GLOBAL CHANGE NEWSLETTER

www.igbp.kva.se

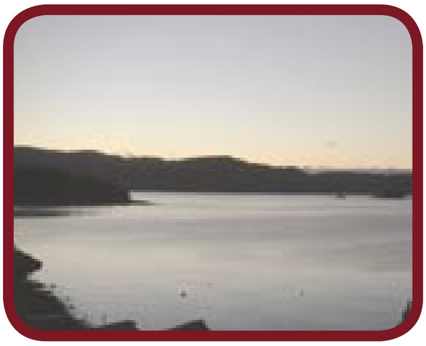
GLOBAL IGBP CHANGE

Issue No. 56 December, 2003

The International Geosphere–Biosphere Programme (IGBP): A scientific research programme for the study of global change

IGBP is sponsored by the International Council for Science (ICSU)

A focus on oceans



Oceans are a source of great resources for humankind, but are also critical to the dynamics of the Earth System due to their strong role in controlling global energy and material budgets, and hence in regulating global climate. In this issue of the Global Change NewsLetter we consider past, current, and future research relating to global change and the oceans. Firstly, a summary of some completed JGOFS research is presented, describing the factors controlling the efficiency of the "biological pump" in the Southern Ocean and the implications for past and future global climate variability. In the *Discussion Forum*, current research from GLOBEC provides an alternative perspective to that in the previous NewsLetter on the issue of changing ocean fish stocks. In *Integration*, the future of global change research related to the oceans is considered. Key research objectives are articulated, and the programmatics of how ocean research will be advanced by IGBP and its collaborative partners are explained, including a description of synergisms expected between GLOBEC and the new IMBER project.

From page 2

Other science

In the other science articles in this issue interim results from aerosol monitoring in Portugal are discussed, the potential of glaciers as monitors of climate change is described, and advances in our ability to simulate the climate over the last 1000 years using coupled atmosphere-ocean general circulation models are described. This latter article is presented as a highlight from the last issue of PAGES News that was devoted to Holocene research.

Contents

Science Features

What regulates the efficiency of the biological pump in the Southern Ocean?

R.F. Anderson

The Southern Ocean is characterized by both a high rate of nutrient supply to surface waters and a low efficiency of biological utilization – a unique combination. The strong westerly winds that circle Antarctica generate a steady up-welling of nutrient-rich deep water. Only about half of the nutrients brought to the surface in the Southern Ocean are used by phytoplankton and thereby exported into deeper waters as biogenic detritus. The unused half is carried back into the deep ocean by deep and intermediate waters that form in the Southern Ocean. The term "biological pump" describes the set of processes that transform inorganic carbon and nutrients into organic matter in sunlit surface waters and transport this organic matter down through the water column in particulate forms. In terms of its effect on atmospheric carbon dioxide (CO_2), the efficiency of the biological pump can be expressed as the fraction of available nutrients that is used for primary production and then exported as organic detritus.

Interest in the factors regulating nutrient use in the Southern Ocean increased with the discovery that changes in the efficiency of the biological pump may have contributed to the glacial-interglacial variations in atmospheric CO_2 recorded in ice cores. Over the past four glacial cycles, each roughly 100,000 years long, atmospheric CO_2 dropped from 280 ppm during interglacial peaks to 200 ppm during glacial periods [1]. The ocean is the only carbon reservoir on Earth capable of exchanging the required amount of CO_2 with the atmosphere at a rate sufficient to account for these changes. However, it is not known how ocean processes induced these changes. Past changes in atmospheric CO_2 are well correlated with the changes in air temperature over Antarctica recorded in ice cores, suggesting that the Southern Ocean may play a role in regulating

JGOFS fades into the sunset

JGOFS – the Joint Global Ocean Flux Study – cosponsored by IGBP and SCOR, fades into the sunset on 31st December 2003 after over a decade of fieldwork, synthesis, and modelling. The final meeting of the Executive Committee was in September 2003, in Bergen, Norway – the location of the International Project Office sponsored by the Research Council of Norway and the University of Bergen. In this issue of the Global Change NewsLetter we present a summary of one of the JGOFS projects. Photograph: Hardangerfjord, Bergen, Norway, September 2003 (Toshiro Saino, Nagoya University, Japan).

glacial-interglacial changes in atmospheric CO_2. Climate-related changes in the efficiency of the Southern Ocean's biological pump may also affect the ocean's ability to take up CO_2 in the future, as atmospheric CO_2 increases and the world warms. To predict such changes however, requires an understanding of the processes and conditions that currently regulate nutrient use in the ocean.

Oceanographers have long understood that light and grazing can limit phytoplankton growth and thus limit nutrient use. During winter in the Southern Ocean, light conditions are unfavourable for growth as solar irradiance is low, mixed layers are deep, and large areas are covered by sea ice. Studies of the North Pacific Ocean, where nutrient use is below maximum potential efficiency, have shown grazing by zooplankton maintains phytoplankton biomass at levels too low to consume available nutrients. In addition to light and grazing, phytoplankton growth and nutrient uptake in the Southern Ocean are limited by iron availability [2,3,4].

Investigation of each of these potentially limiting factors and how they regulate the overall efficiency of the Southern Ocean's biological pump were the primary objectives of the US JGOFS Antarctic Environment and Southern Ocean Process Study (AESOPS) [5], conducted between August 1996 and April 1998. This interdisciplinary study focused on the growth season in the highly productive continental shelf of the Ross Sea and in the open ocean region of the Antarctic Circumpolar Current (ACC) between New Zealand and the Ross Sea. This article summarises results from a series of cruises from October 1997 until March 1998 (Figure 1).

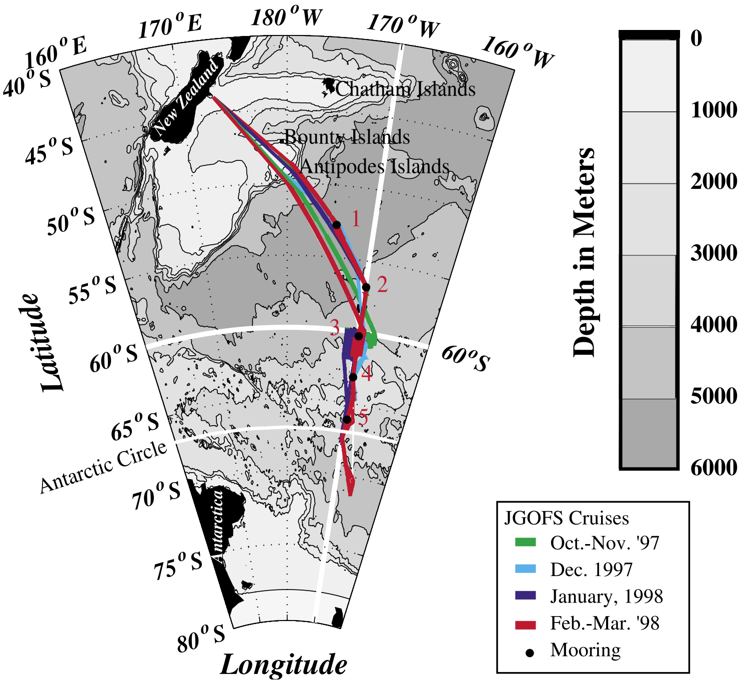


Figure 1. AESOPS cruises of the Antarctic Circumpolar Current between October 1997 and March 1998.

"In addition to light and grazing, phytoplankton growth and nutrient uptake in the Southern Ocean are limited by iron availability."

The ACC comprises a series of fronts in which the eastward flow of water is concentrated into high-velocity jets that often extend from the surface to the sea bed. Nutrient-rich Upper Circumpolar Deep Water comes up to the surface between the Antarctic Polar Front (APF) and the southern boundary of the ACC (SBACC). These are located, respectively, at about 61°S and 65°S along 170°W (Figure 2).

Sea ice in this area was observed to extend nearly to the APF in September-October and melt back to near the Antarctic continent by February. Fresh water released by melting sea ice contributed to the summer stratification of the upper water column south of the APF. Shallow mixed layers enhanced light conditions that were favourable for phytoplankton growth. Mixed-layer depths in late winter exceeded 100 m and sometimes 200 m north of the APF. Surface heating, reinforced by the melting of sea ice south of the APF, reduced mixed-layer depths by December, and the southward retreat of sea ice from December into February left behind shallow mixed layers, sometimes less than 20 m.

By early December light conditions were favourable for phytoplankton growth near the APF, and high phytoplankton biomass followed the retreating ice edge southward [6]. At each latitude along 170°W, high biomass persisted for about a month before declining to low levels. Phytoplankton growth

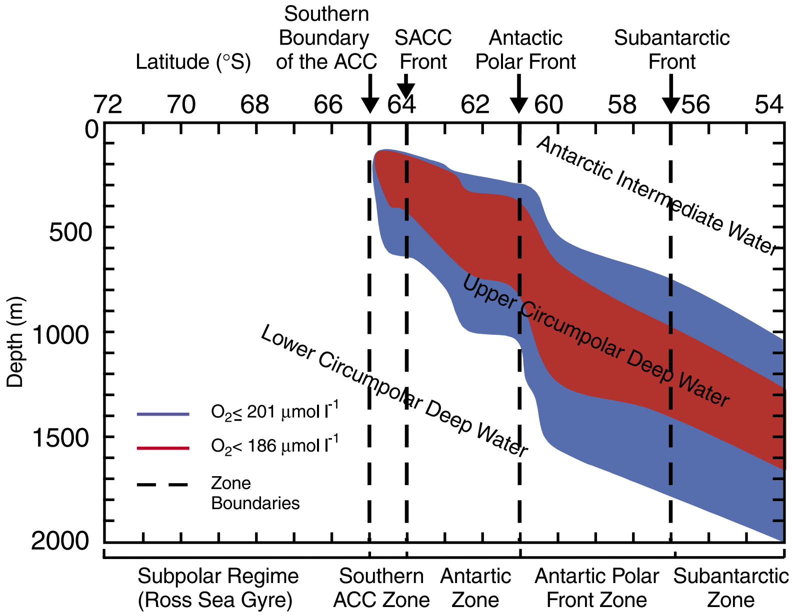


Figure 2. Vertical, south-north section, showing key features of the Antarctic Circumpolar Current. From [8].

was not limited by macro-nutrient (nitrogen, phosphorus and silicon) availability, except north of 55°S where silicon was limiting for diatoms. Although the seasonal increase in phytoplankton biomass was accompanied by draw-down of dissolved nutrient concentrations, even the maximum draw-down of dissolved inorganic nitrogen (occurring between 63° and 65°S during mid-January) used up less than half the nitrate present at the end of the winter, and substantially less was taken up elsewhere and at other times. In contrast, virtually all the dissolved silicon in surface waters north of the SBACC was consumed by diatoms by mid-January [5].

Diatoms (e.g. Figure 3) were abundant (up to 70% of biomass) in the southward-moving band of high phytoplankton biomass, and their growth was responsible for the dramatic draw-down of dissolved silicon. Species abundances followed a cyclic pattern in space and time. The earliest observations at each latitude found a large number of small diatoms, however, as biomass increased, particularly between the APF and the SBACC, the abundance of large diatoms also increased. At peak times, large diatoms represented as much as 80% of the total phytoplankton biomass. Following depletion of dissolved silicon in surface waters north of SBACC, phytoplankton biomass declined, as did the relative abundance of diatoms [7].

The seasonal cycle of phytoplankton biomass and species composition was accompanied by changes in physiological state, and changes in the factors regulating growth and biomass. To the north of the APF, where dissolved silicon concentrations were never high, small cells with relatively high photosynthetic efficiency always dominated the phytoplankton assemblage. Incubation studies using water from north of the APF in early spring showed no silicon uptake response to iron fertilisation, and an increase in total biomass by a factor of only three after a fortnight. South of the APF however, where surface dissolved silicon concentrations were high in early spring, photosynthetic efficiency was low, silicon uptake was stimulated by iron fertilisation, and biomass increased by a factor of more than 30 in a fortnight. In early spring, phytoplankton south of the APF were more stressed and had lower photosynthetic efficiencies than phytoplankton north of the APF. These differences are likely to be at least partly due to iron limitation [8,9].

Similar relationships were observed throughout the summer as the boundary between low and high silicon waters moved southward. In low silicon waters to the north of the boundary, small cells dominated the phytoplankton assemblage, photosynthetic efficiency was high, silicon uptake was stimulated by silicon additions but not by iron, and biomass increased by a factor of 3-5 during incubations. In high silicon waters to the south of the boundary, diatoms were more abundant, photosynthetic efficiency was low, silicon uptake was stimulated by iron addition but not by silicon, and biomass increased by more than an order of magnitude during incubations with added iron.

By March, phytoplankton biomass had declined and small cells dominated the phytoplankton assemblage [7]. However, the photosynthetic efficiency of cells was high north of the SBACC. Reduced photosynthetic efficiencies were found only south of the SBACC in the northern portion of the Ross Sea Gyre. The transition from high to low photosynthetic efficiency across the SBACC coincided with a decrease in dissolved iron concentrations suggesting that the lower photosynthetic efficiency was associated with iron limitation. This spatial pattern is consistent with the higher iron supply north of the SBACC from up-welling [8].

Phytoplankton biomass is primarily reduced by grazing. Shipboard experiments showed that when large diatoms dominated, micro-zooplankton grazing consumed about 60-70% of phytoplankton biomass. In late summer, when small cells replaced large diatoms, micro-zooplankton grazing consumed 95% of phytoplankton biomass, indicating the inability of small grazers to consume the larger diatoms [7]. Meso-zooplankton capable of consuming large diatoms were in low abundance throughout the year, and hence they accounted for only a small portion of phytoplankton biomass [10]. Much of the diatom biomass was aggregated into particles that sank.

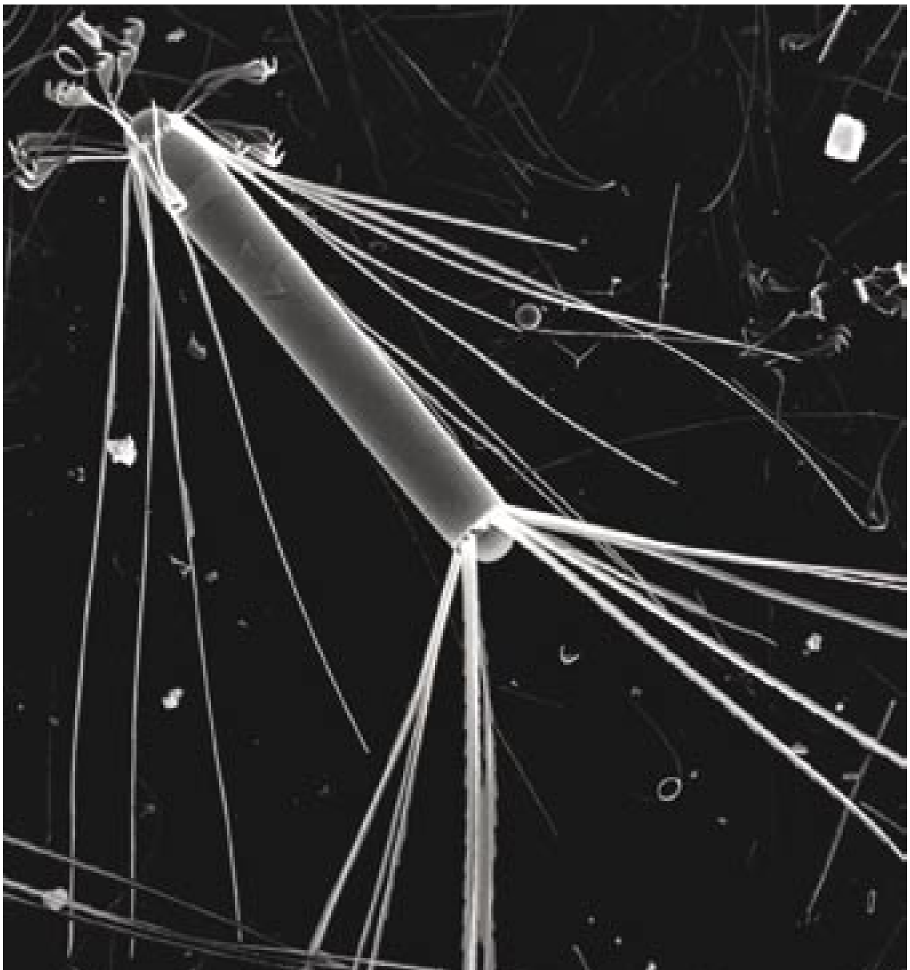


Figure 3: Scanning electron micrograph of a centric diatom from the Ross Sea at magnification 165X. Image from Dee Breger, Lamont-Doherty Earth Observatory

The seasonal cycle of phytoplankton abundance and nutrient use in the study area can be summarised by dividing it into three zones. North of the APF the growth of all phytoplankton is limited primarily by light levels in winter. In summer, the growth rate of large diatoms may be iron limited, but these cells are able to grow, albeit at a sub-optimum rate, until all available silicon is used. Their growth is ultimately limited by silicon availability rather than by grazing. Although small-celled phytoplankton grow with high photosynthetic efficiency, their biomass and thus their nutrient uptake is limited by micro-zooplankton grazing.

South of the southern boundary of the ACC the cycles are less well understood due to a lack of shipboard observations during the period of peak biomass. However, growth is clearly light limited in winter because of sea ice. Phytoplankton assemblages are dominated by small cells even in summer, apparently due to a lack of iron, which limits growth of large cells. Small-celled species have a brief period of growth and high biomass in late summer. Nutrient use is low because of the short growing season and iron limitation.

The most dramatic seasonal changes occur in the middle zone, between the APF and the SBACC. Here, low sun angle, ice cover, and deep mixed layers limit light levels in winter. Small cells are abundant in early spring and near the edge of the retreating sea ice later in the season. Diatom abundance increases in late spring and early summer until these cells constitute most of phytoplankton biomass. Despite iron-limited photosynthetic efficiency, diatoms in the middle zone grow until virtually all of the dissolved silicon in the mixed layer is consumed, as loss to grazing is low. After silicon is depleted, aggregation and sinking remove diatoms from the surface waters. Small-celled phytoplankton are present in the middle zone throughout the summer. Their photosynthetic efficiency is high, suggesting that iron is not a major limiting factor, but their biomass is kept down by grazing. Consumption of inorganic nitrogen and phosphorus is limited by the amount of silicon available to support diatom growth, and by the high efficiency with which small phytoplankton cells are recycled by micro-zooplankton.

In the Southern Ocean, unlike in most other oceans, a large fraction of the phytoplankton biomass is exported below 100 m, despite modest production levels, iron limitation of diatom growth, and grazing pressure on small phytoplankton. Results show annual average export efficiencies for phytoplankton biomass of 15% in the northern zone, 30% in the middle zone, and 50% in the southern zone [6]. High export efficiencies are typical of regions that experience short-lived blooms, such as the North Atlantic Ocean and the Arabian Sea. However, the export efficiencies observed in the Southern Ocean exceed that of any other region studied by US JGOFS. The high export efficiency reflects the low grazing pressure on diatoms, which in turn, leads to low recycling efficiency of diatomaceous material.

These results are only a small step toward understanding the factors regulating the efficiency of the Southern Ocean's biological pump. The southwest Pacific sector is not representative of the entire Southern Ocean, and environmental conditions in the Southern Ocean vary greatly from year to year. Furthermore, the sensitivity of the factors regulating nutrient utilization to climate change must be explored and then incorporated into models of the oceanic carbon cycle, before meaningful simulations can be made of the Southern Ocean's past, present and future role in the regulation of atmospheric CO_2 levels.

Robert Anderson
Lamont-Doherty Earth Observatory of Columbia University
Palisades, NY. USA

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Ground-based aerosol monitoring at Évora, Portugal

A. Silva, M. Costa, T. Elias, P. Formenti, N. Belo, and S. Pereira

Aerosols directly affect the climate by increasing back-scattered radiation and by absorbing solar and long wave radiation. They indirectly affect climate by changing the microphysical properties of clouds and their life span, thereby modifying the planetary albedo and precipitation regime. They play a major role in atmospheric chemistry and hence affect the concentrations of other minor atmospheric constituents. However, the limited information on aerosol properties and dynamics, particularly in the troposphere, is a major uncertainty in climate change prediction and in building regional climate change scenarios. The confidence in current climate change predictions is very low [1], thus warranting detailed investigation of aerosols.

Within Europe, Portugal is a unique location for aerosol studies because it is affected by contrasting air masses [2]. Here, large unperturbed rural areas co-exist with dense pollution-generating industrial and urban agglomerates. Maritime aerosols are a pervasive component of the regional atmosphere – particularly over land adjacent to the western and southern coasts, and the region is also affected by the long-range transport of anthropogenic aerosols emitted in northern Europe, and by desert dust plumes advected from Africa. Desert dust, maritime aerosols, and – frequently during summer – forest fire smoke, account for most of the suspended particle mass [3]. This fraction is very efficient at scattering and absorbing both short- and long-wave radiation.

Both intensive campaigns and long-term monitoring are valuable in aerosol studies. The intensive second Aerosol Characterisation Experiment (ACE2) of IGBP's IGAC project selected Sagres in southern Portugal as a major platform in summer 1997 [4,5]. Long-term monitoring is necessary for understanding climate change implications, in particular to identify major aerosol types, to characterise their spatial and temporal distribution and their optical and physical properties, and to estimate their local and regional radiative forcing. In Portugal, long-term monitoring is being undertaken under the framework of Programa Operacional Ciência, Tecnologia, Inovação/Ciências da Terra e da Atmosfera/2002 (POCTI/CTA/2002), by Fundação para a Ciência e Tecnologia (FCT). Monitoring began in 2002 with measurements from ground-based instruments at Évora (150 km south-east of Lisbon), and is now being extended with measurements from Cabo da Roca (20 km west of Lisbon). The Évora site coincides with the first continental Portuguese Aerosol Robotic Network (AERONET) site, and the Cabo da Roca site, the second continental Portuguese AERONET site, is the western-most site in Europe.

The instrumental payload at Évora includes a multi-wavelength, angular-resolving sun/sky photometer (to measure the light extinction and scattering integrated over the atmospheric column), a multi-wavelength fluxmeter (to measure the spectral down-welling solar flux), and a multi-wavelength nephelometer (to measure the particle volume scattering and backscattering coefficients). At Cabo da Roca a multi-wavelength, angular-resolving sun/sky photometer is in the process of being installed.

Sun/sky photometer measurements can be used to infer the scattering and absorbing properties of aerosols – integrated over the air column. These directly determine the affect of aerosols on the Earth's radiative budget. More detailed vertical profiles are obtained

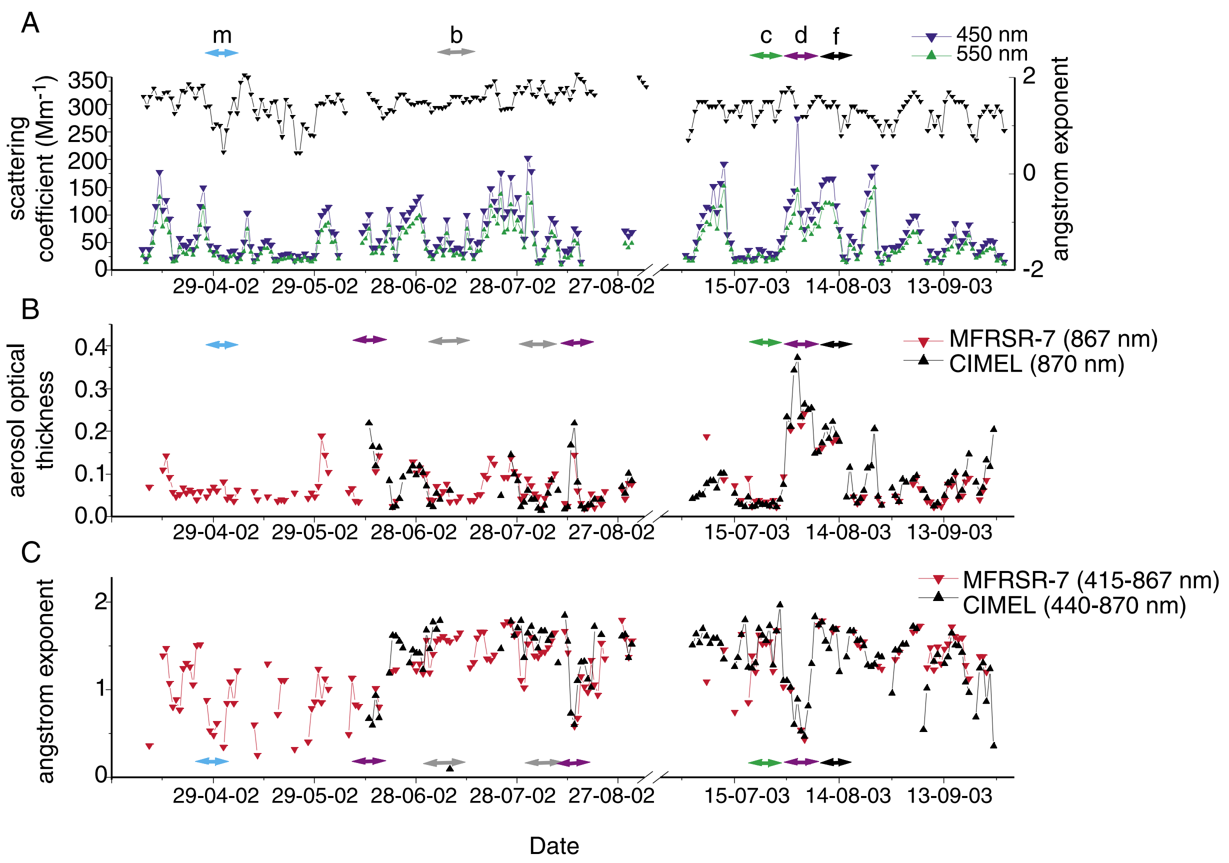

Figure 1. Aerosol properties measured at Évora during 2002 and 2003. A: aerosol volume scattering coefficient at 450 nm and 550 nm wavelengths obtained with the multi-wavelength nephelometer (450 nm - blue triangles and fitted curve; 550 nm - green triangles and fitted curve) and the Angström exponent (black triangles and fitted curve). B: columnar aerosol optical thickness at 867 nm wavelength obtained with a multi-wavelength fluxmeter MFRSR-7 (867 nm) (red triangles and fitted curve) and columnar aerosol optical thickness at 870 nm wavelength obtained with a multi-wavelength angular-resolving sun/sky photometer CIMEL (870 nm) (black triangles and fitted curve). C: Angström exponent obtained with the multi-wavelength fluxmeter MFRSR-7 (red triangles and fitted curve) and with the multi-wavelength angular-resolving sun/sky photometer CIMEL (black triangles and fitted curve).

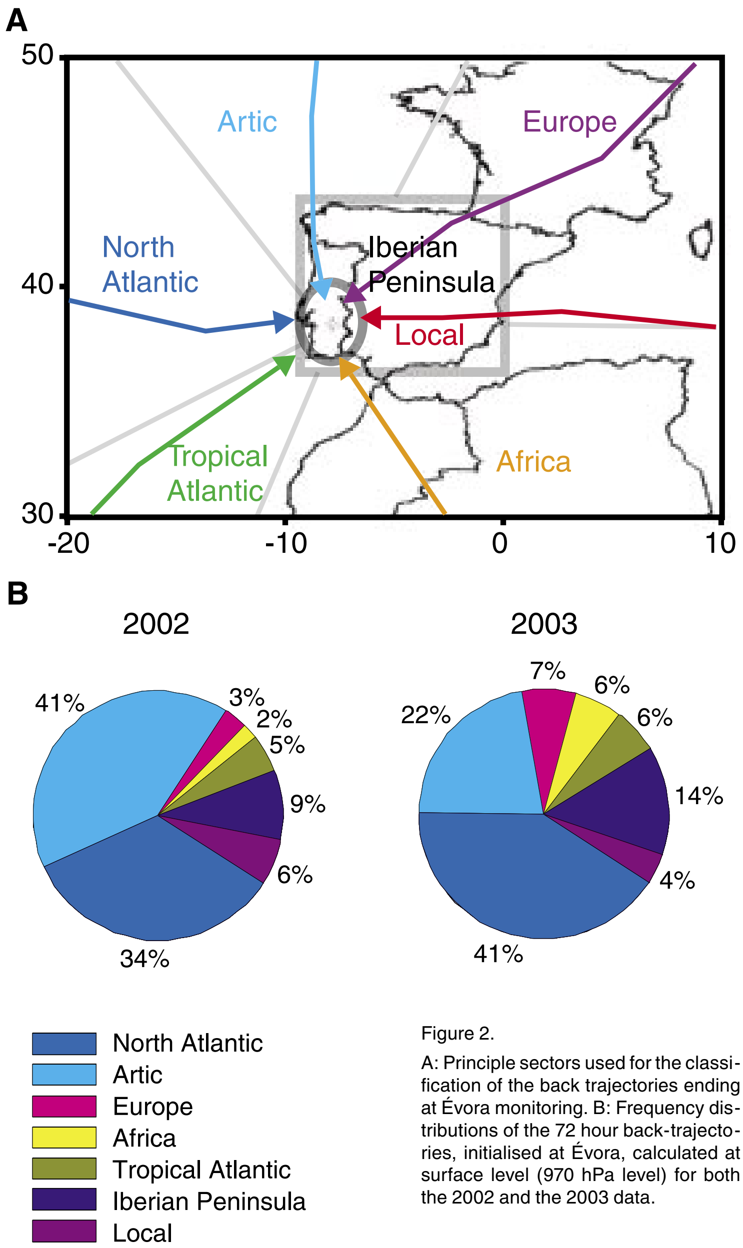

Figure 2.

A: Principle sectors used for the classification of the back trajectories ending at Évora monitoring. B: Frequency distributions of the 72 hour back-trajectories, initialised at Évora, calculated at surface level (970 hPa level) for both the 2002 and the 2003 data.

using a LIDAR that identifies aerosol layers as a function of aerosol content and character, with measurements possible day and night under clear or under cloudy skies (thus overcoming the intrinsic limitations of passive radiometric instruments). Independent measurements from the multi-wavelength fluxmeter check the validity of inferred aerosol properties. These ground-based measurements also help interpret and validate measurements from instruments on MODerate Resolution Imaging Spectroradiometer (MODIS) and Sea-viewing Wide Field-of-view Sensor (SeaWIFS) satellites, and help in the development of their retrieval algorithms – particularly over land, where surface reflection may be of the same order of magnitude as the atmospheric correction. The sun/sky photometer measurements are frequently complemented with radio sounding measurements and trajectory analyses, to help interpret the measurements and to help refine the photometer inversion algorithms.

To date, monitoring has revealed several aerosol situations at Évora. The most frequent (about 50% of the time) reflects the continentally (rural) influenced aerosols – the so-called background conditions (grey line Figure 1b). Situations of exceptional low turbidity are also common in Évora (about 25% of the time) – the so-called aerosol-free conditions, with an aerosol optical thickness sometimes as low as the instrumental uncertainty at 870 nm (green line Figure 1c). Episodes of urban, forest fire, or industrial pollution (black line Figure 1f) and of desert-dust aerosols (violet line Figure 1d) are also apparent, the latter identified by increases in aerosol optical thickness – particularly in the 867 and 870 nm wavelengths, and decreases in the Angström turbidity parameter (Angström exponent) – indicating larger aerosols. The Angström exponent characterises the spectral behaviour of the aerosol optical thickness, and is calculated as the power-law exponent that relates wavelength to the columnar aerosol optical thickness at two or more different wavelengths. In our case two wavelengths were used: 415 and 867 nm for the multi-wavelength fluxmeter MFRSR-7; 440 and 870 nm for the multi-wavelength angular-resolving sun/sky photometer CIMEL and 450 and 700 nm for the multi-wavelength nephelometer. Finally, an episode dominated by marine aerosols can be identified (light blue line Figure 1m).

In 2002 about 70% of air masses came from the north and north-west (North Atlantic and Arctic sectors) decreasing to about 60% in 2003 (Figure 2), and these percentages did not vary much within each year. In 2002 about 15% of the air masses came from the east or south-east (Europe, Africa, Iberian Peninsula sectors) increasing to 27% in 2003, with these contributions mostly occurring June – August (Figure 2). These air masses bring desert-dust aerosols to Europe; some such dust events are indicated in Figure 1. The increase in the proportion of air masses from the east and south-east was due to persistent low pressure systems in June and July 2003.

Combined ground-based and satellite-based measurements following a forest fire in central and southern Portugal in August 2003 were used to validate the observations made by the MODIS satellite over Évora. The MODIS-derived aerosol optical thickness at 550 nm over Évora on 8th August 2003 was 0.42 (Figure 3), while the columnar aerosol optical thickness at 445 nm measured by the Évora multi-wavelength sun/sky photometer was 0.45. The Angström exponents from MODIS (1.34) and from the sun/sky photometer (1.74) are also comparable.

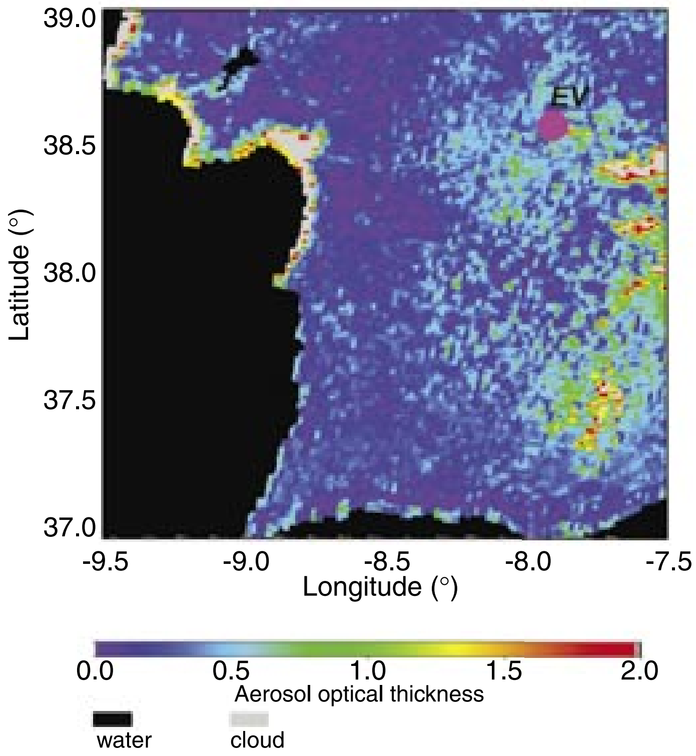

Figure 3. Aerosol optical thickness at 550 nm over Portugal on 8th August 2003 based on MODIS satellite measurements (see online at http://modis.gsfc.nasa.gov). Location of Évora (EV) is indicated.

The long term measurements of aerosol optical thickness and of particle volume scattering and backscattering coefficients at Évora, complemented by analyses of trajectories, are an important step in establishing the aerosol climatology of the western Mediterranean. These results, and others obtained in the eastern Mediterranean area, will contribute to a more comprehensive understanding of role of aerosols in climate forcing in the Mediterranean.

In the last decade several experimental studies of aerosols have been carried out in the eastern Mediterranean area, because various models have predicted the maximum net direct radiative forcing by sulphate to occur in this area. In the western Mediterranean area however, very few experimental studies of aerosols have been conducted, and the uncertainty on the prediction of direct radiative forcing by aerosols is large. Hence the long term measurements of the optical characteristics of aerosols at Évora and Cabo da Roca, and the identification of their main origin and frequency of occurrence, will allow derivation of the climate-relevant aerosol parameters needed to estimate the direct radiative forcing by aerosols converging in the area. These aerosols are primarily maritime aerosols from the North Atlantic ocean, mineral dust blown out from western and north-western Africa, and anthropogenic aerosols from seasonal forest fire smoke. It is expected that the uncertainty on the latest predictions of direct radiative forcing by different aerosols in the western Mediterranean area is lower, and thus regional scenarios of climate change can be updated.

Ana Maria Silva
Physics Department
University of Évora, Portugal
E-mail: asilva@uevora.pt

Maria João Costa
Physics Department,
University of Évora, Portugal
E-mail: mjcosta@uevora.pt

Thierry Elias
Évora Geophysics Centre,
University of Évora, Portugal
E-mail: telias@uevora.pt

Paola Formenti
Laboratoire Interuniversitaire des Systèmes Atmosphériques
Faculté des Sciences et Technologie, Créteil, Paris
E-mail: formenti@lisa.univ-paris12.fr

Nuno Belo
Évora Geophysics Centre,
University of Évora, Portugal
E-mail: nunobelo@uevora.pt

Sérgio Pereira
Évora Geophysics Centre,
University of Évora, Portugal
E-mail: sergiopereira@uevora.pt

Acknowledgements

We thank NASA, CNES, and CNRS for access to AERONET data (available at http://aeronet.gsfc.nasa.gov/. Special thanks go to AERONET investigators and their staff for establishing and maintaining monitoring the sites. MODIS data were acquired from the NASA Earth Science Enterprise, and MODIS algorithms were developed by the MODIS Science Teams. MODIS data were processed by the MODIS Adaptive Processing System and Goddard Distributed Active Archive Center. The Évora sun/sky photometer was funded by FCT, Portugal, through the (POCTI/CTA/2002) project. Air mass trajectories were calculated by using the HYSPLIT model (http://www.arl.noaa/gov/ss/models/hysplit.html).

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Simulating the climate of the last millennium

M.Widmann and S.Tett

The climatic changes of the last millennium are reasonably well understood: compared to earlier periods the uncertainties in climate reconstructions from proxy records are relatively small, and the external forcing factors of the climate system are relatively well known. As a result, comparisons between this portion of the palaeo-record and the 20th century climate record are a good basis for assessing the influence of human activities on the climate. Numerical modelling complements climate reconstructions from proxy records by: (i) reducing uncertainties in climate reconstructions through consistency tests with evidence from proxy data, (ii) helping validate climate models, (iii) generating hypotheses on climatic evolution at locations, or for variables, for which there are no proxy data, and (iv) improving process understanding. Improved process understanding should at least enable differentiation between internal variability and the effects of varying external forcings, and help understand feedback mechanisms.

The simplest climate models are zero- or one-dimensional energy balance models (EBMs), with low computational costs and clear links between simulated processes and climate. The most complex are quasi-realistic, computationally expensive, general circulation models (GCMs), with sub-models for the atmosphere, ocean, and sea ice. The three-dimensional grids for these models typically have a horizontal resolution of a few hundred kilometres, and include 15-100 vertical levels. GCM components for the carbon cycle, chemical processes, land ice, and vegetation dynamics are currently under development. Between the extremes of EBMs and GCMs are models ranging in dimensionality and complexity – for example, earth system models of intermediate complexity (EMICs) that describe the atmosphere and ocean dynamics in less detail than GCMs, but place more emphasis on the roles of vegetation and chemical processes in the climate system.

There are two different ways in which climate models are mainly used: equilibrium simulations, and transient, forced simulations. In equilibrium simulations, the forcing factors for the climate system, such as solar irradiance, atmospheric composition, or the Earth's orbit, are constant within a model run – but may vary between model runs. Equilibrium simulations thus model the mean climate and the statistics of internal climate variability. Transient, forced simulations also include the climate response to time-varying forcings based on historical estimates. Since evolution of the climate system is not completely determined by external forcings, but also contains a stochastic component, even a perfect model with all forcings included will simulate only one of many possible climates consistent with the forcings. This climate will be different from that which took place in the real world, and so comparisons between simulations and reconstructions are only probabilistic.

By the mid-1990s, coupled GCM equilibrium simulations for pre-industrial conditions were generally 100 year simulations, however, 1000 year simulations were possible at some modelling centres including the Geophysical Fluid Dynamics Laboratory (GFDL) – USA, the Max Planck Institute (MPI) – Germany, and the United Kingdom Met Office (UKMO). These longer simulations were used to clarify the roles of the atmosphere and the ocean in generating internal climate variability [1], and in estimating natural variability – the basis for detection and attribution of climate change [2]. However the magnitude of variability derived from the equilibrium simulations was lower than from proxy-based estimates [3], which is likely to be mainly due to the lack of variability caused by external forcing factors [4]. The question of whether the inclusion of natural forcing factors in the simulations leads to a realistic level of variability is still under investigation. A 15,000 year simulation using the GFDL model with a relatively low spatial resolution suggested that large-scale, multi-decadal temperature anomalies with amplitudes of 6-10 standard deviations, could be generated merely by internal processes [5]. Recently, 1000 year equilibrium simulations at higher resolutions (about 300 km) were conducted at UKMO [6] and at MPI. Because these simulations are much longer than the instrumental climate record, they are well suited for testing palaeoclimatic reconstruction methods on decadal to centennial time scales [7,8].

Many transient simulations investigate the climatic effects of anthropogenic emissions of greenhouse gases and aerosols since the mid-19th century [e.g. 9]. The climatic response to changing solar forcing was investigated with a coupled GCM forced by estimates for solar variability from 1700 to the present [10]. The spatial pattern associated with solar forcing was found to be similar but not identical to the signal of changing greenhouse gas concentrations, and the pronounced insolation decrease during the 1820 Dalton Minimum (DM) caused global cooling. Recent modelling also focuses on the insolation minimum during the 1675-1710 Late Maunder Minimum (LMM). A transient EBM simulation, forced by solar and volcanic activity, and anthropogenic greenhouse gases and aerosols, produced a global temperature well correlated with proxy reconstructions [4] – in particular a cooling during the LMM was found. An LMM cooling was also found in a 1000 year simulation using a two-dimensional, zonally averaged atmosphere-ocean model [11]. Note however, that in both models climate sensitivity to changes in forcing can be tuned. A 1000 year EMIC simulation used similar forcings, but also considered deforestation [12]. Northern Hemisphere temperatures correlated well with proxy reconstructions: pronounced cooling due to solar and volcanic forcing occurred during the LMM and the DM, and cooling due to deforestation occurred during the last half of the 19^{th} century.

> "...even a perfect model with all forcings included will simulate only one of many possible climates consistent with the forcings."

Equilibrium simulations using an atmospheric GCM with detailed ozone chemistry coupled to a slab ocean model have modelled the difference between the LMM and the period around 1780 [13]. During the LMM, continen-

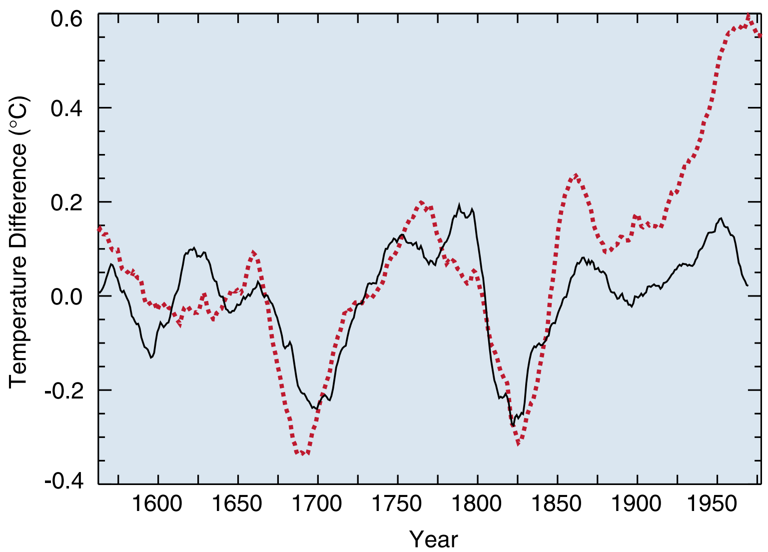

Figure 1. 25-year running averages of modelled global-mean temperature differences from the 1550-1800 mean. Black line: ECHO-G with natural and anthropogenic forcings. Red line: HadCM3 with only natural forcings.

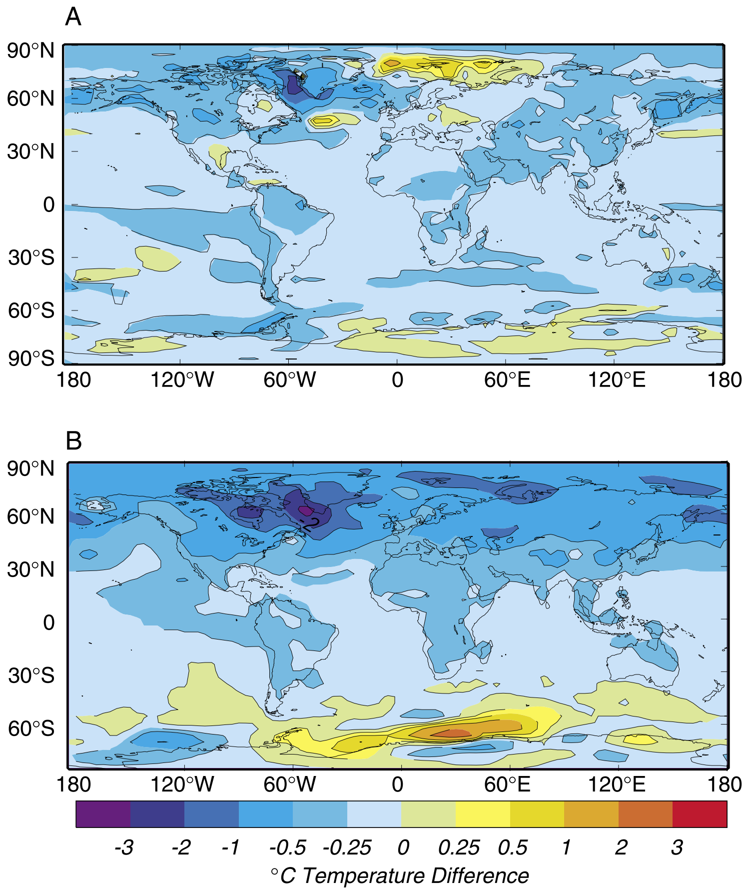

Figure 2. Differences in near-surface temperature for the LMM cooling period (1675-1710) from the 1550-1800 mean; A: HadCM3, A: ECHO-G. Global-means are -0.21°C (HadCM3) and -0.28°C (ECHO-G).

tal surface air temperatures were colder, and some oceanic surface air temperatures were warmer, than 100 years later. This was shown to be related to a change in the Arctic Oscillation/North Atlantic Oscillation, which in turn is driven by variations in the meridional temperature gradient. This temperature signal is consistent with available proxy data, but large areas with inadequate proxy data mean agreements between simulation and observations are not conclusive.

The LMM was also included in 500 year transient simulations of the fully coupled atmosphere-ocean GCMs ECHO-G [14,15] and HadCM3. In preliminary results these models agree on the magnitude of the global mean cooling predicted for both the LMM and the DM (Figure 1). The HadCM3 simulation included only natural forcings, while the ECHO-G simulation included the major anthropogenic and natural forcings. This explains the divergence between the simulations from the mid-19th century. Simulations with only natural forcings, and with natural and anthropogenic forcings, are currently being undertaken with both models. The cooling during the LMM simulated by these models has a spatial structure somewhat different from [13]. Most noticeable in both simulations is a strong cooling in the Northwest Atlantic associated with increasing sea-ice extent (Figure 2). Also apparent is a cooling over Europe and other regions. ECHO-G predicted widespread cooling over the entire northern hemisphere with a maximum of 2°C west of Greenland. In contrast, HadCM3, while still predicting cooling west of Greenland, predicts a larger land-sea temperature differential.

The preliminary results from GCM simulations suggest it is possible to simulate the major features of forced climate variability over the last 500 to 1000 years. Good simulations over this period will allow comparisons with proxy data, and the estimation of the relative contributions of natural and anthropogenic climate forcings, and of internal climate variability, to overall climate variability and change.

Martin Widmann
Institute for Coastal Research
GKSS Research Centre
Geesthacht, Germany
E-mail: widmann@gkss.de

Simon F.B. Tett
Met Office Hadley Centre
University of Reading
Reading, UK
E-mail: simon.tett@metoffice.com

Acknowledgements

This work has been supported by EU and UK Government Met Research contracts. Computer time for HadCM3 simulations was provided by the UK Department of Environment, Food, and Rural Affairs. The ECHO-G transient simulation was part of a Helmholtz Society project. Widmann was supported by the German Climate Research Programme DEKLIM. We thank F.J. González-Rouco and E. Zorita, GKSS Research Centre for access to ECHO-G data. This article is an edited version of the article that appeared in PAGES News, 11(2-3):21-23, October 2003; it reports work that is part of the PAGES HOLIVAR Project.

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National Committee Science

Climate change as recorded by glaciers

P.Wagnon and C.Vincent

Mountain glaciers are widely recognised as excellent indicators of climate change over recent centuries [e.g.1,2,3]. Glacier mass variations can be used to assess climate warming over the 20th century and possibly to also assess anthropogenic influences. Unfortunately, data becomes sparser as we go back in time. Contrary to glacier length variations which result from complex ice flow dynamics, mass balance fluctuations are direct climatic indicators as they directly record solid precipitation in the form of winter mass balance and surface energy fluxes via summer ablation [e.g.4,5]. Since most mountainous glaciers are temperate (i.e. close to the pressure melting point), the excess energy flux at the glacier surface during the ablation season serves mainly for melting and is therefore recorded in the form of a mass change. As a consequence, it is necessary to measure both winter and summer mass balance terms over a sufficiently long period to investigate long-term climate trends, and to combine these with local meteorological data.

For more than four decades CNRS-LGGE[1] has been measuring the annual volume changes of several glaciers in the French Alps. For more than a decade the IRD[2] has monitored the mass balance and energy balance of several glaciers in the tropical Andes of Bolivia and Ecuador. In 2002 these institutions combined their efforts to create an "Observatory of Research in Environment" (ORE). This led to the project GLACIOCLIM[3] which is supported by IRD and local partners for its Andean part and by CNRS-LGGE, INSU[4] and OSUG[5] for its European part. An Antarctic part, supported by IPEV[6] will also be included in this ORE in order to provide ground truth for climate models [e.g.6] and remote sensing estimates [7]. The aim

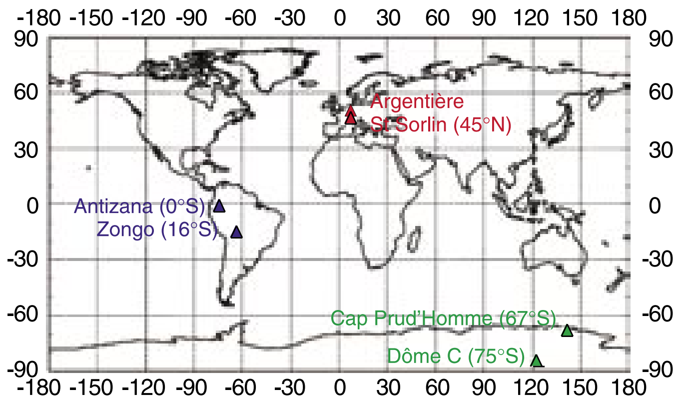

Figure 1. Location of the glaciers studied in GLACIOCLIM.

of GLACIOCLIM is to complete, homogenise, and perpetuate the glaciological and meteorological measurements conducted on selected glaciers or ice sheets representative of various climate zones. GLACIOCLIM represents a unique framework for studying the relationship between glaciers and climate and for estimating the contribution of glaciers to future sea level rise. The glaciological component of GLACIOCLIM represents the French arm of the international World Glacier Monitoring System. In this article we describe the structure of GLACIOCLIM and provide some results from both the European Alps and the Andes.

GLACIOCLIM

The glaciers in GLACIOCLIM lie along a virtual climatic meridian from the equator to the polar regions that includes inner and outer tropical, temperate, and polar climates (Figure 1). The study includes both long-term measurements (Table 1) and short-term energy balance field campaigns, to help understand the link between the glacier melting and meteorological variables. Glaciological and meteorological measurements have begun in the Andes, and glaciological measurements have begun in the European Alps. Meteorological measurements will be added to the Alpine network in 2004 and 2005. The Antarctic component is just starting, with a first field campaign planned for January 2004, and long-term measurements expected to be operational in 2005-2006. As data are collected they are made available at www.geo.unizh.ch/wgms and www-lgge.ujf-grenoble.fr/equipes/glaciers.

Glaciers and Climate – Recent Changes in the European Alps

The cumulative mass balances of the Hintereisferner (Austria), Saint Sorlin (France), and Sarennes (France) glaciers differ greatly in their 20^{th} century-averaged balances, ranging in metres water equivalent per year (m w.e. yr^{-1}) from -0.33 for the Saint Sorlin glacier to -0.62 for the Sarennes glacier (Figure 2). To compensate for these differences each glacier mass balance has been transformed by subtracting its 1953-1999 average mass balance from the annual values, to give cumulative centred mass balances (in m w.e. yr^{-1}) of -0.62 for Sarennes, -0.45 for Hintereisferner, and -0.33 for Saint Sorlin. Data from Claridenfirn Glacier (Switzerland) are also included, as although the glacier's overall mass balance is unknown, mass balance fluctuations can be determined from annual at-a-site measurements (Figure 2). From these data it is seen that cumulative mass balance fluctuations (centred values) reveal a common climatic signal across the European Alps [8].

To determine the origin of this common climatic signal the winter and summer mass balance terms for these glaciers must be compared. This was only possible

Glaciological measurements *(1-4 times per year, depending on site)*	Meteorological measurements *(half-hourly means)*
• Ablation (stakes) • Accumulation (drilling) • Surface velocity (GPS) • Thickness variations (GPS) • Terminus mapping (GPS)	• Wind speed and direction, incident and reflected solar radiation, incoming and outgoing thermal radiation, ventilated air temperature and humidity, precipitation (automatic weather station on nearby moraine) • Daily albedo (terrestrial photographs)

Table 1. Long-term measurements included in GLACIOCLIM.

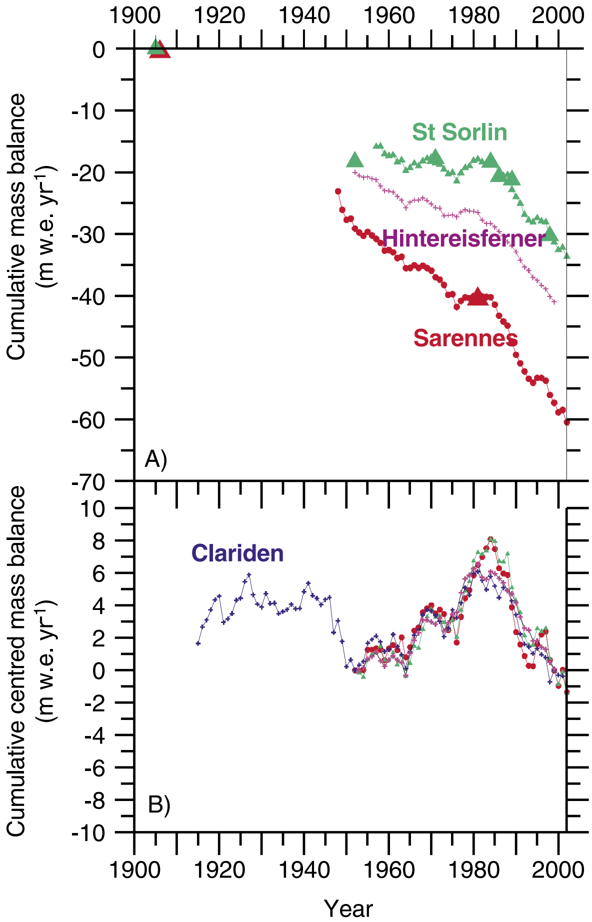

Figure 2. A: Cumulative mass balance of three European Alpine glaciers in meters of water equivalent. The first value of Hintereisferner series has been arbitrarily set to -20 m w.e. in 1953. Small dots and triangles are direct measurements. Large triangles are photogrammetric restitutions from old maps with elevation contours and geodetic measurements. B: Cumulative centred mass balance series of the same glaciers (transformed by subtraction of the 1953-1999 average). The Clariden Glacier has been added. (From [8]).

for Claridenfirn and Sarennes where both observations are available. The summer term is by far the largest component of the annual balance. Comparing 1954-1981 to 1982-2002, ablation between June to September has increased similarly at Claridenfirn (from 0.77 to 1.36 m w.e.) and at Sarennes (from 1.88 to 2.48 m w.e.) [8]. This comparison reinforces the representativeness of mass balance fluctuations over the European Alps and indicates very similar melting rate rises over the last two decades for two glaciers 290 km apart. It is likely therefore that the summer climate changes which affect glaciers are similar over the European Alps.

Glacier Retreat and ENSO Variability in the Andes

During the last decade, glacier mass balances in the Tropics have declined (Figure 3). Large glaciers, such as the Zongo and Antizana, lost between 0.3 and 0.5 m w.e. yr^{-1}, whereas small ones (< 0.5 km^2) – such as the Chacaltaya, have retreated even more dramatically, with deficits as high as 1 m w.e. yr^{-1}. Total extinction of these small glaciers can be anticipated in the next 10 to 15 years based on the 1980-2000 measured rates [9]. The glaciers in the tropical Andes have been retreating in a consistent way, suggesting a common response to a global climate forcing. The main component of this recession is ablation, which has increased dramatically since 1976 – the date of the "Pacific shift". In the last decade, ablation rates in Bolivia

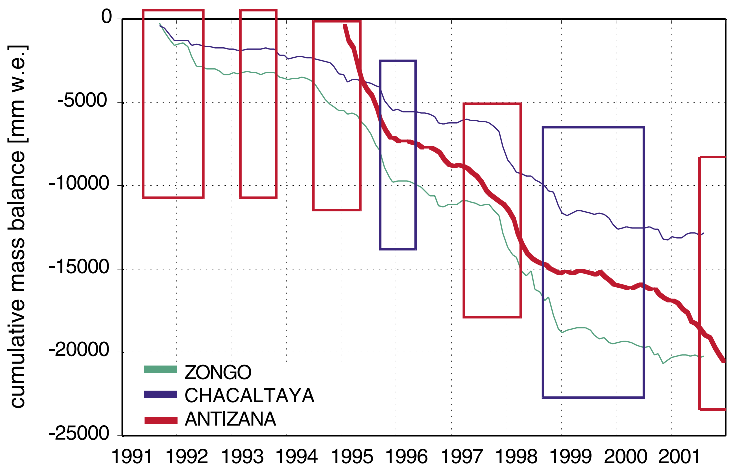

Figure 3.

Monthly mass balance from three glaciers in the tropical Andes based only on ablation zones in specified elevation ranges: Zongo, 5150-5030; Chacaltaya, 5350-5130; and Antizana, 5000-4800 m above mean sea level. Red boxes indicate warm ENSO events (El Niño), and blue boxes cold ENSO events (La Niña) in the Pacific. Warm and cold ENSO periods are for the "Niño 3-4 region" (After [14]).

and Ecuador have increased significantly during the Pacific warm ENSO phases (El Niño) and decreased during the cold phases (La Niña) [10,11] (Figure 3). An energy balance approach has been applied to simulate melting processes during the extreme phases of ENSO [12,13]. These analyses revealed that net all-wave radiation, which is modulated by albedo, is the main factor governing ablation. Albedo, in turn, depends upon snow cover. The precipitation deficit observed in the early wet season (December-February) in Bolivia, and the displacement of the snow/rain limit at high elevations due to a positive temperature anomaly in Ecuador, maintains a low albedo on glacier surfaces during the warm El Niño events. During the cold and wet La Niña events, the opposite situation prevails and ablation strongly decreases. An increased frequency of long and intense warm ENSO events considerably accelerated the glacier retreat since the late 1970s, while less frequent cold events (La Niña) allowed glaciers to briefly save or gain mass. The mass balances lag behind the Pacific by 2-3 months in Ecuador (Antizana) and by 5-6 months in Bolivia (Zongo and Chacaltaya). The stabilisation observed on the Bolivian glaciers during 1992-1993 is believed to be connected to the Pinatubo event [10]. It is probable that the effects of El Niño on glaciers are superimposed on the effects of global warming, but because of the shortness of the records, it has not been possible yet to dissociate the impacts of these two forcing mechanisms.

Conclusions

Glacial retreats around the world indicate a common global response to climate change, despite their geographic restriction to mountainous areas. They can therefore be considered as sensitive recorders of the climate change on a global scale.

Patrick Wagnon
IRD (Institut de Recherche pour le Développement)
Saint Martin d'Hères Cedex, France
E-mail: patrick@lgge.obs.ujf-grenoble.fr

Christian Vincent
CNRS-LGGE (Laboratoire de Glaciologie et de Géophysique de l'Environnement)
Saint Martin d'Hères Cedex, France
E-mail: vincent@lgge.obs.ujf-grenoble.fr

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[1] CNRS-LGGE: Centre National de la Recherche Scientifique - Laboratoire de Glaciologie et de Géophysique de l'Environnement
[2] IRD: Institut de Recherche pour le Développement – UR R032
[3] GLACIOCLIM: the GLACIers, an Observatory of the CLIMate
[4] INSU: Institut National des Sciences de l'Univers
[5] OSUG: Observatoire des Sciences de l'Univers de Grenoble
[6] IPEV: Institut Polaire Paul Emile Victor

The above article describes work associated with one of the French ORE's. ORE's are an initiative of the French Ministry of Research. The French IGBP National Committee hopes to assist in bringing the data and findings of relevant ORE's to the international global change research community.

Global change science at the U.S. National Academies

G.Symmes

The Co-ordinating Committee on Global Change of the United States National Academies (CCGC) [1] serves as the US National Committee for the International Geosphere-Biosphere Programme (IGBP).

In addition to its responsibilities to IGBP, the CCGC is responsible for co-ordinating and integrating the advice that the US National Academies provide to the US federal government on issues of global change science and technology. The last meeting of the CCGC [2] – July, 2003, Keck Center of National Academies, Washington DC – focused on: (i) how the CCGC can contribute most effectively to the IBGP and the joint projects of the Earth System Science Partnership (ESSP), (ii) areas of global change science and technology where a National Academy study could be most valuable, and (iii) future directions of US federal global change science and technology programs. Below, a few of the recent and current activities of the US National Academies in the area of global change are outlined.

Planning Climate and Global Change Research

In 2002 the US Climate Change Science Program (CCSP) was formed to co-ordinate and direct US efforts in climate change and global change research. The draft strategic plan for the CCSP was released in November 2002, and was subsequently reviewed by the National Research Council of the National Academies [3]. The draft plan provides a solid foundation for CCSP, building on the well-established US Global Change Research Program. The plan emphasises the need for science to address national needs – including decision support for the public and private sectors, and identifies many of the cutting-edge scientific research activities that are necessary to improve understanding of the Earth System. However, the review recommended that the draft plan be substantially revised in order to: (i) clarify the vision and goals of the CCSP, (ii) improve its treatment of program management, (iii) fill key information needs, (iv) enhance efforts to support decision making, and (v) set the stage for implementation. A revised strategic plan [4] is currently under review.

Demographic Change in the Developing World

Virtually all of the growth in the world's population for the foreseeable future will take place in the cities and towns of the developing world. Over the next 20 years, most developing countries will for the first time become more urban than rural. The benefits from urbanisation cannot be overlooked, but the speed and scale of this transformation present many challenges, and have considerable global biogeochemical implications. A new cast of policy makers is emerging to take up the responsibilities of urban governance. As many national governments decentralise and devolve their functions, programs in poverty, health, education, and public services are increasingly being deposited in the hands of untested municipal and regional governments. Demographers have been surprisingly slow to devote attention to the implications of the urban transformation. Drawing from a wide variety of data sources, many of them previously inaccessible, the National Research Council of the National Academies has summarised the issues of demographic change in the developing world, and explored the implications of various urban contexts for marriage, fertility, health, schooling, and children's lives [5].

Understanding Climate Change Feedbacks

Over the past decade, much has been learned about the complex natural processes that influence climate variability and change, and the ability to model climate has improved significantly. We

Keck Center of the National Academies, Washington DC, USA.

are now better able to identify those parts of the climate system that are particularly important and not well understood, and which therefore limit the ability to project the future evolution of Earth's climate. The National Research Council of the National Academies has summarised what is known and not known about climate change feedbacks, and has identified the feedback processes most in need of improved understanding [6]. The council concludes that an enhanced research effort is needed to better observe, understand, and model key climate change feedback processes. Three high-priority areas for future research on climate feedbacks are identified: (i) feedbacks that primarily affect the magnitude of climate change (cloud, water vapour, and lapse rate feedbacks; ice albedo feedback; biogeochemical feedbacks and the carbon cycle; and atmospheric chemical feedbacks), (ii) feedbacks that primarily affect the transient response of climate (ocean heat uptake and circulation feedbacks); and (iii) feedbacks that primarily influence the pattern of climate change (land hydrology and vegetation feedbacks; natural modes of climate system variability). The book recommends that stable, accurate, long-term measurements be made of the variables that characterise climate feedback processes, and that climate modelling facilities in the US be given the capability and mandate to test understanding and simulation of these processes. The book also recommends that both global and regional metrics that focus on feedback processes be used to more rigorously test understanding and simulation of these processes in climate models.

Other CCGC Activities

As part of its responsibilities to co-ordinate the many advisory studies that the US National Academies carry out on issues of global change science and technology, the CCGC has developed a new web site to provide an easy way to find information, organised by major topic, on recent reports, ongoing studies, upcoming meetings, and related links [7]. The CCGC is now helping organise a spring 2004 meeting with scientific leaders of ESSP programs and US federal agency program managers, to highlight past accomplishments and future directions of the international global change programs.

Gregory Symmes
Division on Earth and Life Studies
The National Academies
Washington, DC, USA
E-mail: gsymmes@nas.edu

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This document is a summary of the IGBP-SCOR Ocean Vision prepared for IGBP and SCOR by Karin Lochte, with wide community consultation and input. The full document can be downloaded from www.igbp.kva.se/ocean/.

Ocean biogeochemistry and biology: a vision for the next decade of global change research

The ocean plays an active part in regulating global climate. Large-scale changes in the physical, chemical, and biological properties of the ocean can already be observed. Most apparent are changes in marine food web structure, coastal zone eutrophication, and coral reef deterioration. IGBP and SCOR have joined forces in creating an integrated research initiative in ocean biogeochemistry and biology. The IGBP-SCOR "Ocean Vision" focuses on (i) understanding the role of the ocean in Earth System biogeochemistry and (ii) predicting the consequences of global change for ocean biogeochemistry and biology, as a means to investigate pathways towards sustainability.

The Role of the Ocean in the Earth System

The ocean has a vast capacity for storage and exchange of heat and gases, and thus exerts a major control on global climate. It is the most extensive and yet most poorly understood part of the Earth System. Within the Earth System, the ocean is intimately linked with the atmosphere and the land, and so cannot be considered separately when addressing questions of global change (Figure 1). For example, palaeorecords indicate that oceanic processes link the dynamics of atmospheric carbon dioxide (CO_2) to those of dust-borne iron fluxes to the ocean (Figure 2).

The last decade has seen major advances in our understanding of the ocean. For example, trace elements — primarily iron — have been demonstrated (experimentally and in palaeorecords) to be important for ocean productivity. Recently identified micro-organisms (such as the widespread *Archaea* and heterotrophic photosynthetic bacteria) have fundamentally changed our understanding of marine biogeochemistry. The next decade will very likely yield

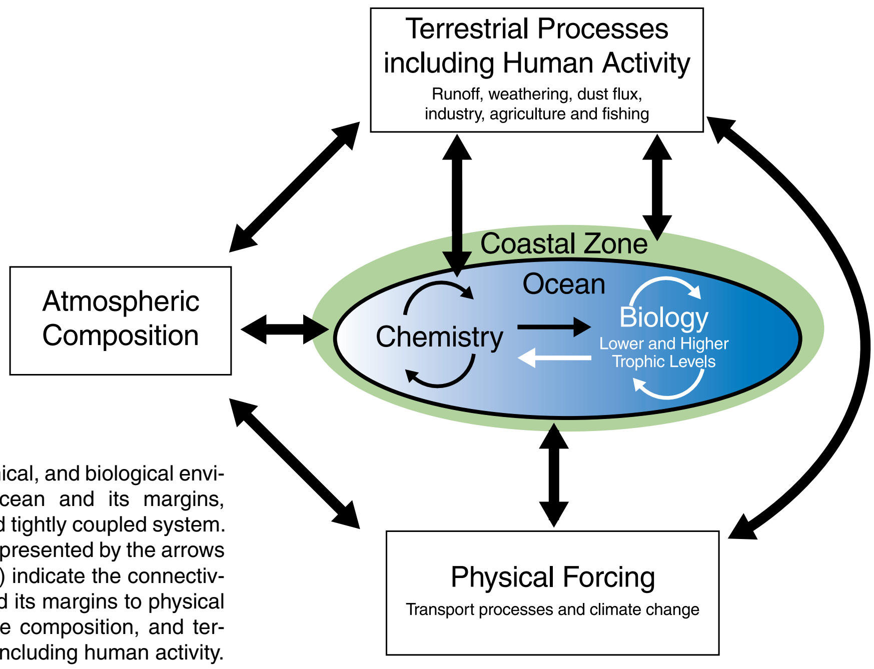
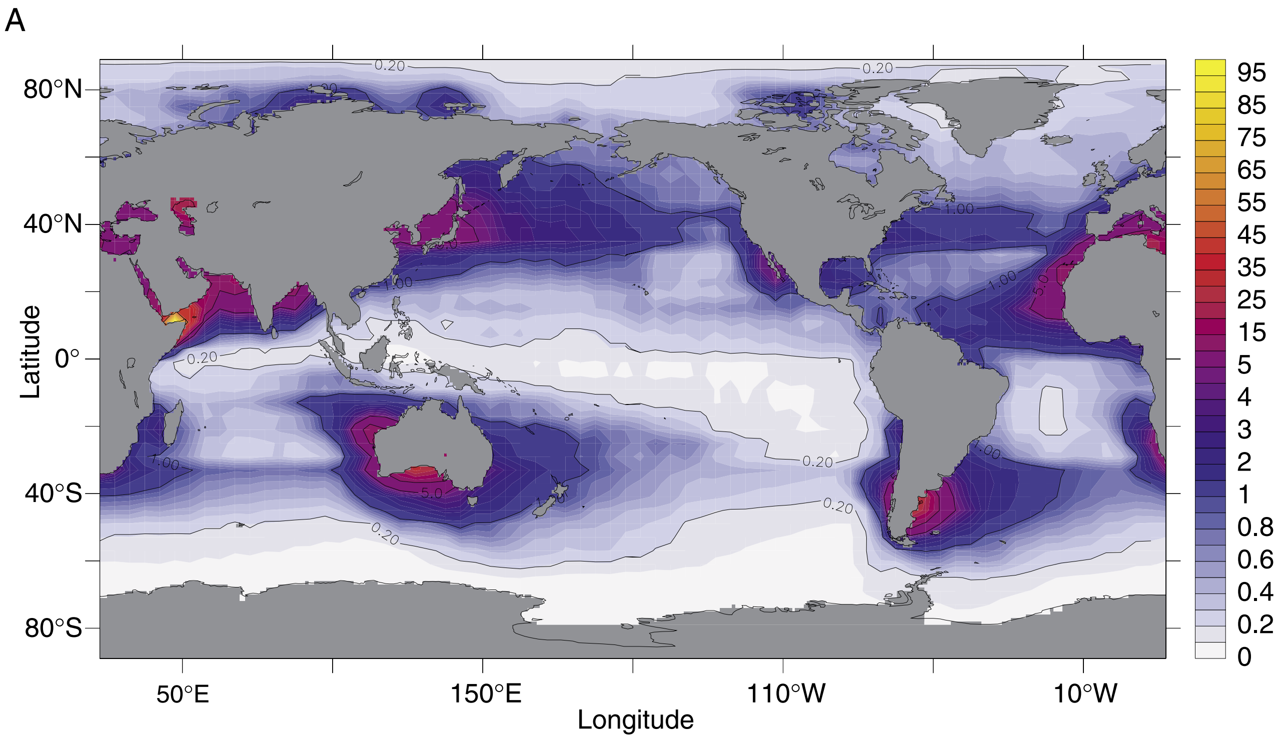


Figure 1.

The physical, chemical, and biological environment of the ocean and its margins, form a complex and tightly coupled system. Global changes (represented by the arrows between the boxes) indicate the connectivity of the ocean and its margins to physical forcing, atmosphere composition, and terrestrial processes including human activity.



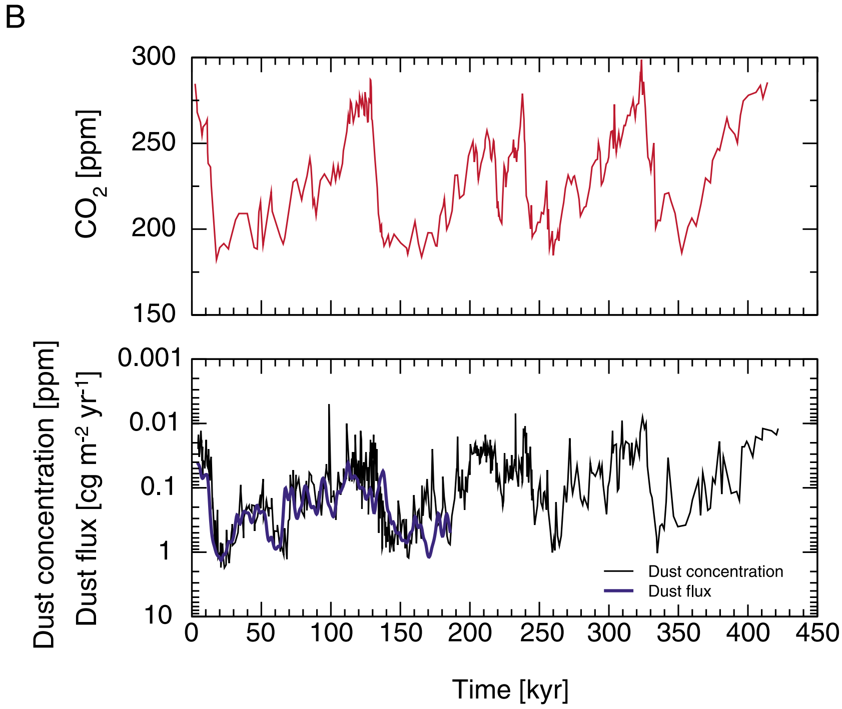


Figure 2.

Dust flux from land supplies iron to the ocean – a limiting element for algal growth in wide ocean areas. Modelled contemporary dust fluxes (A) highlight strong regional differences in dust flux (From: [5] modified by N.Gruber). Antarctic ice cores show an inverse relationship between atmospheric carbon dioxide and dust fluxes (B) (From: [6] modified by N.Gruber). Changes in dust-born iron may have altered biological uptake of carbon dioxide in the ocean and may thus have contributed to a climatic feedback in the Earth System. The mechanisms of such a potential feedback are still uncertain.

further surprising discoveries in the ocean. Despite this progress, many questions on the role of the ocean in global change remain unanswered. Regime shifts are being observed in ocean ecosystems, but in most cases their causes, consequences, and time-scales are uncertain. To fully understand the system will require data for numerous processes, operating over different time-scales. For example, the CO_2 currently being released by the ocean was absorbed centuries, perhaps millennia ago.

Remarkable advances in the understanding of the ocean have been achieved using coupled models, but we still cannot answer key ecological questions. We have limited understanding of damping and amplifying feedbacks between Earth System components, and of abrupt changes in system behaviour. These phenomena are seen in palaeorecords and have emerged from models, but have not yet been observed directly.

Future global change research in the ocean must focus on the triggers and buffers in Earth System dynamics, and on regions most susceptible to global change. Four overarching questions have been adapted from the “Earth System Questions” [1] to guide the development of specific research questions for ocean biogeochemistry and biology:

- What are the critical components in the ocean?
- What are the major feedbacks between the ocean and other Earth System components?
- What are the ocean regions most vulnerable to global change?
- What critical components of the ocean are most sensitive to human action and have greatest impact on humans?

Not all of the many components that determine ocean biogeochemistry are critical for global change. Some change on such long time scales that their importance may not be apparent. Some are more vulnerable to disturbance and may lead to abrupt changes. An analysis of the critical components and their relevance to global change will lead to specific questions such as: (i) will the ocean uptake of anthropogenic carbon continue at present levels for the next century? (ii) what is the role of key species in ocean functioning and what are the implications of species composition changes? and (iii) can, or will, human activities change the dust flux to the ocean to the point where ocean productivity is significantly affected?

Sustainability and the Ocean

Human activities, both on land and in the ocean, are influencing the ocean and at an ever increasing rate. Already 66% of the world’s population lives within 400 km of the coast [2]. Population growth and the expansion of mega-cities in the coastal zone have increased pressure on ecosystems, and made societies more vulnerable to changes in the ocean. Societies rely on ecosystem goods and services from the ocean, and thus on an ability to adjust to the future behaviour of the ocean. Ecosystem goods (for example, food and energy) and services (for example, waste assimilation and transport) are the benefits we derive directly, or indirectly, from ecosystems [3].

About one billion people depend on fish as a source of protein. Total marine capture fisheries production reached 86.0 Mt in 2000, the highest level ever [4]. As a result, fishery-induced restructuring of food webs is one of the biggest direct human impacts on the ocean. Other human impacts include increasing sediment and nutrient (especially nitrogen) export from rivers, other coastal pollution, changing river discharges, marine habitat destruction, and alien species introductions. Humans also affect the ocean via atmospheric changes: increases in atmospheric CO_2 have lowered surface-ocean pH, and rising temperatures and reductions in sea ice are also being observed. Ecological expression of these changes are seen in the degradation of coral reefs and the spreading of dead zones in the Gulf of Mexico and elsewhere.

The inter-dependence of the ocean and human society points to the need to understand the interactions of the ocean with other Earth System components – including humans. Since the beginning of the 20th Century, humans have been a driving force of global change, influencing the Earth System disproportionately to population size and biomass due to growing technological potential and economic demand. Current knowledge is inadequate to maximise sustainable use of marine resources. Studies integrating natural and social sciences are required to provide the knowledge necessary to maintain an acceptable balance between human requirements and ecosystem function. Overarching questions to guide research on human use of the ocean are:

- What states of the ocean could occur which are incompatible with human health and survival?
- What are the options and caveats for geo-engineering in the ocean?
- What structure of institutions is required for the effective and efficient management of marine resources, and the protection of both marine environments and marine-based human communities?

With current technology we have the capability to undertake large-scale manipulations of marine processes to benefit some people, but with costs to others, or to the ecosystem. Examples of such geo-engineering include purposeful ocean sequestration of CO_2, new aquaculture approaches, and exploitation of renewable ocean energy resources. The next decade will undoubtedly see increasing pressure to realise the potential of such options, as global change becomes more pronounced. Scientific knowledge is needed to help identify what ocean resources are most important for human health and survival, and the options for preserving a resilient and functioning marine ecosystem.

Goals and Approach

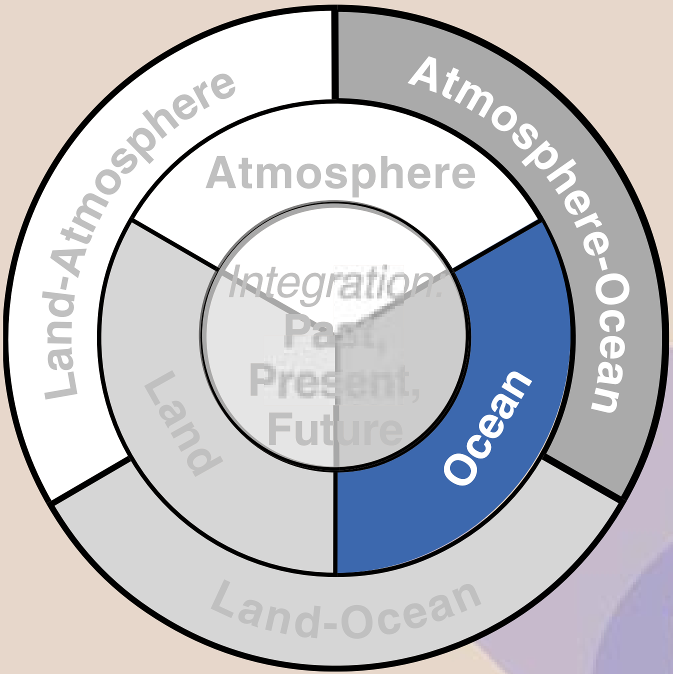
The primary objectives for the next decade of global change research in ocean biogeochemistry and biology are to:

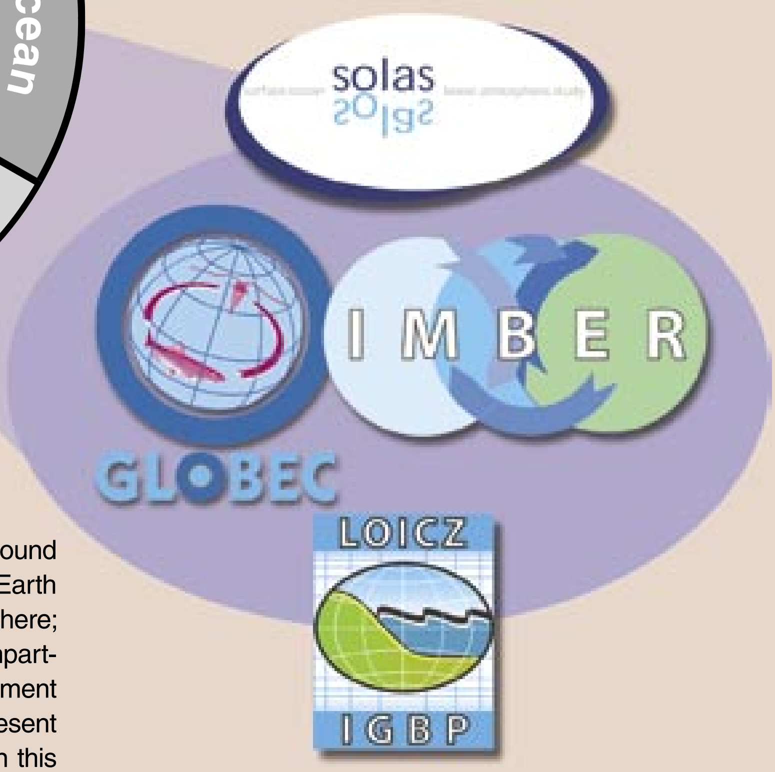
- identify, observe, and describe those components of ocean biogeochemistry and biology that cause, or respond to, global change;
- understand the feedbacks from the ocean to Earth System functioning; and

- predict future changes in ocean biogeochemistry and biology in order to find pathways towards sustainability.

Success will require enhanced multidisciplinary and global collaboration. Many of the vulnerable ocean regions are under-studied due to remoteness or a lack of research capacity. A great effort must be made to be globally inclusive in research, in particular strengthening links between developing country and developed country research. Ocean observing systems are needed to measure key ocean variables that can be linked to terrestrial and atmospheric

Box 1. IGBP Ocean Research in an Earth System Context





IGBP research over the next decade will be built around eight projects: three oriented towards the major Earth System compartments – land, ocean, and atmosphere; three concentrating on the interfaces between compartments; and two focusing on the changing environment of the entire planet – from the past through the present to the future. The ocean project is developing within this structure, in collaboration with SCOR and other co-sponsors. The Ocean Vision provides a scientific framework to guide integrated research.

The ocean project will be implemented through a partnership of GLOBEC and IMBER that will undertake joint activities such as:

- research to address questions such as those posed in the Ocean Vision, starting with a comprehensive food web study;
- periodic scientific syntheses or overview papers;
- open science conferences;
- collaborative research and integrated data management with the IGBP interface projects that have marine components – SOLAS and LOICZ.

Partnership activities will be supervised by a coordinating committee composed primarily of representatives from the GLOBEC and IMBER Scientific Steering Committees (SSCs) and International Project Offices (IPOs), with additional representation from SOLAS and LOICZ as appropriate. The work of the partnership will be facilitated by the co-location of the two IPOs (pending arrangement of suitable financial support) and joint sessions of the two SSCs. The partnership will implement the IGBP ocean project until 2009, when GLOBEC will complete its work. As the partnership evolves, and as more joint activities are developed, a parallel planning process aimed at creating a single, integrated ocean project from 2009 will be undertaken by the two SSCs. To fulfil the Ocean Vision also will require collaboration with scientists from WCRP, IHDP, DIVERSITAS, GOOS, and others.

observing systems. Feedbacks in the Earth System must receive special attention, and humans must be considered as both driving and responding to global change. The challenge for the next decade of global change research in the oceans is to provide the knowledge to underpin policies for sustainable use of the oceans, including policies for impact mitigation and adaptive management.

Recognising the importance of a more integrative research agenda, IGBP has recently been restructured. The projects of the second phase of IGBP are described in Box 1 with a focus on the next decade of ocean-related global change research. Central to this effort is the development of a single ocean research project, the principles for which are outlined in the panel on the right of this page.

Karin Lochte
Head of Biological Oceanography
Institute for Marine Research, University of Kiel
Kiel, Germany
E-mail: klochte@ifm.uni-kiel.de

Wendy Broadgate
Deputy Director, Natural Sciences
IGBP Secretariat
Royal Swedish Academy of Sciences
Stockholm, Sweden
E-mail: wendy@igbp.kva.se

Ed Urban
Executive Director, SCOR
Department of Earth and Planetary Sciences
Johns Hopkins University
Baltimore, USA
E-mail: Ed.Urban@jhu.edu

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Principles agreed by IGBP and SCOR for the development of the IGBP Ocean Project

1. The Ocean Biogeochemistry and Ecosystems (OCEANS) Transition Team, established by IGBP and SCOR in 2002, is charged with developing a new project which has adopted the name Integrated Marine Biogeochemistry and Ecosystem Research (IMBER).
2. IMBER will include research related to ocean biogeochemistry (defined as the science that studies the biological, chemical, and geological aspects of environmental processes, (Libes, 1992)) and biogeochemistry-food web interactions. Its research aims to be complementary to, and linked with, where appropriate, that of GLOBEC.
3. GLOBEC will continue to completion in 2009 as specified in its Implementation Plan.
4. IMBER will develop research activities with a ten-year life, with its scientific emphases thus extending until 2014.
5. IMBER will be allowed to develop its own identity.
6. IMBER and GLOBEC will be encouraged to begin developing joint activities in 2003. The co-sponsors will seek new funding for joint activities, but will also encourage the projects to spend part of their regular funding for such activities. The two SSCs will be encouraged to hold back-to-back or overlapping meetings.
7. The extent and speed of development of joint activities and project integration will be at the discretion of the two SSCs.
8. There will be a single integrated ocean project that includes the scientific activities of GLOBEC and IMBER by 2009.
9. The IGBP-SCOR Ocean Vision will serve as a scientific guide to help not only facilitate the evolution of GLOBEC and IMBER towards a single integrated project, but also identify important scientific interactions between IMBER, GLOBEC, and the interface projects SOLAS and LOICZ. This will help place all IGBP-SCOR ocean projects in the new IGBP Earth System science context.

Acronyms

DIVERSITAS:	an international programme of biodiversity science
GLOBEC:	Global Ocean Ecosystem Dynamics
GOOS:	Global Ocean Observing System
IGBP:	International Geosphere-Biosphere Programme
IHDP:	International Human Dimensions Programme on Global Environmental Change
IMBER:	Integrated Marine Biogeochemistry and Ecosystem Research
LOICZ:	Land-Ocean Interactions in the Coastal Zone
SCOR:	Scientific Committee on Oceanic Research
SOLAS:	Surface Ocean – Lower Atmosphere Study
WCRP:	World Climate Research Programme

In the previous NewsLetter we presented a perspective on the state of global marine fisheries, based on an invited plenary from the 3rd IGBP Congress. In this issue we present an alternative perspective provided by GLOBEC – the Global Ocean Ecosystem Dynamics project, which is co-sponsored by IGBP and SCOR.

Many marine fisheries are in trouble. Dramatic headlines over the last few years have pictured a world of dwindling resources, ecosystem disruptions, and rampant over-exploitation of the sea.

The tangled web: global fishing, global climate, and fish stock fluctuations

Over-fishing has in the past, reportedly led to ecological extinction of marine reptiles and mammals [1]. Furthermore, historical abundances of large consumer species were large compared to present levels [1]. Although controversial (see [2,3]), it has been concluded that the current large predatory fish biomass is only about ten percent of the pre-industrial biomass [4]. The summary of this tale is the concept of “fishing down the marine food webs”, proposed by Daniel Pauly and colleagues [5], and extensively invoked in his recent article in this Newsletter [6]. Fishing down means the removal of large predators as well as the larger fish of the remaining species. The result is an imbalanced ecosystem, reduced to smaller, and often lower valued, fish species.

However, this overwhelmingly negative view of marine fisheries ignores well known management successes, and underestimates the role that the environment plays in the rise and demise of living marine resources. The Food and Agriculture Organisation of United Nations (FAO) reports that 50% of all marine fisheries are fully exploited, 20% are over-exploited, and 10% are depleted [7]. After four decades of consistent increase in total annual catch this rate now appears to be zero or negative [8]. Global marine catches are presently on the order of 85 Mt, while a number of attempts to determine marine fish production potential have provided estimates centred on 100 Mt [9]. If these latter estimates are reasonable, we are just below the production potential for fisheries on the continental shelf regions of the world oceans, a result generally consistent with the FAO appraisal of resource status. While there is little doubt that many long-lived, large predators have been over-fished, large geographical variations are evident, and trends are driven by a small number of traditional resources. Patterns of exploitation have been more ‘balanced’ historically than is implied by the concept of fishing down the food web, with small pelagic fishes and invertebrates comprising a historically important part of the catch. Fisheries for these species are not a recent development. Overall, the more fundamental shortcoming is the limited picture that is often depicted in the media on the state of fish resources and their fluctuations.

The Cycles of Nature

Historical, fishery-independent records provide us with a very different view to that presented by Pauly [6]. Some fish shed scales during their life, and these scales are found in anoxic sediment cores; the relative abundance of these scales is a proxy for fish abundance. 2,200 year-old records in the North Pacific suggest large natural shifts in sockeye salmon abundance [10]. Scale depositions off California show large fluctuations in abundance (or/and distribution) of sardine and anchovy in the last 1700 years, in the absence of any industrial fishing (Figure 1). Importantly, the Californian depositions series show cycles of between 50 and 70 years, a frequency that agrees both with global climate oscillations in recent centuries [11], and cycles in the Length Of The Day (LOD) index that measures variations in the Earth’s

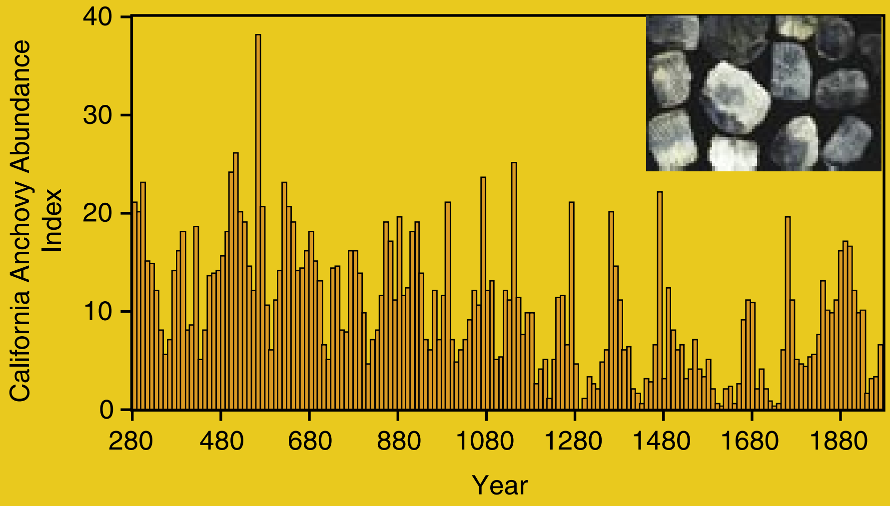


Figure 1. Fluctuations in anchovy abundance based on fish scales deposited in sediments off California (from [31]). Inset photograph of fish scales.

rotational velocity [12]. Such coincidences suggest that natural cycles of productivity may be linked to planetary dynamics. Synchronous fluctuations of fish species abundance in the recent past [13] as well as in palaeorecords [10], albeit inconclusive, support this argument.

There is little doubt that the development of large industrial fisheries, particularly in the second half of the 20th century, has overwhelmed some of these low frequency cycles of natural productivity. But equally, some of these natural cycles are known to have 'overwhelmed' fishery trends. For example, a dramatic change in the composition of bottom-dwelling communities occurred in the north east Pacific in the 1970s. A community that was dominated by invertebrate shrimps (a low trophic level species), changed to one dominated by cod and other groundfishes (Figure 2). The cause for these dramatic changes is unknown, but they were coincident with a large climatic shift in the North Pacific [14] that had dramatic consequences for the entire ecosystem [15]. Other climate-driven changes in the fish communities of this region have been observed in recent times. In 1992 Pacific sardines appeared in catches off British Columbia for the first time in 45 years. By 1995 an experimental fishery was initiated, and by 1997 the stock size off the west coast of Vancouver Island was about 60 kt. In 1997 and 1998 sardines not only remained off Canada's west coast year round, but also successfully spawned in Canadian waters for the first time on record [16]. Equally, the current abundance of Pacific halibut (a large top predator) in this area is considered to be the highest in history [17]. The one-way trip down the food web certainly does not apply in these examples.

The suggestion that climatic impacts can be transferred across trophic levels (bottom-up effects) has received recent support in explaining fluctuations of the North Sea Atlantic cod stock. Zooplankton stocks in the North Sea fluctuate in response to the North Atlantic Oscillation (NAO), but have also been dramatically affected by environmental changes since the mid-1980s [18]. The survival of cod larvae is determined by the abundance and size of its zooplankton prey, thus determining long term changes in cod recruitment [19]. While a favourable prey environment supported the 'gadoid outburst' (cod and hakes) in the 1970s, the poor prey environment since 1985 has exacerbated the impact of over-fishing of the North Sea cod stock (Figure 3), reducing it to the point where a fishing moratorium is being considered.

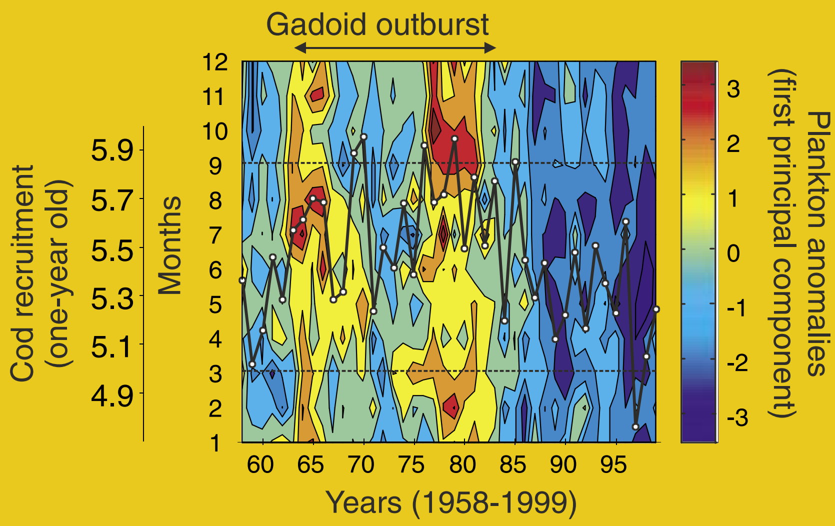
Sustainable Management: an Achievable Goal

Marine resources have been utilised for hundreds of years. Many are sustainably managed through the successful application of the precautionary approach

Figure 2. Changes (from left to right) in the composition of catches in a small-mesh bottom trawl in Pavlof Bay, Alaska, through the naturally occurring regime shift of the 1970s (from [32]).

Figure 3.

Long-term monthly changes (1958-1999) in a plankton index in the North Sea. The main variables related to this index are mean abundance of *C. finmarchicus*, *euphausiids*, mean size of calanoid copepod, and biomass of calanoid copepod. A negative anomaly indicates a low value for the above variables, but high biomass of *C. helgolandicus*. Cod recruitment (one-year old; in decimal logarithm) in the North Sea (curve in black) is superimposed with a lag of one year. The period of the Gadoid Outburst is indicated. Horizontal lines indicate the period (March-September) of larval cod occurrence in the North Sea (from [18]).



[20]. The green sea urchin fishery in British Columbia was brought back from a brink of collapse through careful management, after an early period as a 'gold-rush' fishery [21]. The South African anchovy fishery, that was scaled down in the early 1990s after a period of heavy exploitation, has recovered to record levels in response to both careful management and a favourable environment [22]. Successful management in the north east Atlantic has led to dramatic recoveries for scallops, haddock, yellowtail flounder, herring and mackerel, striped bass, and others [23]. Here, changes involved not so much a fishing down of the food web, but alterations in species dominance at each trophic level.

The results of poor management though, are not always easy to redress. In the 1990s the northern cod stock off southern Labrador and north east Newfoundland collapsed and fishing was stopped. Although over-fishing is believed to be the main cause, severe climate conditions also contributed. Almost half of the decline in stock biomass in the 1980s and early 1990s was due to changes in the mean weight of fish. This was due to reduced growth rates, largely caused by cold temperatures that also affected cod recruitment [24]. A decade later there is little evidence of recovery, even with the moratorium still in place. Over-fishing is certainly decimating many stocks, but the contributions of environmental forces in shaping the trends in many stocks are also clear. Low frequency environmental forcing requires changes in harvesting policies to accommodate changes in production levels so as to avoid over-fishing during periods of lower productivity. This is a principle not widely accepted and even less widely implemented. Synchronicity between fisheries managers and the fish environment is paramount for management to succeed.

Interactions Between Environmental and Human Forcings

Not only do environmental and human factors separately affect fish population dynamics, but these two sets of factors interact, compounding their effects. Recent decades have seen more frequent and stronger climate variations compared to the relative stability of the climate from 1840 to 1923 [25], and fisheries management has often failed to allow for these variations. El Niño Southern Oscillation (ENSO) events are a primary driver of inter-annual climate variability, affecting many fish resources from anchovy off Peru [26] to tuna in the Pacific [27]. A 155-year reconstruction from a central tropical Pacific coral provides evidence of increasing ENSO event frequency during the last century [28], and world oceans have showed signs of warming over the last five decades [29]. Ocean warming will have direct consequences for species distribution and spawning habitats, and indirect consequences for food web stability. Failure to appreciate that the environment is changing, with poorly understood consequences for marine resources, may lead to unsustainable management.

In summary, although dramatic reductions in fish stocks have occurred due to over-exploitation, we should not forget the considerable successes of fisheries management, nor the role of environmental variability in determining both successes and failures. In the end, the concern should not be whether fisheries are simply despoilers of the oceans or puppets in the hands of the climate, but rather how to best meet the increasing human protein needs in a sustainable manner.

The appreciation of the roles of both human exploitation (and needs) and environmental forcing in shaping fish stock abundance lead to the creation of GLOBEC (Global Ocean Ecosystem Dynamics), a 10 year project of IGBP and SCOR. GLOBEC's goal is to advance the understanding of the structure and functioning of the global ocean ecosystem, and its response to physical forcing, so that a capability can be developed to forecast the responses of the marine ecosystem to global change. In its first phase GLOBEC has provided remarkable evidence of the interactive nature between humans and their environment (e.g. [30]. By the time GLOBEC completes its work in 2009 we hope to provide better tools to help manage ocean fisheries in the face of global change.

Manuel Barange
GLOBEC IPO, Plymouth Marine Laboratory
Plymouth, UK
E-mail: m.barange@pml.ac.uk

Francisco Werner
Marine Sciences, University of North Carolina
Chapell Hill, USA
E-mail: cisco@unc.edu

Ian Perry
Pacific Biological Station, Department of Fisheries and Oceans
Nanaimo, Canada
E-mail: perryi@pac.dfo-mpo.gc.ca.

Michael Fogarty
National Marine Fisheries Service, NOAA
Woods Hole, MA 02543, USA
E-mail: michael.fogarty@noaa.gov

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People and Events

New roles and faces

Anna Dalin recently joined the IGBP Secretariat to help organise the public launch of the new IGBP Synthesis book – "Global Change and the Earth System: A Planet Under Pressure" – and to assist in building the IGBP National Committee network. Anna has a diverse background including ethnology, environmental education, public relations, and theatre management and liaison. Most recently, she completed formal studies in Strategic Communications and Public Relations. Anna's skills will help ensure that the launch of the new IGBP Synethsis in late January 2004 will raise the profile of IGBP both in Sweden and internationally. Key media and policy representatives will attend the launch.

IGBP and Related Global Change Meetings for 2004

For a more extensive meetings list please see our web site at www.igbp.kva.se

GLOBEC: SPACC Workshop – Characterising and comparing the spawning habitats of small pelagic fish

12-13 January, Concepción, Chile

Contact: Carl van der Lingen, vdlingen@mcm.wcape.gov.za or www.pml.ac.uk/globec/Structure/RegProgs/SPACC/concepcion.htm

GLOBEC: SPACC Meeting – Spawning habitat quality and dynamics and the daily egg production method

14-16 January, Concepción, Chile

Contact: Leonardo Castro, lecastro@udec.cl or www.pml.ac.uk/globec/Structure/RegProgs/SPACC/concepcion.htm

DIVERSITAS, IGBP, IHDP, WCRP: Global Environmental Change and Human Health

14-16 January, Paris, France

Contact: Anne-Helene Prieur-Richard, prieur_richard@icsu.org

GLOBEC: SPACC Executive Meeting

17-18 January, Concepción, Chile

GLOBEC IPO, Contact: globec@pml.ac.uk or www.pml.ac.uk/globec/Structure/RegProgs/SPACC/concepcion.htm

International Workshop on Global Change, Sustainable Development and Environmental Management in Central Asia

20-22 January, Tashkent, Uzbekistan

Contact: Svetlana Nikulina, svetlana.nikulina@envp.uzsci.net

AGU Ocean Sciences Meeting

26-30 January, Portland, OR, USA

Contact: Ted Strub, tstrub@coas.oregonstate.edu or www.agu.org/meetings/os04/

GLOBEC: UK-GLOBEC Open Meeting

26 February, London, UK

Contact: Phil Williamson, p.williamson@uea.ac.uk or GLOBEC IPO, globec@pml.ac.uk

WCRP: WCRP-JSC Meeting

01-06 March, Moscow, Russia

Contact: WCRP Secretariat, dwcrp@gateway.wmo.ch

IGBP: 19th SC-IGBP Meeting

02-04 March, Moscow, Russia

Contact: Clemencia Widlund, clemencia@igbp.kva.se

SC-IGBP and WCRP-JSC Joint Session

05 March, Moscow, Russia

Contact: Clemencia Widlund, clemencia@igbp.kva.se

IGBP: IPO Executive Officers Meeting

06 March, Moscow, Russia

Contact: Clemencia Widlund, clemencia@igbp.kva.se

GLOBEC: Meeting of ICES Working Group on Modelling Physical-Biological Interactions

10-11 March, Barcelona, Spain

Contact: Celia Marrase, celia@icm.csic.es

Environmental Challenges in the New Millennium

11-13 March, Peshawar, Pakistan

Contact: S. Rehman, epm-uop@pes.comsats.net.pk, shafiq_55@yahoo.com

IHDP: 11th SC-IHDP Meeting

22-24 March, Bonn, Germany

Contact: IHDP Secretariat, ihdp@uni-bonn.de

IOC GLOBEC, SCOR: Symposium on Quantitative Ecosystem Indicators for Fisheries Management

31-03 April, Paris, France

Contact: Philippe Cury, curypm@uctvms.uct.ac.za or Villy Christensen, v.christensen@fisheries.ubc.ca or www.ecosystemindicators.org/

GLOBEC: GLOBEC Scientific Steering Committee Meeting

16-19 April, Swakopmund, Namibia

Contact: GLOBEC IPO, globec@pml.ac.uk

4th World Fisheries Congress – Reconciling Fisheries with Conservation: The Challenges of Managing Aquatic Ecosystems

02-06 May, Vancouver, Canada

Contact: www.worldfisheries2004.org/

12th Annual Scientific Conference, Int. Boreal Forest Research Association: Climate Disturbance Interactions in Boreal Forest Ecosystems

03-07 May, Fairbanks, Alaska

Contact: www.lter.uaf.edu/ibfra/default.cfm

START-IIASA: Advanced Institute on Vulnerability to Global Environmental Change

03-21 May, Laxenberg, Austria,

Contact: Sara Beresford, sberesford@agu.org or www.start.org/links/announce_oppo/P3_Announcement.pdf

ICES-GLOBEC-CCC Working Group Meeting

07-10 May, Bergen, Norway

Contact: Ken Drinkwater, drinkwater@mar.dfo-mpo.gc.ca

ICES-GLOBEC Symposium: The Influence of Climate Change on North Atlantic Fish Stocks

11-14 May, Bergen, Norway

Contact: Harald Loeng, harald.loeng@imr.no or www.imr.no/2004symposium/

Quadrennial Ozone Symposium

01-08 June, Kos, Greece

Contact: Christos Zerefos, ozone2004@geol.uoa.gr

SOLAS: SOLAS SSC Meeting

16-18 June, Bergen, Norway

Contact: Casey Ryan, casey.ryan@uea.ac.uk

CLIVAR 2004: 1st International CLIVAR Science Conference

21-25 June, Baltimore, MD, USA

Contact: info@clivar2004.org or www.clivar2004.org/

PAGES: PAGES SSC Meeting

16-20 July, Nairobi, Kenya

Contact: PAGES IPO, pages@pages.unibe.ch

35th COSPAR Scientific Assembly

18-25 July, Paris, France

Contact: COSPAR Secretariat, cospar@cosparhq.org, or www.copernicus.org/COSPAR/COSPAR.html

Climate Change and Aquatic Systems, Past, Present and Future

21-23 July, University of Plymouth, UK

Contact: www.biology.plymouth.ac.uk/climate/climate.htm

SCAR Open Science Conference: Antarctica and the Southern Ocean in the Global System

25-28 July, Bremen, Germany

Contact: Martina Kunz-Pirrung, Secretary@scar28.org or Eileen Hofmann, hofmann@ccpo.odu.edu or www.scar28.org

3rd Scientific Congress of the Large-Scale Biosphere-Experiment in Amazonia

26-30 July, Brasilia, Brasil

Contact: Michael Keller, michael.keller@unh.edu

SPARC 3rd General Assembly

01-06 August, Victoria, BC, Canada

Contact: norm.mcfarlane@ec.gc.ca or sparc.seos.uvic.ca

3rd International NCCR-Climate Summer School

29-03 September, Ticino, Switzerland

Contact: www.nccr-climate.unibe.ch

Bjerknes Centenary 'Climate Change in High Latitudes'

01-03 September, Bergen, Norway

Contact: conference2004@bjernes.uib.no or Beatriz Balino, beatriz.balino@bjerknes.uib.no or www.bjerknes.uib.no/conference2004/

IGAC: 8th International Global Atmospheric Chemistry Conference

04-09 September, Christchurch, New Zealand

Contact: Kim Gerard, kim@conference.co.nz or www.IGAConference2004.co.nz

SCOR: SCOR General Meeting

27-30 September, Venice, Italy

Contact: Ed Urban, scor@jhu.edu

SOLAS: Open Science Conference

13-16 October, Halifax, Nova Scotia, Canada

Contact: Daniela Turk, solas@dal.ca

Annual Conference of the NZ Coastal Society. Incorporating a LOICZ workshop: The Impact of Major Dams, Diversions, and Water Abstraction on Coastal Sedimentation in NZ

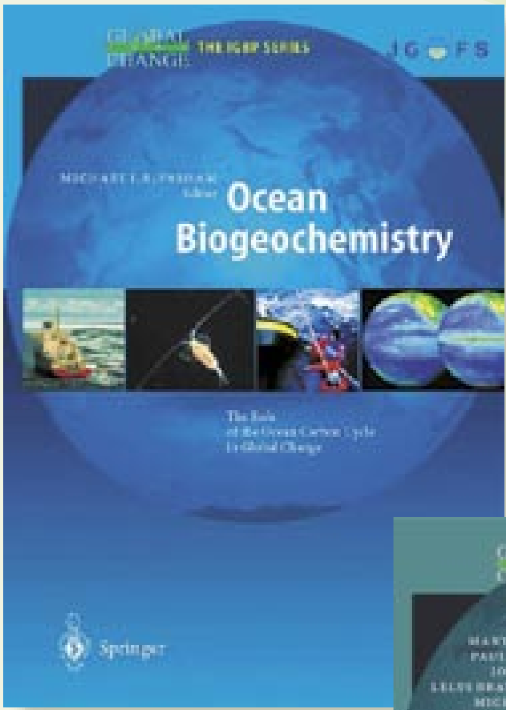
18-20 October, Dunedin, New Zealand

Contact: www.coastalsociety.org.nz/conference2004.html

6th International Symposium on Plant Responses to Air Pollution and Global Changes: From Molecular Biology to Plant Production and Ecosystem

19-22 October, Ibaraki, Japan

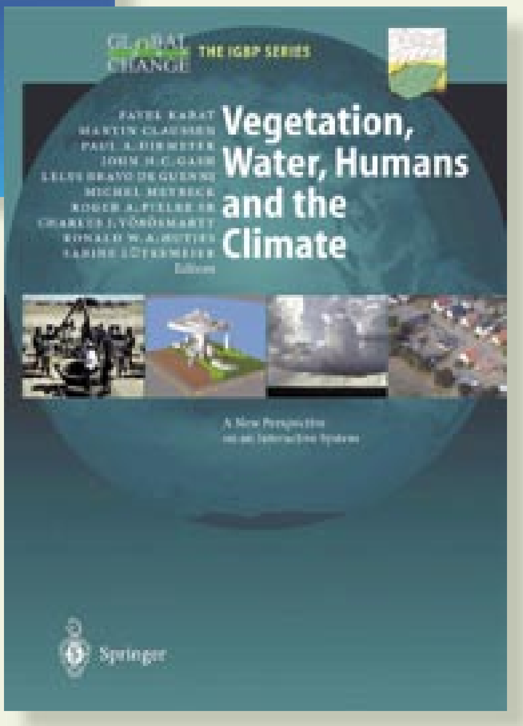
Contact: Luit J. De Kok, l.j.de.kok@biol.run.nl or apgc2004.en.a.u-tokyo.ac.jp/



Ocean Biogeochemistry

MJR Fasham (Ed.)

This book presents an overview of the role of the ocean carbon cycle in global change, based on one of the largest multi-disciplinary studies of the oceans ever. It covers air-sea exchanges of CO_2, the role of physical mixing, the uptake of CO_2 by marine algae, the fluxes of carbon and nitrogen through the marine food chain, and the subsequent export of carbon to the depths of the ocean.



Vegetation, Water, Humans and the Climate

P Kabat, M Claussen, PA Dirmeyer, JHC Gash, LB de Guenni, M Meybeck, RA Pielke Sr, CJ Vörösmarty, RWA Hutjes and S Lütkemeier S (Eds.)

This book describes the interactions between the terrestrial biosphere and the atmosphere via the hydrological cycle, and their interactions with human activities. Measurements from field experiments are complemented by modelling studies simulating flows and transport in rivers, coupled land-cover and climate, and Earth System processes. The impact of humans on river basins, environmental vulnerability, and methods for assessing the risks associated with global change are discussed.

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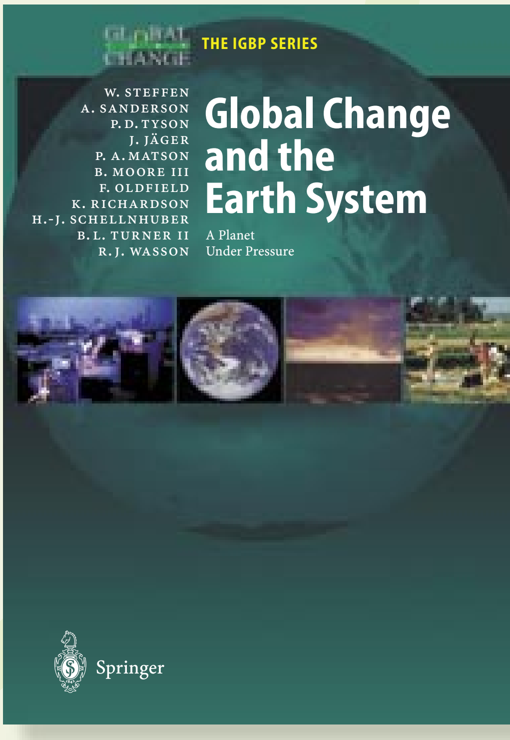
Global Change and the Earth System: A Planet Under Pressure

W Steffen, A Sanderson, PD Tyson, J Jäger, A Matson, B Moore III, F Oldfield, K Richardson, H-J Schellnhuber, BL Turner II, RJ Wasson (Eds.)

This book presents our current understanding of the Earth as a single, integrated system. Based on a decade of IGBP and related research, it explores the functioning of the Earth System before humans, and the ways in which human activities have grown to cause changes that reverberate through the System.



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GLOBAL IGBP CHANGE


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Abstract deadline June 15th 2004
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www.solas-int.org

GLOBAL CHANGE NEWSLETTER

Note to contributors

Articles for *Science Features* should achieve a balance between solid scientific content, and appeal for the broad global change research and policy communities. Articles should be between 800 and 1500 words in length, and be accompanied by one to three figures or photographs (colour or black and white).

Contributions for *Discussion Forum* should be between 500 and 1000 words in length and address a broad issue in global change science. A *Discussion Forum* article can include up to two figures.

Correspondence should be no more than 200 words and be in the form of a Letter to the Editor in response to an article in a previous NewsLetter, or relating to a specific global change issue. Please include author and contact details.

Image quality

Photographic images should be saved in TIFF format. All other images including charts, graphs, illustrations, maps and logos should be saved in vector-based EPS format. All pixel images need to be high resolution (at least 300 pixels per inch).

Some charts graphs and illustrations can be reconstructed at the IGBP Secretariat, however, poor quality photographic images, maps and logos cannot be improved. Material "borrowed" from the Internet cannot be used for publication, as it does not fit the requirements listed above.

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If you have queries regarding image quality please contact John Bellamy, email: john@igbp.kva.se

Deadlines for 2004

Issue	Deadline for material
March	16 February
June	10 May
September	9 August

Send contributions or correspondence by email to the Editor.

Email: bill@igbp.kva.se

Phone: +46 8 16 64 48 Fax: +46 8 16 64 05

GLOBAL IGBP CHANGE

ICSU International Council for Science

www.igbp.kva.se

IGBP's mission is to deliver scientific knowledge to help human societies develop in harmony with Earth's environment. The Global Change NewsLetter serves its readers as a forum for up-to-date information on IGBP science, programmatic development, people and events. Published quarterly since 1989, the NewsLetter is available free-of-charge from the IGBP Secretariat.

GLOBAL CHANGE NEWSLETTER

Edited by Bill Young

Technical Editing by John Bellamy

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(E-mail: bill@igbp.kva.se)

NewsLetter requests and change of address information should be sent to:

IGBP Secretariat
The Royal Swedish Academy of Science
Box 50005, S-104 05 Stockholm,
Sweden

Tel: (+46-8) 16 64 48

Fax: (+46-8) 16 64 05

E-mail: sec@igbp.kva.se

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The IGBP Report Series is published in annex to the Global Change NewsLetter.

ISSN 0284-5865