because Antarctic shelf sediments contain a mix of local and glacially reworked organic carbon, we used the Ramped PyrOx ¹⁴C preparatory method to obtain depositional ages where no biogenic carbonate existed. Once we established retreat timing, we calculated regional retreat rates and explored forcing mechanisms. We generated TEX₈₆-based ocean temperature records, which combined with ice core records of past regional atmospheric temperatures, allow us to assess the mechanisms forcing ice retreat during the last deglaciation. Our study will provide climate modelers with important boundary conditions required to improve model projections of future sea level rise with continued warming.



P3-122

Ice-proximal sea ice conditions in Antarctica since the Last Interglacial

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Sea ice, in close proximity to ice shelves, is vital to their stability and plays a significant role in preventing the catastrophic collapse of ice shelves as recently observed along the Antarctic Peninsula. Investigations into past ice-proximal sea ice conditions, especially across glacial-interglacial cycles, provide crucial information pertaining to sea ice-ice shelf interactions and deepen our understanding of ice shelf dynamics and ocean forcings. Pursuing a multi-proxy approach, we here analysed the novel sea ice biomarker IPSO₂₅ (a di-unsaturated highly branched isoprenoid (HBI)), open marine-related biomarkers (tri-unsaturated HBIs; z-/e-trienes) and diatom assemblages in a sediment core recovered in the Powell Basin, western Weddell Sea. These biomarkers are shown to be reliable proxies for the reconstruction of near-coastal sea ice conditions in the Southern Ocean where the common use of sea ice-related diatoms is distinctly affected by silica dissolution. Our data shed new light on the response of sea ice to the Last Interglacial warming and reveal a highly dynamic sea ice setting with significant shifts from a perennial ice cover to open marine environments over the last ca. 150 ka BP.



P3-095

Warm late Cenozoic bottom water temperatures until 2.2 Ma, revealed from clumped isotopes of ODP Site 1264

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Neogene climate on Earth changed dramatically from an Antarctic ice sheet in its infancy to a warm phase during the Miocene Climate Optimum (~14 Ma), followed by long-term transient global cooling, which culminated in Northern hemisphere glaciation and several glacials. The basis for most of what we know about long-term global climate is derived from long, multi-site composite $\delta^{18}\text{O}$ records from benthic foraminifera.

One of the main problems with the $\delta^{18}\text{O}$ proxy, however, is that it depends not only on the formation temperature of the calcite (cc) of the foraminiferal test, but also on the isotopic composition of the fluid source, in this case the seawater (sw). This means that changes to the $\delta^{18}\text{O}_{\text{sw}}$ —which is influenced by the precipitation/evaporation balance and thus salinity, as well as land ice-volume and oceanography—can mask changes in temperature.

In this study, we use the clumped isotope proxy (Δ_{47}) to provide independent temperature constraints that are based on thermodynamic principles. Clumped isotopes are measured simultaneously to the $\delta^{18}\text{O}_{\text{cc}}$ and enable determination of the $\delta^{18}\text{O}_{\text{sw}}$ that the foraminifera dwelled in.

We reconstruct deep sea temperatures from ~20 Ma to the present by applying clumped isotope measurements to well-preserved benthic foraminifera from Walvis Ridge IODP Site 1264 sediments. Our novel measurements reveal warmer temperatures than traditional oxygen isotope thermometry studies, which is in agreement with recent Δ_{47} temperature reconstructions from the Indian Ocean¹ and the Southern Ocean². These new findings show further evidence that previous estimates of $\delta^{18}\text{O}_{\text{sw}}$ during the Neogene may be flawed, hampering accurate temperature reconstructions solely based on the foraminifera $\delta^{18}\text{O}_{\text{cc}}$. Clumped isotope temperatures allow us to convert assumptions about $\delta^{18}\text{O}_{\text{sw}}$ into measurement-based estimates through time.

1. Modestou et al. 2020, *Paleoceanography and Paleoclimatology*, 2020–003927
2. Leutert et al. (2020), *Climate of the Past Discussions*, 1–26.



P3-100

Pliocene summer monsoon variability in the Western Arabian Sea

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Mineral dust is a major contributor to atmospheric aerosol loading and plays an important role in Earth's climate system. The Arabian Peninsula is the world's second largest dust producing area contributing over 10% of total annual global dust emissions. It is generally agreed that West Asia will become warmer (by up to 4°C average annual temperature above pre-industrial levels by the end of the century). But the response of rainfall to warming in this region is much less well understood. Geological data from past warm intervals can provide valuable context. While terrestrial records provide evidence of past humid intervals, they are less useful in documenting palaeoaridity. The sediments of the Arabian Sea archive long continuous records of continental climate, carried by the windblown dust and riverine material derived from its encircling land masses. But the classic published records of this type are associated with considerable uncertainties. We present new high-resolution data sets (elemental composition derived from XRF core scanning, grain size distributions and radiogenic Nd and Sr isotope composition on the terrigenous fraction) from classic drill sites from ODP Leg 117 (Sites 721/722) for the warm Pliocene (from 3.9 to 3.4 Ma). We compare our records to published palaeo data sets and maps of modern-day dust activation to assess variability in continental rainfall climate with changes in global climate state.



P3-096

Uncovering Mysteries of the Mio-Pliocene Transition

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The benthic oxygen isotope record ($\delta^{18}\text{O}$) is a primary indicator of global climate change during the Cenozoic. These records have allowed us to infer climate events associated with dramatic environmental changes separated by intervals of relative quiescence. Yet, recent work employing other paleoclimate proxies to explore the late Miocene, one of these benthic $\delta^{18}\text{O}$ -inferred 'quiet' intervals, demonstrates that it was also characterized by major environmental and climatic change. Here, we integrate new and published alkenone-derived sea-surface temperature records from the late Miocene through early Pliocene to quantify the magnitude of temperature change associated with the end of the late Miocene cooling trend and start of the warm early Pliocene. Our results indicate a change of +0.7 °C in the tropics and +4 °C in mid latitudes of both hemispheres, which is consistent with the hypothesis of a ~100-250ppm increase in atmospheric CO₂ at this time. Our compilation also allows us to examine regional trends in climate during the early Pliocene. Cooling is evident in most regions between 5.3 and 3 Ma, but most dramatic in the mid latitude North Atlantic (~5–6°C). We propose that subpolar North Atlantic cooling during this time played a central role in setting the stage for major Northern Hemisphere glaciation (NHG). Finally, we use these datasets to identify and quantify a series of global obliquity-paced *hypothermal* events during the early Pliocene that predate major NHG. We propose that these events are akin to Marine Isotope Stage M2, ~3.3 Ma, which has long been regarded as an isolated early false start by the climate system to initiate the late Cenozoic icehouse world.



P3-116

Persistent Iceland-Scotland Overflow Water formation during MIS 11

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The Atlantic thermohaline circulation is one of the tipping elements in Earth's climate system [1] and it remains debated whether future changing boundary conditions, especially freshwater input to the North Atlantic, may affect deep water formation. Deep convection in the Nordic Seas leads to the formation of Iceland-Scotland Overflow Water (ISOW) which is an essential part of the AMOC. However, it is unlikely that surface properties in the Nordic Seas have always been favorable for deep water formation in the past.

During MIS 11 cold and fresh surface conditions prevailed in the central Nordic Seas [2] due to freshwater input from higher latitudes [3]. At the same time, however, a strong and active AMOC [e.g. 4] was reconstructed. Thus, the question arises whether and where deep water was formed in the Nordic Seas. Here, we present authigenic neodymium isotopes extracted from sediment core IODP U1304 from 470 to 374 ka, which is located directly in the modern flow path of ISOW. Today, it is characterized by a strongly radiogenic neodymium isotopic composition, which markedly differs from other North Atlantic water masses.

Starting right at the onset and throughout the interglacial MIS 11c, a radiogenic Nd isotopic signature is switched on and prevailed indicating the presence of ISOW at the core site. Unradiogenic values indicate a return to glacial like conditions during a brief event in MIS 11b. However, during MIS 11a radiogenic values again point to a persistent presence of ISOW.

Thus, although the boundary conditions in terms of freshwater fluxes were unfavorable in the central Nordic Seas, deep water formation presumably occurred in its southern part. This led to the active formation of ISOW, which in turn helped drive the active and strong AMOC during MIS 11.

[1] Lenton et al. (2008), PNAS 105: 1786-1793.

[2] Kandiano et al. (2016), GRL 43: 10929-10937.

[3] Doherty and Thibodeau (2018), Front. Mar. Sci. 5: 251.

[4] Dickson et al. (2009), Nat. Geosci. 2: 428-433.



P3-101

Testing sea surface temperature (SST) proxies in the Bay of Bengal during the latest Pliocene: which proxies can we trust?

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The Indian Monsoon is a critical component of the global weather system, governing heat and moisture transport over southern Asia. However, its past behaviour is poorly constrained, particularly during important climate transitions such as the intensification of Northern Hemisphere Glaciation (iNHG; ~3.3 – 2.4 Ma). Intense monsoon-driven seasonal rainfall leads to strong freshwater fluxes into the Bay of Bengal (BoB), which drastically reduces the salinity and causes stratification that suppresses upwelling. Therefore, reconstructed salinity anomalies from sedimentary archives can theoretically be used to reconstruct past variations in monsoon strength. However, in order to use oxygen isotopes in planktic foraminifera to reconstruct near-surface salinity, it is necessary to also solve for contemporaneous sea surface temperature; but which proxy is the most suitable for this purpose? The unusual oceanographic conditions of the BoB, combined with the low latitude and warm global temperatures, make this especially challenging during greenhouse intervals such as the late Pliocene. Issues have recently been identified with applying the Mg/Ca proxy in planktic foraminifera in late Pleistocene BoB records, related to the depth preference of the species and therefore the calibration applied. Some organic proxies such as the U^{K}_{37} proxy or long chain diol index (LDI) may be saturated at these high temperatures. The relationship between LDI and SST may also break down in the low salinity conditions. There may be issues with sub-surface production of lipids with the archaeal-based TEX_{86} proxy in the seasonally stratified waters. Planktic foraminiferal assemblages could be responding more to changes in salinity than to changes in SST, complicating SST estimation. Here we test various SST proxies at IODP Site U1445 in the northern BoB from the latest Pliocene to the earliest Pleistocene, and attempt to disentangle which proxies might be the most useful in this setting.



P3-048

Modelling 500,000,000 years of climate change with a GCM – the role of CO₂, paleogeography, insolation, and ice extent during the Phanerozoic

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During the Phanerozoic (the last ~0.5 billion years), the Earth has experienced massive changes in climate, spanning the extensive glaciations of the Permo-Carboniferous (~300 million years ago), to the mid-Cretaceous super-greenhouse (~100 million years ago). Recently, several studies have used geological data to reconstruct global mean temperatures through this period, as a way of characterising the zeroth-order response of the Earth system to its primary forcings. However, there has been little modelling work that has focussed on these long timescales, due to uncertainties in the associated boundary conditions (e.g., CO₂ and paleogeography) and to the computational expense of carrying simulations spanning these long timescales. Recently, paleogeographic (Scotese and Wright, 2018) and CO₂ reconstructions (Foster et al, 2017) have emerged, and model and computational developments mean that we can now run large ensembles of relatively complex model simulations. In particular, here we present an ensemble of 109 simulations through the Phanerozoic, with a tuned version of HadCM3L that performs comparably with CMIP5 models for the modern, and is also able to produce meridional temperature gradients in warm climates such as the Eocene in good agreement with proxy data. We show that the model produces global mean temperatures in good agreement with proxy records. We partition the response to changes in the different boundary conditions (CO₂, paleogeography, ice extent, and insolation), and, through energy balance analysis, to surface albedo versus cloud versus water vapour changes. We also illustrate the ocean and atmospheric circulation changes, with a focus on the role of the changing geography (e.g. the role of a coherent circumglobal ocean in the early Phanerozoic).



P3-050

A continental arc volcanism trigger for OAE2?

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The geological record is punctuated by intervals of widespread oceanic anoxia and organic carbon (OC) sequestration known as Oceanic Anoxic Events (OAEs). The latest Cenomanian aged OAE2 (~94 Myr ago), defined by a positive carbon isotope excursion (CIE), is considered the best developed of the OAEs and is viewed as a potential analogue for future ocean deoxygenation. Massive submarine volcanism, typically attributed to the emplacement of the Caribbean Large Igneous Province (LIP), is currently considered the most likely trigger for OAE2 despite several discrepancies with this scenario including that: a) the timing and duration of OAE2 vs major pulses of LIP volcanism are not clearly aligned, b) the magnitude and emission rate of volcanogenic CO₂ required to reproduce the CIE in carbon cycle models are difficult to reconcile with LIP volcanism, and c) the magnitude of the CIE requires elevated OC burial in distal, open marine settings that are geographically distant from continental or LIP-derived nutrients inputs.

Massive explosive subaerial volcanism coinciding with OAE2 offers an alternative explanation. We present coupled detrital ϵ_{Nd} and $^{87}Sr/^{86}Sr$ records from three IODP sites spanning the proto-Atlantic Basin which all show an abrupt shift towards a common isotopic endmember at the onset of OAE2, matching volcanic ash from the late Cretaceous continental arcs of North America but incompatible with a LIP provenance. Abundant bentonites in the latest Cenomanian of the Western Interior Seaway as well as a shift towards more radiogenic $\epsilon_{Nd}_{authigenic}$ and increased smectite abundance in the OAE2 interval at multiple locations across the Atlantic and Tethys further argue for an episode of widespread volcanic ash deposition. We propose that volcanic ash deposition fertilized wide expanses of the end-Cenomanian oceans, acting together with climate warming and the down-stream effects of LIP volcanism to maintain increased carbon sequestration throughout OAE2.



P3-072

Early Eocene Pacific deep ocean temperatures from clumped isotope thermometry

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Past greenhouse climates can provide important background information for future climatic conditions given ongoing climate change. In particular, by better understanding the main processes influencing the climate system under such boundary conditions, we can improve future climate projections significantly. Thereby, reconstruction of deep ocean temperature is the key to access estimates of global mean temperature and for understanding past ocean circulation patterns.

The early Eocene includes the warmest interval of the last 66 million years. Deep ocean temperature reconstructions so far are mostly based on stable oxygen isotopes and Mg/Ca data. However, deep-time temperature reconstructions with these proxies are challenging as various factors potentially influence the results. Carbonate clumped isotope thermometry can add new important constraints as this proxy is independent of past ocean water chemistry.

A recent study by Meckler et al. (in review) reconstructed Cenozoic temperatures derived by carbonate clumped isotope thermometry of the Atlantic Ocean. Their low-resolution record shows temperature swings in the early Eocene on million-year time scales. In this study, we test if these swings represent global or regional Atlantic deep ocean temperatures by a new deep Pacific clumped isotope temperature record based on benthic foraminifera from ODP Site 1209. Once combined, the data from both ocean basins will improve our understanding of global temperature and ocean circulation during the early Eocene greenhouse world.



P3-097

Extending exploration of late Pliocene climate variability (PlioVAR) into the early Pliocene and Miocene (PlioMioVAR)

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The Pliocene (~2.6-5.3 Ma) and the Miocene (~5.3-23 Ma) are globally warm climate states with atmospheric CO₂ concentrations estimated to be similar and/or higher than today. The Pliocene and Miocene are characterized by higher global mean surface temperatures (~2-3 °C), reduced ice volume, and reduced ocean and atmospheric strength in comparison to pre-industrial. The mid-Pliocene warm period (MPWP) has long been a data-model comparison target for the paleoclimatology community. We present here the results of a marine data synthesis effort generated by the PAGES-PlioVAR working group (Pliocene climate variability across glacial interglacial cycles). We explore the changes to the baseline climate state and orbital-scale climate variability associated with the transition from the MPWP into the early Pleistocene, a transition associated with expansion of northern hemisphere ice sheets and falling atmospheric CO₂. We show that regional responses in sea-surface temperatures and sea level can be detected, but may differ in their timing between regions.

We also introduce a new PAGES working group (PlioMioVAR) which seeks to better understand glacial-interglacial variability extending through the Pliocene and Miocene. Although CO₂ during the MPWP is estimated to be similar to today, there is increasing need to expand into the early Pliocene and Miocene to better understand higher CO₂ and globally warm equilibrium climate states, including the mid-Miocene Climate Optimum, helping to inform data-model comparisons to understand future climate change. PlioMioVAR aims to expand the stratigraphical framework of PlioVAR to include low and high-resolution stratigraphy datasets for a variety of proxies, including sea surface temperature, productivity, and benthic stable isotopes, for the early Pliocene through the Miocene. We outline here our approach to this endeavour, including data synthesis protocols and practices, and our first targets for analysis.



P3-083

Less extreme polar amplification during warm periods and deeper than surface coccolithophore production: evidence from coccolith clumped isotopes

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Reliable temperature and CO₂ reconstructions are key to improve climate model predictions. The application of widely-used temperature proxies have well-known limitations linked to water chemistry dependence (Mg/Ca and δ¹⁸O), uncertainties of the signal depth (TEX₈₆), and saturation at high temperatures (U^k₃₇). The application of clumped isotope thermometry, which is only thermodynamics-dependent, to calcite produced by coccolithophores, ensures an euphotic zone surface ocean signal.

Here we use new coccolith separation and cleaning techniques to apply clumped isotope thermometry to well preserved coccolith samples from North Atlantic sediments during the last 16 Ma, world-wide located Holocene core top samples, and a monospecific *Coccolithus pelagicus* sediment trap sample in the North Atlantic. Clumped isotope (Δ₄₇) calcification temperatures from the sediment trap sample are consistent with satellite-derived temperatures, adding up to the limited, yet agreeing evidence of lack of vital effects in coccolith Δ₄₇. Given the good preservation of downcore North Atlantic coccoliths, a ~10°C colder North Atlantic reconstructed from coccolith Δ₄₇ compared to U37k'-derived temperatures, indicate a less extreme polar amplification than previously thought during warm intervals, which agree better with climate models.

The colder than surface calcification temperatures observed in core top coccolith Δ₄₇, especially in low latitudes, is consistent with a deeper habitat than generally regarded for coccolithophores. Overestimation of SSTs by U^k₃₇ from the same samples may in part be explained by the assumption of alkenone calibrations of an invariably surface habitat, and highlights the potential need to improve our understanding of widely-used temperature proxies. Δ₄₇ applied to coccolith calcite is a promising new proxy for temperature reconstructions, and new faster separation methods will allow its wider application.



P3-063

Surprisingly Sturdy: Coralline algae habitat function shows structural resilience across the Paleocene-Eocene Thermal Maximum

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The skeletons of marine calcifiers such as corals and coralline algae provide protection against the elements and predation. For coralline algae, the 3D structure is influenced by environmental parameters such as temperature and light availability, which affect growth rates, cellular structure, and mineral chemistry, whereas physical parameters such as wave exposure affect overall morphology. Therefore, assessing these skeletal changes provides an insight into how calcification might be impacted by future climate change.

What is often overlooked is how skeletal changes may affect species function in the ecosystem. For coralline algae, a habitat forming organism, their 3D structure and subsequently the structural integrity is vital to their ecosystem function.

Finite Element Analysis (FEA) allows us to assess form and function within biological organisms, by computing stress and strain within a model to points of failure. Using FEA, the internal structure of coralline algae has been interrogated for their response to global change. By applying this technique to the geological record, we have assessed how the ecosystem function of coralline algae has been altered in response to environmental changes during the Palaeocene Eocene Thermal Maximum (PETM). Due to the rapid warming and ocean acidification event, the PETM is argued to be one of the best analogues in the geological record to gain an insight into future global change on calcifiers. Results show that increasing temperatures and CO₂ concentrations causes coralline algae to form weaker skeletons. However, modelled stresses are comparable to contemporary species suggesting that this structural integrity weakening does not limit habitat formation potential. By analysing changes in the internal structure of coralline algae, we can link environmental change to structural integrity and ultimately their ability to support biodiversity.



P3-089

Investigating mid-Miocene climate dynamics in southern hemisphere oceans with Δ_{47} and $\delta^7\text{Li}$

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The middle Miocene is an important analogue for warmer future climates: it is the most recent time in geological history with atmospheric CO₂ concentrations similar to those proposed for 'business as usual' future climate scenarios. The mid-Miocene also experienced significant variations in climate, including a pronounced warm period followed by cooling as inferred from a step-like increase in $\delta^{18}\text{O}$ in benthic foraminifera. Our understanding of these events is, however, hampered by a paucity of quantitative climate reconstructions, particularly from the deep ocean. Here, we present deep ocean temperature records from several deep water locations in the Southern Hemisphere (ODP Sites 747 [Kerguelen Plateau] and 761 [Wombat Plateau], and IODP Site 1171 [Tasmanian Gateway]) from carbonate clumped isotope paleothermometry on benthic foraminifera. In addition, we measured foraminiferal $\delta^7\text{Li}$ at one of the sites to examine coeval changes in global weathering and erosion.

Overall, our results suggest slightly warmer bottom water temperatures than previously reported using Mg/Ca thermometry, though the new temperatures are generally within uncertainty. Interestingly, temperatures in the Southern Ocean (Sites 747 and 1171) suggest bottom water temperatures were more dynamic than previously observed, with multiple cooling episodes during the transition in benthic $\delta^{18}\text{O}$. Our $\delta^7\text{Li}$ data clearly illustrate changes in weathering and erosion similar to previous global scale warming and cooling events. The observed rapid pulse of high weathering and erosion rates during warming, followed by a longer recovery during cooling, are consistent with a temperature control on the hydrological cycle. Over long timescales, our combined temperature – weathering intensity records illustrate the lag between weathering and CO₂ drawdown and the resulting climate system response.



P3-064

Foraminifera-bound nitrogen isotope evidence for reduced ocean suboxia during the Paleocene-Eocene Thermal Maximum

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The long-term consequences of global warming on ocean suboxia remain poorly understood due to a lack of long-term historical observations and discrepancies in model simulations. The Paleocene Eocene Thermal Maximum (PETM) is considered to be the fastest known pre-anthropogenic global warming in Earth's history, with reconstructed changes resembling in some aspects the RCP 8.5 IPCC AR5 projections for future climate. Therefore, this interval represents a potential past-analogue scenario that can offer insights into the consequences of ongoing global warming on ocean oxygenation. Here, we analyzed the nitrogen isotopic composition of the proteinaceous linings of planktonic foraminifera (FB- $\delta^{15}\text{N}$) in the PETM intervals of Pacific ODP sites 1210 and 865, Southern Ocean site 690, Atlantic sites 1263 and 401 and Indian site 213, covering the major biogeochemical provinces of the ocean. Our results indicate that, contrary to expectations, core-PETM conditions were associated with a large reduction of the East Pacific Oxygen Deficient Zones (ODZ) with respect to pre- and post-PETM conditions. We will discuss possible mechanisms of ODZ contraction during the PETM and their implications for the future state of ODZs and marine nitrogen cycle under anthropogenic warming.



P3-060

Exploring links between excess magmatism during the North Atlantic continental breakup and the Paleocene-Eocene Thermal Maximum (PETM) – a marine palynological approach

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The Paleocene-Eocene Thermal Maximum (PETM; 56 million years ago) was a ~200 kyr period of extreme global warming, ocean acidification and ecosystem shifts, marked by a globally recorded major negative carbon stable isotope excursion (CIE) of 3-4‰ in sedimentary records. The sharp <10 kyr onset, followed by a ~100-170 kyr period with relatively stable carbon isotope values, referred to as 'the body' of the CIE, are attributed to massive inputs of ¹³C-depleted carbon into the ocean-atmosphere system, followed by a 70-100 kyr recovery phase. One hypothesized source of this carbon is the massive release of thermogenic methane and CO₂ from hydrothermal craters in the North Atlantic Igneous Province (NAIP). To test this hypothesis and other possible links between NAIP volcanism and rapid PETM-warming, International Ocean Discovery Program (IODP) Expedition 396 recovered sections from 21 holes, including an infilled hydrothermal vent crater and a series of thick PETM successions from this region. These yield expanded PETM successions containing e.g., microlaminated diatomite which potentially record seasonal variations through much of the PETM, and allow biostratigraphical, paleoenvironmental and paleoclimatological analysis in unprecedented resolution. Here, we use dinoflagellate cyst stratigraphy to constrain the timing and duration of climate variability during the PETM onset, which is essential to establish links between NAIP volcanism and global changes at the PETM. Furthermore, we focus on reconstructing climate and environmental variability during this interval on a decadal scale, using quantitative marine palynology, and notably dinoflagellate cysts as paleoenvironmental indicators for e.g., changing sea surface conditions. Our results provide a first glimpse at the environmental changes in the immediate vicinity of the vent systems and how perturbations of the carbon cycle affected climate conditions in the northern mid-latitudes in unprecedented detail.



P3-131

Deglacial mobilization of ancient carbon from thawing permafrost to Laptev Sea sediments

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The warming of the Arctic is causing rapid thawing of permafrost, which holds twice as much carbon as currently is in the atmosphere. Future sea level rise and warming in the Arctic will aggravate permafrost thaw and thereby causing the previously frozen ancient organic carbon to be remobilized and degraded. The subsequent release of greenhouse gases to the atmosphere from degrading permafrost is one of the most likely positive climate feedbacks that might intensify global warming. A few carbon-cycle models have investigated the link between deglacial permafrost carbon remobilization and the impact on atmospheric CO₂ concentrations. However, the regional occurrence, timing and rate of carbon release from degrading permafrost is still poorly constrained because only a limited number of deglacial records on carbon mobilization are currently available. In this study, we use a high-resolution marine sediment record from off the Lena River outflow located on the Laptev Sea continental slope. Deglacial permafrost thaw events were reconstructed using biomarkers and radiocarbon dating of terrigenous material. New AMS ¹⁴C dates from calcareous foraminifera were used to improve the existing age-depth model. We combined records of mass accumulation rates at the core location and age at deposition of terrigenous biomarkers, in order to determine the occurrence of past massive permafrost degradation and mobilization. We found that high accumulation of terrigenous biomarkers coincides with peaks in rapid sea level rise, suggesting that permafrost carbon mobilization was caused mainly by coastal erosion. Our results provide evidence of several millennia old terrestrial carbon deposited in Laptev Sea sediments during the last deglaciation. These findings further contribute to and extend the limited data sets on the age of deglacial permafrost carbon from the Arctic shelves and provide additional insights on the fate of permafrost carbon soils in a warming climate.



P3-123

Regional sea surface temperature variability of the western North Pacific throughout the past 150 ka.

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Over the past decades, instrumental data show a regionally inhomogeneous, but significant rise of sea surface temperatures (SSTs). However, on geological timescales, knowledge of spatially resolved regional warming is still limited. The North Pacific is a key area for climate change due to heat transport and the ocean-atmosphere interaction of carbon dioxide. Its geographical extent covers one of the largest contiguous areas on earth as a tightly connected ecosystem. Only a few sediment cores to date have reached the penultimate glaciation and beyond, thus providing a full record of the Last Interglacial. In this study, we present alkenone-based SST reconstructions from the Okhotsk Sea and the open western North Pacific covering the past 150 ka, thereby providing data of the last warmer than present conditions during MIS 5 and especially the Last Interglacial (Eemian ca. 130-116 ka BP). Our records are chosen from several oceanographic and climatic settings of the western North Pacific in order to detect a similar or different rise and fall of SSTs over global warming and cooling events. The investigation shows different trends over the glacial-interglacial cycle, depending on the location of the sediment cores. To provide a better, large-scale overview through space and time, previously published records were considered and used to complement our own investigation. On multi-millennial timescales, we provide evidence that during MIS 5, SSTs were not stable, but characterized by rapid warming and cooling events of up to 3° C. Interestingly, similar observations were also reported in the Bering Sea and the North Atlantic, suggesting a close atmospheric and interoceanic link of temperature changes in the Northern Hemisphere.



P3-075

Simulation of Arctic sea ice within the DeepMIP Eocene ensemble: thresholds, seasonality and factors controlling sea ice development

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The early Eocene greenhouse climate maintained by high atmospheric CO₂ concentrations serves as a testbed for future climate changes dominated by increasing CO₂ forcing. In particular, the early Eocene Arctic region is important in the context of future CO₂ driven climate warming in the northern polar region and associated shrinking Arctic sea ice. Here, we present early Eocene Arctic sea ice simulations carried out by six coupled climate models within the framework of the Deep-Time Model Intercomparison Project (DeepMIP). We find differences in sea ice responses to CO₂ changes across the ensemble and compare the results with available proxy-based sea ice reconstructions from the Arctic Ocean. Most of the models simulate seasonal sea ice presence at high CO₂ levels (≥ 840 ppmv = 3x pre-industrial (PI) level of 280 ppmv). However, the threshold when sea ice permanently disappears from the ocean varies considerably between the models (from < 840 ppmv to > 1680 ppmv). Based on a one-dimensional energy balance model analysis we find that the greenhouse effect likely caused by increased atmospheric water vapor concentration plays an important role in the inter-model spread in Arctic winter surface temperature changes in response to a CO₂ rise from 1x to 3x the PI level. Furthermore, differences in simulated surface salinity in the Arctic Ocean play an important role in the control of local sea ice formation. These differences result from different implementations of river run-off between the models, but also from differences in the exchange of waters between a brackish Arctic and a more saline North Atlantic Ocean that are controlled by the width of the gateway between both basins. As there is no geological evidence for Arctic sea ice in the early Eocene, its presence in most of the simulations with 3x PI CO₂ level indicates either a higher CO₂ level and/or models miss important mechanism/feedback.



P3-052

The High Low: combining high- and low-resolution temperature reconstructions to investigate tropical climate variability across the Cenozoic

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Sea surface temperatures (SSTs) in the low-latitudes have a major influence at both the local and global scale on Earth's radiative budget, hydrological cycle and ecosystems. Across the Cenozoic era, Earth experienced periods of extreme warmth with elevated greenhouse gas concentrations relative to present, yet characterization of low-latitude SSTs during periods of warmer-than-modern climates is limited. Today tropical SSTs rarely exceed 30°C and paleoclimate reconstructions from the tropical Pacific have shown a consistency in this threshold over the late Cenozoic. However, some proxy reconstructions provide evidence for SSTs exceeding this limit throughout the Cenozoic and point to greater dynamism in low-latitude SST evolution in response to global cooling and warming events. It remains to be established whether these discrepancies are due to proxy biases; secondary and long-term effects on carbonate Mg/Ca derived SSTs whilst non-thermal biases exist for organic geochemical approaches to reconstructing SSTs. To investigate a consistency, or lack of, in low-latitude SSTs through the Cenozoic, and considering proxy biases in temperature reconstructions, we present combined low (clumped isotopes) and high (in-situ trace element analysis) resolution results from IODP Site U1443 in the equatorial Indian Ocean across the late Cenozoic (30-0 Ma).



P3-051

Ar/Ar ages of granitoid pebbles from IODP Expedition 382 Sites in Iceberg Alley, Scotia Sea, Antarctica

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The eastern Scotia Sea is known as Iceberg Alley, where large numbers of icebergs are brought to the Antarctic Circumpolar Current via the Weddell Sea Gyre. Icebergs transported through Iceberg Alley today can have traveled in the coastal current from anywhere around the Antarctica margin, but are sourced mostly from the Weddell Sea sector. The Weddell Sea sector drains parts of the Peninsula, West, and East Antarctic Ice Sheets. Sites U1536 and U1537 in Dove Basin and U1538 in Pirie Basin provide nearly continuous records of climate and ice sheet variation through the last 3.3 million years. Although with lower recovery, Site U1536 extends into the Miocene and Site U1538 extends through the lower Pliocene. Large dropstones are very unusual in the latest 1 million years, and they become more abundant through the early Pleistocene and Pliocene. At the more northern site, U1538, abundant dropstones as young as 1.3 Ma were found, but at U1536 and U1537, high abundances are only found older than ~2.5 Ma. A variety of dropstone lithologies were observed and sampled during IODP Expedition 382. In this presentation we report on the ⁴⁰Ar/³⁹Ar results of hornblende or biotite from seventeen sampled dropstones of broadly granitoid composition and texture (diorite through granite). Two single step fusion experiments and one step-heating experiment were conducted on each sample. Of the seventeen, five have ages consistent with Ross/Pan-African sources, ten have typical West Antarctica ages between 90 and 175 Ma, one is approximately 300 Ma and one has very complicated systematics that we tentatively interpret as Grenvillian with a substantial younger partial resetting. Combined with ongoing studies of the dispersed sand provenance as well as the potential sources around the Weddell, these data will help to elucidate the state of the ice sheets and ice shelves through the Neogene.



P3-113

Disentangling the drivers of SW European hydroclimate variations during an interglacial 0.5 million years ago

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Marine Isotope Stage (MIS) 13, ~500 ky ago, represents a Quaternary interglacial of primary interest due to the unexpected enhancement of monsoon systems under a cool climate characterised by low atmospheric CO₂ and larger ice volume than the present interglacial. Yet, key questions remain about its regional expression (intensity, climate variability, length) and underlying forcing factors. Here we examine the SW Iberian vegetation and terrestrial climate during MIS 13 directly compared with the sea surface temperatures using sediments from IODP Site U1385, and combine those terrestrial-marine profiles with climate-model experiments. We show for the first time that MIS 13 stands out for its large forest expansions with a reduced Mediterranean character alternating with muted forest contractions, indicating that this stage is marked by a cool-temperate climate regime with high levels of humidity. Results of our data-model approach reveal that the dominant effect of MIS 13 insolation forcing on the regional vegetation and precipitation regime in SW Iberia is amplified by the relatively large extent of the ice-sheets in high northern latitudes. In qualitative agreement with the pollen-based evidence, model results show that ice-sheet forcing triggers an increase in the SW Iberian tree fraction along with both intensified winter and summer rainfall.



P3-117

Indian monsoon rainfall variability and vegetation changes during MIS 11

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The Indian Summer Monsoon (ISM) is among the Earth's most extreme hydrological regimes, delivering freshwater to billions of people and the diverse flora and fauna inhabiting the region. It brings up to 90% of the annual rainfall into the Core Monsoon Zone (CMZ) in central India, where the ISM has its most representative expression. Alarming, the uncertainty in ISM precipitation projections is still high due to the complexity of simulating its various interconnections. High-fidelity ISM proxy records of past interglacials, periods of reduced ice volume as the Holocene, are thus critical to address long-standing questions regarding the role of the primary forcings (insolation, ice volume and CO₂) in driving ISM natural variability.

Here we focus, for the first time, on the Indian monsoon-induced vegetation change during MIS 11 (425-374 ka), an important interglacial analogue of the Holocene and projected global warming. Based on pollen analysis at Site U1446 strategically retrieved from the CMZ, atmospheric-driven vegetation changes are directly compared with terrestrial-marine profiles from the same site and model simulations to explore the ISM response to primary forcings. We find that this interglacial is marked by three major forest phases with high abundances of evergreen and deciduous elements reflecting strong ISM rainfall, and that are separated by open vegetation periods indicating a shift towards drier conditions due to reduced ISM. In addition, the pollen-based vegetation record of Site U1446 shows a clear imprint of millennial-scale variability throughout MIS 11, including during full interglacial conditions, which points the existence of other forcings besides northern-latitude ice sheet instability.



P3-082

The influence of SST on the loss and development of coral reefs in the Coral Sea

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The Queensland Plateau in the Coral Sea has one of the best constrained geologic histories of coral reef expansion and demise since the early Miocene. The development coral reefs in the past is not well understood with a number of theories proposed for their loss and expansion. Coral reefs were first established in the Early Miocene in the Coral Sea. In the Late Miocene, between 11 and 7 Ma, the reef area on the Queensland Plateau declined by ~50% leading to a partial drowning and a change in platform geometry from a reef rimmed platform to a carbonate ramp. The modern atoll reefs were reestablished around 3.6 Ma although the Great Barrier Reef only developed around 0.7-0.6 Ma. The loss of the reefs has often been tied to the expansion cool nutrient rich waters in the Coral Sea during the Late Miocene. This model has been used to explain the loss and expansion of corals in other parts of the globe. However, there have been questions about the planktonic $\delta^{18}\text{O}$ based Sea Surface Temperature (SST) records on which they are based and how accurately they reflect SSTs. Here we show new TEX_{86} SST data from the Queensland Plateau from two sites (ODP site 811 and 820) showing temperature changes from the Late Miocene to present. Our data shows instead of cooler SSTs during the Late Miocene in fact SSTs were warmer than the modern Coral Sea and at the upper end of the modern coral window. Therefore, it is unlikely that cooler SSTs during the Late Miocene caused the loss of corals on the Queensland Plateau. Instead, the loss seems to have been driven by the restricted growth combined with high SST driven lower growth rate and increases in subsidence at the same time among other drivers. Given the modern debate about the future of coral reefs under current climate predictive scenarios it is worth pointing out that a similar series of changes is occurring in the modern ocean.



P3-074

The Middle Eocene Climatic Optimum in the Tasman abyssal plain: a benthic foraminiferal record

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During the Middle Eocene Climatic Optimum (MECO), at ~40 Ma, the oceans registered a global warming of 4-6°C that interrupted the gradual cooling trend of the Eocene. This was an enigmatic event, which shares some characteristics with the Eocene hyperthermal events, like a negative $\delta^{18}\text{O}$ excursion associated with warming, an increase in atmospheric pCO_2 , and a shallowing of the carbonate compensation depth (CCD). However, the MECO had a much longer duration, its onset does not coincide with a global negative carbon isotope excursion in marine carbonates, and carbonate dissolution in the deep sea was greater than expected, raising questions about the carbon cycle during warming events. Its consequences on deep-sea ecosystems are not well understood either, and more studies are needed to evaluate its effects on deep-sea biota and the relative role of changes in carbon flux vs. warming on the ocean floor.

The MECO interval was recovered at Site U1511 during International Ocean Discovery Program Expedition 371. The site lies in the Tasman abyssal plain at 4,858 m water depth, and Eocene sediments were deposited below the CCD. Although calcareous microfossils are absent, benthic foraminifera show well preserved assemblages composed of agglutinated species, which allow us to investigate for the first time assemblage turnover and paleoenvironmental changes across the MECO below the CCD. Assemblage turnover and the occurrence of opportunistic benthic foraminifera point to environmental instability at the seafloor during the MECO. The integration of these data with published litho- and magnetostratigraphic studies and multi-elemental XRF data analyses contributes to an understanding of the MECO at abyssal depths. The comparison of our results with other intervals characterized by high temperatures and elevated pCO_2 will allow an assessment of how global changes affect the deep ocean and their ecosystems in general.



P3-061

Carbon sequestration and ocean acidification timescales following Paleocene-Eocene carbon cycle perturbations

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Paleocene-Eocene climates were perturbed by a series of carbon injections with different magnitudes that produced short-lived (<200 kyr) global warming/ocean acidification events. These carbon cycle perturbations offer opportunities to gauge poorly constrained carbon sequestration timescales, and to identify their underlying relationships with ocean acidification recovery. Here, we use new stable carbon isotope ($\delta^{13}\text{C}$) and calcium carbonate (CaCO_3) records from Contessa Road (Italy), and published data from Site 1262 (Walvis Ridge) to constrain carbon sequestration and ocean acidification recovery timescales for six Paleocene-Eocene carbon cycle perturbations. Contessa Road records indicate that the largest carbon cycle perturbation, the Paleocene-Eocene Thermal Maximum (PETM), contained at least two light carbon releases. The second light carbon injection was an orbitally controlled event that occurred ~85 kyr after the PETM onset. Light carbon injections associated with the PETM, and other early Eocene carbon cycle perturbations, were followed by exponential carbon removal trends. Half-life ($t_{1/2}$) values of ~6-26 kyr for these events coincide with ocean acidification recovery timescales. These carbon removal estimates are also an order of magnitude smaller than modern carbon cycle $t_{1/2}$ estimates (>100 kyr), which suggests enhanced light carbon sequestration following Paleocene-Eocene carbon cycle perturbations. Similar $t_{1/2}$ estimates for these events with contrasting magnitudes reveal that light carbon uptake may have been accelerated according to the size of the initial carbon injection. Accelerated light carbon sequestration periods after Paleocene-Eocene carbon releases were followed by long-term orbitally controlled organic carbon burial and carbon uptake through chemical weathering. These processes may have reestablished the climate system after Paleocene-Eocene carbon cycle perturbations.



P3-129

What do dinoflagellate cyst sedimentary records in the Santa Barbara Basin reveal about the warming ocean?

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Understanding abrupt environmental changes, including those caused by the rapidly warming ocean is a challenging task and requires a compilation of long term environmental or paleoenvironmental data. Such data are hard to obtain and often even harder to interpret because of unevenness in sampling coverage, potential issues with compiling data at different temporal scales, or complexities associated with paleoproxy-based interpretations. Dinoflagellate cysts are sensitive and reliable paleoenvironmental indicators, and their use has increased over the last decades, especially for high-resolution applications in the Pacific Ocean. Dinoflagellates are one of the most diverse and abundant groups of microalgae in coastal environments and are major primary producers. During their life cycle, many dinoflagellates produce highly resistant organic-walled resting cysts that accumulate in sediments, and their records contain information about upper water masses at the time of deposition.

In this presentation, we summarize what we have learned from high-resolution dinoflagellate cyst sedimentary records that span from seasonal to annual, annual to decadal, decadal to centennial, and centennial to millennial scales in the Santa Barbara Basin (SBB), southern California. The SBB is a deep semi-enclosed basin located on the NE Pacific margin and is characterized by high primary productivity and restricted deep-water circulation resulting in exceptionally preserved sedimentary records under anoxic conditions. The basin has been extensively studied over decades and can now be considered one of the best-researched sites on dinoflagellate cysts in the world. Cyst census data from the contemporary sedimentary trap record, last century sediments, as well as from the Holocene and the Last Interglacial cores allow us to observe changes in the ecosystem responding to the warming ocean. We attempt to reconcile these inferences and provide a unifying interpretation of our observations.



P3-124

Export of pre-aged carbon to the Bay of Biscay at the end of the LGM

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The last deglaciation was the most recent relatively well-documented period of pronounced and fast climate warming. As such, it holds important information for our understanding of the climate system. Notably, the mechanisms leading to rapid atmospheric CO₂ changes during this period are incompletely defined. While research into terrestrial organic carbon reservoirs has been instrumental in exploring the possible sources of atmospheric CO₂ during these periods of rapid change, the underlying processes are not yet fully understood. Here we investigate the mobilization of organic carbon to the Bay of Biscay at the mouth of the English Channel, where an enhanced terrigenous input has been reported for the last glacial-interglacial transition. We have established an accurate and robust chronological framework for this deposition, showing enhanced rates of sediment accumulation from approximately 20.2 to 15.8 cal ky BP. The compound-specific radiocarbon dating of *n*-alkanoic acids isolated from the sedimentary archive disclosed the deposition of pre-aged carbon with pre-deposition ages of up to ca. 30,000 yr, constituting the first direct evidence for the presence of ancient organic matter at the core location. In the light of what has been reported for other regions with present or past permafrost conditions on land, this result points to the possibility of permafrost and/or petrogenic carbon export to the ocean, caused by processes that likely furthered the observed changes in atmospheric CO₂.



P3-106

An eastern equatorial Pacific nutrient tongue during the warm Pliocene

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The El Niño-Southern Oscillation (ENSO) is the largest source of global climate variability, yet it is unclear how it will respond to increasing atmospheric pCO₂. One approach is to reconstruct upper equatorial Pacific conditions strongly impacted by ENSO (i.e., temperature and nutrients) during the Pliocene (~5-to-2.5-million years ago), when pCO₂ was as high as today. The general consensus suggests the currently cool waters of the eastern equatorial Pacific “cold tongue” first developed in the late Pliocene / early Pleistocene. However, our new records of bulk sediment and microfossil-bound N isotopes suggest the continual persistence of the eastern “nutrient tongue” over the past 5 million years. Considering the strong relationship between temperature and nutrients in the modern equatorial Pacific, these are surprising results. Here we work to reconcile our findings with additional records of Plio-Pleistocene equatorial Pacific sea surface temperature and pH.



P3-055

Earth system sensitivity constrained from Cenozoic global cooling

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Paleoclimate archives integrate the overall behavior of all feedbacks in the climate system, including those that are difficult to incorporate in climate models or too slow to be resolved by the observational record. Geologic proxies thus offer unique insight into the multi-millennial temperature response of the climate system to outside forcing, termed the Earth system sensitivity (ESS). To constrain past ESS, we capitalise on recent advancements in the quality of the Cenozoic proxy record by providing up-to-date compilations of surface temperature for eight key intervals spanning the time from 55 to 3 million years ago. Results demonstrate that Earth was considerably warmer than today during all intervals and that temperature anomalies were amplified at high latitudes. However, proxies disagree on the magnitude of past warmth, with terrestrial (mainly paleobotanical) methods yielding milder temperatures than those of the surface ocean (mainly geochemical). We estimate that Earth's surface cooled by approximately 9 °C from the early Eocene to the Pliocene. Calcite $\delta^{11}\text{B}$ and phytoplankton $\delta^{13}\text{C}$ across the same eight intervals suggest that cooling was driven by a steep decline in atmospheric CO_2 concentrations of about 850 ppm, implying a low or moderate ESS. At the same time, cold conditions of the preindustrial and late Pleistocene are inconsistent with a similarly low ESS. We infer that ESS was magnified during the Quaternary and attribute this to the albedo effect of nascent ice sheets in the Northern hemisphere. Use of the preindustrial reference climate to assess past ESS is therefore inadvisable due to its apparent position within a sensitivity domain distinct from that of the remaining Cenozoic.



P3-110

The role of buoyancy forcing for spatio-temporal SST variability across multiple time scales

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Analyses of observational data (from year 1870 AD) show that SST anomalies along the pathway of Atlantic Water transport in the North Atlantic, the Norwegian Sea and the Iceland Sea are in-phase at decadal and longer time scales. A similar in-phase SST anomaly relationship is observed over hundreds of thousands of years during parts of the Pliocene (5.23–5.03 Ma, 4.63–4.43 Ma and 4.33–4.03 Ma). However, when investigating CMIP6 SSP126 future scenario runs (next century) and Pliocene (5.23–3.13 million years) reconstructions, three additional phase relations emerge: 1) The Norwegian Sea being out of phase with the North Atlantic and the Iceland Sea (Pliocene; 4.93–4.73 Ma and 3.93–3.63 Ma); 2) The Iceland Sea being out of phase with the North Atlantic and the Norwegian Sea (Pliocene; 3.43–3.23 Ma); 3) The North Atlantic being out of phase with the Norwegian and Iceland Seas (future trend). Hence, anti-phase relationships seem to be possible in equilibrium climates (Pliocene) as well as in response to transient forcing (CMIP SSP 126 low-emission future scenario). Buoyancy is a key forcing for inflow of Atlantic water to the Norwegian Sea. Therefore, we investigate the impacts of buoyancy forcing on the phase relation between SST anomalies in the North Atlantic, Norwegian and Iceland Seas. This is done by performing a range of idealized experiments using the Massachusetts Institute of Technology general circulation model (MITgcm), in a setup representing the North Atlantic-Nordic Seas region. Through these idealized experiments we can reproduce three out of four of the documented phase relations: in-phase relationships under weak to intermediate fresh water forcing over the Nordic Seas; the Iceland Sea out of phase with the North Atlantic and the Norwegian Sea under weak atmospheric warming over the Nordic Seas; and the North Atlantic out of phase with the Norwegian and Iceland Seas under strong atmospheric warming over the Nordic Seas.



P3-057

The effect of rate of temperature and sea level change on foraminiferal species diversity

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Marine sedimentary deposits on the Atlantic Coastal Plain record paleoecologic data from Paleogene and Neogene climate intervals when sea level and sea surface temperature (SST) were higher than at present. To understand the impact on the shallow water habitat of not just the magnitude of change but also the rate of change, we compared SST and sea level data to foraminiferal species diversity metrics from paleoclimate intervals recorded in cores and outcrops in Maryland and Virginia to predict how modern diversity may be affected in the near future. We assessed foraminiferal diversity across climate events of a range of magnitudes and durations, superimposed on different background climate states: the Paleocene-Eocene Thermal Maximum (PETM, ~56 Ma), a short and rapid warm peak during a greenhouse climate, the Miocene Climatic Optimum (~16.9-14.7 Ma), a longer warm interval at the peak of a greenhouse climate, the Middle Miocene Climate Transition (~14.7-13.8 Ma), representing slow and punctuated global cooling, and the mid-Piacenzian Warm Period (~3.3-3.0 Ma), a warm period during overall global cooling. PETM data from the South Dover Bridge sediment core from southeastern Maryland include benthic and planktic foraminiferal assemblages, sea level and SST estimates, and the duration of two carbon isotope excursions (CIEs) that signify environmental perturbations. Interestingly, while benthic diversity decreased across the PETM, planktic diversity increased due to the addition of excursion taxa. Both benthic and planktic assemblages were more affected by the larger CIE, indicating the importance of the duration of the event. Results from similar analyses of the Middle Miocene BG&E core (southeastern Maryland) and Piacenzian cores and outcrops (southeastern Virginia) will be presented. This research provides a preliminary indication of foraminiferal diversity changes to be expected in the near future under the current rate of rising temperatures and sea level.



P3-114

Reconstruction of past environmental variations in the semi-arid brazilian Nordeste through last interglacials

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The climate system is moving to an anomalous warm state. Past warm periods of the Quaternary, known as interglacials or odd Marine Isotope Stages (MIS) represent excellent case studies to investigate the response of vulnerable components of climate system to warm conditions. Our knowledge of the intertropical zone behavior during last interglacials is still poor. The Nordeste (Northeast of Brazil) is a semi-arid region encompassing several biomes, i.e. Atlantic rainforest and caatinga, with distinct hydrological patterns. Meteorological features over Nordeste are nowadays driven by: (i) the position of the Intertropical Convergence Zone. ii) the interhemispheric sea surface temperature (SST) gradient and (iii) the trade wind regime.

Past environmental changes in the Nordeste region are documented until the last interglacial (MIS 5e). The aim of this work is to further extend the understanding of the teleconnections between vegetation and hydroclimate (continent-ocean system) over the last three interglacials. It is based on the investigation of a marine sedimentary core GL-1180 collected on the eastern Brazilian continental margin and covering up the last 300 kyrs.

A multi-proxy approach relying on organic geochemistry tracers has been developed, combining the analysis of bulk (elemental and isotopic) and molecular compositions along this core. Past oceanic (SST), continental (vegetation cover) and hydrological conditions will be reconstructed using lipid biomarkers including GDGTs, long-chain alkenones and diols, plant waxes and sterols.

Preliminary results suggest that Nordeste experienced notable changes in hydrological conditions over the three last interglacials, even though the climate was overall dry. Remarkable episodes such as Heinrich events (H1, H4, and H5) and MIS extrema (5e, 7d and 9b) were associated with more humid conditions in the Nordeste. Biomarkers analyses are under progress to precise environmental changes during these periods.



P3-120

A Paleotemperature Analysis from the outer Amundsen Sea suggests several Pleistocene West Antarctic Ice Sheet collapses, but not during MIS-5e

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Two degree warming has been suggested as a likely threshold for West Antarctic Ice Sheet (WAIS) collapse. With circumantarctic warming, increased winds enhance delivery of warm Circumpolar Deep Water (CDW) to submarine grounding lines, driving ice sheet retreat, notably in the Amundsen Sea sector. To strengthen ice sheet models of past changes and forecast future ice sheet configurations, this study uses the bimodal morphometrics of the dominant Southern Ocean diatom *Fragilariopsis kerguelensis* to infer paleo-ocean temperatures over the last 620ka in the outer Amundsen Sea. The paleotemperature estimates are calculated by the temperature-calibrated ratio of two distinct morphotypes determined from image analysis software (Glemser and Kloster, *Polar Biology*, 2019). We find that ocean temperatures in the outer Amundsen Sea exceeded the 2°C threshold during MIS-9 (2.7°C), MIS-11 (4.2°C) and an extended warm interval including MIS-13 (5.5°C), MIS-14 (4.7°C), and MIS-15 (5.0°C). MIS-5e, the penultimate interglacial, was nominally warmer than present (0.8°C), but we have no evidence that the Amundsen Sea reached +2°C, suggesting that it may not have been warm enough to confidently point to WAIS collapse via the Amundsen Sea corridor.



P3-062

Provenance and weathering changes during the PETM in the Salisbury Embayment

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The Paleocene-Eocene Thermal Maximum, or PETM, is one of the closest approximations to modern-day warming. Insights into hydrologic changes from this time period can provide insight into our future, warmer world. The PETM sediments from the Mid-Atlantic Coast of the United States have been extensively studied, and record significant changes during this event, including orders of magnitude increases in sedimentation rates and changes in clay mineralogy, with a significant increase in kaolinite content. It has been debated whether this increase in kaolinite is due to the reworking of previous deposits or authigenic formation during the PETM itself. This study seeks to better characterize these changes by means of analyzing the lead and strontium isotopic compositions as well as the concentrations of titanium, cesium, and zirconium relative to aluminum of the bulk and clay-sized fractions to track changes in provenance. Lithium isotopes are used to track changes in weathering congruency, i.e. the rate of dissolution to clay formation. Bulk sediments demonstrate significant excursions in isotopic and trace metal composition, likely reflecting the changing grain-size and lithology across the PETM. Tracers within the clay-sized fraction of sediments vary little throughout the core and are generally consistent with measured values of the Raritan Formation, a proposed sediment source. Lithium isotopes demonstrate an approximately -2.5% excursion during the PETM, interpreted as a decrease in sediment residence time. These results are then compared to high-resolution CAM5 model output of hydroclimate changes in the region. Model output demonstrate significant increases in extreme precipitation resulting from both CO₂ and orbital forcing. Combining these lines of evidence, our data suggests an increase in both weathering and transport resulting from an enhanced hydrologic cycle, with potentially little change in the sourcing of material.



P3-068

An ultra-high resolution diatom study of Paleogene diatomites of the Norwegian Sea (IODP Exp. 396) with implications for PETM seasonality and volcanic-sourced nutrients

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Diatom-dominated biosiliceous sediments accumulated in many parts of the global ocean during the lower Paleogene, including the PETM. Witkowski et al. (*CotP*, 2021) hypothesized that high diatom productivity in the North Atlantic was triggered and maintained largely by continentally sourced nutrients derived from high rates of tropical weathering. Volcanic tephras can also be a regional source of enhanced primary and export productivity and result in enhanced carbon sequestration (Longman et al., *ESR*, 2019). In 2021, IODP Exp. 396 in the Norwegian Sea recovered extensive lower Paleogene diatomites. Most significantly, thick diatomites were recovered near volcanic sources associated with sill emplacement and shallow water hydrothermal vent complexes (HTVC), coincident with the PETM. It is hypothesized that the volcanic activity and sill emplacement remobilized sedimentary carbon, releasing greenhouse gasses into the atmosphere, driving the PETM carbon isotope excursion and the associated hyperthermal event. Organic carbon-rich, often finely laminated and pristinely preserved diatomite accumulated near a drilled vent structure. The 80 m thick PETM age diatomites most proximal to the structure (Site U1568) was diagenetically altered, but superbly preserved diatoms were recovered nearby (Site U1567), offering an unprecedented opportunity to study fine-scale environmental changes during these critical climate transitions. Preliminary analyses of these materials show what may represent individual seasons of deposition. Siliceous ashes often accompany diatoms, suggesting that volcanic activity contributed to both nutrient seeding of the productivity and retarded post-depositional dissolution of the diatoms. Ongoing research into the nature and chemistry of the ashes and the diatoms will result in better understanding of this relationship. Furthermore, diatom analysis will document environmental conditions and diatom evolution through these events in unprecedented detail.



P3-093

Investigating the Early Miocene Extinction Enigma

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The Early Miocene is a relatively understudied period of Earth's history, yet the largest known extinction of open-ocean sharks in their 400-million-year evolutionary history occurred in the Early Miocene, with over 70% of denticle types disappearing suddenly around 19 Ma. This extinction marked a permanent step-change in the pelagic marine vertebrate community, with shark diversity remaining permanently decimated to the modern day. However, the timing and mechanism of this dramatic extinction is enigmatic: there are no known major climatic or oceanographic events to be implicated in such a major extinction. Here I present a compilation of paleoceanographic and paleontological data spanning the Early Miocene to gain insights into the ocean environment and marine ecosystem before and after the shark extinction. There is evidence for a widespread sedimentary gap in Early Miocene aged deep-sea sediment cores: fewer than 10% of the sediment cores investigated appear to have a biostratigraphically complete Early Miocene section, making high-resolution records rare. While paleoproxy evidence from stable isotopes are inconclusive, there are significant turnovers in a variety of marine clades between the late Oligocene and middle Miocene, and there is a turnover in pelagic fish tooth community in the middle of the Early Miocene, extending the extinction to include open ocean mid-level consumers. Finally, there is preliminary evidence for shifts in proxies recording nutrient availability, oxygenation and ocean circulation from the late Oligocene to the middle Miocene. Together, these lines of evidence suggest that changing oceanographic conditions may have reverberated up through the food web, leading to an ecological threshold that disproportionately impacted top predators. However, more high-resolution proxy records from the interval are needed to uncover the drivers of this enigmatic extinction event.



P3-094

Terrestrial and marine temperature evolution across the Miocene Climatic Optimum in the eastern North Sea Basin

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The Miocene Climatic Optimum (~16.9–14.7 Ma) was the most recent interval in Earth's history with greenhouse conditions, which prevailed for nearly 2 million years. The optimum was associated with elevated atmospheric CO₂ (~400–600 ppm) and higher global temperatures, and therefore the optimum is considered one of the best analogues for future climate scenarios. However, existing temperature records, especially from northern high-mid latitudes, are relatively scarce. This limits our understanding of the global temperature evolution across the climatic optimum.

Here, we present a multiproxy low-resolution temperature record from a ca. 250 m long sediment core which spans a shallow marine Miocene (ca. 20 to 8 Ma) succession, located at ~56°N (eastern North Sea). The water depth at the core location oscillated between 0 and 200 m during the Miocene.

The updated pollen record shows mean annual temperatures between 16 and 18 °C prior to the optimum, and 18–20 °C during the optimum. Alkenone-based sea surface temperatures reached a maximum value of 29°C at the climatic optimum. Both records also show, in accordance with global records, a gradual cooling following the Miocene Climatic Optimum. Further, the elevated sea surface temperature during the climatic optimum corresponds with a higher relative abundance of warm-water dinoflagellate cyst taxa.

According to our preliminary results, bottom water temperature (derived from clumped isotopes measured on molluscs) in the Miocene oscillated between 6.8 (+/-1.8) °C and 9.5 (+/- 2.3), with no apparent trend over time. Such low bottom water temperatures are difficult to reconcile with a rather shallow water depth and high sea surface temperatures. Therefore, to exclude either vital or contamination effects, we are planning to additionally obtain bottom water temperature from the calcareous benthic foraminifera, which are present in the core.



P3-054

A 60-million-year tropical seawater temperature record

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Deep-sea foraminifer oxygen isotope records have been widely applied to analyze climate dynamics and ice volume variability over the last 66 million years on a resolution of several millennia. Although such deep ocean records are commonly regarded as global climate records, their temperature component is principally restricted to that of areas of deep-water formation. To assess important climate parameters such as global average temperature, polar amplification of temperature change, and their relation to atmospheric $p\text{CO}_2$, continuous reconstructions of tropical climates are crucial.

We started generating paleotemperature and dinoflagellate-cyst based paleoecological reconstructions on sediments recovered at Ocean Drilling Program Site 959 (eastern equatorial Atlantic) approximately a decade ago and admit these activities have gotten thoroughly out of hand. By now, the record includes >1500 datapoints of the biomarker-based paleothermometer TEX_{86} , representing the first continuous, single-site, equatorial seawater temperature record spanning the past 60 million years. Although resolution differs between intervals, pending the specific scientific questions underlying their generation, the total record mirrors long-term Cenozoic climate trends as known from the benthic oxygen isotope records, including warming towards the early Eocene, cooling towards the Oligocene, Miocene warming and finally cooling towards present-day climate. On top of the million-year trends, multiple transient climate perturbations are recorded coeval with the deep-sea climate records. This congruence indicates that 1) TEX_{86} is a reliable proxy for reconstructing tropical temperature variability from orbital to multi-million-year timescales, particularly when combined with dinoflagellate cyst paleoecology to assess regional oceanographic changes, and 2) deep ocean and tropical temperatures share a common forcing throughout the Cenozoic, likely $p\text{CO}_2$ and associated feedbacks.



P3-077

Cloud feedbacks drive non-linear Eocene surface warming in the DeepMIP ensemble

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Early Eocene geological records indicate a large increase in global mean surface temperatures compared to present day (by $\sim 14^{\circ}\text{C}$) and a greatly reduced meridional temperature gradient (by $\sim 30\%$ in SST). However, reproducing these large-scale climate features at reasonable CO_2 levels still poses a challenge for current climate models. Recent modelling studies indicate an important role for shortwave (SW) cloud feedbacks to drive increases in climate sensitivity with global warming, which helps to close the gap between simulated and reconstructed Eocene global warmth and temperature gradient. Nevertheless, the presence of such state-dependent feedbacks and their relative strengths in other models remain unclear. We perform a systematic investigation of the simulated surface warming and the underlying mechanisms in the recently published DeepMIP ensemble. We advance previous energy balance analysis by applying the approximate partial radiative perturbation (APRP) technique to quantify the individual contributions of surface albedo, cloud and non-cloud atmospheric changes to the simulated Eocene top-of-the-atmosphere SW flux anomalies. All analysed models show an increase of the equilibrium climate sensitivity at higher global mean temperatures. This is associated with an increase in the overall strength of the positive SW cloud feedback with warming in those models. This non-linear behavior is related to both a reduction and optical thinning of low-level clouds, albeit with intermodel differences in the relative importance of the two mechanisms. The new APRP results can differ significantly from previous estimates based on cloud radiative forcing alone, especially in high-latitude areas with large surface albedo changes.



P3-121

Last Interglacial sea ice variability and paleoceanography of the Labrador Sea

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The Last Interglacial period, Marine Isotope Stage 5e (MIS 5e ~116.1-128 kyr BP), is thought to have had a warmer, but less stable climate than the present interglacial. Proxies from the deep- and surface subpolar North Atlantic Ocean in fact show prominent instabilities pointing toward coupled ocean-climate variability. Sea ice has the potential to strongly influence ocean and climate, but its presence and extent throughout MIS 5e is poorly constrained. To evaluate sea ice's role as a driver, or amplifier, of ocean variability, we reconstructed the sea surface hydrography and sea ice variability at the Eirik Drift, Labrador Sea. The reconstruction is based on biomarkers (IP₂₅, sterols), dinoflagellate cyst assemblages and stable isotopes from the penultimate deglaciation, MIS 5e and early MIS 5d. Our results show that the glacial MIS 6 was likely characterized by a thick multi-year sea ice cover. The surface ocean experienced large variability through the first half of MIS 5e. The initial 1500 years (128–126.5 kyr BP) were characterized by the presence of a seasonal sea ice-marginal zone accompanied by a strong halocline. As the sea ice retreated, cool, likely polar-sourced, water remained until an abrupt surge of sea ice marked the final pulse of the remnants of the deglaciation. The second half of MIS 5e (123.5–116.1 kyr BP) was characterized by more stable and warm surface ocean conditions, before a return to increased (seasonal) sea ice conditions in MIS 5d. Initial comparison with deep ventilation proxies (benthic foraminiferal $\delta^{13}\text{C}$) indicates a potential close link between sea ice, surface hydrography and deep circulation.



P3-104

Climate and carbon cycling across the mid-Pliocene Warm Period

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The mid-Piacenzian or mid-Pliocene Warm Period (mPWP; 3.264-3.025Ma) is the most recent period of sustained global warmth, which stands in contrast to the more variable and progressively cooler Pleistocene glacial-interglacial climate which followed. Global temperatures were 3°C higher than the pre-industrial level, with atmospheric carbon dioxide ($p\text{CO}_2$) reaching up to 410ppmv, making the mPWP the nearest past analogue for future warm climate. Thus, proxy reconstructions that can accurately capture biological response to past and projected $p\text{CO}_2$ are crucial in understanding future climate scenarios.

Here we present initial high-resolution climatic variability and carbon cycling records from oxygen and carbon isotopes, assemblage, and morphometry of coccoliths – calcium carbonate exoskeletons produced by marine phytoplankton coccolithophores – from sediments collected during the IODP Expedition 361 at the Mozambique Channel (U1476; 15°49.25'S, 41°46.12'E; 2166m water depth), spanning 2.96 and 3.40Ma at 0.5 to 3.7kyr resolution.

We find strong precession-related 23-kyr cyclicities prior to M2 glaciation. These cycles are associated with negative coccolith fraction $\delta^{18}\text{O}$ ($\delta^{18}\text{O}_{\text{CF}}$) excursions coinciding with increasing upper ocean primary productivity resulting from a more vigorous Mozambique Channel Throughflow, forced by precession minima and northern hemisphere summer insolation maxima. A change in orbital configuration in upper ocean temperature and stratification records, from precession to obliquity, occurs after M2, with an overall climate background of 100-kyr glacial-interglacial cycles in upper ocean primary production, indicating commencement of the longer-term 100-kyr cooling trend observed through the Pleistocene. Periodicities at the eccentricity band, often linked to Pliocene ice volume, are shown in the $\delta^{13}\text{C}_{\text{CF}}$ supporting prior findings on tight coupling between ice volume and carbon cycle changes, analogous to those recorded during the late Pleistocene.



P3-078

Deep-sea temperature change across the Eocene-Oligocene Transition

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The abrupt onset of large-scale Antarctic glaciation approximately 34 million years ago, at the Eocene-Oligocene Transition (EOT), was the pivot point in Cenozoic climate history between greenhouse and icehouse climate states. Our understanding of this event relies heavily on benthic foraminiferal oxygen isotope ($\delta^{18}\text{O}_b$) records but the paucity of independent temperature reconstructions prevents an assessment of the contributions of temperature and ice volume to the rapid $\delta^{18}\text{O}_b$ increase that marks the onset of large-scale Antarctic glaciation. Here we present records of deep-sea temperature change for the EOT using clumped isotope thermometry which enables explicit temperature reconstructions independent of seawater chemistry. Our data come from the eastern equatorial Pacific (EEP; IODP Sites U1333 and U1334 and ODP Site 1218) and northwest North Atlantic (IODP Site U1406). Our records from the EEP provide the first direct evidence for deep-sea cooling associated with the onset of large-scale Antarctic glaciation but suggest that onset of the cooling precedes the earliest Oligocene oxygen isotope step by ~100 kyrs. The cooling in the EEP is short-lived and within 300 kyrs of the EOIS deep-sea temperatures return to values similar to those of the late Eocene. Thus, our EEP records take a similar form to a boron-isotope based reconstruction of atmospheric CO_2 concentrations from the Tanzania Drilling Project (Pearson et al., 2009) and suggests that the establishment of a large Antarctic ice sheet did not lead to a long-term cooling of the global deep ocean. Early Oligocene deep-sea cooling in the North Atlantic, ~200 kyrs after the EOIS, is absent from the EEP. This suggests the deep-sea temperature history of the North Atlantic was likely influenced by changes in ocean circulation and highlights the importance of records from multiple ocean basins to constrain the magnitude of different regional temperature changes from the late Eocene to the early Oligocene.



P3-056

Sensitivity of the West Antarctic Ice Sheet to +2°C (SWAIS 2C)

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The West Antarctic Ice Sheet (WAIS) presently holds enough ice to raise global sea level by 4.3m if completely melted. Despite efforts through previous land and ship-based drilling on and along the Antarctic margin, unequivocal evidence of major WAIS retreat or collapse in times of past warmth has remained elusive. Yet such data are vital to inform numerical models aimed at quantifying predictions of future sea level rise.

The International Continental Scientific Drilling Program (ICDP) project ‘Sensitivity of the West Antarctic Ice Sheet to a Warming of 2°C (SWAIS 2C)’ will constrain past and current drivers and thresholds of WAIS dynamics to improve projections of the rate and size of ice sheet changes under a range of elevated greenhouse gas levels in the atmosphere as well as the associated average global temperature scenarios to and beyond the +2°C target of the Paris Climate Agreement.

Researchers, engineers, and logistics providers from Australia, Germany, Italy, Japan, New Zealand, Republic of Korea, United Kingdom, and United States have established an international partnership comprised of geologists, glaciologists, oceanographers, geophysicists, microbiologists, climate and ice sheet modelers, and engineers to tackle the specific research objectives and logistical challenges associated with the recovery of Neogene and Quaternary geological records from the West Antarctic interior adjacent to the Kamb Ice Stream and at Cray Ice Rise.

New geophysical surveys at these locations have identified drilling targets in which new drilling technologies will allow for the recovery of up to 200m of sediments beneath the ice sheet. The scientific and technological advances developed through this program will enable us to test whether WAIS collapsed during past intervals of warmth and determine its sensitivity to a +2°C global warming threshold.



P3-108

Early to Late Pliocene climate change at mid-latitude North Atlantic Site U1313

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The early Pliocene, with atmospheric CO₂ concentrations at levels similar to today, is seen as a case study for Earth's future climate evolution. During this period the progressive closing of the Central American Seaway led to increased poleward heat and salt transport within the Atlantic with North Atlantic Deep Water (NADW) becoming warmer and saltier and resulting in an enhanced Atlantic Meridional Overturning Circulation (AMOC). To evaluate the stability of the Pliocene AMOC, we are producing centennial-scale surface and deep-water records for IODP Site U1313 (41°N, 33°W, 3412m) for the interval from 3.3 to 4.4 Ma. This site is ideally located to monitor past AMOC changes with North Atlantic Drift waters at the surface and NADW, exported by the deep western boundary current, in the deep. Surface water variations are reconstructed based on the stable isotope data of the planktonic foraminifer genus *Globigerinoides* sp. and on Mg/Ca derived temperatures during the late Pliocene, whereas deep-water changes are revealed by the stable isotope records of the benthic foraminifer genus *Cibicides*. Besides the interglacial/glacial cycles, higher frequency oscillations are recorded in the foraminiferal records. Varying surface water conditions, especially during Late Pliocene interglacial periods, are observed and we will use the pending Mg/Ca temperature data to assess if they are linked to salinity changes. The high-frequency oscillations are related to precession forcing, especially its harmonics in the 5.5 kyr and 11 kyr ranges. The benthic δ¹³C values indicate nearly continuous NADW presence and confirm a strong AMOC throughout the studied interval, also during most of the glacial periods. During the early Pliocene, glacial stage Gi 6 had a stronger impact on the AMOC than Gi 2 and Gi 4. Overall, the AMOC was strong throughout, but experienced high frequency oscillations at a level similar to the middle Pleistocene interglacial periods.



P3-049

Long term Cretaceous climate evolution contextualises Oceanic Anoxic Events 1d and 2

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During the Mesozoic, Earth experienced a series of abrupt and short-lived episodes of widespread oceanic anoxia known as Ocean Anoxic Events (OAEs). They are characterised by severe global warming, likely triggered by volcanic degassing of CO₂. Impacts include shifts in the carbon and hydrological cycles, changes to weathering and nutrient delivery, extinction events, and elevated productivity and carbon burial. Despite their importance in understanding the deep-Earth/ocean/atmosphere system, the environmental impacts and causal mechanisms of OAEs have yet to be fully resolved, and are particularly poorly understood in the Southern Hemisphere. Furthermore, background conditions are often not examined to provide context for these geologically rapid events. This project reconstructs climate, palaeoceanography and biotic responses in the Mentelle Basin (SW of Australia) leading up to, during, and after OAEs 1d and OAE 2 during the mid-Cretaceous, through analysis of core material collected during International Ocean Discovery Program (IODP) Expedition 369.

Using the carbon isotope composition of bulk organic matter, the TEX₈₆ sea surface temperature (SST) proxy, Nd and Sr isotopes, and elemental data from XRF core scanning, we demonstrate that the Mentelle Basin likely experienced a stable environment from the late Aptian – early Cenomanian. During this time SSTs were ~29-30°C, and black claystone lithology with stable εNd and BIT values indicate a consistent detrital source. A greater period of sensitivity follows for around 3 million years, until OAE 1d, where a transient shift in sediment source and composition suggest a short-term impact on the hydrological cycle. Between OAE 1d and OAE 2 is a period of elevated variability in sediment provenance, productivity, and SSTs. OAE 2 expresses a suite of dramatic changes in the basin, studied in greater detail in the future. These data show the extremity of climatic shifts over OAEs compared to background conditions.



P3-086

Investigating shifts in SST, primary productivity and circulation in the Pacific Sector of the Southern Ocean during the Late Miocene

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With growing concern over current rising global temperatures and increased urgency to understand how the climate system operates in a warmer state, the Miocene (~23.3 - 5.05 Ma) is a critical time period to understand, as it is the most recent period of sustained warmth prior to the onset of Northern Hemisphere glaciation in the early Pliocene. The Miocene features significantly increased warmth in both the tropics and poles (Herbert et al. 2016), making this period crucial to better understand feedbacks and shifts in climate sensitivities that might be expected in a warmer climate (Burls et al. 2021). However, continuous records from the Miocene are rare as there are frequently hiatuses in sediment cores during this time. In particular, the Southern Ocean (SO) – a region of critical importance for climate feedbacks – is extremely undersampled, and there are no records from the open ocean Pacific Sector of the SO. This study focuses on site U1541 (54°12.756'S, 125°25.540'W) from IODP Expedition 383 and is the first record from the Pacific Sector of the Southern Ocean during the late Miocene and early Pliocene (~8.3-3.3 Ma). During the transition period from ~8-7 Ma, we find a decrease in bulk carbonate $\delta^{13}\text{C}$ and CaCO_3 content, concurrent with the global “Late Miocene Carbon Isotope Shift” event. This is coupled with an increase in $\delta^{15}\text{N}$, nitrogen and total organic carbon contents, potentially indicating an increase in productivity, or shifts in nitrate availability or source during this period. We combine these analyses with sea surface temperature estimates from foraminifera $\delta^{18}\text{O}$ and alkenones to better elucidate changes in primary production, nutrient utilization in the Southern Ocean during this time, as well as analyzing shifts in meridional SST gradients with resultant consequences for shifts in structural climate sensitivity during a warmer climate.

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P3-109

Atlantic ocean heat transport response to a stronger mid-Pliocene AMOC

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The mid-Pliocene warm period (3.264–3.025 Ma) is the most recent geological period during which the atmospheric CO₂ concentration was similar to present-day values (ca. 400 ppm). Sea surface temperature proxies indicate amplified warming over the North Atlantic in the mid-Pliocene with respect to the pre-industrial period, which may be linked to an intensified Atlantic Meridional Overturning Circulation (AMOC). Earlier results from the Pliocene Model Intercomparison Project Phase 2 (PlioMIP2) show that all models in the PlioMIP2 ensemble simulate a stronger AMOC in the mid-Pliocene than in the pre-industrial. However, no consistent relationship was found between the stronger mid-Pliocene AMOC and the Atlantic northward ocean heat transport (OHT). In this study, we investigate the dynamics behind the ensemble's variable response of the Atlantic OHT to the stronger AMOC. This is done by separating the total Atlantic OHT into two components associated with either the overturning circulation or the wind-driven gyre circulation. While the ensemble mean OHT by the overturning circulation is increased significantly in magnitude in the mid-Pliocene, it is partly compensated by a reduction of OHT by the gyre circulation in the northern subtropical gyre region. This reduction originates from zonally asymmetric warming in the mid-Pliocene subtropical North Atlantic, rather than from changes in the subtropical gyre circulation itself. The varying degree of compensation among PlioMIP2 models results in a variable response of the total Atlantic OHT to a strengthened AMOC. Our results indicate that considering the behavior of the separate OHT components is essential for gaining a more complete understanding of the OHT associated with a stronger mid-Pliocene AMOC.



P3-087

Inferences from an outstanding late Miocene Western Pacific Warm Pool benthic stable isotope record (IODP Site U1488)

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The late Miocene is an enigmatic period where our modern climate system is founded. The equatorial Pacific comprises 50% of all tropical water masses and is vital to the global heat transport, the hydrological cycle and carbon cycle dynamics. The El Niño/La Niña phenomenon of the equatorial Pacific is a significant component of Earth's climate system influencing global precipitation and temperature anomalies. Anthropogenic global warming projections for 2100 predict climate conditions last seen in the late Miocene. Therefore, the late Miocene dynamics related to the El Niño-/La Niña-like phenomenon are critical information for future climate.

Prerequisite to reliably reconstruct El Niño-/La Niña-like conditions across the equatorial Pacific on Milankovitch time scales are synchronized records on accurate astronomical age models. Here we present an outstanding high quality benthic stable carbon and oxygen isotope record from IODP Expedition 363 Site U1488 located in the Western Pacific Warm Pool Site spanning 6.0 to 9.7 Ma. We developed an astronomically calibrated benthic isotope stratigraphy for Site U1488 and establish an accurate correlation to high-resolution records from eastern equatorial Pacific Sites U1337 and U1338 (IODP Exp. 320/321), creating the first robust stratigraphic comparison across the equatorial Pacific Ocean down to the orbital cycle level. Carbon isotope data of U1448 reveal a remarkably clear imprint of orbital eccentricity and fine details on the structure of the Late Miocene Carbon Isotope Shift. Oxygen isotope data document and reconfirm the shift from eccentricity-precession- to obliquity-dominated variability as observed in the eastern equatorial Pacific. This new stratigraphic synchronization of the equatorial Pacific drill core records will allow testing of the true extent of permanent El Niño-like conditions proposed for the warm late Miocene, and examining their driving forces and global impacts.



P3-098

The potential to investigate Pliocene seasonality with high-resolution stable isotope records from the bivalve *Angulus benedeni benedeni*'s shells

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Obtaining temperature data from the mid-Piacenzian warm period (mPWP) is of key importance in understanding the coming changes brought upon by anthropogenic climate change. The mPWP, a high-CO₂ world with a paleogeography similar to modern times, has been used to validate and improve climate model retrodictions. Validating climate models requires robust proxy data. Here, we increase the potential of this proxy database by showing that the extinct tellinid bivalve *Angulus benedeni benedeni* can be used for stable isotope-based temperature reconstructions. This species is found in the mid-Piacenzian sediments of the southern North Sea basin. Oxygen isotope and carbonate clumped isotope measurements on the shell of *A. benedeni benedeni* resulted in a mean annual temperature reconstruction of 13.5±3.8°C. This is 3.5°C warmer than the pre-industrial North Sea and in line with global Pliocene temperature estimates of +2-4°C above pre-industrial values. Oxygen isotope thermometry suggests summer and winter temperatures of 18.5±3.9°C and 6.4±3.9°C and a corresponding seasonal range of 12°C. This range should be regarded as a minimum. The preliminary clumped isotope dataset does not (yet) enable confident seasonality reconstructions, but we show that this is possible with a larger dataset. Sclerochronologic analysis showed that *A. benedeni benedeni* could live for up to a decade and likely experienced slower growth during winter. The pristine nature of the aragonitic shell material was verified through electron backscatter diffraction analysis (EBSD), X-ray diffraction and X-ray fluorescence. The various microstructures as obtained from the EBSD maps have been described, and they provide a template for pristine material against which potentially altered shells may be compared. The bivalve *A. benedeni benedeni* can be used to unravel marine conditions in the Pliocene North Sea basin at a seasonal scale, yielding enhanced insight into imminent western European climate conditions.



P3-103

Origin of iceberg rafted debris delivered to Prydz Bay, East Antarctica during the mid-Pliocene Warm Period

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During the mid-Pliocene Warm Period (mPWP), ~3.3-3.0 ma, Earth experienced climatic conditions similar to those projected for the mid to late 21st century. Atmospheric CO₂ levels fluctuated between 285-450 ppm, global sea level was between -40 to +15 m. compared with today, and global temperatures were at times 2-3°C warmer than present. As such, the mPWP represents a fantastic geological analogue with which to study the impacts of near-future warming.

Here, we present high resolution counts of iceberg rafted debris and clay mineralogy measurements from ODP Site 1165, located in Prydz Bay offshore East Antarctica. These data are placed within an updated chronostratigraphic framework, based on published ages and newly acquired sedimentary Ba/Ti measurements. This improved age control allows for better comparison with global climate proxies, including sea level estimates. We use these data to investigate the potential role that East Antarctic ice mass changes may have had in global sea level fluctuations during the mPWP. We use these new data to assess the stability of East Antarctic ice sheets under climatic conditions expected of the mid to late 21st century.



P3-112

Insolation and CO₂ induced variations in the sea ice of the last nine interglacials and their comparison with the future

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Understanding the sea ice variability and the mechanisms involved during warm periods of the Earth is essential for a better understanding of the sea ice changes at the present and in the future. Based on simulations with the model LOVECLIM, this study investigates the sea ice variations during the last nine interglacials and focuses on the inter-comparison between interglacials as well as their differences from the present and future. Our results show that LOVECLIM has a reasonable performance in simulating sea ice variations. The results show that the annual mean Arctic sea ice variation is primarily controlled by local summer insolation, while the annual mean Southern Ocean sea ice variation is more influenced by the CO₂ concentration but the effect of local summer insolation can't be ignored. The lowest Arctic sea ice area results from the highest summer insolation at MIS-15, and the lowest Southern Ocean sea ice area at MIS-9 is explained by the highest CO₂ concentration and moderate local summer insolation. As compared to the present, the last nine interglacials all have much less sea ice in the Arctic annually and seasonally due to high summer insolation. They also have much less Arctic sea ice in summer than the double CO₂ experiment, which makes to some degree the interglacials possible analogues for the future in terms of the changes of sea ice. However, compared to the double CO₂ experiment, the interglacials all have much more sea ice in the Southern Ocean due to their much lower CO₂ concentration, which suggests the inappropriateness of considering the interglacials as analogues for the future in the Southern Ocean. Our results suggest that in the search for potential analogues of the present and future climate, the seasonal and regional climate variations should be considered.



P3-090

Eastern Equatorial Atlantic climate variability during the onset of the Miocene Climatic Optimum

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The Miocene Climatic Optimum (MCO, ~17-15 Ma) is a relatively warm interval that interrupted the Cenozoic cooling trend and bears analogies with projected *end-of-the-century* climate. Proxy data and model simulations indicate deep-water temperatures of ~8°C higher than present day and atmospheric $p\text{CO}_2$ values of 500-600 ppmV. However, to be able to use Miocene paleoclimate records to quantify key climate parameters like the polar amplification of climate change, accurate reconstructions of tropical surface oceans are required.

We present 2–4-kyr resolution records of tropical sea surface temperature (SST) variability based on TEX_{86} at Ocean Drilling Program Site 959 in the eastern equatorial Atlantic Ocean spanning the early to middle Miocene (~15 – 18 Ma). Using chemo- and biostratigraphic tie points, we built an astronomical age model by tuning bulk carbonate oxygen- and stable carbon isotope ratios, magnetic susceptibility, and elemental concentrations to eccentricity, obliquity and precession.

Average SST (calibrated with TEX_{86} -H) rose by ~2°C across the onset of the MCO (~17 Ma). Thereafter, bulk carbonate $\delta^{13}\text{C}$, mainly paced by eccentricity, increased by ~1‰ and indicates the onset of the Monterey Excursion. Pronounced lithological variability is apparent from highly variable magnetic susceptibility, % CaCO_3 and colour records, which underline a depositional setting that alternates between predominantly biogenic silica, increased carbonate deposition and/or a terrigenous component (i.e., clays). Across the onset of the MCO, an important transition from glacial-interglacial-forced SST variability before ~17 Ma to a highly sensitive depositional system between ~17 – 16.5 Ma is recorded. The latter is characterized by high-amplitude SST variability ($\pm 3^\circ\text{C}$), concurrent with Ba_{bio} productivity peaks, which strongly respond to obliquity and 100-kyr eccentricity. This suggests that a highly dynamic monsoon-driven upwelling regime was present at Site 959 during the MCO.



P3-118

Last Interglacial subsurface warming on the Antarctic shelf triggered by reduced deep-ocean convection

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The global mean sea-level was likely ~3-6 m higher at the Last Interglacial (LIG) compared to pre-industrial (PI), with an Antarctic contribution estimated at 3 to 5 m sea-level equivalent. Antarctic ice-sheet modelling studies suggest that such an ice-mass loss from Antarctica requires a subsurface warming on the Antarctic shelf of ~3°C compared to PI. Here, we show that such a subsurface warming is simulated in an equilibrium experiment of the LIG performed with the ACCESS-ESM1.5. Reduced deep-ocean convection in the Weddell and Ross Seas, arising from reduced sea-ice cover, are the primary drivers of this subsurface warming, reaching +2.4°C at 430 m depth. The associated changes in meridional density gradients and surface winds lead to a weakened Antarctic Circumpolar Current but strengthened Antarctic Slope Current, which further impact subsurface temperatures around both East and West Antarctica, with a maximum warming of +3.1°C at 125 m depth on the East Antarctic shelf. Subsurface warming induced by enhanced stratification could therefore have triggered ice-mass loss from the Antarctic ice-sheet, which would have further amplified the stratification and warming.



P3-084

Exploring long-term oceanic N cycling and budget over the last 12 Myr

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A lack of long records from globally distributed regions beyond denitrification zones prevents us from understanding the whole oceanic N budget, specifically on million-year timescales.

Dramatic climate changes since the Miocene provide an opportunity to explore long-term oceanic N cycling and budget. In this project, I am going to generate bulk sediment N isotope records ($\delta^{15}\text{N}_{\text{bulk}}$) since the late Miocene (~12 Ma) from 19 globally distributed sites. Our preliminary results from Site U1490 in WEP and U1338 in EEP show consistent increasing trend in $\delta^{15}\text{N}_{\text{bulk}}$ values by ~6-8‰ over the last 12 Myr, indicating increased denitrification while global cooling. This increasing trend is verified by a foraminifera-bound $\delta^{15}\text{N}$ ($\delta^{15}\text{N}_{\text{fb}}$) record at Site 872 from the tropical Pacific (Auderset et al., 2021), which supports that the general trend is not controlled by diagenesis. Our preliminary results from Site U1541 from the Southern Ocean show same pronounced shift of increasing $\delta^{15}\text{N}_{\text{bulk}}$ values by ~5-8‰ as U1490 during ~8.5-7 Ma, which are consistent with new $\delta^{15}\text{N}_{\text{fb}}$ records from the tropical Pacific and the eastern Pacific (Wang et al., 2021). Productivity records at Site U1541 suggest that this shift does not likely represent changes in utilization alone. Thus, our results suggest that there is likely a global shift in the average $\delta^{15}\text{N}$ value of the whole ocean ($\delta^{15}\text{N}_{\text{mean}}$) during the late Miocene. The low $\delta^{15}\text{N}_{\text{bulk}}$ values before ~ 8.5 Ma are likely related to the disappearance of the East Tropical Pacific denitrification zone and then a subsequent $\delta^{15}\text{N}_{\text{mean}}$ shift to higher values due to the intensified water column denitrification. The global increase in denitrification might lead to a net N loss of the whole oceanic fixed N inventory and I will test this by building a box model to constrain the N budget. This project provides insight into fundamental questions such as how regional and global N-dynamical processes played a role in climate-nutrient-carbon feedbacks on long timescales.

Poster abstracts



Topic 4: Improving Our Understanding of a Warmer World

virtual posters



Pv-401

Are modern planktic foraminifera suggesting us oceanographic/ climate changes in the Adriatic Sea?

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If the information about modern planktic foraminifera in the Mediterranean Sea are not abundant, they are virtually absent for the Adriatic Sea. Our data set includes at least three complete years of data from sediment traps of two moorings (Southern Adriatic), and plankton nets collected in summer 2004 and spring 2007 in the Central and Southern Adriatic. We compared the results with the assemblages present in the core tops of the Central and Southern Adriatic, conveniently selected to represent the modern time by means of stratigraphic and geochemical data. During the years 2013-2014-2015-2017 sediment traps (depth 500, 130, 125m) show *Hastigerina pelagica*, a taxon recorded as absent or very rare in the Mediterranean modern assemblage literature (nets/traps), as one among the most abundant taxa, with frequency peaks occurring in spring just after chlorophyll-a maxima. This trend is somehow expected, as *H. pelagica* is a carnivorous taxon with the diet composed predominantly by copepods. In the few samples available for the years 1995 and 1997 (spring) *H. pelagica* is absent. The herbivorous taxa *Globigerinita glutinata*, along with *Globigerina bulloides* and *Turborotalita quinqueloba*, are more frequent at the end of the winter, just preceding *H. pelagica* peaks, with the highest values in 1995 and 1997. Plankton nets confirm the high abundance of *H. pelagica* (down to 450m w.d.), along with *Globigerinella siphonifera*. The modern assemblage from the core tops is composed by *T. quinqueloba*, *G. bulloides*, *Globigerinoides ruber*, *G. glutinata*, *Globigerinella calida*, *G. siphonifera* and *Orbulina* while *H. pelagica* is absent, confirming the fragility/dissolution of the thin test. The unexpected abundance of *H. pelagica* in Adriatic may be due to the increase of the water temperature, changes of the circulation pattern of the water masses entering or forming in the Adriatic (EMT/BiOS), variation of the trophic status and/or the food quality.



Pv-406

How will the tropical Pacific respond to global warming? The importance of timescale when considering apparent paleo-paradoxes

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Several oceanic and atmospheric mechanisms have been put forward to describe the response of the tropical Pacific to global warming. Still uncertainties persist in their interaction and relative importance, with projections varying substantially across climate models. When we turn to the last time in Earth's history that atmospheric CO₂ estimates exceed 400 ppm, the Pliocene, several apparent paradoxes appear, clouding our view of the tropical Pacific during the Pliocene and its utility as a potential analogue for future warming. However, when proper consideration is given to the timescales associated with the oceanic and atmospheric mechanisms that support tropical Pacific climate variability, several of these apparent paradoxes can be resolved. The first apparent paradox is between the reduced east-west SST gradient (weaker Walker Circulation) mean-state reconstructions for the Pliocene and the strengthening of the east-west SST gradient during 20th century warming. This paradox can be resolved by considering the transient versus equilibrium processes involved in response to global warming. The second apparent paradox is evidence for ENSO during the Pliocene even while the mean state resembled more El Niño-like (i.e., El Padre) conditions. This apparent paradox is resolved by the relative importance of coupled feedbacks, other than the thermocline feedback, generating inter-annual variability in the Pliocene. Thirdly, an apparent paradox between the reduced Pliocene east-west SST gradient, indicative of reduced wind-driven upwelling, and evidence of enhanced biological productivity in the east Pacific where productivity is typically driven by upwelling. This apparent paradox can be reconciled by evidence for older, more acidic, and nutrient-rich water reaching the equatorial Pacific by way of a Pacific meridional overturning circulation during the Pliocene, providing a mechanism for enhanced productivity existing alongside a reduced east-west SST gradient.



Pv-403

Complex spatio-temporal structure of the Holocene “Thermal Maximum”

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Inconsistencies between Holocene climate reconstructions and numerical model simulations, formalized as the “Holocene Temperature Conundrum”, question the robustness of both climate models and proxy temperature reconstructions. Indeed, climate reconstructions suggest that the early-middle Holocene Thermal Maximum (HTM) lasting until ~ 4 kyr ago was followed by gradual cooling, whereas climate models indicate continuous warming across the Holocene. The discrepancy may be due, in part, to seasonal biases in proxy-based climate reconstructions, but it may also imply that the sensitivity of climate models to external forcing and internal mechanisms needs to be reevaluated, which bears important implications for future climate projections. Here, we analyze a global database of Holocene paleotemperature records to investigate the spatiotemporal structure of the HTM. Continental proxy records mostly encompassing the middle and high latitudes (30°N-70°N) of the Northern Hemisphere show a “classic” HTM, which typically occurred between 8 and 4 ka. In contrast, marine proxy records, which span a wider spatial distribution indicate that the Holocene temperature optimum occurred between 11 and 7 ka in mid to high northern latitudes (30°N-70°N), yet a clear climate anomaly is missing in the tropics. The amplitude of the marine HTM varies with latitude, with the largest anomalies corresponding to the latitudinal bands of today’s oceanic frontal zones, thus highlighting critical interactions between surface ocean dynamics and climate change.



Pv-404

Transient dwarfism among Tethyan calcareous plankton across the Eocene Thermal Maximum 2 (ETM2)

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Dwarfism episodes among calcareous plankton have been linked to biotic stress, e.g. during global warming events. However, only few studies exist for calcareous plankton size data across the early Eocene hyperthermals, except for the Paleocene/Eocene Thermal Maximum (PETM ~56 Ma). Here, we present an integrated record based on calcareous plankton abundances, size data, geochemical and dissolution proxies on two Tethyan sections, Terche and Madeago (NE Italy), that span the Eocene Thermal Maximum 2 (ETM2, ~54 Ma) and its associated warming and change in carbonate chemistry. The data show major transient changes across this event which are not caused by dissolution. The ETM2 warming impacted the foraminifera across the entire upper-water column. Warm surface-dweller *Acarinina* markedly increases in abundance while the cool deeper-dwellers *Chiloguembelina* and *Subbotina* declined. Calcareous nannofossils are suggested to be more sensitive to nutrient supply rather than warming and record surface waters eutrophication during the ETM2. We suggest that the enhanced hydrological cycle increased nutrients input into these sections close to the shore. We documented for the first time a striking reduction of up to 40% in all planktic foraminiferal genera at the ETM2. The loss of symbionts (bleaching) is unlikely the possible cause of dwarfism, at least for the deeper dwellers that were also impacted. Size reduction, potentially both reduction of sizes within population and replacement by smaller taxa, also impacted calcareous nannofossils, though at a lesser extent, as indicated by the increased abundance of the small placoliths *Toweius* and *Ericsonia*. The onset of the ETM2 is linked to an increase in Hg/TOC (ppb/wt%) which we relate to volcanic activity. We hypothesize that the dwarfism was the strategy adopted to face multiple stresses linked to volcanic episodes and coupled with upper water-column modifications induced by the ETM2 warming.



Pv-402

Planktic foraminiferal response to the Early Eocene Climatic Optimum (EECO, ca 53-49Ma): biostratigraphy and quantitative abundances from Hole 762C (Exmouth Plateau, Indian Ocean).

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The EECO (ca 53-49 Ma) is a crucial interval of time to explore the marine biota response to past global warming as it records the Earth temperatures and pCO₂ peak of the entire Cenozoic Era. The unicellular planktic foraminifera are a major group of open-marine calcifiers to investigate in this view as a group extremely sensitive to paleoenvironmental changes and largely utilized in biostratigraphy. Recent studies highlight that the EECO significantly impacted the abundance and diversity of the symbiont-bearing genus *Morozovella*. This genus, close to the carbon isotope excursion (CIE) known as J event, markedly and permanently decreased in abundance and diversity in the Atlantic and Pacific Oceans whereas abundance and diversity of genus *Acarinina* concomitantly increased. In addition, *Morozovella* species switched their coiling direction (the ability to add chambers in clock or counter clock-wise) from dominantly dextral to dominantly sinistral within 200-400 kyrs after the CIE K/X event, whereas *Acarinina* maintains both below and within the EECO rather proportional dextral and sinistral coiling direction. The detailed record from Atlantic and Pacific Oceans also underlines diachroneities among planktic foraminiferal biohorizons. We decided to explore planktic foraminiferal biostratigraphy, quantitative abundance and coiling direction from Hole 762 C (Exmouth Plateau). This site, though affected by some core breaks, records several CIEs below and within the EECO. The study of this site is essential to outline a global perspective of planktic foraminiferal response to the EECO due to its far southern high latitude location of northwest margin of Australia. Our dataset provides new biostratigraphic data suitable for a required Eocene zonal scheme revision and new insights on the resilience of planktic foraminifera from southern Indian Ocean, essential for a more comprehensive understanding of past global warming events in light of the current climate changes.



Pv-407

Eocene Climate and Ecological Dynamics from IODP Site U1553, South Campbell Plateau

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Understanding the functioning of high-latitude climates and ecosystems during the Eocene is critical for constraining the mechanisms that sustain warm climates. The South Pacific Ocean remains a major geographic gap in our understanding of these dynamics. IODP Expedition 378 recovered a record of Eocene climate at Site U1553, a state-of-the-art re-drill of the spot-cored, single hole legacy DSDP Site 277, from the South Campbell Plateau (55°S paleolatitude). Here we present stable isotopic and planktic foraminifera assemblage results across the early Eocene (56-52 Ma) to investigate changes in water column structure and ecological dynamics in response to secular and rapid warming. Similar to other lower latitude sites, we observe an increase in abundance of the planktic genus *Acarinina* relative to *Morozovella* close to the J event (~53.3 Ma), a hyperthermal thought to usher in the Early Eocene Climatic Optimum (EECO, Westerhold et al. 2018). Future work will investigate the physiological response of these two genera to warming as well as genus diversity across this ecological switch. Paired stable isotopes of planktic and benthic species show a convergence of $\delta^{18}\text{O}$ during the EECO, largely driven by an increase in *Acarinina* spp. $\delta^{18}\text{O}$, pointing to major hydrographic changes with warming (e.g. Shepherd et al. 2021). Carbon isotope gradients weaken over time to a lesser degree. Stable isotopes of the benthic species *O. umbonatus* (infaunal) show a much stronger excursion across a hyperthermal event than *N. truempyi* (epifaunal), falling outside the species' relationship established at Site 1209 (Westerhold et al. 2018), possibly indicating changing porewater chemistry during peak warming. Continued work will increase the resolution of stable isotopic and foraminifera assemblage work to further constrain the record of Eocene climate at Site U1553.

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Pv-408

Model performance in simulating the mid-Holocene Green Sahara

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The Green Sahara Period, spanning about 11,500 to 5,000 years ago, offers an opportunity to test the ability of climate models to simulate large-scale changes in northern African climate through the strengthening of the West African Monsoon. In this study, we evaluate the performance of four models in simulating the mid-Holocene (6,000 BP), namely – EC-Earth, iCESM, CCSM4-Toronto, and the GISS Model E2.1-G. Two scenarios are considered for each model – a standard PMIP scenario simulated with the mid-Holocene orbital parameters and greenhouse gas concentrations with vegetation prescribed to pre-industrial conditions, as well as a Green-Sahara (GS) scenario which additionally considers factors such as enhanced vegetation, reduced dust, presence of lakes, and land and soil feedbacks. All mid-Holocene scenarios capture an increase in monsoonal precipitation in northern Africa. However, a comparison of the two mid-Holocene scenarios reveals significantly higher precipitation in northern Africa for all the GS scenarios relative to the PMIP scenarios – an observation consistent across all models. Accompanied by a strengthened Saharan Heat Low, these changes in the West African Monsoon are also linked to polar amplification, a stronger Indian Summer Monsoon and alterations to the Walker circulation. Model results are in agreement with pollen-based SAT records, multi-proxy SST records and African lake level records. This comparison indicates that a realistic simulation of the mid-Holocene Green Sahara requires consideration of multiple factors in addition to orbital and greenhouse gas forcings.



Pv-405

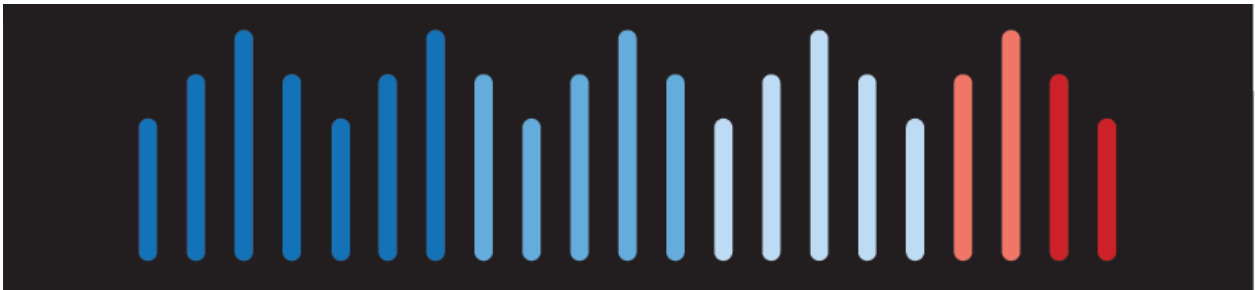
The last interglacial cycle in the SE Caribbean and its relation to riverine (Orinoco-Amazon) discharge variability

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Understanding of climate mechanisms that operated during the last interglacial cycle (~140-110 ka) remains incomplete, not least due to the lack of high-resolution archives from the tropical regions. Here we present sedimentological (i.e., Zr/Rb record, grain size distribution), organic (i.e., alkenone C₃₇ concentration) and planktic foraminiferal assemblage data from a SE Caribbean location (core MD99-2198, 1330 m water depth), directly influenced by Orinoco and Amazon outflow waters. The end of the penultimate (Saalian) glaciation is characterized by coarse sediments that can be explained by a reduced supply of clay material from the Orinoco and Amazon rivers due to global sea level lowstand and shelves exposure. This time interval is further marked by increased fluxes of *N. dutertrei* and *G. bulloides*, possibly linked with the expansion of coastal upwelling, and is in analogy with the situation during the last glaciation. A two-phase Heinrich Stadial 11 is characterized by high abundances of oligotrophic species *G. aequatorialis* and deep-dwelling species *G. truncatulinoides* indicating a southward shift of the North Atlantic Subtropical Gyre and/or reduced fertilization by the Orinoco River. The strong decline in surface productivity during this time is corroborated by low foraminifera fragmentation and low alkenone concentrations. During the subsequent interglacial period we detect changes in foraminiferal assemblage, i.e., in terms of preservation as well as alkenone abundances which combined are interpreted as evidence for the Orinoco River run-off variability. The time of early Weichselian glacial inception is marked by accumulation of particularly fine-grained sediments, indicating increased delivery of fluvial clays, which possibly is a result of coeval changes in global sea level and the Orinoco and Amazon rivers discharge. We then compare our results with published Holocene records to improve our knowledge of glacial-interglacial climate forcing mechanisms.

Poster abstracts



Topic 5: Innovations to Overcome Knowledge Gaps

on site posters



P1-127

Planktonic foraminifera $\delta^{18}\text{O}$ and modulation of the orbital signal

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Climate change on orbital time-scales is frequently studied using $\delta^{18}\text{O}$ from planktonic foraminifera. $\delta^{18}\text{O}$ reconstructions are used as proxy for temperature change, as aid in the construction of age models and to deduce the drivers of climate change by looking at frequency power spectra. An important two-step assumption is made using these approaches, namely that the signal of the orbital cycles is not modulated 1) between the solar radiation that reaches the top of the atmosphere and the sea surface environmental changes, and 2) in the translation of the environmental changes into the $\delta^{18}\text{O}$ composition of the foraminiferal shell. The complexity of these two steps make it difficult to validate the assumptions behind these major paleoclimatological approaches. In this research we aim to validate the second part of this assumption that is underpinning many paleoclimatological investigations: do species-specific living habitats of foraminifera in the water column and throughout the year modulate the recorded $\delta^{18}\text{O}$ signal with respect to the orbital forcing? We will do this by combining the isotope-enabled LOVECLIM Earth system model with the foraminifera growth model FAME and investigate the response of $\delta^{18}\text{O}$ from three species of foraminifera to obliquity and precessional cycles.

We find that the planktonic foraminifera $\delta^{18}\text{O}$ response to astronomical forcings is dominated by annual mean changes in sea-surface temperature, thus corroborating a key assumption underlying many geological climate reconstructions. Nonetheless, there are also many places in which changes in the depth habitat, temperature-dependent growth rates, seasonality and $\delta^{18}\text{O}$ of the sea water modulate the foraminifera $\delta^{18}\text{O}$ signal. Because of these modulations, planktonic foraminifera $\delta^{18}\text{O}$ time series can have very different characteristics compared to the orbital forcings, including limited spatial coherence as well as limited inter-species coherence at a single location.



P1-120

Development of the ancient DNA proxy in the Southern Ocean as a tool to explore diatom variations in abundance and diversity over the late Holocene

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Sedimentary ancient DNA (sedaDNA) is a molecular tool transferred from ecology to paleoceanography, now being applied in the Southern Ocean (SO) seafloor. Important variations in the abundance of ecologically-important diatom genera (e.g., *Chaetoceros*, *Thalassiosira* and *Fragilariopsis*) have been described in SO sediment cores through microfossil counts. However, many diatom species undergo dissolution during settling and therefore are not preserved in the sediment, which can be alleviated using complementary sedaDNA analyses. First, we optimized both the extraction and sequencing library preparation protocols to ensure higher total DNA yield, good inhibitor removal and low dimer concentrations for amplicon and shotgun sequencing. In particular, we target the V9 region of the eukaryotic-specific small subunit ribosomal RNA-gene, as well as a diatom-specific region within the gene encoding the large RuBisCO subunit. These amplicons are widely used in modern phytoplankton studies, and have also been tested in previous paleogenomics studies, producing a signal of the microbial diversity at a low sequencing cost. In a second step, sedaDNA will be analysed in a deep-sea core from the northern Antarctic Peninsula (61°59.23S, 55°05.63W, collected at 1295m water depth), covering the Late Holocene, and compared to the classical diatom counting approach together with other proxies such as Highly Branched Isoprenoids for past sea-ice coverage. DNA sequencing will allow us to confirm and refine the composition of diatom communities preserved in this core, thanks to genetic reference databases from contemporary ocean sampling, including baseline data from *Tara Oceans* in the SO. Our novel approach aims to understand adaptative responses of diatom communities to past environmental changes in the SO by the analysis of species diversity variations over time and via functional analyses targeting genes coding for key biological functions (e.g., those encoding ice-binding proteins).



P1-123

Metabarcoding resolves morphospecies diversity trends: a case study of fjord foraminiferal eDNA

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Climate and environmental changes pose risks to the marine realm worldwide, with negative effects on function and diversity of ecosystems. Foraminifera are widely recognised as reliable and sensitive environmental indicators, contributing to resolving marine biodiversity and ecosystem changes on wide spatial and temporal scales. However, conventional studies rely on microscopic observations, a limited taxonomic range and selected size fraction. With this approach, putatively important and ecologically informative parts of the community (i.e., small-sized, cryptic and/or organic-shelled species) are disregarded. Molecular tools emerged as a potentially time- and labour-efficient alternative to observation-based methods, promising comprehensive biodiversity assessments by the recognition of environmental DNA (eDNA) in sediments. There is a growing body of foraminifer eDNA studies, although so far focussing on deep-sea sediments, or polluted areas for biomonitoring applications. Here we focus on biodiversity responses to both natural and anthropogenic environmental trends in a coastal setting. We studied benthic foraminiferal eDNA from surface sediments of a fjord system, Swedish west coast, across a wide environmental gradient (incl. bottom-water salinity, dissolved oxygen concentrations, water depth). The foraminiferal eDNA data comprised typical species morphologically recognised in the fjords, in addition to a great diversity of previously unrecognised taxa. The communities showed a differentiation between fjords in both alpha and beta diversity, in agreement with morpho-assembly trends. Responses to short-term environmental variability were less straightforward, although some potential new bioindicators for environmental stressors could be identified. Our study demonstrates the performance of eDNA as a proxy for contrasting environments, and discusses possible applications and limitations for biodiversity studies.



P1-129

ForCry: expanding the horizons of the boron isotope pH proxy with ice and lasers.

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Boron isotope measurements of foraminifera provide unique insights into past variations in atmospheric CO₂ concentrations, global CO₂ fluxes between exogenic reservoirs, and ocean carbon storage. However, these measurements are hampered by both the large sample requirements of typical boron isotope solution analyses (1–4mg of carbonate) and the slow throughput of samples (~15 per analytical session) related to time consuming analyses and lengthy chemical separation stages. Low foraminiferal abundance in deep-sea sediment cores and during particular high interest climate events thus limits the applicability of the boron isotope pH-CO₂ proxy. Although recent analytical advancement in the application of laser ablation multi-collector, inductively coupled plasma mass spectrometry (LA-MC-ICPMS) offers the opportunity to analyse single foraminifera specimens, there is a tension between sample size vs. individual level variation, cleaning efficacy, and data precision. Here we present a new method which allows for planktic foraminiferal samples with a combined mass of ~200µg CaCO₃ (~10–20 individuals), maintaining a full cleaning protocol and providing precision of <<1‰ which is commensurate with unanswered oceanographic questions. These new measurements are achieved using cryostage (CS)-LA-MC-ICPMS, whereby the samples are frozen into a blank-free water ice matrix. We show that this novel method can reproduce glacial-interglacial changes in surface ocean δ¹¹B-pH at multiple locations, as well as provide data from previously inaccessible archives with low foraminiferal abundance or foraminiferal species with a low boron content. To further test our method, we measured multiple planktic species spanning the upper water column to reconstruct the palaeo-thermocline during glacial and interglacial states. By overcoming a major limitation with the boron isotope pH proxy, we can explore new research avenues and carbon cycle changes at enhanced temporal and spatial resolution.



P1-125

Cross-calibration of paleoclimate proxies: A new approach

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A novel method for accurate and precise determination of trace elements, lithium isotopes, and boron isotopes from the same carbonate and/or seawater sample aliquot has been developed. Multi-proxy calibrations are required to constrain the carbonate system parameters as well as temperature and salinity. Such multiple proxy approach utilises different aliquots of the same carbonate specimen based on mass requirement for each proxy. Even though a species and size specific approach is adopted this approach can result in variability in proxy composition between aliquots due to vital effect. Thus one to one correlation between proxies is not possible through utilisation of different aliquots.

Our new method utilises the same carbonate or seawater fraction for determination of trace metal to calcium ratio, and multiple metal isotope ratios. Thus, this method eliminates possible variability between aliquots of the same sample due to vital effect and allows for robust cross calibration of proxies. To validate the method, the following samples were processed: (i) seawater. ii) modern coral, and (iii) core top planktonic foraminifera. Calcite samples were chemically cleaned, leached and then dissolved in 0.5M nitric acid; whereas, seawater samples were acidified to 0.5M HNO₃. An aliquot from the sample was taken for trace metal analyses, and the rest was subjected to micro-distillation. The distilled fraction was used for the B isotope analyses, and the distillation residue was column processed for lithium isotope analyses. The same column elution protocol can be utilised to quantitatively purify multiple different elements (viz. Mg, K, Ca, and Sr) and analyse for isotope ratio. We analysed downcore foraminifera samples from a gravity core collected from the southern ocean (45° 00.1522' S, 72° 00.2673' E) during the SOE – 11 (conducted by the Ministry of Earth Sciences, India) for high-resolution reconstruction of seawater carbonate parameters for the Holocene.



P2-134

Morphological variations of calcite microfossils synchrotron-based μ CT reveal the last 200 years of environmental changes at the Baltic Sea entrance

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Human activities in coastal areas have accelerated during the last 200 years. Environmental changes resulting in a combination of three threats, i.e., deoxygenation, warming, and ocean acidification, impact particularly sub-polar regions. To better understand these environmental challenges, we need to develop tools to compare our present situation with previous periods less impacted by anthropogenic activities. Foraminifera are marine microorganisms often with a CaCO_3 shell (test), which readily fossilize in marine sediments. Morphometric changes of the test are increasingly used thanks to the high-resolution 3D development imagery acquired with microcomputed tomography (μ CT). In this project, we analyzed a set of 124 specimens recording the period from pre-industrial into present-day conditions at the entrance of the Baltic Sea/Öresund. In this area, widespread hypoxia events have been recorded due to combined natural climatic variability and anthropogenic pressures, and foraminiferal fauna has changed profoundly in the last 200 years. We hypothesize that the foraminifera will respond to the environmental variations by having changed test morphology. Here, we describe an easily reproducible and efficient post-data routine with free software to analyze the morphometrics of the whole test (thickness, calcite volume, calcite surface, number of pores). We illustrate the efficiency of this post-data routine with a study case, using 4D time series. Especially, the changes in test morphometrics indicated a decreasing trend in test thickness, by 36% in the early 2000s. Moreover, the calcite surface and the number of pores indicated increasing trends, by 63% and 151% respectively. These outstanding results corroborate the accumulation of multiple stressors occurring in this area. Finally, our project demonstrates that the synchrotron-based μ CT is a high-resolution, non-destructive, and time-efficient method to reveal past environmental evolution.



P2-142

Towards Quaternary Arctic sea ice reconstructions with sedimentary ancient DNA: building a modern database for calibrating new DNA-based proxies

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Sea ice has a crucial role in the regulation of the Arctic climate system, and by extension to the global climate. Our knowledge of its historical variation is limited to satellite records of decadal timescales, which considerably hampers our understanding on how past climate has influenced sea ice extent in the Arctic. Latest modelling efforts indicate that the Arctic may be sea ice free in summer by 2050, making the appreciation of the effects that such major change will have on Arctic ecosystems of paramount importance. Here, we will present the efforts conducted within the AGENSI project (www.agensi.eu) to build a reference DNA metabarcode database of modern environmental samples, i.e. surface sediments, sea water and/or sea ice samples, along two north-south transects across the sea ice edge north of Svalbard and on the Yermak Plateau. This database is used to calibrate eukaryotic DNA-based sea ice proxies, based on the observed eukaryote distribution patterns in both sediment and water or ice samples. The proxies will then be applied to the geological records, where the biodiversity signal contained in sedimentary ancient DNA can be used to reconstruct the past variability in Late Quaternary sea ice extent.



P1-137

Proxy Assimilation for Reconstructing Climate and Improving Model (PARCIM)

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Much of our understanding of historical climate comes from reanalysis based on instrumental data, but their length limits their use in studying longer-term climate variations. Paleoproxy data from sediment cores, sclerochronological archives, and ice core records are long enough to monitor multidecadal variability. Producing a reanalysis based on proxy data is challenging because proxies have different temporal resolution, spatial extent, and age uncertainties and the computational cost of producing such a reanalysis is high. For this reason, most reanalysis based on proxy data have been produced using offline data assimilation approach. Online data assimilation has recently shown potential with a linear inverse model. We aim to produce a fully online data assimilation reanalysis constrained by a refined marine proxy with the Norwegian Climate Prediction model that combines the Norwegian Earth System Model (NorESM) and the Ensemble Kalman Filter. Moving towards fully online assimilation will also enable online multi-parameter estimation that has shown great potential with NorESM and as such mitigates long-lasting model bias. PARCIM is a new strategic project from the Bjerknes Center, which aim to create the first online millennium-long paleo-climate reanalysis, using modern data assimilation, model, and wealth of paleo-proxy archives. The secondary objectives are to study past climate variability and mitigate long-standing model biases.



Pv-506

Proxy Potential of Trace Element/Calcium Ratios in planktic Oxygen Minimum Zone Foraminifer *Globorotaloides hexagonus*

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The presence and extent of the low-oxygen, low-pH regions known as Oxygen Minimum Zones (OMZ) play a key role in global climate and marine nutrient cycles. Understanding how OMZ environments have changed through time could help elucidate the drivers of past, and potentially future, OMZ migration, expansion, and contraction. However, the scarcity of proxies for conditions in these deep pelagic environments often hinders our ability to reconstruct OMZs. Here we present the trace element to calcium ratios (TE/Ca) of shells of the foraminifer, *Globorotaloides hexagonus*, recovered live from discrete depth (MOCNESS) tows through the upper oxycline and OMZ in the Eastern Tropical North Pacific (21°N, 118°W). We compare TE/Ca in foraminiferal calcite with temperature (Mg/Ca), salinity (Na/Ca), and oxygenation and carbonate chemistry (Sr/Ca, Mn/Ca, Zn/Ca) at the time of capture using both solution (pooled) and laser ablation ICP-MS approaches. From these measurements, we are able to derive a new Mg/Ca:temperature relationship specific to *G. hexagonus*, which appears more temperature sensitive than most other species. We also find an increase in Sr/Ca and a decrease in Mn/Ca and Zn/Ca with increasing oxygenation in the OMZ. While covarying environmental parameters make linking trends to isolated variables difficult, we suggest that using multi-element signatures of conditions within the OMZ from fossil shells could elucidate important criteria such as oxygenation and/or carbonate chemistry, and potentially source waters.



P2-140

A new approach to reconstruct Late Quaternary sea ice evolution in the Southern Ocean

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Ice shelves are a crucial tipping element of the West Antarctic Ice Sheet, and sea ice protects the ice shelves from disintegration. Currently we know very little about sea ice, ice shelves and their interaction on geological time scales. This can be attributed to the lack of suitable sediment records and the limited availability of tools (or proxies) for sea ice and ice shelf reconstructions. Following a cruise with Polarstern, we now have access to a unique set of sea floor samples and a sediment core extending back to the Last Interglacial in the Weddell Sea. The samples will be analyzed for organic biomarkers, paleontology (diatoms, dinoflagellates) and paleogenomics. The paleogenomics approach involves using sedimentary ancient DNA metabarcoding (18S rRNA V9), as well as a quantitative PCR technique for tracing key individual sea ice organisms. The data will be combined to determine the role of sea ice in Antarctic ice shelf (in)stability and Southern Ocean circulation over the last ca. 130,000 years. We will specifically focus on the Last Interglacial, where we compare our proxy records with climate model experiments to obtain a dynamical insight into the natural variability and interaction of sea ice and ice shelves, their impact on ocean circulation and the Antarctic Ice Sheet, and consequently, global sea level.



P1-135

Pyleoclim: Paleoclimate Timeseries Analysis and Visualization with Python

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We present a Python package geared towards the intuitive analysis and visualization of paleoclimate timeseries, Pyleoclim. The code is open-source, object-oriented, and built upon the standard scientific Python stack, allowing to take advantage of a large collection of existing and emerging techniques. We describe the code's philosophy, structure and base functionalities, and apply it to three paleoclimate problems: (1) orbital-scale climate variability in a deep-sea core, illustrating spectral, wavelet and coherency analysis in the presence of age uncertainties; (2) correlating a high-resolution speleothem to a climate field, illustrating correlation analysis in the presence of various pitfalls (including age uncertainties); (3) model-data confrontations in the frequency domain, illustrating how to perform spectral comparisons of model and observed datasets. We show how the package may be used for transparent and reproducible analysis of paleoclimate and paleoceanographic datasets, supporting FAIR software and an open science ethos in the field. The package is supported by an extensive documentation and a growing library of tutorials shared publicly as videos and cloud-executable Jupyter notebooks.



P1-130

“Seeing through” the carbonate-ion effect on $\delta^{13}\text{C}$: field calibrations and a new mechanistic model

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One of the largest controls on foraminiferal $\delta^{13}\text{C}$ is the carbonate ion effect, wherein $\delta^{13}\text{C}$ exhibits a strong negative, linear relationship with seawater $[\text{CO}_3^{2-}]$ (or pH). Accounting for this effect is necessary to properly interpret $\delta^{13}\text{C}$ data from foraminifera, as it can produce larger shifts in downcore $\delta^{13}\text{C}$ than those caused by secular variations in $\delta^{13}\text{C}_{\text{DIC}}$. Yet, despite evidence that the effect is strongly species-specific, effect sizes in most species are unknown, and no mechanistic explanation for the carbonate ion effect on $\delta^{13}\text{C}$ has been proposed. We present new species-specific effect-size estimates obtained from a combination of field and core data. We additionally present a new chemical model of foraminiferal calcification that couples a diffusion-reaction model of the diffusive boundary layer to a kinetic box model of the cell interior. We show how pH-dependent changes in CO_2 diffusion through the microenvironment and cell interior can explain the origins of the carbonate-ion effect, with implications for constraining effect sizes and calcifying fluid pH in extinct species.



P1-124

Sedimentary ancient DNA Reveals Biodiversity Shifts in the Last Interglacial Labrador Sea

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Sedimentary ancient DNA, *sedaDNA*, analyses are increasingly used for reconstructing paleo-ecosystems in the marine environment. A key strength of *sedaDNA* work is the ability to reconstruct a broad range of biodiversity. *SedaDNA* metabarcoding, i.e. the total extraction and analysis of short taxonomically-informative DNA fragments from sediment samples, extends paleo-biodiversity reconstructions to non-fossil forming taxa. Here, we present the first *sedaDNA*-based reconstruction of eukaryote biodiversity through the Last Interglacial using 88 samples collected from a giant piston core from the Eirik Drift, Labrador Sea. The reconstruction is based on metabarcoding the V7 hypervariable region of the 18 SSU rRNA gene with the Illumina MiSeq platform. Our *sedaDNA* record describes the general eukaryote biodiversity and identifies biodiversity stages through the Last Interglacial in the Labrador Sea. We identified a range of taxa including dinoflagellates, diatoms, annelids, chlorophytes, and copepods, among many others. Both alpha and beta diversity [tc1] show variability during the last interglacial, which cannot be fully explained by sample age. We further queried the beta diversity using a split moving window analysis to identify possible biodiversity shifts. Biodiversity shifts were defined as the transition points where the community composition of one sample differed significantly from the samples around it. The highest incidence of these biodiversity shifts occurred between ~116 kya and ~126 kya. We then binned the record using the identified shift points in the record, making different biodiversity stages. Our analysis indicates that different key taxa are associated with these biodiversity stages.



P3-132

Early Pleistocene Antarctic Iceberg Rafted Debris at IODP Sites U1536 and U1537 Quantified by Convolutional Neural Networks

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In the early Pleistocene, the 41-kyr obliquity period dominates major climate proxy records such as benthic foraminiferal oxygen isotopes. This observation is difficult to reconcile with the classic Milankovitch orbital forcing model that predicts that global ice volume is controlled by summer insolation that is dominated by both the 23-kyr precession period and 41-kyr obliquity period. This contradiction is the basis for the “41-kyr problem,” and a number of hypotheses have been put forth to explain the perplexing lack of precession in the record of ice volume from ~3 to 1 million years ago. A proxy for glacial ice discharge is iceberg-rafted debris (IRD); when icebergs calve off of the land and float out to sea, they deposit IRD into marine sediments. IRD grains are distinctly different from the fine-grained low-energy, silty clays typically found in deep ocean sediments and we can use them as a proxy for glacial ice discharge. IODP Expedition 382 recovered two high-resolution records of Pleistocene sedimentation with abundant IRD in the Scotia Sea at Sites U1537 and U1536. Quantifying IRD concentrations in sediment cores has historically been done either by hand (counting it in a sieved sample) or by visually counting IRD in sediment core x-ray images at 1-cm depth spacing. IRD is identifiable within the x-ray images as granule- to pebble-sized black shapes with sharp edges. We have developed a computer vision approach to make this process more consistent and efficient. This approach uses convolutional neural networks to identify IRD from thousands of X-ray images that were taken on the JOIDES with a core passthrough X-Radiograph. The identified IRD is then counted and measured by the computer and from this analysis, we present a new, high-resolution record of the distribution and flux of early Pleistocene Antarctic IRD. With this new dataset, we will examine the pacing of IRD input relative to major glacial-interglacial cycles and orbital forcing.



P3-134

Evaluating Saharan dust proxies from Holocene sedimentary records in southern Iberia

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Saharan–Sahel soil dust aerosols affect the biogeochemical and ecological cycles from oceans and continents and thus have an important impact on the global environment and even human health. Due to its high CaCO₃, N and P content, Saharan dust significantly increases the pH of rain-water and influences the chemistry of soils and water masses over European regions and can exert an important role fertilizing both, alpine lakes and marine sea surface. For this reason, understanding past evolution of Saharan dust deposition over Europe is vital to furthering our knowledge about present day ecosystems and modern climate. Marine and lacustrine records have been used to reconstruct long-term Saharan dust input in southern Iberia. Various geochemical (e.g. Si, Ti, K, Zr, Fe or Ca) and mineralogical (e.g., palygorskite, kaolinite) proxies have been used to reconstruct dust input. Here we summarize and compare different marine and lacustrine aeolian records to evaluate the most robust Saharan dust proxies during the Holocene. This comparison indicates that the signal of the eolian dust is clearer in the alpine wetlands than in the marine sedimentary records. The Zr/Al ratio depicts a similar trend in all the Sierra Nevada records, likely controlled by the Saharan dust input, which is enriched in zircons. Zr/Al ratio in marine records appears to be affected by contour currents in some records. Our reconstruction suggests an early increase in Saharan dust input in southern Europe ~7.0 cal. kyr BP, which can be tentatively related to the decrease in precipitation over the greenish Sahara. Afterward, a sharper increase in dust input occurred ~5.5-4.5 cal kyr BP, which could be due to the desertification of North Africa and the western Mediterranean aridification and the establishment of the present-day atmospheric conditions.



P2-136

Incorporating erosion into coral mound aggradation rates by statistical analysis of age frequency distributions

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Coral mounds allow for the study of paleoceanographic conditions by analysing the development of mound aggradation rates over up to hundreds of kiloyears. The overall evolution of those carbonate skeleton frameworks depends on a complex interplay of different factors like seawater temperature, nutrient supply, salinity, current strengths and sediment deposition, among others.

Commonly, on- and offset of coral growth are determined conservatively by selecting the oldest and the youngest age of a growth period. This however does not take into account weathering and erosion of the exposed coral skeletons. The goal of this study is to improve the accuracy of growth period determination by estimating the erosion rate λ for coral mounds. This parameter can be used to correct for information loss due to erosion and become thus more accurate.

We estimate λ by analysing peak heights of Th/U age distributions over up to several hundred kiloyears. These distributions are constructed by kernel density estimation as a probability density determinator. This method, unlike histograms or probability density plots, does not introduce misleading statistical artefacts. We compare the age distribution frequencies to coral-independent climate signals, such as $\delta^{18}\text{O}$ from benthic foraminifera. This way we are able to associate coral mound aggradation rates to approximately similar climate conditions at the respective location for different points in time. For independent coral mounds from the Atlantic, an exponential decrease in peak heights with time is observable, that does not match with paleoceanographic conditions, but is explainable with the age information loss due to erosion processes. We derive rough estimates of the parameter λ for several regions in the Atlantic (e. g. Gulf of Cadiz and off Angola) and show how it translates into corrected growth periods.



P2-131

Upper ocean conditions in the glacial Tropical Pacific from oxygen isotopes in planktonic foraminifera

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Planktonic foraminifera contain information about past climate in their shells, but interpreting this information is limited by the uncertainty in their depth habitats. In Lakhani et al. 2022, we compiled existing data on subsurface-dwelling species and updated calcification depth estimates for these species. Here, we outline two novel techniques using planktonic foraminifera $\delta^{18}\text{O}_c$ to reconstruct the state of the tropical Pacific for the Last Glacial Maximum (LGM). The first technique uses an assumed functional form for the thermocline to create a regression for predicted $\delta^{18}\text{O}_c$ as a function of depth. Using five species of planktonic foraminifera that calcify at different depths in the water column (*G. ruber albus*, *T. sacculifer*, *G. tumida*, *N. dutertrei*, and *P. obliquiloculata*), along with a benthic measurement at a shallow water depth (~600 m-1000 m), we can constrain plausible thermocline changes between the modern and the LGM at individual core sites across the Pacific. The second technique uses inverse modeling to estimate the Pacific ocean-atmosphere mean state. Using the statistics of the modern ocean through principal component analysis, we show that the Tropical Pacific mean state can be estimated using these foraminiferal measurements. Using a transfer function to convert foraminiferal $\delta^{18}\text{O}_c$ to density, we validate this model for the modern ocean with simulated and observed data and show preliminary results from this model for the LGM based on LGM foraminiferal $\delta^{18}\text{O}_c$.



P2-141

Assessment of biomarker-based sea ice and ocean temperature reconstructions along the Antarctic continental margin

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Over the past decade, the highly branched isoprenoid (HBI) diene IPSO₂₅ (Belt et al., 2016), has gained pronounced attention as a proxy for sea-ice reconstructions in the Southern Ocean. A particular advantage of this lipid is its good preservation in near-coastal environments where opal dissolution often hampers the application of diatoms as sea ice proxies. Sea ice reconstructions in these environments, however, are crucial to better understand sea ice – ice shelf interactions. Recent studies propose the additional consideration of phytoplankton-derived biomarkers such as certain sterols and/or tri-unsaturated HBIs alongside IPSO₂₅ to determine the so-called PIPSO₂₅ index - a novel approach targeting on semi-quantitative sea ice estimates (Vorrath et al., 2019; Lamping et al., 2020). In order to further test and validate the reliability of this index and also to evaluate GDGT-based ocean paleothermometers in polar latitudes, we investigated seafloor surface sediments from the Amundsen Sea, the Antarctic Peninsula and the Weddell Sea and compare the proxy-based sea-ice and ocean temperature reconstructions to satellite observations and instrumental measurements. While we note the general capability of these proxies to properly determine oceanic key variables, we also identify weaknesses associated with uncertainties regarding source specificity of certain lipids and existing calibrations.

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P2-130

Individual Foraminifera Analysis of Magnesium/Calcium paleothermometry for multiple species and sedimentation settings: Cleaning procedures and applications

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Individual foraminifera analysis (IFA) Mg/Ca has been increasingly used to study past climate variability, but the cleaning procedure for IFA Mg/Ca remains technically challenging. We report an improved cleaning procedure that yields comparable Mg/Ca values for single-specimen and conventional multi-specimen measurements. We tested several methods by adjusting the cutting of foraminiferal shell, the inclusion of reductive cleaning, and the duration of the reaction. The goal is to achieve maximum contaminant removal while minimizing sample loss, assessed by considering the intensity of trace elements/Ca indicative of contamination. The cleaning protocols were applied to six species of planktic foraminifera and three different types of samples from two sedimentation settings. Our results show that most of the cleaning protocols tested were effective at removing clay minerals as indicated by Al/Ca values. The exception is hemipelagic sediments, which require more repetitions of the clay mineral removal step. Both heating and reductive cleaning increase sample loss. As reductive cleaning does not substantially improve cleaning effectiveness for pelagic sediments, this step and heating are excluded from the final recommended procedure. With this procedure, similar Mg/Ca values can be obtained for both IFA and bulk measurements. Temperatures calculated from the IFA Mg/Ca values for different species are also consistent with their habitat depth in the water column. The average IFA Mg/Ca data of *Trilobatus sacculifer* from a sediment trap series follow the temporal trend of the sea surface temperature. The mean value and distribution of IFA Mg/Ca differ in trap samples from different depths, as data from the deeper trap show lower values, consistent with the effect of partial dissolution on foraminiferal Mg/Ca. In conclusion, the proposed IFA Mg/Ca cleaning procedure appears to be applicable for different species and sample types.



P1-132

Non-destructive sedimentological and geochronological descriptions using radiographic and laminographic images

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The visual description of sediment cores and other geo-archives (e.g., speleothems, fossils, rocks, corals, etc.) is limited by what can be observed from the surface of a sample. Further probing of such samples using physical and/or chemical property data may provide further information. However, these data generally consist of 1D records/time series, that cannot describe 3D features of the sample. Here, we present an overview of a wide variety of geo-archives—including marine sediment cores—that have been imaged using surface photography, as well as X-ray radiography and laminography. Laminography is a technique that allows the computer software to build a pseudo-3D image of a (core) sample, similar in fashion to a full-3D tomographic image. Yet in contrast to tomography, laminography results are rapid to generate (10 minutes per meter of section) and data files are manageable on a standard desktop computer, without the need for specialist software. X-ray imaging (radiography and laminography) of geological samples is non-destructive and can reach resolutions down to 54 micrometres. Laminographic images can be generated at different depth levels of a sample, or under different rotational angles. Advanced X-ray imaging allows for a more detailed description of density contrasts, which permits the targeted sampling as features of interest are non-destructively identified. Furthermore, sclerochronological descriptions of biogenic or fossilized materials are aided by non-destructive imaging. Lastly, grainsizes, bioturbation, ice-rafted debris, and varves/laminae, can be quantified based on radiographic and laminographic results. These data aid environmental or stratigraphic interpretations.



P2-139

Tracking Southern Ocean sea ice extent with winter water: A new method based on the oxygen isotopic composition of foraminifera

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Southern Ocean sea ice plays a central role in the oceanic meridional overturning circulation, transforming globally prevalent watermasses through surface buoyancy loss and gain. Buoyancy loss due to surface cooling and sea ice growth promotes the formation of bottom water that flows into the Atlantic, Indian, and Pacific basins, while buoyancy gain due to sea ice melt helps transform the returning deep flow into intermediate and mode waters. Because northward expansion of Southern Ocean sea ice during the Last Glacial Maximum (LGM; 19–23 kyr BP) likely enhanced deep ocean stratification and contributed to lower atmospheric CO₂ levels, reconstructions of sea ice extent are critical to understanding the LGM climate state. Here, we present a new sea ice proxy based on the ¹⁸O/¹⁶O ratio of foraminifera ($\delta^{18}\text{O}$). In the Southern Ocean, buoyancy loss during austral winter creates a cold surface mixed layer that persists in the sub-surface during spring and summer. The extent of the cold sub-surface layer, known as winter water, parallels that of the winter sea ice edge. The presence of winter water above relatively warm deep water also creates an inverted temperature profile that is reflected in equilibrium estimates of $\delta^{18}\text{O}$. Thus, paired analysis of planktonic and benthic foraminifera can be used to infer winter sea ice extent. To demonstrate the feasibility of the $\delta^{18}\text{O}$ method, we present a compilation of *N. pachyderma* and *Cibicides* spp. results from the Atlantic sector that yields an estimate of the winter sea ice edge consistent with modern observations. We will also discuss whether $\delta^{18}\text{O}$ analyses of individual *N. pachyderma* can be used to estimate sea ice extent in the absence of benthic $\delta^{18}\text{O}$ data.



P2-125

Data Assimilation in Transient Simulations of the Last Deglaciation

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The interval of the Last Glacial Maximum to the Early Holocene provides an excellent test to understand the transient response of Earth's climate system to external forcing. Comparing transient model simulations and proxy-based global surface temperature reconstructions over this interval indicate differences in timing, amplitude, and speed of deglacial warming. Paleoclimate data assimilation provides a tool to evaluate the range of climate trajectories by combining paleoclimate data and models. Here, we assimilate surface temperatures from 80 paleo-records to transient simulations of the last deglaciation using a newly developed Earth system model of intermediate complexity CLIMBER-X (Willeit et al., 2022). The model is capable of simulating ~10,000 years per day, making it appropriate for transient runs over the last deglaciation. In addition, the model is coupled with the Parallel Data Assimilation Framework (PDAF) to implement an efficient variant of ensemble Kalman filtering (Nerger and Hiller, 2013). We select the indirect and online approach for the data assimilation and use a method based on empirical orthogonal functions to add stochasticity to the model. Finally, we evaluate the impact of the data assimilation on the climate trajectories as simulated by CLIMBER-X.

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P3-138

The mechanistic of nitrogen incorporation into coral calcite: a review of the nitrogen isotope proxy in corals

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Scleratinian coral skeletons and reef cores have become one of the central climate archives for tropical palaeoclimate reconstructions. Biogeochemical proxies, such as coral skeletal-bound nitrogen isotopes ($\delta^{15}\text{N}$), have become increasingly important providing, in some cases, monthly information on the biogeochemical processes in the coral reef environment. Applications include sub-seasonal to annual reconstructions of nutrient sources, ocean circulation dynamics, and past coral bleaching. These applications require a better understanding of the sources, residence time, and incorporation mechanisms for the nitrogen in the organic matrix. Here, we present a novel seasonal dataset of $\delta^{15}\text{N}$ in coral cell tissue, symbiodiniaceae cell tissue, whole tissue, and underlying skeleton from multiple reefs around Taiwan to investigate the nitrogen cycling between coral tissue and the skeleton. The preliminary data show that the $\delta^{15}\text{N}$ in coral cell tissue is primarily correlating with the $\delta^{15}\text{N}$ of the source nitrogen to the coral reef, while the variabilities in the $\delta^{15}\text{N}$ of symbiodiniaceae cell tissue are influenced by species specific processes that probably lead to differences in the internal nitrogen cycling. In particular, the $\delta^{15}\text{N}$ of coral tissue and symbiodiniaceae are linearly correlated for *Porites* spp. and *Acropora* spp. which may indicate a tight internal nitrogen cycling between the two pools. Yet, variabilities in the $\delta^{15}\text{N}$ of symbiodiniaceae for *Pocillopora* spp. appear to be influenced by the photosynthetic activities. We plan to combine our new dataset with NanoSIMS measurements of ^{15}N -labelled nitrogen incorporation into coral calcite to fully understand the nitrogen pathway from ocean water into the calcite lattice and identify the main source of skeletal-bound nitrogen.



P2-138

Sea ice history of the Central Arctic from Marine Isotope Stage 3 to present using sedimentary helium isotopes

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Sea ice coverage in the Arctic Ocean has consistently declined over the past 40 years. Climate models vary widely in their projections of when the Arctic will experience ice free conditions under future warming scenarios. While past climate states offer a potential opportunity to test sea ice distributions in models, the few available proxies for past sea ice conditions are hampered by low sedimentation rates and poor carbon preservation.

Here we present a new inorganic sea ice proxy based on sedimentary $^3\text{He}/^{230}\text{Th}$ ratios and apply this proxy to reconstruct sea ice coverage in the Central Arctic Ocean over the last 45 kyr. Sedimentary ^3He is mainly delivered by extraterrestrial interplanetary dust particles, which rain to the seafloor at a well-known, constant rate in space and time. Sea ice can block the input of extraterrestrial ^3He to the sea surface. Sediments lacking ^3He represent periods of increased sea ice coverage, provided that the sea ice is permanent or carries the ^3He elsewhere when it melts. Sedimentary ^{230}Th also accumulates at the seafloor at a known rate, but is produced by uranium decay in seawater and is not greatly affected by ice conditions. The $^3\text{He}/^{230}\text{Th}$ ratio, compared to the expected burial ratio, thus serves a sea ice coverage proxy.

Our reconstructions show that Arctic Ocean sea ice coverage underwent dynamic shifts over the last 45 kyr. Sea ice coverage increased from late Marine Isotope Stage 3 towards thick, permanent ice coverage during the LGM, as deduced from a cessation of ^3He delivery to the seafloor. Breakup of this permanent ice occurred around 14-15 ka, leading to a minimum in sea ice coverage during the early-mid Holocene. Finally, sea ice coverage increased again during the late Holocene. By comparing our results with other sea ice proxies and reconstructions of Arctic Ocean nutrient cycling, we probe the large-scale climatic processes impacting past Arctic sea ice extent.



P2-126

What do paleothermometers tell us about the mid-Pleistocene transition? The combination of Mg/Ca, clumped (Δ_{47}) and conventional ($\delta^{18}\text{O}$) stable isotope in planktonic foraminifera

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The Mid-Pleistocene transition (MPT - 1.2 Ma to 0.8 ka) allowed the establishment of the Late Pleistocene climate with the 100 ky orbital cycles. The orbital variations alone cannot explain the shifts in climatic periodicity of the MPT. The evolution of internal mechanisms and feedbacks have been called upon, in relation with the global cooling trend, the expansion of Ice Sheet and/or the decline in $[\text{CO}_2]_{\text{atm}}$. A key point is therefore to accurately reconstruction of oceanic temperatures (SST) and to decipher the processes driving climate variations.

Here, we studied the marine sediment core MD96-2048 taken from south Indian Ocean in the source region of the Agulhas current. We compared 5 thermometers: alkenone, TEX86, foraminiferal transfer function (TF), Mg/Ca and clumped isotope (Δ_{47}). All thermometers have been measured at high resolution, except for Δ_{47} that focuses on the maximum of glacial (G) and interglacial (IG) periods over the last 1.2 Ma. Strong differences are observed between the 5 derived-SST: the alkenone and TEX86 recorded higher temperatures than the other proxies. Alkenone-SST do not show G-IG variations within the MPT. The Mg/Ca- and the TF-SST show a good agreement to each other, while the Δ_{47} -SST are systematically colder than the other SST proxies.

The $\delta^{18}\text{O}$ is dependent on SST and $\delta^{18}\text{O}_{\text{sw}}$, which is regionally correlated with the salinity (SSS) in the present-day ocean. The Mg/Ca is controlled by SST and affected by SSS and pH, while the Δ_{47} is only SST-dependant. If the present-day $\delta^{18}\text{O}_{\text{sw}}$ -SSS relation was the same during the MPT, we can separate changes in $\delta^{18}\text{O}_{\text{sw}}$ from SST effects and reconstruct past SSS. The $\delta^{18}\text{O}$, Mg/Ca and Δ_{47} combination may then allow the reconstruction of SST, SSS and pH. We used this new approach to estimate the long-term evolution of past SST, SSS and pH across the MPT. The SST (excepted for Δ_{47}), SSS and pH results show that amplitude of G-IG variations was insignificant between 1.2 and 0.8 Ma and increased after the MPT.



P2-135

Assessing distributions of dinoflagellate cysts and diatoms in surface sediments of the Chukchi Sea to reconstruct changes in the upper water masses.

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Dinoflagellate cyst and diatom analyses were performed on 22 surface sediment samples from the Chukchi Sea in order to document their geographical distributions in one of the most understudied sections of the Arctic Ocean and to examine the influence of upper water masses on these two major groups of phytoplankton. Total concentrations vary from 0.9 to 5.9 x 10⁶ valves g⁻¹ for diatoms and from 0.8 to 12.5 x 10³ cysts g⁻¹ for organic-walled dinoflagellate cysts, with the highest values for both groups observed in the southern part of the Chukchi Sea and away from the Bering Strait. Well-preserved microfossils were recovered, with a total of 35 and 88 taxa of dinoflagellate cysts and diatom, respectively. The most abundant diatoms are *Paralia sulcata*, *Thalassiosira antarctica*, *T. nordenskioldii*, and *Chaetoceros* spp., whereas cysts of autotrophic *Alexandrium* spp., *Operculodinium centrocarpum*, and heterotrophic *Islandinium minutum* and *Brigantedinium* spp. were most common in dinoflagellate cyst assemblages. As expected, cysts produced by heterotrophic dinoflagellate were more abundant where sedimentary diatom concentrations were the highest. Statistical analysis identified three major dinoflagellate cyst and diatom clusters: 1. Sites influenced by the Alaska Coastal Current in the eastern part of the Chukchi Sea are characterized by high abundances of *P. sulcata* and *O. centrocarpum*; 2. The western part and Herald Canyon in the northwestern part of the Chukchi Sea are distinguished by *Chaetoceros* spp., *T. antarctica* and cysts of *Alexandrium* spp. and affected by the Siberian Coastal Current and Bering Shelf Water; and 3. Assemblages in the southern part of the Chukchi Sea have noticeable abundances of *T. nordenskioldii*, cryophilic group of diatoms and heterotrophic *Islandinium minutum*. This work revealed the potential applicability of the combined use of diatoms and dinoflagellate cysts for reconstructions of past dynamic water mass changes in the Chukchi Sea.



P3-135

Reconstructing climate variability over the last 250 ka of Africa's southern Cape applying X-ray fluorescence scanning and documenting the use of luminescence dating on marine sediments

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This study discusses the marine records of hydroclimate changes in Southern South Africa in the last 250 ka, with a particular focus between 100-50 ka. This period was critical for human cognitive behavioural and technological evolution and is the focus for the SapienCE centre. The regional past climate and its drivers remain unresolved in detail as continuous high-resolution records from this area are lacking. A new marine sediment core site (MD20-3592), covering continuously 250 ka can help to fill in existing knowledge gaps as it adds to the spatial coverage of climate archives available. The core sites documents both terrestrial- and ocean hydroclimate variability because they accumulate both terrestrial sediments and biogenic marine inputs. The former are mostly from local sources, such as the mouths of the Breede, Gourits, Gamtoos, and Sundays rivers. These terrestrial inputs can record rainfall variability in the river catchments.

Here we present the elemental compositions data of the core based on X-ray fluorescence scanning. Moreover, we will examine the comparison to nearby marine and terrestrial proxy records to identify commonalities and differences, and see if the same climate mechanisms invoked for the other records are at play here. Preliminary results suggests that the regional hydroclimate is affected by both local insolation changes caused by orbital precession, and high latitude forcing that varies on timescales associated with orbital obliquity and eccentricity.

Furthermore, in addition to conventional chronometric techniques ($\delta^{18}\text{O}$, ^{14}C and tuning), we have applied luminescence dating techniques to MD20-3592. This latter method has the advantage of being able to date older sediments than radiocarbon (~200 ka vs ~50 ka), though uranium-series modelling is required to yield accurate ages. Consequently, luminescence dating of marine sediment cores is in its infancy, and the potential of this technique to produce accurate ages will be discussed.



P1-131

Multiproxy age-depth models for ocean sediment cores: combining age inferences from radiocarbon and benthic $\delta^{18}\text{O}$ stratigraphic alignment

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Accurate and precise ocean sediment core age models are essential to reconstruct past climate events, yet age models are often constrained by only a single dating proxy. Radiocarbon dating directly dates sediment layers, yet this method is restricted to the last 50 ka BP, suffers from surface reservoir ages and is often low resolution. Benthic $\delta^{18}\text{O}$ stratigraphic alignment provides an alternative technique but diachronous $\delta^{18}\text{O}$ signals can cause age errors up to 4 kyr. We present a new Bayesian age model construction algorithm called BIGMACS (Bayesian Inference Gaussian process regression and Multiproxy Alignment of Continuous Signals), which combines age information from radiocarbon and benthic $\delta^{18}\text{O}$ data. BIGMACS also constructs continuous benthic $\delta^{18}\text{O}$ stacks which allows users to create alignment targets from neighboring cores that share homogeneous $\delta^{18}\text{O}$ signals.

Age models are realistically constrained with an empirically derived prior model of sedimentation rate variability which removes subjectivity from the age model construction process. Likelihoods for radiocarbon ages and benthic $\delta^{18}\text{O}$ values from individual cores are modeled with a Student's-t distribution that is robust to outliers. Age model samples are drawn in proportion to their posterior probabilities using a hybrid of particle smoothing and Markov Chain Monte Carlo algorithms. Continuous stacks are constructed after alignment via a Gaussian process regression. Sediment core age models based on both radiocarbon and benthic $\delta^{18}\text{O}$ alignment to improved regional stacks have the potential to reduce age uncertainty and improve the accuracy and precision of paleoceanographic climate reconstructions.



P2-132

Assessing Na/Ca as a proxy for salinity of surface and subsurface waters in the subtropical North Atlantic

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Temperature and salinity proxies are crucial to reconstruct changes in past ocean circulation. Despite a variety of marine temperature proxies, proxies of salinity are limited. Traditionally, for salinity reconstruction, $\delta^{18}\text{O}$ records from planktonic foraminifers are corrected for temperature and ice volume changes ($\delta^{18}\text{O}_{\text{w-ice}}$) and converted to salinity by local salinity- $\delta^{18}\text{O}_{\text{w-ice}}$ relationships calibrated on modern conditions. At the interface between water masses in subtropical to subpolar regions, the reconstructions are less reliable as the local salinity- $\delta^{18}\text{O}_{\text{w-ice}}$ relationships may change with the prevailing water masses. For example, extremely light meltwater $\delta^{18}\text{O}$ signatures originating from melting ice sheets may bias the relationship. Yet, the reconstruction of glacial to interglacial salinity changes in addition to cooling/warming rates in the subtropical Atlantic are crucial to assess their effect on the Atlantic Meridional Overturning Circulation.

In this study, we apply new Na/Ca data in combination with $\delta^{18}\text{O}$ and Mg/Ca from surface and subsurface dwelling planktonic foraminifers to test the feasibility of Na/Ca as a proxy for salinity changes and to investigate temperature and salinity gradients across the Azores Front over the last glacial cycle. We use new sediment cores from the central North Atlantic between 32 °N and 42 °N, across the northern boundary of the North Atlantic subtropical gyre and Azores Front (AF). Latitudinal shifts of the AF position on glacial- interglacial time scales and the potential influence of meltwater in this region make the transect ideal to test the feasibility of Na/Ca as a new salinity proxy.



P2-143

Sedimentary ancient DNA from the sympagic dinoflagellate *Polarella glacialis* as a novel sea ice proxy

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Sea ice is a critical and sensitive component of the Earth System. Reconstructing the past extent of sea ice in the world's oceans is a phenomenal challenge that has motivated the development of several proxy approaches, all with considerable limitations. Sea ice biomarkers (highly-branched isoprenoids, including IP₂₅) have become widely used over the past decade. However, it is still unknown exactly which species produce these molecules and under what conditions. Notably, their applicability in nearshore settings influenced by glacial runoff has been questioned.

Marine sedimentary ancient DNA is an emerging approach with the potential to revolutionize the field of paleoceanography. We will present results from a large international study focused on sedimentary DNA from the sympagic dinoflagellate *Polarella glacialis* (*Pgla*-DNA). This species is widely distributed in the Arctic and its resting stages (cysts) are exported to the seafloor following sea ice melt. We successfully quantified *Pgla*-DNA in Arctic marine and fjord surface sediments and two marine sediment cores spanning the Holocene. We propose *Pgla*-DNA as a novel proxy for sea-ice reconstructions both in marine and glaciated fjord environments, where biomarker and microfossil approaches can be limited. As *Polarella glacialis* occurs in both the Arctic and Antarctic regions, it may be useful as a sea-ice proxy in both hemispheres.



P2-128

Exploring systematic bias in $U^{K'}_{37}$ in the Mediterranean Sea through alkenone flux and coccolith clumped isotope measurements in a 28-year sediment trap record

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In Mediterranean Sea surface sediments, the alkenone-based $U^{K'}_{37}$ paleothermometer produces reconstructed temperatures often 4-5 °C below mean annual sea surface temperatures (SSTs) in the overlying waters. Paleoclimate studies interpret $U^{K'}_{37}$ SSTs as being a winter temperature, however, sediment trap studies suggest that coccolithophores mostly bloom in fall and spring. In addition, alkenone production below the mixed layer or in low-nutrient conditions could also lead to low proxy temperatures. To identify the source(s) of this proxy bias and thereby improve the reliability of $U^{K'}_{37}$ temperatures in the Mediterranean Sea, we here analyze alkenones in sediment traps set in the ultraoligotrophic Ionian Sea between 1991 and 2018, with traps set at multiple depths (about 500, 1500, and 2500 m) between 1999 and 2011. Comparison of the highest and lowest $U^{K'}_{37}$ values with satellite-based SSTs indicates a delay of about 45 days for material to reach the upper trap. After adjusting for this, $U^{K'}_{37}$ values translate into temperatures generally 3-8 °C lower than satellite-based SSTs throughout the seasonal cycle. This suggests that low $U^{K'}_{37}$ SSTs in Mediterranean Sea sediments are not simply an effect of seasonal production and export, but that alkenone production below the mixed layer or the impact of limited nutrient availability may also contribute to proxy bias.

To explore this further, clumped isotope measurements will be performed on coccoliths isolated from selected samples. This data will provide evidence of the habitat temperature and depth of coccolithophores in the Eastern Mediterranean Sea, shedding further light on the source of bias on the $U^{K'}_{37}$ paleothermometer in this region.



P2-133

“Shackleton site” unveils persistent millennial climate variability through the Pleistocene in the Iberian Margin

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The Iberian Margin is well-known as a strategic place to understand past climatic and oceanographic changes due to the rapidly accumulating sediment and comprises a high-fidelity record of millennial climate variability for the late Pleistocene. It is a very sensitive place to high and low latitude processes, and one of the few in the world where the direct correlation of marine-ice-terrestrial linkages are possible. In 2011, during the IODP 339 Site U1385 (the “Shackleton site”) was drilled at water depth of 2582 mbsl, with a total depth of 155.9 m below seafloor in multiple holes. The oxygen isotope record confirms that Site U1385 contains a continuous record of hemipelagic sedimentation from the Holocene to 1.45 Ma (MIS 47). Published results from Site U1385 establish the great promise of the Iberian margin to yield long and reference records of millennial-scale climate change and for land–sea -ice comparisons. The Sea Surface Temperature (SST) and the major oceanographic shifts were record on the Iberian Margin records for the last 1 million years. This data allowed to identify major climatic disruptions such as the MBE and MPT, the increasing glaciations at MIS 22 (~900ka event), also the high temperatures even during the so called “luke-warm” interglacials, and extremely cold stadial events linked with the meltwater discharges into the NE Atlantic. Here we present, for the first time, the completed U1385 record of SST and water masses shifts over the last 1.45 Ma. The new data show an entire interpretation of the one major climatic transition, MPT, and helps to understand the underlying mechanisms on glacial/interglacial and, also at centennial to millennial scales. This SST record for this reference site will fulfil the puzzle to document past hydroclimate changes and its relation to global climate change. Even more, important as in a few months the new IODP Expedition 397 will extend this remarkable sediment archive through the Pliocene.



P1-119

Ancient DNA use for investigating the response of soft-tissue species to the Northern Antarctic Peninsula climate over the last thousand years

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The soft-tissue phytoplankton, such as haptophytes or cryptophytes, representing up to 50% of the phytoplankton assemblages, plays an important role in the carbon cycle as first trophic level of the Southern Ocean ecosystem. However, their modern distribution in the Southern Ocean is not very well known as few dedicated studies have been published so far. Even less is known about their past distribution and evolution because, as these soft species do not produce any tests, conventional micropaleontological studies cannot be applied. In this study, we used a novel approach using sedimentary ancient DNA (*sedaDNA*) preserved in the 4m-long marine sediment core TG-03 (61°59.2295°S, 55°05.63°W, 1295 m), retrieved in the northern Bransfield Strait in the northern Antarctic Peninsula (NAP) where important blooms of soft-tissue phytoplankton have been observed, to track the distribution and abundance of these groups over the last thousands years. We combined *sedaDNA* metabarcoding and shotgun using eukaryotic specific amplicon sequences of the 18S-V9 region, with highly branched isoprenoids (HBIs) and TEX^{L86} to (1) determine respectively the response and adaptive processes of the soft-tissue groups to sea-ice and ocean subsurface temperature changes over the last millennia. 2) identify which major hydroclimatic parameters drove their past evolution and (3) better predict their future variation. Those data will be then compared to previously oceanographic and atmospheric reconstructions derived from marine and lake sediment cores as well as ice cores around the Antarctic Peninsula.



P1-136

“climatearchive.org”: the Google Earth for paleoclimate data

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We can only fully understand the past, present and future climate changes by bringing together data and process understanding from a broad range of environmental sciences. In theory, climate modelling provides a wealth of data of great interest to a wide variety of disciplines (e.g., chemistry, geology, hydrology), but in practice, the large volume and complexity of these datasets often prevent direct access and therefore limit their benefits for large parts of our community. We present the new online platform “climatearchive.org” to break down these barriers and provide intuitive and informative access to paleoclimate model data to our community. The current release enables interactive access to a recently published compilation of 109 HadCM3BL climate model simulations covering the last 540 million years. Key climate variables (temperature, precipitation, vegetation and circulation) are displayed on a virtual globe in an intuitive three-dimensional environment and on a continuous time axis throughout the Phanerozoic. The software runs in any web browser — including smartphones — and promotes data exploration, appeals to students and generates public interest. We further show ongoing work on the next phase of the platform, which aims to develop new tools for integration into a more quantitative research workflow. These include easy online generation and download of maps and time series plots of the underlying model data. Data can also be exported as global fields or CSV files for any user-selected location for further offline analysis, such as use in spreadsheets. Finally, we outline future integration of new sources of model and geochemical proxy data to simplify and advance interdisciplinary paleoclimate research



P1-128

Ground-truthing the diatom-bound nitrogen isotope paleo-proxy: A progress report

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Past changes in the input/output and internal cycling of bioavailable N in the marine and lacustrine environments can be reconstructed by analysing the N isotopic composition (the $\delta^{15}\text{N}$) of organic matter in the sedimentary record. Bulk sedimentary $\delta^{15}\text{N}$ signatures, however, can be compromised by secondary alteration and external N inputs, so that recently, the focus has shifted to measuring the $\delta^{15}\text{N}$ of organic matter that is trapped and protected in the mineral structure of (micro-)fossils.

The goal of this study is to ground-truth the diatom-bound N isotope paleo-proxy in marine and lacustrine environments through a combination of experimental and field studies. First, we want to investigate how the $\delta^{15}\text{N}$ signature of diatom frustule-bound N is acquired (i.e., how well it tracks the nitrate source) by determining the relationships among the $\delta^{15}\text{N}$ values of the nitrate source to the diatoms, the $\delta^{15}\text{N}$ of the bulk diatom biomass, and the $\delta^{15}\text{N}$ of diatom frustule-bound N, in laboratory diatom culture experiments, as well as in the modern ocean water column and in lakes. Second, we will examine whether the fractional decomposition in the water column and/or diagenetic effects in the sediment during early burial alters the pristine N content and the $\delta^{15}\text{N}$ signature of diatom-bound N over time. Towards this goal, we combine N isotope analyses of sediment trap, surface sediment, and downcore sediment material from a time-series study of varved sediment cores from a lake in Sweden, and perform degradation experiments with diatom biomass from cultures. Third, we want to explore, for the first time, the application of the diatom-bound $\delta^{15}\text{N}$ proxy in lacustrine sediments.

We will present the concept and first preliminary results from our ground-truthing study, which eventually will allow us to assess the integrity of diatom-bound N as a proxy for paleoenvironmental change in marine and lacustrine sediments.



P2-137

Effect of light intensity on the stable isotope composition of the Arctic and Antarctic sea-ice proxy IPSO₂₅.

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Certain highly branched isoprenoid (HBI) biomarkers (i.e. IP₂₅ and IPSO₂₅) are valuable proxy indicators of palaeo-sea-ice extent in the Arctic and the Antarctic [1] when identified in marine sediments [2]. However, some previously established influence of irradiance on the stable isotope composition (i.e. $\delta^2\text{H}$ and $\delta^{13}\text{C}$) of some other lipid classes (sterols, phytol and alkenones) in cultures of marine diatom and coccolithophore cultures (*Thalassiosira pseudonana* [3] and *Emiliana huxleyi* [4]) suggests that there may be a hitherto underexplored dimension of HBIs as tools for palaeo-sea-ice reconstruction. Previously, however, we showed that irradiance can influence growth rate, yield [5] and the $\delta^{13}\text{C}$ of a further HBI (C_{25:3}) [6] in cultures of the benthic diatom *Haslea ostrearia*. However, the effect of irradiance on $\delta^2\text{H}$ and $\delta^{13}\text{C}$ of polar HBI-synthesising diatoms and links to sedimentary HBI deposits remains underexplored. In this study we present preliminary $\delta^2\text{H}$ and $\delta^{13}\text{C}$ data for the sea-ice biomarker proxy IPSO₂₅ obtained from cultures of the sea-ice diatom *Haslea crucigeroides* [7] grown under naturally occurring irradiances (10-100 $\mu\text{mol m}^{-2} \text{s}^{-1}$) [8]. We also present $\delta^2\text{H}$ and $\delta^{13}\text{C}$ data for IPSO₂₅ from a range of Arctic and Antarctic environmental samples, including a sediment core obtained from the Canadian Arctic. We discuss a novel concept model to explain the relationships between $\delta^2\text{H}$ and $\delta^{13}\text{C}$ of IPSO₂₅ and irradiance under different sea-ice scenarios. Our study explores new opportunities to develop HBI proxies further towards quantifying sea-ice concentration.

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P3-133

Core-top calibration of Lithium isotopic ratio in in-faunal benthic foraminifera

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The chemical composition of seawater is varying with time. This variation is primarily controlled by fluctuations in the rates of chemical weathering of the continents (mountain uplift), seafloor spreading (hydrothermal (HT) circulation), and in-situ chemical processes in marine sediments (authigenic clay and dolomite formation). The seawater strontium ($^{87/86}\text{Sr}$) and lithium ($\delta^7\text{Li}$) isotope records for the Cenozoic provide evidence for secular variation in seawater chemistry as a response to changes in silicate weathering rate and regime on the continents. Chemical weathering consumes CO_2 from the atmosphere and causes global cooling. However, the recent foraminiferal culture experiments and abiogenic calcite precipitation studies indicate that the carbonate system parameters like pH and DIC may exert secondary control on $\delta^7\text{Li}$ of calcite. This necessitates the identification of a new archive for the reconstruction of long-term changes in seawater chemistry

The planktonic species are subjected to high amplitude and high-frequency variations in seawater chemistry at seasonal to diurnal timescale. They are the faithful recorder of short-term changes; however, this complicates their application for long-term seawater chemistry. In contrast, benthic foraminiferal species secrete their CaCO_3 shell under quasi-constant bottom water temperature, salinity, CO_3^{2-} ion saturation, and pH. In-faunal benthic, especially *Uvigerina* spp, have even restricted variations in the physio-chemical properties of their growth environment, hence making them the preferred choice for the archive of chemical composition of seawater.

We will present the $\delta^7\text{Li}$ calibration results of core-top samples covering various oceanic basins to investigate the impact of different pH, DIC and redox chemistry of porewater on calcite isotopic composition. We will apply our newly developed method for accurate determination of $\delta^7\text{Li}$ of benthic samples containing sub-nano gram quantity of lithium.



P2-129

Contrasting vertical distributions of recent planktic foraminifera off Indonesia during the southeast monsoon: implications for paleoceanographic reconstructions

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The accuracy of paleoceanographic and paleoclimatic reconstructions based on planktic foraminifera is as good as our understanding of the ecology of the organisms. Here we present field observations of planktic foraminiferal abundances (>150 μm) from 5 depth intervals between 0-500 m in 37 sites off Indonesian islands. The total planktic foraminiferal assemblage comprises 29 morphospecies, with 11 morphospecies accounting for ~90% of the total assemblage. The species composition and dominance in the net samples are broadly consistent with surface sediments observations. The abundance and vertical distribution of planktic foraminifera are low offshore west Sumatra and increase toward offshore south Java and the Lesser Sunda Islands (LSI). The average living depth of *Trilobatus trilobus*, *Globigerinoides ruber*, and *Globigerina bulloides* increases eastward, while *Neogloboquadrina dutertrei*, *Pulleniatina obliquiloculata*, and *Globorotalia menardii* remains constant. We interpret the overall zonal and vertical distribution patterns in planktic foraminiferal abundances as a response to the contrasting upper water column conditions during the southeast monsoon, i.e., oligotrophic and stratified offshore Sumatra (non-upwelling) vs. eutrophic and well-mixed offshore Java-LSI (upwelling). Overall, the inferred habitat depths of selected planktic foraminifera species agree with those from sediment trap samples and surface sediments off Sumatra, but not with those from surface sediments off Java-LSI. The discrepancy might arise from the different temporal coverage of these sample types. Our findings highlight the need to consider how foraminiferal assemblages and ecology vary on shorter timescales, i.e., from “snapshots” of the water column captured by plankton net to seasonal and interannual variability recorded in sediment traps, and how these changes are transferred and preserved in deep-sea sediments.



P3-136

Climate effects on archaic human habitats and species successions

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It has long been believed that climate shifts during the last 2 million years played a pivotal role in the evolution of our genus *Homo*. However, given the limited number of representative palaeo-climate datasets from regions of anthropological interest it has remained challenging to quantify this linkage. We use an unprecedented transient Pleistocene Coupled General Circulation model simulation in combination with an extensive compilation of fossil and archaeological records, to study the spatio-temporal habitat suitability of five hominin species over the past 2 million years. We show that astronomically-forced changes in temperature, rainfall and terrestrial net primary production had a major impact on their observed distributions. During the early Pleistocene hominins primarily settled in environments with weak orbital-scale climate variability. This behaviour changed drastically after the mid-Pleistocene-transition when archaic humans became global wanderers who adapted to a wide range of spatial climatic gradients. Analysis of the simulated hominin habitat overlap from ~300-400 thousand years ago further suggests that anti-phased climate disruptions in southern Africa and Eurasia contributed to the evolutionary transformation of *Homo heidelbergensis* populations into *Homo sapiens* and Neanderthals, respectively. Our robust numerical simulations of climate-induced habitat changes provide a novel framework to test hypotheses on our human origin.



P1-133

Medical computed tomography of polar sediment cores – an indispensable prerequisite for any subsequent core-based study

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Polar shelves exhibit complex seafloor morphologies with multiple depositional environments including various till deposits, such as end, ground or side moraines, mass-wasting deposits, varved and ice-rafted detritus (IRD)-bearing sediments. Classical core description, geochemical logging and sediment sampling do not always allow their identification, classification and/or quantitative evaluation due to ambiguous structures on splitted core surfaces, insufficient logging or sampling resolution, and limited sample sizes. Medical computed tomography (medicalCT) is a fast and cost-effective methodology to non-destructively analyse the entire core volume with sub-millimetre resolution. Furthermore, their calibration to Hounsfield units allows a cross-evaluation of multiple core scans from various medicalCT devices without major limitations. In sediment cores from polar shelves, medicalCT allows the 3-dimensional assessment of IRD, synsedimentary tectonic fractures, mass-wasting-related and other sedimentary structures, and bioturbation traces that significantly improve and supplement classical core description and core logging analyses. The study presents various examples from Baffin Bay that highlight the knowledge gain from medicalCT-based core analyses for the reconstruction of the depositional history of the core – an indispensable prerequisite for any subsequent core-based study.



P1-134

Deep and detailed insights into developmental change during the *Globorotalia plesiotumida*–*tumida* transition: understanding mechanisms of speciation using CT scanning

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Plasticity in developmental trajectories can contribute to the origin of novel traits and species divergence via the expression of previously cryptic variation in response to environmental change. Finding evidence for plasticity-led evolution in the fossil record remains challenging due to the poor preservation of developmental stages in many organisms. Planktic foraminifera are ideally suited for addressing this knowledge gap, because adult organisms in species in which development has been studied retain information about all the ontogenetic stages they have undergone. Here we map changes in the developmental trajectories of 68 specimens in the *Globorotalia plesiotumida*–*tumida* lineage of planktic foraminifera from the late Miocene until Recent using high-resolution computer tomography techniques. The transition within the *G. plesiotumida*–*tumida* lineage is set against a late Miocene cooling trend, which is characterized by an increase in surface-water stratification and a subsequent drop in primary productivity.

Our unique dataset shows that the transition from the ancestral *G. plesio-tumida* to the descendant *G. tumida* is preceded by an increased variability in total cumulative volume—an important indicator of reproductive success in this taxon. The transition interval is marked by a distinct shift in developmental trajectory, which supports a rapid lineage division rather than gradual change. We suggest that the global cooling trend in the late Miocene and associated reorganisation of surface water flow and ecosystems result in high levels of plasticity—particularly in the early stages of development—and have contributed to divergence in the ancestral morphology. Larger temperature gradients lead to a proliferation of available niches. The large variation in developmental trajectories that we uncover within our samples emphasizes the need for high-throughput approaches in studies of ontogenetic change in the fossil record.



P2-127

Evaluating hydroxylated isoprenoidal GDGT-based temperature proxies in surface sediments from the global ocean

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Recently developed hydroxylated isoprenoid GDGT (OH-GDGT) based temperature proxies show promising results for reconstructing past temperature changes. Yet, large uncertainties relating to their biomarker sources, response to non-thermal factors, variation between local versus global scale, etc. remain unexplored. Here we compiled an extensive global core-top dataset of OH-GDGTs with both newly generated and previously published data. We studied the variations of OH-GDGT distribution in the global ocean and evaluated the applicability of different OH-GDGT based proxies (%OH, RI-OH, RI-OH', OH^c, OH^l) as paleothermometers.

The results confirm a strong temperature signal in the OH-GDGT distribution. A strong negative relationship is observed between OH-GDGT-0 with sea surface temperature (SST) ($R^2 = 0.8$, $p < 0.001$) and positive relationships are observed for OH-GDGT-1 ($R^2 = 0.44$, $p < 0.001$) and OH-GDGT-2 ($R^2 = 0.61$, $p < 0.001$) with SST. Among the proxies evaluated, the OH^c proxy, based on both OH-GDGTs and non-hydroxylated isoprenoidal GDGTs showed highest correlation with SST ($R^2 = 0.92$, $p < 0.001$). Results from our global calibration with SST, when applied to few regional studies showed reconstructed temperatures based on the OH^c proxy to be in the range of SST from other proxies (TEX₈₆, U^K₃₇), unlike SSTs exclusively based on OH-GDGT proxies (RI-OH, RI-OH'). Hence, we recommend using proxies based on both OH-GDGTs and isoprenoidal GDGTs to obtain better temperature estimates than proxies based on one of these GDGT groups (RI-OH/RI-OH', TEX₈₆).



P1-122

Using sedimentary ancient DNA to reconstruct the impact of Holocene environmental change on Arctic ecosystems

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Arctic ecosystems are highly sensitive to climate change and are currently being altered by increasing water temperatures and changes in sea ice conditions. These rapid changes will inevitably have profound effects on biodiversity and productivity. In order to understand the ongoing impact of climate warming on Arctic ecosystems, it is essential to assess the response of biodiversity to past changes in environmental conditions. To date, such paleodiversity studies are limited to groups of organisms that can be found as (micro)fossils in the sediment record. This leaves a very incomplete picture of the entire Arctic ecosystem.

Within a Norwegian-Polish collaborative project (NEEDED, Nordic Seas Sedimentary Ancient DNA) we now aim to establish sedimentary ancient DNA sequencing as a new tool for reconstructing past changes in entire marine communities. The project focuses on the continental shelf in the Nordic Seas, near Svalbard, Eastern Greenland and Bear Island, and aims to reconstruct environmental and biodiversity changes throughout the Holocene.

Here, we present the first, preliminary metabarcoding results from a Holocene sediment record from the Hinlopen Strait, northern Svalbard. We extracted ancient DNA and trace a wide range of eukaryotic taxa through time to estimate past changes in diversity and productivity. These paleogenomic data will be compared to other proxies, changes in sea ice cover and water temperature.

This work is supported by the Norwegian Financial Mechanism for 2014-2021, project no 2019/34/H/ST10/00682.



P3-137

Past human adaptation to diverse biomes

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How past variations in climate and vegetation shaped human adaptation, migration, and survival remains unresolved. We identify past human habitat preferences and temporal changes using a new transient 3-million-year earth system-biome model simulation and an extensive hominin fossil/archeological database. According to our analysis, early African hominins predominantly lived in open environments such as grassland and dry shrubland. Migrating out of Africa, hominins had to adapt to temperate and boreal forest environments. By linking location and age of hominin sites with corresponding simulated regional biomes, we also find that our ancestors actively selected for spatially diverse environments. Our results, which challenge previously proposed hominin environmental selection mechanisms, reveal a statistically discernable linkage between past human evolution, migration, and vegetation conditions.



P1-121

Sedimentary ancient DNA – unlocking past responses of primary producers to climate change

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Sea ice is a key component for the functioning and services of polar marine ecosystems. Yet climate warming is threatening these ecosystems with so far unconstrained responses and feedbacks of primary producers, which are the basis of the marine food web, drivers of biogeochemical cycles, and responsible for CO₂ uptake and export. It is crucial to explore past environmental change impacts to understand their long-term effects, to improve predictions about future primary productivity and biodiversity, and ultimately to improve ocean and cryosphere risk assessments. Sedimentary ancient DNA (*sedaDNA*) is a developing tool with the potential to identify ecosystem shifts by covering a broad spectrum of phyla in a single run, tracing organisms who do not leave a fossil record, or which are difficult to identify morphologically due to their size, convergent evolution or differentially adapted ecotypes. By analyzing *sedaDNA* from marine sediment cores from around Greenland, we aim to uncover how the composition and diversity of primary producers, particularly diatoms, changed during the Holocene. We will show the first results of DNA metabarcoding (*rbcL*, 18S) applied to the marine sediment core AMD14-204C (N 73.261050, W 57.899780) taken in the vicinity of Upernavik (Northwest Greenland). The majority of sequences derived by the *rbcL* marker are assigned to centric diatoms (57%), while 13% are assigned to pennate diatoms. Assignments contain typical cold-water, or sea-ice associated species (e.g., *Porosira glacialis*, *Chaetoceros socialis*, *Nitzschia frigida*, *Pauliella taeniata*). A large share of sequences remains unassigned due to gaps in the reference database. Although a taxonomic assignment is not needed to assess diversity changes or to trace a sequence variant through time, it limits ecological interpretations. This indicates the need for a close collaboration between taxonomists and geneticists to fill this gap for unlocking the full potential of *sedaDNA* in the future.

Poster abstracts



Topic 5: Innovations to Overcome Knowledge Gaps

virtual posters



Pv-504

A new, extended version of the DCESS Earth System model

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Climate and carbon cycling on Earth are results of complex and subtle interrelationships among different Earth system components. Here we present a new, extended version of the low-order Danish Center for Earth System Science (DCESS) model (1). This new version, DCESS II, contains improvements in model geometry and physical/biogeochemical processes but retains the simplicity and spirit of the original model. Principal changes include better ocean/atmosphere resolution, atmospheric gas transport, nitrogen and methane cycling (2), an improved sea ice model, an extended land biosphere module considering different vegetation types (3), dynamical meridional large-scale ocean circulation, stability-dependent ocean vertical diffusion (4) and more realistic Antarctic Bottom Water formation.

Model results are tested against observational data and different forcing scenarios have been made to assess model performance. The model reproduces well main characteristics of modern-day climate and ocean/atmosphere property distributions, but some minor differences are present due mainly to the simplicity of the model. This new DCESS model version is well suited to run long-term simulations to study deep-time global climate and environmental change. Here advantage can be taken of model simplicity in modifying the land/ocean distributions and/or including different processes/elements such as sulfur or iron as required without the need for large computational resources.

Some of the features of DCESS II are direct coupling to an Antarctic Ice Sheet model, inclusion of orbital forcing, synthetic sediment cores from distinct ocean sectors and Southern Ocean westerlies forcing.

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Pv-501

An improved North Atlantic benthic $\delta^{18}\text{O}$ stack demonstrates precession pacing of Late Pleistocene glacial terminations

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The mechanism responsible for ~100-kyr cyclicity in Late Pleistocene glaciations is one of the most enduring questions in paleoclimate. Characterizing the response of the climate system to orbital forcing requires precisely dated and continuous paleoclimate archives with small, well-defined uncertainties. Distinguishing whether one orbital cycle is more important than another for triggering ~100-kyr glacial terminations requires both an accurate, non-orbitally tuned age model and a statistical measure of orbital influence. Because precession is the shortest cycle, its apparent influence is disproportionately diminished by age model uncertainties and noise in climate proxy records. Untuned Late Pleistocene age estimates for benthic $\delta^{18}\text{O}$ stacks (e.g., Huybers and Wunch, 2005; Lisiecki, 2010) have uncertainties of ~10 kyr (i.e., half a precession cycle) beyond the range of radiocarbon dating.

We investigate the roles of precession and obliquity in triggering terminations by measuring the orbital phases associated with termination onset in North Atlantic benthic $\delta^{18}\text{O}$ records. Non-orbitally tuned ages are generated by correlating North Atlantic ice-rafted debris peaks to well-dated weak monsoon intervals in Chinese speleothems, with age uncertainties less than +/- 4 kyr. Multiproxy probabilistic stacking software, called BIGMACS, is used to generate a 650-kyr stack of eight North Atlantic benthic $\delta^{18}\text{O}$ records, enhancing the signal-to-noise ratio of the proxy signal. The effects of precession and obliquity on termination timing are evaluated using the Rayleigh's R statistic for the orbital phases of terminations, as in Huybers and Wunsch (2005). The stack yields statistically significant values for both precession and obliquity, with precession having a higher R value (0.76) than obliquity (0.66). Thus, we conclude that precession is at least as important as obliquity in triggering glacial terminations.



Pv-503

Mg/Ca banding in morozovellids: implications for Eocene paleothermometry

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Many species of modern foraminifera have distinct bands of high Mg/Ca ratios within their test walls that are believed to be biologically controlled. Furthermore, the proportion and distribution of these bands varies between species, which may influence Mg/Ca-temperature relationships used for paleotemperature reconstructions. Indeed, these relationships, which are based on extant species of foraminifera, are species-specific. Very few studies have compared intra-test Mg/Ca heterogeneity in extinct species with that in modern species, despite the obvious implications for paleothermometry in intervals where no extant species present. We used electron probe microanalysis, EPMA, to investigate Mg distribution in the fossil tests of two species of planktonic foraminifera from the extinct muricate genera, *Morozovella*, which is commonly used in Paleogene sea surface temperature reconstructions but has a test morphology distinct from modern forms. Mg/Ca maps from the tests of *M. crater* and *M. aragonensis* show striking banding patterns with up to 10 pairs of alternating high/low Mg/Ca bands across the test walls. The banding patterns show many similarities to modern forms but some important differences, which support a slight deviation from traditional growth models in these species. The maps offer important insights into how applicable modern Mg/Ca-temperature relationships are for ancient intervals.



Pv-505

The role of ice age climate in archaic human interbreeding

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Almost all living people outside of Africa carry ~2% of Neanderthal genomes, with some from Southeast Asia and Oceania sharing up to 5% of Denisovan DNA. Although genomic data document multiple episodes of interbreeding among Neanderthals, Denisovans and *Homo sapiens*, it remains unclear when, where and how often the interbreeding between these hominin populations took place. Here we study the Neanderthal-Denisovan admixture during the past 400 thousand years using a novel habitat model that integrates extensive fossil, archeological, and genetic data with unprecedented transient Coupled General Circulation Model simulations of global climate and vegetation. Our Pleistocene hindcast of past hominins' habitat suitability reveals pronounced climate-driven zonal shifts in the main overlap region of Denisovans and Neanderthals in central Asia. These shifts, which influenced the timing and intensity of potential interbreeding events, can be attributed to the response of climate and vegetation to past variations in atmospheric CO₂ and northern hemisphere ice-sheet volume. Therefore glacial/interglacial climate swings likely played an important role in archaic human gene flow and genetic diversification.



Pv-502

Difference in photosynthetic rates between *Trilobatus sacculifer* and *Globigerinella siphonifera*: Implications for carbon sources for photosynthesis

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The microenvironment surrounding photosymbiotic planktonic foraminifera, where calcification takes place, is greatly affected by rapid biological activities such as photosynthesis and respiration. Therefore, information on the photosynthetic activities of the symbiotic system is essential for interpreting geochemical proxies, such as $\delta^{13}\text{C}$, recorded in foraminiferal tests. Recently, active chlorophyll fluorometry has been adopted as a useful tool for the immediate estimation of photosynthesis. In order to make use of this measure to estimate actual carbon dynamics through photosynthesis, the relationship between two photosynthetic rates (electron transport rate; ETR and carbon assimilation rate; P) needs to be correlated. Here, we compared these two rates for *Trilobatus sacculifer* and *Globigerinella siphonifera*, using fast repetition rate fluorometry and ^{14}C tracer experiments. The results showed a significant positive correlation between the two measures for both species, indicating that carbon assimilation can be estimated by the fluorescence method. However, the regression slopes representing the apparent electron demand for carbon assimilation (e-/C) were significantly different between the two species, and were surprisingly high considering the theoretically and empirically realistic values of e-/C. We hypothesized that this high e-/C might be due to the use of unlabeled respired carbon (underestimation of P). Simple mass-balance calculations suggested that a significant amount of carbon should be derived from host respired CO_2 , and that this contribution was higher in *G. siphonifera*. Our attempts to couple ETR and P could comprehensively reveal interesting perspectives on the close interactions that exist within photosymbiotic systems. Moreover, our results suggest that when using geochemical parameters such as $\delta^{13}\text{C}$ as paleoceanographic proxies, it is important to note that the potential magnitude of the photosynthetic effect varies among species.

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