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# Polar Environment and Climate

# The challenges

CONFERENCE PROCEEDINGS

## International Symposium

*Organised by the EC Directorate-General for Research*

*Brussels, 5-6 March 2007*

*European research in the context of the International Polar Year*

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### Brussels, 5-6 March 2007

## European research in the context of the International Polar Year

Edited by Damien Cardinal and Elisabeth Lipiatou
Climate change and Environmental Risks Unit
Environment Directorate

Organised by DG Research, Climate Change and Environmental Risks Unit

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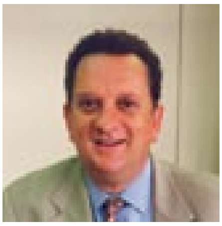
# *FOREWORD*
# *Conference proceedings*



The polar regions are especially vulnerable to climate change. Much of the research shown on these pages paints a grim picture. Arctic ice is disappearing at an alarming rate, fed by a disproportionately high warming of the Arctic climate. The local habitat is struggling to adapt, and some ecosystems and species may disappear altogether, while others face emerging health risks as climate warming allows alien diseases to take hold. The Antarctic region faces other threats, like the ever-increasing ozone hole.

Nor are the polar regions on their own. The influence of these regions on our global climate is essential – from the disruption of the Gulf stream by the melting of the Greenland ice sheet to the acceleration of global warming as the cryosphere (global permanent ice cover) shrinks. The Poles, both the Arctic and the Antarctic, are thus acutely vulnerable. And the whole world is more vulnerable as a result.

This makes research in the polar regions all the more necessary and urgent. A glance through the titles of the proceedings shows what a multidisciplinary effort polar research is - from climatologists to biologists, and from engineers to economists. Above all, polar research is costly. The remoteness and the harshness of conditions make expeditions very expensive and permanent bases a logistical nightmare.

That has encouraged international collaboration for a long while back. European researchers have been at the forefront of polar research since the 19th century, and the European Union is continuing this fine tradition by supporting large transnational efforts like DAMOCLES, EPICA, and the proposed new Aurora Borealis research ice breaker. In terms of knowledge, we are still scratching the surface of what is happening in the polar environments. The relationship between air, sea and land is not well understood, our historical records of climate are still sparse. The costs and sense of urgency is spurring on research cooperation – joint efforts are more likely to succeed where individual efforts fail.

The International Symposium on "Polar environment and climate: The challenges – European research in the context of the International Polar Year" was organised by the Directorate-General for Research. More than 160 participants from 21 countries attended the meeting. It was the largest international event in relation with the launch of the International Polar Year.

With climate change now more than ever in the public eye, with the IPY now underway, we hope that these proceedings will contribute to the engagement of scientists, policymakers and the general public, and encourage the next generation of polar researchers. They should also provide a useful basis to build the future European research policies in the polar regions. A crucial component is public outreach – the polar regions hold the popular imagination but remain little understood, and properly disseminated polar research can help bridge this gap. This still-pristine environment needs to be understood before it is altered forever.

***J.M. Silva Rodríguez***
***Director-General for Research, European Commission***

# *Acknowledgements*

The International Symposium "Polar environment and climate: The Challenges – European research in the context of the International Polar Year" would not have been possible without the support and commitment of all the colleagues of the Climate Change and Environmental Risks Unit. We are also grateful to the other units of the Environment Directorate, to the Research Infrastructure and Communication Units of DG Research, for the support they provided to organise this event.

Furthermore we would like to thank all the speakers, chairs and attendees who contributed to its success by providing valuable inputs during the meeting and in these proceedings. The symposium has contributed to highlight our current understanding of the Polar Regions in the fields of environment and climate and to identify research needs which are reflected in this publication. All documents related to this symposium can be found on the web page:
http://cordis.europa.eu/sustdev/environment/ev20061023.htm

We foresee that the symposium and its associated publication will be a useful contribution for the development of the 7th Research Framework Programme and to raise awareness of the policy makers on the importance of the Polar Regions for our environment and climate.

***The Editors***

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# OPENING REMARKS

## European research — focusing on polar change

**Janez Potočnik**
*Commissioner for Science and Research*

**Ladies and Gentlemen,**
It is a great pleasure for me to open this Symposium entitled 'Polar environment and climate – The challenges', which marks the beginning of the International Polar Year.
Research into our Earth's poles is not new. After all, the first international polar year was in 1882. And the most recent was in 1957. That was also the year when the European Community was created.

Now, as we celebrate 50 years of building up the European region, we also see the effects of 50 years of breaking down our polar regions. For example, in the last 50 years, temperatures in the Antarctic Peninsula have risen by 2.5 degrees.
And parts of the Antarctic Peninsula, along with Alaska and Siberia, have been the three fastest warming regions on the planet in the last two decades.
Why is this climate change important? Because the Antarctic acts as a buffer, protecting us from excessively rapid warming. It accounts for 90% of the ice in the world and is over three times the size of Europe.

In the North Pole, the Arctic Ocean will be ice-free in summer by 2060 if the current warming trends continue. This will not only affect the four million people living in that area. It will also affect many others, including people here in Europe: in terms of our climate, our ecosystems and our living conditions.

Today, awareness about the environment and our changing climate is probably the highest it has ever been.
It is an issue which stretches from local government to international institutions, from public sector to private sector, from supermarkets to Hollywood's Oscar ceremony.

The argument about whether climate change is influenced by mankind seems to be over. The recent conclusions of the fourth Intergovernmental Panel on Climate Change (IPCC) gave the clearest indications so far that we have contributed to this change.

And the business case for acting sooner rather than later was put forcefully by the 'Stern' report. It stated clearly that 'the benefits from strong, early action on climate change outweigh the costs'.
So why is polar research so important to tackling climate change?
The North and South Poles hold key information. And it is information that becomes more important each day. The Poles act as a sort of environmental library, having documented changes over many ages.

They give us a clue as to what will happen in the next stage of climate change, from previous examples. Their information relates not just to changes in climate, but in ecosystems and societies.

So the launch this year of the EU's Seventh Research and Development Framework Programme, also called FP7, comes at an important time. Climate change and polar research will feature prominently in FP7, which lasts for seven years and has a budget of over €54 billion.
The first FP7 calls for proposals have already been published. They include topics related to polar research and climate change. Future FP7 calls are also planned in this area, including ones focusing on sea-level rise, UV radiation, the climate change impact on biodiversity and ecosystems, and human health issues.
The overall climate themes that FP7 will develop include:

- Climate change impacts on the atmosphere and on the water cycle and resources;
- Downscaling models to predict local impacts;
- Natural, social and economic impacts of climate change and related extreme events;
- Mitigation and adaptation strategies; and
- Awareness-raising.

I find this last point particularly important. We need to make people aware of climate and environmental issues not just for their own benefit, but to maintain support for the policies and funding allocated to deal with these issues.

And if anyone needs to be aware, it is the youth of today, will be most affected by the climate change of tomorrow.
That is one of the reasons I am particularly pleased to see representatives of International Polar Year National Youth Committees here today. This symposium will give young scientists an overview of European Research in the polar regions.

I hope that you can spread the word to other young scientists about the importance of polar research, which is one of the main objectives of the International Polar Year. And I am aware that we can learn from you, too.

Communicating science is not just a possibility - It's a necessity. A good example of this is the DAMOCLES mobile exhibition, which will be launched this evening. It will help people understand what the DAMOCLES project does. I recommend a visit.

DAMOCLES is the largest ongoing EU-funded polar research project. Its name stands for 'Developing Arctic Modelling and Observing Capabilities for Long term Environmental Studies'. The Commission has contributed €16 million to this project, which will examine the interaction of ice, the atmosphere and the oceans.

DAMOCLES is an excellent example of how EU research and development framework programmes support climate research. But this is not new.

Today the European Commission is publishing a report entitled 'European research on polar environment and climate – results and information from FP5 and FP6 projects'. The report highlights nearly 60 projects directly or indirectly related to polar issues that we have financed over the last 10 years.

Most have covered climate, but some have focused on environment and health, natural resources, research infrastructures and coordination activities. And the research results have made important contributions – for example to the IPCC report.
One of the results came from the EPICA project. It produced the longest atmospheric carbon dioxide record. This shows that we haven't experienced such high $CO_2$ levels for the last 650 000 years.

Not many people know that these findings are included in Al Gore's film 'An Inconvenient Truth', which won an Oscar for best documentary feature.

In a way, this is a good example of why climate research needs to be an international effort. DAMOCLES, for example, is an EU-funded project involving 48 different institutions from 12 European countries, as well as Russian federation partners and cooperation with the USA and Canada.

International cooperation is fundamental in polar research. Not just for the usual reasons of joining together the best brains from all over the world and the added networking.

Polar research also needs to be international because it is so expensive. As the Polar Regions are so isolated and unwelcoming, research there can be among the most expensive in the world.

But perhaps the most important reason for an international approach to polar research is that it is an international issue. Nobody will escape the effects – either direct or indirect – of global warming.

Today's interdisciplinary symposium, organised by DG Research, is an excellent example of this international approach. We have 160 participants from 21 different countries. We have high quality speakers covering a wide range of specialities – and seven of them are lead authors of the IPCC reports.

Over the course of today and tomorrow, we can look forward to hearing the latest information on climate change, health, infrastructures, natural and socio-economic impacts and public awareness of the polar regions.

We can also look forward to some frank discussions at the round table event. We need this debate. Not just to identify the research fields of the future for the polar regions, but also to feed into shaping future policy.

In the EU, we rely on sound scientific advice when formulating our policies in areas such as research, energy and the environment. This was the case with the Commission's Communication on climate change released in January, which aims to see temperature rises limited to less than 2 degrees beyond pre-industrial levels.

I believe today's symposium is one of the steps that we need to take along the road to finding more and better answers to the situation we have created.

Ladies and Gentlemen,

Having today's event in Brussels is timely because, with the launch of the International Polar Year and the EU's new Research and Development Framework Programme, we have the opportunity to show that climate research can make a difference – and soon.

So I thank you for being here and I wish you all a successful symposium.

***Thank you.***

**Janez Potočnik**
***Commissioner for Science and Research***

*Polar Environment and Climate*

# General session:
## IPY and environment
## and climate in the polar regions

# REPORT from CHAIR

## General session on IPY and environment and climate in the polar regions

***Jean-Claude Gascard***
***Université Pierre et Marie Curie, Paris, France***
**jga@locean-ipsl.upmc.fr**

Five presentations were introduced during the first general session of the International symposium related to polar environment and climate. Two of the five presentations dealt with ice, snow and frozen ground in general (Peter Lemke) and with Arctic change in particular (Ola Johannessen). The three other presentations dealt mostly with the European Strategy for Polar Research (Elisabeth Lipiatou and Carlo Alberto Ricci & Paul Egerton) and the International Polar Year (Dave Carlson).

'Ice is an important component of the Earth's climate system and is linked to the surface energy budget, the water cycle, sea level change and the surface gas exchange,' said Prof. Peter Lemke. Ice integrates climate variations on a wide range of time scales and it represents a visible expression of climate variability and change. In the Arctic, the retreat of sea-ice especially in summer, has already shown a strong impact on the ecosystem and on the erosion of permafrost coasts, with subsequent negative effects on human settlements in Alaska and Siberia.'

'Global warming is more extreme in the Arctic regions and the prediction is for a strong increase in air temperature and a significant decrease in the ice cover,' said Prof. Ola Johannessen. 'The global warming in Arctic regions can have both positive and negative effects, and the Greenland ice sheet is a "wild card" in the global climate system as it has a significant impact on the global sea level rise and thermohaline circulation.'

'The European Commission supports research in polar regions through the implementation of its Framework programmes,' said Elisabeth Lipiatou Head of Unit at the Environment directorate in Brussels. In FP7 the following core areas were focused upon: functioning and abrupt changes in the Earth's climate system, Natural and anthropogenic emission and pressures, Greenhouse gas budget, future climate and natural, socio economic impacts and adaptation, mitigation and policies.'

'Multilateral cooperation on the usage of research infrastructures in polar regions to create a European Polar Framework programme was presented by Carlo Alberto Ricci and Paul Egerton. European contributions to global polar organisations amount to about 50% or more of total contributions for SCAR and IASC. European countries have a large capacity in polar regions as they operate 22 Arctic and 25 Antarctic research stations, 31 polar ships and 26 aircraft.'

'IPY will involve thousands of scientists, nearly 50 000 people from at least 60 nations. IPY will represent the largest coordinated international scientific effort in 50 years said David Carlson, Director of the IPY. IPY will focus on urgent polar and global issues including ice melt and sea level rise, changes in global ocean circulation and polar oceanic ecosystems, polar sources and sinks in the global carbon cycle, and human well-being and community vulnerability in polar populations. IPY will stimulate cooperation and collaboration across a broad range of scientific specialties, from geneticists to glaciologists and from anthropologists to astronomers. IPY will offer unprecedented data management and communication challenges and will represent a unique opportunity for a large step forward in making science available and accessible to the general public. European researchers and European countries play key leadership roles in IPY science.'

From the various presentations made during the first session of the symposium and the round table discussion at the end of the symposium, a strong emphasis was made on **Sustainable Polar Observations Systems** and several major aspects were considered:

- The first aspect involved key processes regulating negative and positive feedbacks (albedo) between air, sea and ice and heavily depending on thresholds (freeze/melt).
- The second aspect concerned numerical modelling and a strong and urgent need for acquiring data necessary to initialise, to constrain and to refine models for improving model sensitivity and model prediction. In addition, both observers and modellers were invited to participate in the experimental design of long-term, sustainable observation networks.
- The third aspect emphasised the fact that polar regions are not isolated but part of the global climate system and should be considered as such. That implies that strong links need to be developed for global issues and programmes such as WCRP, GCOS and GOOS.
- The fourth aspect concerned the development of an efficient synergy between scientific consortia and national, European and/or international agencies to provide the necessary infrastructures to operate in the harsh environment of the Arctic and to stimulate the design of innovative high technology adapted to the polar environment.
- A dedicated effort regarding data management, data accessibility and sharing, data quality control and dissemination and data archiving was expressed by all speakers.
- A strong need was stated for education at all levels (schools, high schools, colleges) and training for teachers and students. Plans for dissemination and exploitation of knowledge should be an intrinsic part of any research programmes as well as summer schools dedicated to the training of the next generation of polar researchers.
- Finally, and due to the large impact of environmental sciences, a strong need for developing broad public outreach (press conferences, scientific media, web sites) was expressed by all the speakers and participants.

# SPEAKERS

## Observations in snow, ice and frozen ground

**Peter Lemke**
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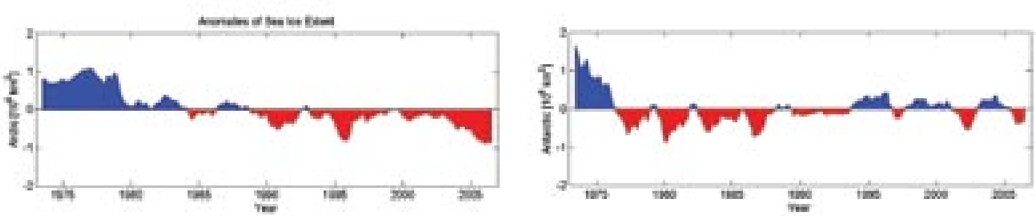
Ice is a dominant feature at high latitudes and high altitudes on Earth. Ice on land stores about 75% of the world's fresh water. The volumes of the Greenland and Antarctic ice sheets are equivalent to approximately 7 m and 57 m of sea level rise, respectively. All mountain glaciers amount to about 5% of the Greenland ice sheet.

Ice is an important component of the climate system, and is linked to the surface energy budget, the water cycle, sea level change and the surface gas exchange. Ice integrates climate variations on a wide range of time scales, and it represents a visible expression of climate variability and change. Because of the positive temperature-ice albedo feedback, some cyrospheric components act to amplify both changes and variability. However, some, like glaciers and permafrost, act to average out short-term variability and so are sensitive indicators of climate change. Ice is found at all latitudes, enabling a near-global assessment of cryosphere-related climate changes.

The area and volume of ice on Earth have undergone large variations in the past, associated with the ice ages and shorter-term fluctuations, like the Little Ice Age. In recent decades, the decrease of ice is correlated with rising temperatures, especially in the Arctic and in most mountain regions, with significant impacts on ecosystems and human societies. Changes of the ice mass on land have contributed about 1.2 mm/year to recent sea level rise, which is of the order of 3.1 mm/year. On a regional scale, many glaciers and ice caps play a crucial role in fresh water availability. In the Arctic, the retreat of sea ice (see Figure), especially in summer, has already had a strong impact on the ecosystem and on the erosion of permafrost coasts, with subsequent negative effects on human settlements in Alaska and Siberia.
Recent results are presented on the evolution of snow, sea ice, glaciers, ice sheets and frozen ground, with special emphasis on the differences between the Arctic and Antarctic.

**Figure: Anomalies of sea ice extent in the Arctic (left) and Antarctic (right), indicating the contrasting evolution in both polar regions (Data source: Hadley Centre, Met Office, UK).**



# Success measures of the International Polar Year — European and international opportunities and challenges

**David Carlson**
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The International Polar Year 2007 – 2008 has drawn extraordinary interest from scientists of many specialities and many nationalities. A cautious assessment prior to the IPY start shows more than 200 international projects, addressing a wide range of physical, biological and social research topics in polar regions. With thousands of scientists, and including students, engineers, technicians and other support staff so essential to polar research, IPY will involve nearly 50 000 people from at least 60 nations. IPY will represent the largest coordinated international scientific effort in 50 years.

IPY research will focus on urgent polar and global issues, including ice melt and sea level rise, changes in global ocean circulation and polar oceanic ecosystems, polar sources and sinks in the global carbon cycle, and human well-being and community vulnerability in polar populations. We can and should expect excellent research and startling discoveries in every area of IPY science. But, does this accumulation of IPY research products ensure IPY's success, or does IPY face additional requirements and challenges?

IPY will stimulate cooperation and collaboration across a broad range of scientific specialties, from geneticists to glaciologists and from anthropologists to astronomers. Which new tools, new journals, new meetings, new data conventions, new funding sources and processes, and new mechanisms for collaboration will develop during IPY and how will the science community sustain successful interdisciplinary interactions after IPY? IPY will present unprecedented data management and communication challenges and opportunities, internally among a broad range of scientific specialties and externally to science education systems at all levels and to the general public. How will free and open data access work during IPY, and how and where will it continue after IPY? Will data publication become a recognised international standard and will the IPY free and open data policy extend to open and free access to scientific literature? In its total science and outreach effort, and in an age of geobrowsers, webcasts and increasing public discussion of climate change, IPY will represent a unique opportunity for a large step forward in making science available and accessible to the general public – will IPY succeed and if so what impact will that attention and success have on the future conduct of science?

European researchers and European countries play key leadership roles in IPY science. European researchers, operating through the multinational science programmes of the European Union, have an opportunity and responsibility to lead on these international and interdisciplinary collaboration, data exchange, and public impact issues.

# Climate and environmental change in the Arctic

**Ola M. Johannessen**
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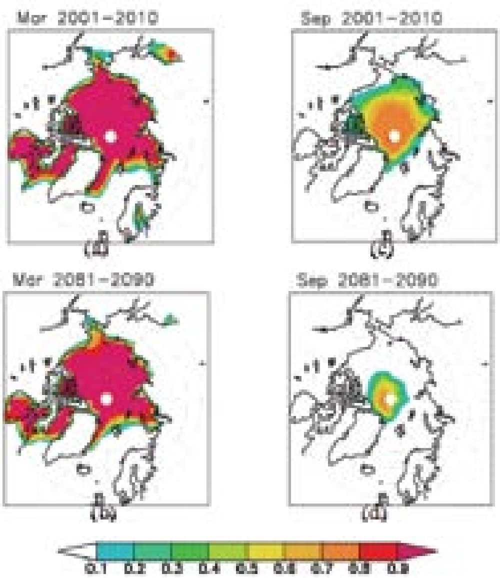
Global warming is more extreme in the Arctic regions. The air temperature has increased to double that of the global average over the last 100 years, the ice cover is decreasing at a rate of 3-5% per decade while the thicker multi-year ice is decreasing at a rate of 7-10% per decade, the river discharge from Russia is increasing, the tundra-permafrost is thawing and the snow cover on land is decreasing. Furthermore, in the past few years the Greenland ice sheet has lost mass along its edges – more than the accumulation increase in the interior. The Greenland ice sheet is a 'wild card' in the global climate system with significant impact on the global sea level rise and a potentially strong impact on the thermohaline circulation (Gulf Stream decrease). However, it should be pointed out that strong natural variability at the interannual time scale takes place in the Arctic region and also causes strong regional variability.

**Climate-model simulation of ice concentration due to $CO_2$ doubling. (a) Winter 2005; (b) Winter 2085; (c) Summer 2005; (d) Summer 2085. From Johannessen, et al. (2004) Tellus, 56A, 328-341**




Johannessen, et al. (2004) Tellus, 56A, 328-341

The prediction for the Arctic region is a strong increase in the air temperature and a significant decrease in the ice cover. A blue Arctic Ocean is predicted during the summer time at the end of this century. However, the many recent IPCC-coupled climate models also indicate a strong wide spread in the results – so one should be careful with the interpretation.

If the predictions turn out to be valid, then global warming will have a strong impact on the ecosystem and fisheries, living conditions for humans and polar bears, offshore and onshore oil and gas exploration and production, ship transportation along the Northern Sea Route, on society, economy and energy supply (25% of the remaining oil and gas reserves is estimated to be in the Arctic region). However, it should be pointed out that the IPCC models have not taken into account the potential impact of the increased melting and discharge of fresh water from the Greenland ice sheet – giving increased uncertainty to the predictions. Another important issue which has not been taken into account is the potential increasing uptake of $CO_2$ by a 'Blue Arctic Ocean'.

Global warming in the Arctic region can have both positive and negative effects. It is easy to understand that a retreating ice cover will make off-shore oil and gas production easier in the future. On the other hand, the thawing of the tundra and permafrost will cause problems for the onshore gas and oil industry. Furthermore, the thawing permafrost will cause a lot of infrastructure problems for the population living in this region. Another big question is what will happen with the huge methane reservoirs which at present are frozen in the permafrost – also located offshore. The state-of-art of the Arctic climate system and its potential impact on society will be given.

# *European strategic frameworks for research in the Polar Regions*

**Carlo-Alberto Ricci[1], Paul Egerton[2]**
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Over the last few years, there have been major steps towards the enhancement of the coordination of polar research programmes in Europe leading to steps to formalise multilateral cooperation on the usage of research infrastructures in the polar regions and actions to create a European strategic framework for nations to launch joint research programmes such the concept of *'A European Polar Framework Programme'*.

## EUROPEAN CAPACITY IN THE POLAR REGIONS

In 2005, the European Polar Board, a strategic body of the European Science Foundation (25 polar institutions of 19 countries, including Russia), successfully proposed to the European Commission the development of an ERA-NET covering research cooperation in the polar regions. The European Polar Consortium (EUROPOLAR)[1] is composed of 25 ministries and funding agencies, with the main objectives of identifying and characterising critical elements for deepening the collaboration between European polar research agencies, harmonising management processes and strengthening European polar coordination in a global context. The national annual investment in polar research by the 19 consortium countries totals €300 million. This includes management of polar research activities, infrastructures, project grants and outreach activities excluding salaries. The critical mass of these programmes under EUROPOLAR enables Europe to engage in a strong and coordinated way with countries such as the United States, Canada and other international partners. It makes possible negotiations and interconnected planning between the main governmental agencies.

**Some statistics on European contributions to global polar organisations:**

- 13 out of 26 consultative members of the Antarctic treaty are European countries.
- 16 out of 31 effective members of SCAR are European countries.
- 5 out of 8 effective members of the Arctic Council are European countries.
- 13 out of 18 effective members of IASC are European countries.

European countries have a large and sophisticated capacity in the polar regions as they operate 22 Arctic and 25 Antarctic research stations, 31 polar ships and 26 aircraft. The European stations are distributed all over the two polar regions and in most cases provide landing facilities which allow internal and external air connections. Among the different European partners there are formal agreements for running polar stations such as Samoylov (Germany and Russia), AWIPEV (France and Germany), Ny-Ålesund Marine Laboratory (Norway and other nations) and EISCAT (Sweden, Finland, Norway, China, France, Germany and others) in the Arctic and Concordia (Italy and France) and Wasa (Sweden and Finland) in the Antarctic. An example of European multilateral cooperation in polar science infrastructure is the European Economic

Interest Group "Geophysica", which provides the strategy, the technical feasibility, the coordination and the field operations for stratospheric research based on the Russian M55 Geophysica aircraft. A major joint (French-Italian) research: Infrastructure CONCORDIA on the Antarctic Polar Plateau is providing the basis for enhanced European cooperation in many scientific domains.

## POLICY RELEVANCE OF EUROPEAN POLAR RESEARCH

The European Union has a great regional interest in the Arctic since it is a crucial area for climate change studies as well as environmental, social, energy, trade and security policies. The Northern Dimension is a critical pillar of the European Union in its political and geo-strategic interactions with the Russian Federation and neighbouring countries. The coordinated polar research programmes can provide very powerful information in support of decision making at the national and EU governmental level. The European Polar Consortium is developing mechanisms for integrated analysis of relevant policy information under the POLAR ALERT initiative of EUROPOLAR. The countries of the Russian Federation have been strong partners in the EUROPOLAR ERA-NET and this is important in terms of contributing towards the implementation of the Common European Research Space between Russia and the European Union, especially in the Arctic region where critical research, environmental and energy security issues are on the agenda.

The principle studies of the European countries in the Arctic focus on quantifying global climate change, predicting and monitoring changes in Arctic environment and ecosystems, developing new technologies and improving human and social health. In recent years, many joint programmes in the Arctic have been launched. Examples of specific large-scale research collaborations in the Arctic are DAMOCLES, IPY-CARE, GRIP and ENVINET. A recent analysis of the European Polar Programmes (undertaken under the auspices of the European Polar Consortium) indicates that in Antarctica the highest percentage of European scientific activities focuses on climate change research in addition to earth science studies. Astronomy and Astrophysics in the Antarctic is a developing frontier area for Europe especially in that it requires high investment. The fields of 'Polar Genomics' and 'Life in Extreme Environments' are also exciting areas of growth. Several large scientific projects, with European participation, are carried out in Antarctica; for example, the research areas of climate history performed by deep core ice drilling, evolution and biodiversity programmes, studies of the inter-hemispheric interactions and space studies.

## IMPORTANCE OF THE INTERNATIONAL POLAR YEAR

The International Polar Year 2007-2008 offers a unique opportunity to European countries to participate in internationally coordinated projects such as the five SCAR projects (EBA, ACE, AGCS, SALE, ICESTAR), and other international projects such as TASTE-IDEA, and EUROPOLAR initiatives in Polar Climate Science, International Ice Core Science, and Polar Frontier Science. Regarding education, outreach and communication activities the European Polar Board has led the way at the European level in coordinating initiatives in this field, including developing networks for media officers and enabling the creation of a European Educational Gateway for teachers and students to access the polar regions. A significant number of European countries carry out activities at a political level and also target the public, policy makers, media and governmental institutions. These are carried out both on a regular basis and also by dissemination actions as for example special events, contests, seminars and electronic media.

The participation in the International Polar Year, and related activities around the event has produced an "explosion of ideas" which will be seen as an intellectual asset for forthcoming researchers and investors; it will contribute to a significant change in investment and the level of cooperation providing a legacy for the next scientists, technology development and knowledge. Many of the partners are in the process of planning their outreach activities, and for some of these information can be found on the national IPY committees' web pages. The European Polar Consortium and the European Polar Board are very important platforms for European planning and participation in the International Polar Year 2007-2008 and for planning common strategies.

## INFRASTRUCTURES OF EUROPEAN SCALE AND SCOPE

The development of infrastructures such as the European research icebreaker vessel AURORA BOREALIS identified on the recent EC ESFRI Roadmap as a large-scale facility of European Interest in the post-IPY period and during the FP 7 will also be major activities that will allow Polar Research to grow at the European level.

## POLAR AGENCY COOPERATION IN THE EUROPEAN RESEARCH AREA

Europe is in a phase where many possibilities for the development of polar research strategies and logistics are emerging. This is due to existing collaboration between partners and countries – both within Europe and with other international partners. However, even if significant elements play in favour of an increase in mutual cooperation and integration at a European level, a number of obstacles persist and should be removed. One of the obstacles is the limited ability to perform research funding transactions across borders. At the present time this limits scientific and logistical possibilities. Another obstacle is a general fragmentation of scientific activities and coordination of infrastructures. This can result in duplication of effort and increase the costs of European Polar science. The enhanced networking of polar observing systems and polar stations for the provision of essential research services will be important areas where the European Polar Board and European Polar Consortium will cooperate with the European Commission FP7 programmes in the future. This will allow increased efficiency and coordination of the existing European assets and enable a greater scientific impact at the global level.

## FUTURE STRATEGIC FRAMEWORKS

Even though there are some obstacles for sharing funding across borders there are also some serious intentions and collaborations already set up for future actions. There is a need for commitment to connected planning and identification of common research strategies between the partners. Bilateral agreements are common. However, it would be desirable to encourage the development of European multi-lateral partnerships, with common priorities and elements of shared investment. In this respect, the possibility of connected planning and long-term prioritisation of research topics at a European level needs to be further examined – strategic test case programmes in areas such as climate change should be pursued. Programme planning is intimately linked with the availability and suitability of supporting research infrastructure. It is therefore essential that when joint activities are prioritised or planned, the information flow between national programme managers from funding agencies and infrastructure managers is optimised at all stages of the planning process. The development of a European Strategic Framework for Polar Research Programmes is underway within EUROPOLAR ERA-NET and the construction and implementation of a future 'European Entity for Polar Programmes' is a very real possibility arising out of such discussions.

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# Polar environment and climate: European Research in the Seventh Framework Programme

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The European Commission has long supported research in the polar regions by setting priority themes in the calls for proposals of its Framework Programmes. Almost 60 research projects in FP5 and FP6 related directly or indirectly to polar issues have been funded over the last decade. Most of these initiatives were related to climate research due to the changes the poles are currently facing and their importance for the earth's climate. Through FP6, the European Commission supports the largest project endorsed by the International Polar Year, DAMOCLES, which is an integrated ice-atmosphere-ocean monitoring and forecasting system designed for observing, understanding and quantifying climate changes in the Arctic.
Environment and health, natural resources, research infrastructures and coordination activities were the other themes supported. Details on all these FP5 and FP6 projects can be found in the summary reports released on the occasion of the International Polar Year '*European Research on Polar environment and climate- Results and information from FP5 and FP6 projects*' freely available on the website of the Environment Directorate of DG Research.[1]

In the FP7 Environment Programme, under the sub-activity '*Pressures on environment and climate*', the following core areas have been underscored:

- Area 1: The Earth System and Climate: Functioning and Abrupt Changes
- Area 2: Emissions and Pressures: Natural and Anthropogenic
- Area 3: The Global Carbon Cycle – Greenhouse Gas Budget
- Area 4: Future Climate
- Area 5: Climate Change: Natural and Socio-economic Impacts
- Area 6. Response Strategies: Adaptation, Mitigation and Policies

Research in the polar regions is potentially suitable in all these areas and the priority themes of the Framework Programmes for research are based on results acquired during previous and ongoing programmes. For instance, in the first FP7 call for proposals published end 2006, polar issues are included under two topics which are at the current science frontier *i*) Stability of the thermohaline circulation (with a large impact on Europe's climate) and *ii*) Investigating life in extreme environments. The thermohaline circulation call builds heavily on past and current multidisciplinary projects on the interactions between ocean, cryosphere and climate (DAMOCLES, ASOF-N, ASOF-W, IPY-CARE, GLIMPSE, etc). There will also be topics relevant to the research in polar regions that are scheduled for the future FP7 calls: paleo-environment, sea-level rise and ice sheets, UV radiation, carbon budget and cycle, future climate, climate change impacts on biodiversity and ecosystems, and human health issues.

## POLAR CATALOGUE:

http://ec.europa.eu/research/environment/pdf/Polar_catalogue_final.pdf

## FP7 ENVIRONMENT:

http://cordis.europa.eu/fp7/cooperation/environment_en.html

# 1. Past climate

# REPORT from CHAIRS

## Session on past climate

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The talks of this session described wonderful and complementary archives of past climate variability from ice cores, trees, marine and lake sediment cores. Each has its own characteristics in terms of dating, the time scale covered and the climatic variables that can be reconstructed or measured. From the analyses of the water composition and of impurities in **ice cores**, reconstructions of, for instance, air temperature and circulation changes and volcanic activity over more than 800 000 years are now possible. Furthermore, the air bubbles trapped in the ice provide a unique record of past atmospheric composition, allowing the clear relationship between past changes in $CO_2$ and temperature to be shown. One of the major advantages of **tree rings** is their ability to be dated exactly over more than 5 000 years. They provide very useful information on high frequency climate change as well as on the coherency of climatic change in various regions. Moreover, they are often of sufficient resolution to allow a distinction to be made between causes and effects during a climatic event. Measuring carbon isotopic ratios in trees provides information on the evolution of the carbon cycle and in particular on the response of trees to changes in the atmospheric $CO_2$ concentration. **Marine and lake sediment cores** provide information on the longer term evolution of the climate system, allowing, for example, study of the inception of the Greenland ice sheet about 3.5 million years ago or the shift in the dominant period of the glacial-interglacial cycle from 40 ky to 100 ky about 1.2 million years ago. Despite the quality of the information already obtained, each of the talks emphasised the importance of careful dating and calibration of those archives and that additional work on those issues is necessary.

Because many direct measurements and satellite data cover only very short time spans, these archives of past climate are key in allowing recent trends to be put into a longer time-scale. While contemporary data are of course essential to understand our current climate, they cannot sample the full range of natural variability. Proxy records are thus essential for improving our understanding of the mechanisms and timescales of climatic changes under the widest range of conditions, including those that share characteristics with the climate expected for the next decades or centuries. The proxy data are also a unique way to test the ability of models to reproduce climate changes. This should enable us to determine which are best able to reproduce past conditions, and thus which should provide the most reliable projections of the future. For this reason, paleoclimate data will allow us to reduce the uncertainty on climate change projections.

During the session, some specific suggestions were raised:

- Where possible, past and future climate should be viewed as a whole and not separately. This is particularly critical in studying variability on the 10-100 year time scale, but this is also valid for longer time scales (e.g. what is the stability of the Greenland Ice Sheet? What are the climate conditions consistent with an ice-free Arctic? When is a glacial inception due?)

- Data assimilation using proxy data, the record of instrument readings and model results would allow the greatest amount of information possible to be derived from the available sources and tools. A proper assimilation of the proxy information requires specially adapted 'proxy' models, which map the climate information (temperature, precipitation) onto variables that can actually be observed such as oxygen isotopic ratio.

# SPEAKERS

## The Antarctic ice core record: a useful archive for a better understanding of our climate and environment

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Antarctic and Greenland ice core archive past changes in the atmosphere and contain unique information on our climate and environment. The Antarctic ice provides the longest record covering several glacial-interglacial cycles over the past million years. Because of its extremely low content in carbonate aerosols or dust, and in organic material, the Antarctic record exhibits the purest memory of past changes in atmospheric $CO_2$. On the other hand, Greenland ice contains a unique and detailed record of the past changes in the climatic and atmospheric environment of the northern Hemisphere. The comparison between Antarctic and Greenland ice records allows us to investigate the north-south climatic connection.

As attested by the inclusion in the 2007 IPCC assessment of a full chapter devoted to the paleoclimatology, the record of the past is used to simulate our future climate. Ice core results already have led to important discoveries relevant to the future, such as the empirical evidence of the Arrehnius prediction concerning the large contribution of $CO_2$ to the glacial-interglacial warming, the late Quaternary unprecedented high levels of the contemporary greenhouse trace-gas concentrations, or the ability of the Earth's climate to prompt abrupt changes of 10°C or more within a few decades like the Dansgaard / Oeschger events during the last glacial period over Greenland.

We present here some of the most recent results obtained on the two EPICA* ice cores that are relevant to the future. The EPICA DC (EDC) core has been recovered from near the top of Dome C, one of the major domes in East Antarctica, and is appropriate to deliver a long and well-preserved climatic record. The approximately 3 260 meter long EDC core provides a record going back 800 000 years, i.e. about 2 times longer than the famous Vostok record [*Petit, et al.*, 1999]. The correlation between the EDC temperature record reconstructed from the ice isotopic profile and the stack marine benthic record [*Lisiecki and Raymo*, 2005], a first order indicator of sea level variations, suggests that the main temperature variations observed in Antarctica over the last 800 000 years have a large geographical significance, indeed a global character. The results clearly indicate a change in the climate mode around 450 000 years ago, with much warmer interglacials during the last 5 interglacials, including the Holocene period [*EPICA-COMMUNITY-MEMBERS*, 2004].

The Vostok record revealed a close relation between greenhouse gases and climate over the four last glacial-interglacial cycles. It is important in terms of climate forcing and feedbacks to know what happened with this relation when the climatic mode was different. $CO_2$, $CH_4$ and $N_2O$ measurements on EDC are now available back to 650 000 years ago [*Siegenthaler, et al.*, 2005; *Spahni,* *et al.*, 2005]. On the whole, and in particular for $CO_2$ and $CH_4$, the less warm interglacials found prior to the 'Vostok era' exhibit lower greenhouse gas concentrations and the apparent sensitivity between $CO_2$ and climate remains stable throughout the six glacial-interglacial cycles. This suggests a rather stable relationship between $CO_2$ and Antarctic climate over this time interval.

The second EPICA drilling site is also located in East Antarctica, but in a region of high snow accumulation and facing the Atlantic basin, which make the EPICA DML 2 760 meter long core more appropriate for investigating with good resolution the last glacial-interglacial cycle and, by comparison with the Greenland ice core record, the phase relationship between climate changes in the 2 hemispheres, a key for understanding the Earth's climate dynamics. Currently, one of the major results obtained from the EPICA DML core analysis reveals that each of the Greenland glacial Dansgaard-Oeschger events has a counterpart in Antarctica, with the amplitude of the Antarctic warm events being linearly dependent on the concurrent stadial in the North, suggesting a similar reduction in the meridional overturning circulation [*EPICA-COMMUNITY-MEMBERS*, 2006].

*The European Project for Ice coring in Antarctica (EPICA) is a joint European Science Foundation (ESF) / European Commission (EC) scientific programme, funded by the EC and by national contributions of 10 European nations. EPICA MIS is the EC project, which is currently supported in the frame of the Sixth Framework Programme. The project includes two deep drilling sites in east Antarctica: EPICA DC, close to the site of the new French-Italian permanent station of Dome Concordia, and EPICA DML at the German Kohnen station.

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# Dendroclimatological evidence of Arctic temperature changes through recent Millennia: current evidence and research prospects

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General circulation models (GCM) forced with increased greenhouse gases indicate greater surface warming over the Arctic region compared to other regions of the world. Recent multi-model averages suggest warming of 4 to 5 degrees Celcius in annual mean temperatures by the end of the current century over large areas of Northern Eurasia, though most of this warming is apparent in winter and the North Atlantic and surrounding land areas are also likely to experience much less warming.

Recent selected instrumental temperature evidence for Arctic and Eurasian regions is briefly reviewed and compared with simulated temperature data produced by a single GCM (HadCM3) experiment that included a combination of “natural” and “anthropogenic” forcings.

Extensive tree-ring records in the form of replicated chronology time series are now available, covering wide areas of the northern landmasses, especially north of 65º latitude, across all of Northern Eurasia. These extend centuries back before the start of most record-keeping using instruments. At important locations in Northern Fennoscandia, and the Yamal and Taimyr areas of northern Siberia the recovery and analysis of sub-fossil pine and larch wood has allowed the production of greatly extended chronology series reaching back over millennia. Together these tree-ring derived data provide a substantially longer, uniquely well-dated and annually-resolved timeframe compared to available records of measured temperatures and one within which the character of observed recent warming across Northern Eurasia can be compared.

Examples of summer temperature reconstructions are shown to illustrate the temporal and selected spatial patterns of warming and cooling episodes over the last 2 000 years in northern Eurasia and 7 000 years in Northern Fennoscandia. These highlight the aperiodic nature of distinct warming and cooling events that are characteristic of temperature changes in these regions. They also show clear evidence of the importance of volcanic forcing of past major cool excursions. A new analysis of the changing large-scale coherence in temperature variability across Northern Eurasia, based of the use of Kendall’s Concordance calculated for three long ring-width chronologies, provides evidence of unprecedentedly high coherence in large-scale temperature trends in the most recent century compared to the last 2 000 years. The extent to which this is consistent with the evidence of temperatures simulated by one GCM experiment using anthropogenic forcings is discussed.

Some high latitude temperature-sensitive tree-ring records display variability that has been shown to ‘diverge’ from measured temperature trends over the last few decades of the 20$^{th}$ century, despite the fact that they display strong coherence during prior centuries. It has been speculated that this phenomenon has an anthropogenic origin and also that it may represent a ‘breakdown’ between the assumed temperature control of tree growth at high latitudes. The evidence for and implications of this 'divergence' will be briefly discussed.

Finally, the potential and importance of future dendroclimatological research and the scope for integrated climate model studies will be assessed.

# *Past climate variations around the Arctic on millennial to multi-decadal scales: marine and terrestrial evidence*

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The Arctic Ocean has, since its formation, passed through different physical and environmental stages (Figure 1). These stages witness a transition of the Polar Basin from a stagnant and oxygen deficient ocean through a temperate upwelling basin into a cold and ventilated ocean, which today has profound impact on the global ocean circulation.

**Figure 1. Outline of the tectonic evolution of the Arctic Ocean**

A major element in the evolution of Cenozoic environments has been the transformation of the global oceans from warm Eocene oceans with low latitudinal and bathymetric thermal gradients into the recent modes of circulation characterised by strong thermal gradients, oceanic fronts, cold deep oceans and cold high latitude surface waters. The transition to today's world, with Antarctica covered by a continental ice-cap and seasonally variable but persistent sea-ice cover in the Arctic, is linked to both the change in climate that increased latitudinal gradients and to oceanographic changes that connected surface and deep-sea circulation between high and low latitude oceans. Thus, throughout the course of the Cenozoic, the climate on Earth has changed from one extreme (e.g. the Paleogene 'Greenhouse' situation lacking ice) to another (the Neogene 'Icehouse' situation with bipolar glaciations).

The lack of knowledge about the role that the Arctic played in the maintenance and development of these climatic extremes is a major gap in our ability to understand and model global environmental change. Continuous data series from the Arctic Ocean is often a weak point in any global model. Paleoclimate reconstructions are therefore important to improve our understanding of the behavior of the climate system over different time scales and fundamental in providing important data to validate models of climatic situations different from those covered by the short instrumental record.
A key mechanism in Earth's climate system is the coupling between ocean and climate. Studies that can unravel this coupling, such as correlations between marine and terrestrial records, are of high priority as they can tell about the climate system's dynamics and feedback. Lack of suitable material from the central Arctic prevents documentation of the long term history of the Arctic sea-ice cover and ocean climate. Scientific drilling in the Arctic Ocean is therefore vital in obtaining

records with preserved information on the transition from the warm, high-$CO_2$ environment of the Paleogene to the present glacial situation. Arctic Ocean processes and feedback may have been pivotal in bringing the world into and out of the ice ages. Most of the comprehensive climate models predict almost complete disappearance of summer sea-ice by the end of this century. If the sea-ice should disappear we are, however, faced with a situation which has analogues in the past, from which important knowledge can be gained.

Long and continuous data series from IPY related investigations of natural archives such as lake sediments, ice cores, and marine sediments can, therefore, provide an important base line for studies of recent changes in the Arctic by documenting the range of natural variability and the geographic patterns of responses to past environmental forcing.

# Past and present response of the northern forests to changes in atmospheric carbon dioxide

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## INTRODUCTION

The northern forests of Europe and elsewhere play an important role in both the carbon and hydrological cycles, and they also contain a valuable archive of information on past climate. Where the trees are growing under stress, close to the tree line, for example, the width of the annual rings can provide a proxy measure of past summer temperatures. The relative density of the rings, measured using X-ray techniques, can be even more powerful (Briffa et al. 2004), and in recent years it has become feasible also to measure changes in the stable isotopic composition of the rings (McCarroll and Loader 2004), providing a more direct link to changes in carbon and water balance.

All of these approaches rely on the uniformitarian principle that the past and present response of trees to climate is directly comparable and that calibration against modern climate data can be used to reconstruct quantitatively the climate of the past. However, there is clear and growing evidence that this assumption may not be valid. Several authors have pointed to a divergence between tree ring proxies and climate data during the industrial period (Briffa et al. 1998). One possible explanation could lie in a changing response of trees to the increasing concentrations of carbon dioxide in the air. This can be investigated by measuring the stable carbon isotope ratios in tree rings.

## PAST RESPONSES

The results of the EPICA project have demonstrated large variations in the amount of $CO_2$ in the atmosphere. Over the last four glacial cycles, the $CO_2$ content of the atmosphere changed by up to 100ppm, with values as low as 180ppm occurring during glacials, and rising to more than 280ppm during the interglacials. The tree species that comprise the northern forests survived those large swings in atmospheric $CO_2$ and so we can expect them to be well adapted to changing atmospheric $CO_2$ levels. However, the evidence from at least the last 600 000 years suggests that trees have not experienced the elevated levels that have been reached in recent decades as a result of anthropogenic emissions.

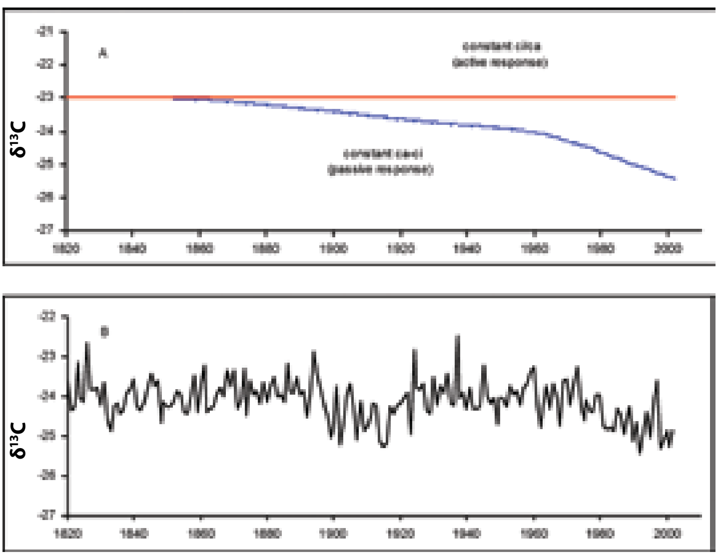
Trees, and other plants, are able to respond in a plastic way to changes in atmospheric $CO_2$ levels by adjusting their stomatal conductance. The water molecule is smaller than that of either $O_2$ or $CO_2$ and so membranes that allow gas exchange inevitably leak water vapor. Stomata evolved in order to control the balance between carbon gain and water loss. When the amount of $CO_2$ in the atmosphere rises, trees can reduce stomatal conductance to limit water loss whilst maintaining a constant ratio of internal to external $CO_2$ concentrations. The relationship between atmospheric $CO_2$ levels and the frequency of stomata on leaves has been the subject of a large amount of research and some controversy (Wagner et al. 2004).

The relationship between atmospheric $CO_2$ levels and stomatal conductance is even clearer from measurements of the stable carbon isotope ratios in tree rings. When atmospheric $CO_2$ levels are stable, the ratio of $^{13}C$ to $^{12}C$ in tree rings is effectively a measure of the internal concentration of $CO_2$ (McCarroll and Loader 2004). The ratio of $^{13}C$ to $^{12}C$ is expressed in the delta notation relative to a standard as $\delta^{13}C$ in units of per mille (‰). As atmospheric $CO_2$ levels rise, trees could in theory remain entirely passive, in which case the difference between atmospheric (ca) and internal (ci) concentrations of $CO_2$ would remain constant. Since $\delta^{13}C$ values are a function of the ratio ci/ca, this would result in a substantial decline over the industrial period. A tree giving an average pre-industrial $\delta^{13}C$ value of -27‰, for example, would show a ~1‰ fall between 1850 and 1950 and a further fall of ~1.5‰ between 1950 and 2005 (Fig. 1). In fact, the results from many studies suggest that a passive response to industrial increases in $CO_2$ is very unusual (Saurer et al. 2004; Waterhouse et al, 2004). On the contrary, most trees display a strong active response, with internal concentrations of $CO_2$ rising much less steeply than atmospheric concentrations, so that the ratio ci/ca remains nearly constant. After mathematical correction for changes in the isotopic ratio of $CO_2$ in air (Suess correction), therefore, the $\delta^{13}C$ values of tree rings often remain nearly constant for most of the industrial period, with variations from the mean representing a palaeoclimate signal.

## PRESENT RESPONSE

As atmospheric $CO_2$ levels continue to rise far above levels experienced in the past, it seems reasonable to assume that at some point the trees of the northern forests, and elsewhere, will reach a threshold beyond which they will no longer be able to respond by reducing stomatal conductance. Indeed, recent results from several EU-funded projects (FOREST, PINE, ISONET and MILLENNIUM) suggest that for some trees the threshold may already have been reached.

**Figure 1.**
**A: Changes in tree ring $\delta^{13}C$ that would be expected since AD 1820 given an active response, with increasing water use efficiency, or a passive response and constant water use efficiency.**
**B: Changes in $\delta^{13}C$ obtained from seven Scots pine trees in northern Finland. Note that between 1820 and 1970 the values remain nearly constant, but then decline rapidly. These trees may have reached a threshold beyond which water use efficiency cannot continue to increase.**



At the Laanila experimental forest in northern Finland (68˚30'N, 27˚30'E, 220m asl), for example, the Suess corrected $\delta^{13}C$ values obtained from the latewood cellulose of seven Scots pine (*Pinus sylvestris*) trees show virtually no decline over the period 1850 to 1970, despite rising levels of atmospheric $CO_2$ (Gagen et al. 2007). This indicates a strong active response with a reduction in stomatal conductance keeping pace with rising $CO_2$ levels to maintain a constant ci/ca ratio. After 1970, however, $\delta^{13}C$ declines steeply and it is the difference between ca and ci that remains nearly constant (Fig. 1). The decline in $\delta^{13}C$ is certainly not driven by changes in climate. In this area the main controls on tree ring $\delta^{13}C$ are summer sunshine, temperature and water availability, and a decline in $\delta^{13}C$ would indicate falling temperature or rising precipitation, neither of which is true (McCarroll and Pawellek 2001). A reasonable explanation is that the trees have reached the threshold beyond which they are no longer able to respond to rapidly rising $CO_2$ levels by reducing stomatal conductance. The effect is that internal concentrations of $CO_2$ are rising and therefore $\delta^{13}C$ is falling. Published and unpublished results from several other sites in Europe and elsewhere suggest a non-linear response to rising atmospheric $CO_2$, and in each case the trend is from an active to a more passive response (Waterhouse et al. 2004).

## CONCLUSIONS

The trees of the northern forest have responded in an active way to the anthropogenic increase in atmospheric $CO_2$ levels. They have reduced their stomatal conductance to the extent that the ratio of internal to external $CO_2$ concentrations has remained near constant. The dominant effect is that trees have increased their water use efficiency, and the level of moisture stress has therefore declined. This long-term reduction in moisture stress may, in part at least, explain the widely observed reduction in the climate sensitivity of tree ring width and density measurements.

There is limited but growing evidence that the plastic response of trees to increasing $CO_2$ levels may be approaching a threshold. At many sites trees show a non-linear response, with $\delta^{13}C$ levels falling in a way that cannot be explained by changing climate. At some sites there is an abrupt change from constant to steeply falling $\delta^{13}C$, indicating that water use efficiency has ceased to rise and is remaining constant. If this is true then it suggests that the trees of the northern forests may be losing their tight control over their carbon/water balance, with profound implications for the carbon and hydrological cycles.

## ACKNOWLEDGEMENTS

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Polar Environment and Climate

# 2. Present changes and observations

# REPORT from CHAIRS

## Session on present changes and observations

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In Session 2, the five presentations addressed currently observed processes and changes in the atmosphere, at the air-sea boundary and in the ocean. The talks illustrated the significance of the polar regions for the whole earth system and the significant teleconnections that exist between high and low latitudes. All the presentations were based on intensive observation and all demonstrated limitations in the current state of knowledge in their areas for both polar regions.

Results for polar stratospheric ozone over the Arctic indicate that, though the Montreal Protocol is working, severe ozone loss is still occurring over the Arctic and formation of an Arctic ozone hole cannot be ruled out during the next two decades, with significant UV exposure implications for Europe. There is evidence that changes in climate as a result of greenhouse gas effects are affecting the Arctic ozone layer. Increasing cooling of the Arctic stratosphere over the past 40 years and the increased presence of stratospheric clouds, promoting increased ozone loss in winter, appears to be at least in part a function of greenhouse effects. However, the magnitude of the observed cooling cannot be simply attributed to the direct radiative effects of increasing greenhouse gas concentrations and suggests an as yet unknown dynamic feedback mechanism or some effect of long term climate variability. In addition, recent results suggest the known polar ozone loss processes are much less efficient than originally thought and it would appear that much of the observed Arctic ozone loss is due to an unknown process. Identifying and understanding this loss mechanism should be a priority.

In the lower atmosphere, polar meteo-rologists and climate researchers have been accumulating data and developing increasingly sophisticated models to interpret and predict polar weather patterns. Significant atmospheric processes such as the Arctic Oscillation or the North Atlantic Oscillation are well documented but still incompletely understood. Polar feedbacks and parameterisations are key processes in the global climate system. Current climate models indicate that the largest human induced warming will occur in the polar regions, but the limitations of these models are illustrated by the considerable variation in magnitude between model predictions. Data on the polar regions are still extremely scarce given their global significance, and this needs to be addressed through circum–polar synoptic data studies and a focus on understanding the feedbacks between natural, external and anthropogenic forcing factors. The complexity of the climate system needs more sophisticated atmosphere-ice-ocean coupled models that include components for aerosols, cloud schemes (and greenhouse gas release from Arctic permafrost). More field data and particularly knowledge of specific polar processes (e.g. cyclones) are also required to improve understanding of these highly dynamic processes. Polar climate modelling cannot be undertaken without reference to atmospheric processes located at lower latitudes and a synthesis of regional and polar processes is needed.

The interaction of atmosphere and ocean is evidenced in studies of the global carbon cycle. High latitude oceans, particularly the Southern Ocean, play a critical role in the uptake and biological sequestration of anthropogenic carbon from the atmosphere. The anticipated reductions in deep water formation related to slowing down of meridional overturning circulation could seriously impact this role. The evidence of increasing acidification of ocean waters due to $CO_2$ uptake approaching saturation levels will result in reduced ocean buffering capacity. These changes could result in a net positive feedback of the ocean carbon cycle to atmospheric $CO_2$. The low pH environment would also be catastrophic for organisms with calcareous exoskeletons such as pteropods, coccoliths and corals, especially those in cold oceans. There is a lack of detailed information on ocean-atmosphere gas exchange and on oceanic carbon cycling that compromises global modelling of the significance of polar oceans. Such data would also need to be put into context with the palaeo record.

The vast scale of heat and salt transfer northwards is a substantial influence on climate in the Northern Hemisphere and understanding the processes and multi-decadal changes requires intensive study of not only the Arctic Ocean but also sub-Arctic and North Atlantic waters. Currently, record high temperatures and salinity have been observed over the Scottish Shelf spreading along the eastern boundary to the Fram Strait; but these are still poorly parameterised and modelled so their significance is difficult to establish. At present it seems unlikely that the known fluxes of inflows and outflows for the Arctic Ocean will yield a balanced budget, suggesting as yet unknown transport processes. Studies are needed to measure all significant Arctic and sub-Arctic ocean fluxes at high resolution both simultaneously and long term, and the proposed integrating Arctic Ocean Observing System could address these issues. However it would need to be further integrated with meteorological observation programmes and with cryospheric observations (sea ice, ice sheets, permafrost).

During the past 20 years, there has been a significant linear trend of the Arctic sea ice shrinking by 10% and thinning by 40%. All three coupled climate models tested for the Arctic Climate Impact Assessment (ACIA 2004) indicate that by 2080 there would be no sea ice in the Arctic at the end of summer. The recent accelerated changes seem linked to complex Arctic weather patterns, to the heat input from thermohaline circulation and to cryospheric melt contributions. Whilst there are several possibilities for changes in Arctic heat flux influencing sea ice thickness, the scale of these parameters are at the threshold of existing observational capabilities. Meteorological studies do not yet adequately understand Arctic atmospheric processes and recent studies in the Arctic Ocean have revealed sub-surface super-cooled ice formation never previously observed which suggests our understanding of heat and salinity processes in Arctic waters is also far from complete.

All these presentations relate to European Union funded projects and therefore show a primary focus on the Arctic, though comments from speakers and the audience did recognise that the Antarctic has a similarly critical role in ocean circulation, carbon cycling and sea-level rise. The Arctic has greater immediacy for Europe due to its proximity and the rates of observed change. Whilst the polar regions have critical relevance to global processes, a lack of data as well as substantial gaps in our knowledge remain. Data sets need to be collected according to a coordinated pan-Arctic/Pan-Antarctic approach to provide the data needed to support more effective interpretation and modelling whereas focused detailed studies are required to gain an understanding of underlying mechanisms. Better integration of atmosphere, ocean and sea ice studies and data exchange are essential to make progress but there is relatively little evidence of vertically integrated studies in the polar regions. The significance of biological activities to these studies of ocean, atmosphere and sea ice was not emphasized. There is evidence of oceanic DMSO production influencing cloud formation, sea ice brines may contribute reactive brominated compounds to the polar atmosphere and biological communities will influence carbon fluxes. It was also pointed out that the meeting audience was somewhat imbalanced in terms of research area representation and this should be considered in interpreting the outcomes. The IPY is a very good opportunity to develop systems of monitoring/long-term observation, and data incorporation into models but Europe needs a longer term strategy for addressing polar observation and modelling.

# SPEAKERS

# Polar stratospheric ozone loss: current understanding and links to changes in climate

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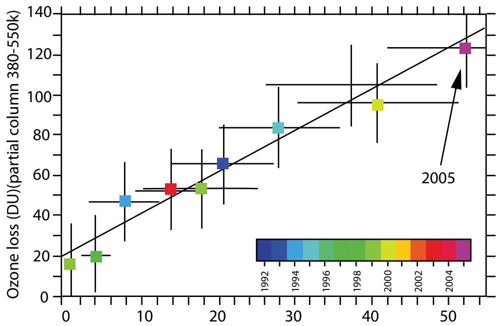
Large dynamic variability of the Arctic ozone layer makes it difficult to separate anthropogenic chemical ozone loss from natural variability. To precisely measure the rate of chemical ozone loss in the Arctic stratosphere we have developed the Match approach. The technique is based on the statistical analysis of a large number of 'matches'. A match is defined as a pair of ozonesonde measurements, where both sondes are launched to probe the same air parcel at different times, as it passes over the respective sounding site. To coordinate the launches of the sondes, calculated air parcel trajectories that take into account modelled diabatic subsidence rates are used to track and to forecast the motion of previously probed air parcels [e.g. Rex et al., 1997]. Match results, based on the coordinated launches of 600 to 1 400 ozonesondes per winter, are now available for most Arctic winters since 1991/92 and the Antarctic winter 2003. Additional Arctic and Antarctic Match campaigns are planned during the International Polar Year.

The chemical loss of column ozone for Arctic winters exhibits a near linear relation with the volume of air at temperatures low enough to support polar stratospheric clouds (VPSC) during each winter (Figure 1). The 2004/2005 Arctic stratosphere was exceptionally cold, particularly below 18 kilometers, leading to a value of VPSC 25% larger than the previous record value. Accordingly, column ozone loss in the 2004/2005 Arctic winter was the largest ever observed, in line with the relationship established for prior winters. These large losses during Arctic winter 2004/2005 contributed to low total column ozone over parts of Europe during March 2005.

**Figure 1. Ozone loss versus VPSC for years since 1992. The slope of the linear fit indicates that 15.6 DU additional ozone loss will occur per Kelvin cooling of the Arctic stratosphere (Rex et al., 2006).**



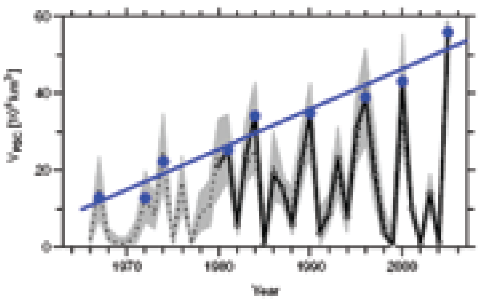

The slope of the relation between column ozone loss and VPSC provides an empirical measure of the sensitivity of chemical loss of Arctic ozone to changes in stratospheric temperature (for contemporary levels of chlorine and bromine) and provides an important metric for chemical transport models and coupled chemistry climate models that are used in both diagnostic and prognostic studies of polar ozone loss.

Figure 2 shows the evolution of VPSC since the 1960s, derived from stratospheric temperature analyses for the Arctic [Rex et al., 2006]. Over the past 40 years, the cold

Arctic winters became colder, resulting in larger values for VPSC. This long term change in the temperature conditions in the Arctic stratosphere is responsible for the large degrees of chemical ozone loss in the Arctic that were observed during a number of winters since the mid-1990s and which cumulated in record ozone losses in the Arctic winter 2004/2005.

The long-term data shown in Figure 2 relies on radiosonde analysis and is independent of the introduction of satellite observations or assimilation system changes. A linear fit through the solid points in Figure 2, which represents maximum values of VPSC for 5-year intervals, has a slope of 9.9+/-1.1 x 106 $km^3$ per decade, with very similar results if 4 to 10 year intervals are chosen to select the maximum values. It is unlikely (well below 1% probability) that this estimated tendency towards colder Arctic winters is a purely random event or is caused by inconsistencies in the meteorological data set [Rex et al., 2006].

**Figure 2. VPSC over the past 40 years from two meteorlogical analysis. Gray shading represents uncertainly, blue points maximum values during 5-year intervals (Rex et al., 2006).**




The change in temperature during the cold winters is qualitatively consistent with a general cooling of the stratosphere expected due to increasing levels of greenhouse gases. But it is considerably larger than expected from the direct radiative effect of increasing greenhouse gas concentrations. The reason for the magnitude of this change is not clear and it could be due to long-term natural climate variability or a currently unknown dynamic feedback mechanism.

In both hemispheres the observed rates of ozone loss are larger than can be explained by known stratospheric chemistry, based on current recommendations for kinetic parameters [Sander et al., 2006] and standard levels of stratospheric bromine [Rex et al., 2003]. However, calculated chemical loss rates of polar ozone substantially increase in models that assume: (1) a larger photolysis cross section of the $Cl_2O_2$ molecule (within the range of uncertainty of current laboratory studies of the cross section), which leads to more efficient ozone destruction by the ClO dimer cycle and (2) higher levels of stratospheric bromine, as has been suggested by recent measurements. These two changes result in overall good agreement between observations and theory [Frieler et al., 2006].

However, very recent progress in laboratory measurements now allow a much more reliable measurement of the $Cl_2O_2$ cross section. These measurements suggest that all previous studies were large overestimates [Pope et al., 2006]. These new results from the laboratory mean that the catalytic cycle that was so far believed to be the most efficient ozone loss cycle, the ClO dimer cycle, nearly shuts down and the second most efficient cycle, the ClO+BrO cycle, becomes much less efficient. Overall, calculated ozone loss becomes very small in model runs that are based on the cross sections from Pope et al. [2006]. These recent results suggest that we do have a fundamental lack of understanding of the chemical process that drives polar ozone loss.

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# *Observed and modelled polar climate: regional feedbacks and global links*

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## MOTIVATION

Arctic and The Antarctic are the cold poles of the atmospheric circulation and influence the global circulation through the meridional energy gradient between the tropics and the poles. Present climate models suggest that the largest human-induced warming will take place in the Arctic and the Antarctic, although there are considerable variations in the magnitude of the warming between the models. The temporal development of atmospheric circulation structures over years and several decades differs between different projections from the same model, suggesting large natural variations. Therefore, the challenge is to identify and model the important components of the climate system and to explore this in order to assess and predict changes in the Arctic and Antarctic climate system caused by natural and anthropogenic effects. Because of the complexity of the climate system, this research requires modelling and prediction studies that include interactions between the processes in the atmosphere, oceans, cryosphere, land surfaces and the biosphere encompassing time scales ranging from hours to centuries.

This approach includes improvements in global and regional models of the Arctic, especially in the physical parameterisation schemes for radiation, planetary boundary layer turbulence, clouds and aerosols. A key scientific focus is to clarify the robustness of Arctic climate change and the dynamic and thermal feedback processes responsible for the large climate variations. The projections of future climate changes are complicated by complex interactions and nonlinear feedbacks of the Arctic climate system with other parts of the world as a result of global teleconnections. For this reason, current estimates of future climate changes for the Arctic based on coupled Atmosphere-Ocean General Circulation Models vary significantly. The model results disagree as to both the magnitude of changes and especially the regional aspects of these changes.

The main goal of the EU funded GLIMPSE project (Global Implications of Arctic Climate Processes and Feedbacks) was to address the deficiencies in understanding the Arctic by developing, in concert with the ARCMIP (Arctic Regional Climate Model Intercomparison Project), improved physical descriptions of Arctic climate feedbacks in atmospheric and coupled regional climate models and to implement the improved parameterisations into global climate system models to determine their global influences and consequences for climate variations over several decades.

## EVALUATION OF AN ENSEMBLE OF HIGH RESOLUTION ARCTIC REGIONAL ATMOSPHERIC CLIMATE MODELS

Funding for coordination of ARCMIP activities is provided by the International Arctic Research Consortium, and the Global Implications of Arctic Climate Process and Feedbacks (GLIMPSE **http://www.awi-potsdam.de/www-pot/atmo/glimpse/index.html** project). The primary ARCMIP activities have focused on coordinated simulations by different regional climate models and their evaluation using observations from satellites and field measurements. The combination of model inter-comparison and evaluation using observations allows the assessment of strengths and weaknesses of model structures, numerics and parameterisations. The simulation experiments are carefully designed so that each of the models operates under the same external constraints (e.g. domain, boundary conditions). The ARCMIP experiment has been conducted for the 1997/1998 period of Surface Heat Budget of the Arctic Ocean, and included extensive field observations and accompanying satellite analyses. It has been described in Rinke et al. (2006).

## COUPLED REGIONAL MODELS OF THE ARCTIC CLIMATE SYSTEM

A coupled regional climate model of the Arctic climate system has been developed at AWI as described in Rinke et al. (2003) and Dorn et al. (2007). This coupled model is based on the atmospheric model HIRHAM, parallelised version, 110×100 grid points, horizontal resolution 0.5° and 19 vertical levels and the ocean–ice model NAOSIM, which uses MOM-2 with elastic-viscous-plastic sea ice rheology, horizontal resolution 0.25° and 30 vertical levels. The boundary forcing is based on ERA-40 data. A series of sensitivity experiments concerning the influence of sea ice parameters have been carried out with this coupled Arctic climate system model.

## GLOBAL IMPACTS OF ARCTIC FEEDBACKS CONNECTED WITH TELECONNECTION PATTERN

Recent observational studies of the Arctic region reveal significant changes in temperature, sea ice distribution, precipitation, permafrost distribution and other climate variables. In order to attribute these changes to internally generated and externally forced climate variations, a general understanding of Arctic climate variability in the context of global climate variability is necessary.

Sensitivity runs over 500 years with a fixed solar constant (1365 W/m$^2$) and $CO_2$ (353 ppm), and a new ice and snow albedo scheme for the Arctic has been carried out by use of the state-of-the-art coupled climate model ECHO-G. The Arctic sea ice coverage within ECHO-G improved, especially the minimum extend and area in summer. The global impact of improved Arctic sea ice and snow albedo leads to annular mode structures similar to the Arctic Oscillation as shown in Dethloff et al. (2006). This implies an influence on the meridional coupling between the energy sources in the tropics and the energy sink in the Arctic and would have strong implications for $CO_2$ scenario runs.

## DYNAMIC CHEMICAL FEEDBACKS BETWEEN THE TROPO- AND STRATOSPHERE

A new coupled Atmosphere-Ocean General Circulation Model (AOGCM) with simplified stratospheric chemistry, has been developed at the AWI Research Unit Potsdam (Brand et al. 2007). ECHO-GiSP ECHAM & HOPE-G including the Stratosphere, created by AWI research unit Potsdam, is based on an ECHO-G basic version (39 level up to 1Pa ~ 80km) provided by the Department of Meteorologie of the Free University in Berlin, and the MECCA chemistry module, developed at the MPI for Chemistry in Mainz. Two 125-year simulations of ECHO-GiSP were performed. These runs were carried out with fixed chemical boundary conditions. One run only included the dependence of chemistry on the model dynamics, the other also included the feedback, i.e. from the tracer concentrations back to the model dynamics via radiation processes. This led to changed zonal wind distributions and planetary wave patterns with influences on the Arctic Oscillation structure. These results indicate changes in the dynamical-chemical feedbacks between the tropo- and stratosphere.

## INFLUENCE OF IMPROVED PERMAFROST DESCRIPTION ON FUTURE CLIMATE CHANGES

A new land-surface model has been coupled with the regional climate model HIRHAM in the Arctic permafrost region taking into account six moisture layers in the soil as described by Saha et al. (2006, 2006a). The new coupled atmosphere-soil model has reduced the cold winter bias in the soil and improved also the summer 2m air temperature. The new land surface scheme has a significant influence on the future projection of the Arctic temperature, precipitation and mean sea level pressure.

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# The poleward spread of warmth through subarctic seas: achievements and challenges

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In the hundred years since Helland Hansen and Nansen (1909) first mapped-out the pathways of oceanic exchange between the North Atlantic and Arctic Ocean, we have made much progress in adding the two things that these early pioneers could not know: the amount of these fluxes, and the variability of the system. The oceanic fluxes of volume, heat and salt that pass north across the Greenland-Scotland Ridge from the Atlantic to the Arctic Mediterranean have now been soundly established by direct measurement under the EC VEINS and EC-ASOF/MOEN programmes, as have the corresponding fluxes to the Arctic Ocean (Ingvaldsen, Asplin, & Loeng, 2004 a,b; Schauer et al 2004). We now know that the 8.5 million cubic metres per second of warm salty Atlantic Water that passes north across this ridge carries with it, on average, some 313 million megawatts of power and 303 million kilograms of salt per second (Østerhus et al 2005). As it returns south across the Ridge in the form of the two dense overflows from Nordic Seas, its salinity has decreased from about 35.25 to 34.90 or less and its temperature has dropped from 8.5°C to 2.0°C or less. Not surprisingly, surrendering this amount of heat is of more than local climatic importance.

From our lengthening records, we find that multidecadal change has pervaded the whole full-latitude span of northern Atlantic, subarctic and Arctic seas over the entire 110-year period since Nansen's drift of the *FRAM*. In the present phase of this change, the temperature and salinity of the Atlantic Water flowing into the Norwegian Sea over the Scottish Shelf has never been greater in 100 years and, by piecing together our records, we can trace the spread of this recent extreme warmth along the eastern boundary to the Fram Strait and beyond.

Today's challenge lies in prediction. We glimpse a number of factors, processes and unknowns that will have to be assembled before we can move beyond the simple tracking of warmth poleward to the more exacting business of foreshadowing and explaining change from Atlantic inflow to its outflow to the Arctic. These include a) the possibility of a contributing influence from upstream hydro-variability in the Atlantic subtropics (Curry et al 2003); b) the influence of the Atlantic Sub-polar Gyre in feeding a changing subtropical/sub-polar mix of waters into the Arctic Mediterranean across the Greenland-Scotland Ridge (Hatun et al 2005); c) the transport, variability and forcing of the largely unmeasured offshore branch of the Norwegian Atlantic Current and its relationship (if any) to that of the inshore, long-Slope branch; d) the relationship between heat flux and transport in the Norwegian Atlantic Current off Svinøy and the Atlantic Multidecadal Oscillation (AMO) of Sutton and Hodson (2005; Skagseth et al 2007); e) the changing balance between local and remote factors in determining the warmth of inflow through the Barents Sea Opening (BSO); and f) the daunting business of measuring the heat transport through Fram Strait to the Arctic Ocean (ASOF-N Group) in the presence of large variability and strong recirculation. On the latter point, our most intensive observation effort in ASOF by A-W-I and NPI has pointed out the need for *high resolution* observations along the *entire* boundary, since Schauer (A-W-I pers comm) makes a compelling case that the variable oceanic heat transport through individual passages such as Fram Strait can only be determined with reference to the prevailing temperature of the compensating in/outflow through all other passageways to the Arctic Ocean. This, in turn, is a compelling argument for a simultaneous, pan-Arctic observation scheme as advocated by ASOF, and for the integrated Arctic Ocean Observing System (iAOOS) proposed for the IPY (Dickson 2006), whose major European contribution is the DAMOCLES Integrated Project of the EC.

# Carbon cycling at high latitudes — bottleneck for anthropogenic $CO_2$ and precursor to ocean acidification

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## INTRODUCTION

In contrast to the atmosphere, where $CO_2$ is a fairly inert gas, $CO_2$ reacts with seawater and dissociates in the ocean mainly into bicarbonate and carbonate ions. Therefore, the world ocean provides a much larger carbon reservoir than the atmosphere and the terrestrial vegetation including soils. The ocean is the ultimate long-term sink for anthropogenic carbon mainly from emissions due to fossil fuel combustion, land use/fires, and cement manufacturing. The ultimate marine $CO_2$ uptake capacity is determined by the availability of carbonate ions in the water column, which can also be mobilised from marine calcium carbonate sediments and can be supplied by river runoff from land. The biological carbon cycling (organic pump, calcium carbonate counter pump) modulates the physical and chemical carbon cycling if changes in ocean circulation, nutrient availability, and environmental conditions occur. For the marine uptake of anthropogenic $CO_2$, the physical and chemical carbon cycling is of first order quantitative importance, while the impact of marine $CO_2$ buffering will primarily affect marine organisms and ecosystems.

## THE OCEANIC CARBON SINK

Anthropogenic carbon is taken up by the oceans through air-sea gas exchange at the sea surface. This excess carbon is transported down to deeper layers by ocean circulation and mixing. This downward transport to the ocean depths and sea bottom takes place in the high latitude oceans where surface water is cooled and enriched in salinity during sea ice formation. This downward transport process of anthropogenic carbon is considered the 'bottleneck' for marine $CO_2$ uptake. The potential reduction in deep water formation anticipated by a slowing down of the oceanic meridional overturning circulation would narrow this bottleneck and lead to a net positive feedback of the ocean carbon cycle to atmospheric $CO_2$ (see, e.g. Friedlingstein et al., 2006), though the biological organic carbon pump itself would work a bit more efficiently during a slowing down of the general circulation. Currently, a decrease in the northern North Atlantic air-sea difference in $pCO_2$ is observed, raising the possibility of an ongoing decrease in total $CO_2$ uptake kinetics in the area (Omar and Olsen, 2006; Olsen et al., 2006). Water which is already saturated with respect to anthropogenic carbon will be advected into the Arctic Ocean. Reduced deep water production rates due to a retreat of sea ice away from shelf seas, a reduction in general ocean overturning, and an increased advection of already $CO_2$ saturated water from lower latitudes may contribute to an accelerating positive feedback to climate change. The Southern Ocean represents a very large volume of seawater and hence also a large inorganic carbon inventory. Current estimates about the anthropogenic carbon content in the Southern Ocean water column are difficult to assess due to the high degree of dilution and the large variability (Cant from different methods).

## OCEAN ACIDIFICATION

Uptake of anthropogenic $CO_2$ by the oceans is leading to a change of the in general slightly alkaline ocean towards more acidic conditions (i.e. the anthropogenic $CO_2$ in the ocean causes the marine pH value to sink). Due to the temperature dependency of the inorganic marine chemistry system and the vertical mixing at high latitudes, the negative pH change in surface as well as deep waters is first seen at high latitudes (Orr et al., 2005). While the occurrence of ocean acidification is virtually certain, we are only beginning to estimate in detail the potentially severe consequences for marine ecosystems (Raven et al., 2005). These consequences will be most severe at high latitudes, where the pronounced seasonal cycle can lead to high amplitudes in surface ocean $pCO_2$ and pH, and associated extreme values.

## HIGH LATITUDE PROCESSES AND PREDICTIVE MODELLING

In order to make a reliable prediction of the anthropogenic carbon sinks at high latitudes and the impacts as well as feedbacks due to ocean acidification, we need a quick understanding of the associated processes and their upscaling in coupled physical-biogeochemical models. Times series stations for measurement of physical, chemical and biological variables would be needed to monitor the ongoing changes and to calibrate models for more reliable predictions of the quickly changing polar regions.

## ACKNOWLEDGEMENTS

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# *Will the Arctic sea ice disappear in summertime in the foreseeable future?*

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## INTRODUCTION

The consensus of coupled atmosphere-ocean models under scenarios of increasing greenhouse gas forcing, is that anthropogenic global warming will be enhanced in the northern high latitudes due to complex feedback mechanisms in the atmosphere-ocean-ice system. The predicted magnitude of warming in the Arctic over the next 50 years is ~3-4°C or more than twice the global average. This suggests that the Arctic may be the location where the most rapid and dramatic changes (e.g. a shrinking sea ice cover and a glacial meltdown) may take place during the 21st century. Recent synthesis reviews of fragmentary observational evidence taken together provide a reasonably coherent portrait of Arctic change, indicating that the last 2-3 decades have experienced unusual warming over northern Eurasia and North America, reduced Arctic sea ice, marked changes in Arctic Ocean hydrography, reduced glaciers and snow cover, increased runoff into the Arctic and thawing permafrost. There have clearly been significant advances through observations and models in recent years. However there remain many key uncertainties concerning the fundamental processes underlying Arctic climate system changes in the past, present and future and how to model them, the spatial-temporal characteristics of Arctic climate change and the bio-geophysical and socio-economic consequences for Europe.

Many of the fundamental processes of Arctic climate dynamics are not fully understood. For example, the Arctic warming in the recent decades has coincided with decadal-scale anomalies in atmospheric phenomena such as the North Atlantic Oscillation NAO, which affects temperature, precipitation and storm patterns in Europe. The NAO appears as part of the broader Arctic Oscillation AO – the Northern Annular Mode (NAM) of atmospheric circulation variability – that involves changes in the strength of the atmospheric polar vortex, characterised by strong troposphere-stratosphere coupling. There is evidence of other modes of atmosphere-ocean-ice variability in the Arctic, but neither their spatial-temporal characteristics nor linkages to the NAO/AO and teleconnections to extra-tropical regions, have been determined. Moreover, mesoscale processes and their feedbacks (e.g. those governing fluxes at the atmosphere-ocean-ice interface) are neither well-quantified nor well-represented in models.

During the past 20 years, important changes have been observed in the Arctic Ocean. The most spectacular concerns the mean thickness of sea ice which, according to large-scale surveys (SCICEX) carried out during the 1990s by US nuclear submarines equipped with upward looking sonars (ULS), has decreased by as much as 40% over large areas of the central Arctic basin (Rothrock et al., 2003), one of the most drastic changes in our environment reported in recent years. Half of the Arctic Ocean is usually covered with sea ice at the end of the summer just before the next winter (freezing) season begins. This is mainly due to a fresh water lid originating from Arctic river run-off which insulates sea ice from the deeper, warmer and saltier water masses of Atlantic origin beneath. This insulation effect is reinforced by a cold halocline layer located at a shallower depth above the Atlantic layer. The origin of this cold halocline, and its spatial, seasonal, inter-annual variability are all matters of active research (Rudels et al., 1996, Steele and Boyd 1998). Several elements of variability have been observed occurring concurrently in the ocean and in the atmosphere, such as (1) a strong correlation (>0.9) between the length of the summer melt season (from 60 days to 80 days) and changes in sea ice thickness between consecutive winters (1994-2001) as shown by Laxon et al. (2003); (2) large intrusions of Atlantic water in the Canadian basin (Schauer et al 2002); (3) a retreat of the cold Arctic halocline from the Eurasian basin (Steele and Boyd 1998); and (4) an amplification due to synchronicity of the so-called decadal Arctic Oscillation (AO) and the inter-decadal low frequency (LFO) North Atlantic Oscillation (Polyakov and Johnson 2000) characterised by (a) a decrease in sea level pressure (Walsh et al., 1996); (b) an increase in air surface temperature (Rigor et al., 2000); and (c) changes in wind regime from anti-cyclonic to cyclonic (Proshutinsky et al., 1999). However, nothing is as dramatic as the Arctic ice pack thinning from more than 3m on average to less than 2m over a large part of the central basin of the Arctic Ocean. Observations supported by models, indicated a sustained decrease of mean sea ice thickness from the late 1980s until the mid 1990s by as much as 10 - 15 cm/year in the trans-polar drift, but there is no reliable statement allowing us to extrapolate this decline into the future. This is in contrast with the five models selected by ACIA (among many more models considered by IPCC). All five models predict a quasi disappearance of the Arctic Multi Year Ice in 30 - 50 years from now. The level of confidence for this kind of prediction is still low. Models and observations still are at odds on time and space variability of the Arctic ice pack and associating both models (including model intercomparison) and observations is highly stimulating work. DAMOCLES aims to address the need to gather synoptic data about the entire system including ice draft, ice drift, ice area and concentration, sea level pressure and surface air temperature, inversion layer in the lower atmosphere and halocline layer in the upper ocean, advection of heat and salt (fresh water) by ocean currents, heat advection versus convection by winds and surface albedo. It is necessary to monitor the air-sea ice fluxes not only across the air-snow-ice-ocean interfaces, but also across the atmospheric and oceanic boundary layers and from the inversion layer in the lower atmosphere down to the cold halocline in the upper ocean. Air temperature inversions close to the surface are typical of Arctic regions. These inversions have important implications for energy exchanges between the surface atmospheric boundary layer and the lower troposphere. Over the past 20 - 30 years, radiosonde data have shown that surface air temperatures have increased as much as 0.25°C per year and inversion depths have decreased as much as 20 metres per year north of the Arctic Circle. This might be due to a number of factors such as increased low cloud cover, greenhouse gases or warm air advection from lower latitudes. In the ocean, the cold halocline plays a major role because of its powerful effect in disconnecting the surface fresh and cold polar mixed layer from the underlying warm and salty water masses of Atlantic origin. The efficiency of the halocline in limiting heat exchanges with the underlying warm water, which is the only source of heat for the Arctic, is mainly due to the fact that the salinity gradient (the halocline) is located well above the main thermocline and heat exchanges across the main thermocline are decoupled from heat exchanges within the surface mixed layer. Past observations have shown a weakening and shallowing of the cold halocline in the central basin of the Arctic Ocean, enhancing the ocean vertical flux of heat and contributing to sea ice melting (Steele and Boyd 1998). Assuming that the cold Arctic halocline originates from the Arctic shelf seas when brine-enriched water masses are produced during winter following sea ice formation, is the halocline structure weakening due to less sea ice formed on Arctic shelves in winter? There are other possibilities tied to the different potential origins for the Arctic cold halocline such as winter convection (Rudels et al 1996) and/or Arctic intermediate water mass formation near the ice edge or near the polar front (Steele and Morison 1995).

Concerning dynamics, the motion of sea ice influenced by surface winds and surface currents and the deformation of the ice pack under stress, strain and shear, are strongly related to sea ice thickness distribution. This is a key parameter for all modelling aspects and a challenging issue as far as observations are concerned. Sea ice thickness distribution influences the rate of heat input to the atmospheric and oceanic boundary layers. Heat losses from open water are two orders of magnitude higher than those over perennial ice, which means that 1% of open water within the ice pack would correspond to half of the heat loss by the ocean to the atmosphere. Also, the pack offers much less resistance to compression when a substantial amount of open water and very thin ice are present. Consequently, the two extremes of thin ice and thick pressure ridges have to be carefully examined for sea ice thickness distribution, and this is a major challenge for all Arctic Ocean observing systems. Arctic Ocean conditions are affected by large-scale climate variability and change (e.g. NAO/AO) and the Arctic Ocean itself plays a major role concerning the surface energy and freshwater budgets, and it exports a significant amount of freshwater into the North Atlantic in areas of deep water formation such as the Greenland, Irminger and Labrador Seas, from where a significant part of the global oceanic THC is driven. Therefore, we need to improve our understanding of the large-scale circulation in the Arctic Ocean and the Fram Strait as well as dense water convection on the continental slopes. Moreover, in order to understand, parameterise and predict large-scale variability in the Arctic Ocean and its impact on climate, one needs to take explicitly into account a number of typical meso- and small-scale processes that dictate how properties (e.g. heat, salt, momentum, nutrients, tracers and pollutants) are transferred throughout the entire Arctic marine ecosystem. Again, one of the most intriguing results comes from numerical models which tend to predict a reduction by 80% of Arctic sea ice during summer by the end of this century, while during winter the now-seasonally ice-covered Barents Sea will be ice free. How reliable is this kind of prediction?

Would the Arctic Ocean be free of sea ice in the summer like the Antarctic Ocean and should Arctic perennial sea ice be listed among endangered species as predicted by all large-scale climate models? At the moment this is hard to tell but it is easy to understand that this represents a challenging and urgent question for the scientific community and also for society, since it would certainly have a huge impact on the northern hemisphere and global climates. There is a range of important potential bio-geophysical consequences and associated socio-economic impacts of a shrinking ice cover. Therefore, it is essential that we improve our abilities to model and assess these changes and their impacts during this century.

## DAMOCLES

The Arctic Ocean Observing System (DAMOCLES) specifically calls for large-scale (basin), long-term and synoptic observations at high resolution and accuracy compatible with qualitative model requirements (AOMIP, ARCMIP). This has direct implications for observations involving autonomous instrumentation operating over long periods of time and adapted to the harsh and remote polar environment. The DAMOCLES concept is designed in part from the knowledge and the 'know how' acquired during previous successful Arctic experiments such as the International Arctic Buoy Programme (IABP) and the Surface HEat Budget of the Arctic Ocean (SHEBA). DAMOCLES will use very innovative technology to merge what we have learned from these programmes into a multi-year, basin-scale fully integrated approach. Like IABP, DAMOCLES will provide long-term, continuous and reliable sets of observations over a large domain of the Arctic Ocean, but also it will measure at dedicated places all relevant parameters along the vertical, and across several critical, layers and interfaces starting from the inversion layer in the lower atmosphere and the atmospheric boundary layer, then across sea ice and the upper ocean mixed layer down to the cold halocline. The DAMOCLES will continuously operate 12 ice-tethered platforms inside a vast domain (500 000 km$^2$) of the central Arctic basin. DAMOCLES will make extensive use of Ice Profiling Sonars on neutrally buoyant floats for measuring sea ice thickness distribution over a large domain of the deep central Arctic Ocean encompassing the trans-polar drift and the Beaufort gyre. This system will be maintained throughout the entire International Polar Year (2007-2008). ULS will be adapted to autonomous underwater ballast controlled floats using SOund Fixing And Ranging (SOFAR acoustics) for long-range navigation under ice. In addition, DAMOCLES will also maintain all the monitoring effort across Fram Strait initiated during the VEINS and ASOF EU funded programmes. The Fram Strait monitoring array will be upgraded by using the novel Sea-Gliders technology under ice in cooperation with APL (Seattle UA, PI C. Lee) which is actually operating sea gliders in Davis Strait. It is quite clear that DAMOCLES will have to rely extensively on new technology to reach the main goal of a fundamental understanding and reliable prediction of Arctic Ocean variability. Finally, DAMOCLES will rely on large scale surveys from icebreakers across the whole Arctic Ocean. Mainly conducted during the summer season once a year, such surveys aim to: (a) service and reset the DAMOCLES autonomous array from year to year and (b) complete in situ data collection, in particular hydrology and water samples for tracers analysis including Arctic shelves in combination with other programmes (SEARCH, NABOS, SBE etc.)

DAMOCLES should operate all year long and for several years in a quasi autonomous mode. The DAMOCLES project will be implemented around eight tightly linked Work Packages. The first three WPs are dedicated to the observations both in situ and from space (remote sensing) of key Arctic climate parameters characterising respectively sea ice, the atmosphere and the ocean. WP1 led by DAMTP and FIMR concerns sea ice and four main tasks including sea ice thickness, sea ice categories, sea ice dynamics and sea ice mass balance. WP2 led by FIMR and the University of Hamburg concerns the atmosphere and three main tasks: the Atmospheric Boundary Layer (ABL), Arctic cyclones (polar lows) and Arctic clouds, radiative fluxes and surface albedo. WP3 led by NPI and AWI concerns the ocean and four main tasks: the northward transport of warmth to the Arctic, the transport of heat, fresh water and sea ice across Fram Strait, water mass transformation on the shelves (Barents Sea) and brine formation, the Shelf-Basin Exchanges and circulation in the central basin, and the return flow. These three WPs are strongly linked to WP4 led by SMHI, NERSC and Met.no. WP4 is very central to the DAMOCLES project. It is dedicated to data assimilation in various models (climate models and NWP forecasting models) and data integration before being transferred to data access and dissemination. WP6, led by the Norwegian Meteorological Institute, will directly collect data (level 1) from WP1, WP2 and WP3. Level 1 data correspond to the initial data processing (cal/val) occurring in each of the three WP1, 2 and 3 in charge of data acquisition. WP4 assimilating data from WP1, WP2 and WP3 in climate and forecasting models, will be used for dealing with impact scenarios in WP5 which is led by IMR and FIMR. WP7 led by NERSC and CICERO will be in charge of the DAMOCLES public outreach, training and education activities, contact with end-users and networking for international cooperation. Due to the very innovative technology developed in the context of DAMOCLES, WP8 (led by AWI and NERSC) will be entirely dedicated to hightech instrumentation and in particular to underwater acoustics used for long-range navigation (low frequency transducers) and high data rate transmission (HF acoustic modems). WP8 will also be the place to deal with heavy logistics (icebreakers), aircraft (helicopters) and ice camps. Two manned camps on drifting ice will be contributing to DAMOCLES during the IPY: TARA Arctic sea ice camp during a two year (2006-2008) Nansen-like voyage across the Arctic Ocean and the trans-polar drift on a Russian NP 35 ice camp in 2007-2008.

The research proposed in DAMOCLES requires large and multi-disciplinary resources that can only be mobilised by a joint effort of a broad European consortium which includes all the major polar research institutions in Europe. The main activities will include: (1) collection, analysis, integration of synoptic and new high resolution data sets concerning sea ice (WP1), the lower atmosphere (WP2) and the upper ocean (WP3) over a large domain of the Arctic Ocean and Subarctic Seas; (2) field experiments with deployment of new in situ observation systems based on very innovative high technology (WP8) in underwater acoustics for long-range navigation and short-range data transmission (ice profiling sonars on floats, acoustic modems for underwater data transmission between various platforms, sea glider profiling through the water column for measuring temperature and salinity (sea gliders are also used shuttle shuttle data between floats and surface transponders linked to satellites); (3) use of new satellite remote sensing (Cryosat WP1); (4) use of state-of-the-art assimilation and climate models (WP4) as well as regional forecasting models (NWP) and process-oriented models (HELMI, WP1); (5) state-of-the-art data bank (formatting and archiving), access and dissemination (WP6); (6) exchange programmes for 5 scientists and training and education for students during summer schools (WP7); (7) coordinated dissemination (public outreach, end-users WP7) and exploitation activities.

The results of DAMOCLES will be important for socio-economic issues such as impacts (WP5) on ecosystems and fisheries: sea transportation, $CO_2$ cycle, human living conditions thanks to a very significant improvement in our ability to predict extreme climate change affecting both the atmosphere (AO/NAO amplification) and the ocean (MOC/THC shutdown), and resulting in extreme weather events (storm tracks shifts, intensification of polar vortex and polar lows). DAMOCLES will be implemented by a consortium of 48 partners including eight SMEs and 40 main Institutions from 10 European countries including 2 partners from new Member States (Poland and Estonia) and also four partners from the Russian Federation over a period of 4 years. The overall objectives of DAMOCLES are to make systematic observations of atmospheric and oceanic parameters in the Arctic and subarctic domain, including those of sea ice, so as to improve forecasting of the Arctic marine and atmospheric environment, consolidate long-term observations for the modelling and in particular prediction of extreme climate events, establish common European databases and contribute to international programmes (IPY/iAOOS, ISAC/SEARCH, WCRP/CliC). The research will focus on development of advanced observation and forecasting systems involving very innovative high performance technology specially adapted to ice-covered oceans, extending the ARGO system as far north as the Pole.

The DAMOCLES programme of activities carried out under Sub-priorities 6.3 ‘Global change and Ecosystems’ will strengthen the necessary scientific basis, including socio-economic assessments and tools and management practices, for the future orientation of the European Union strategy for sustainable development. DAMOCLES will provide a cross-cutting dimension between sustainable development and energy and transport sub-priorities as defined by the European Council, by specifically including impact studies in the general framework of the programme (WP5). DAMOCLES will also contribute to strengthening the scientific and technological capacities needed for Europe to understand the processes controlling global change, and thus to preserve the ecosystems and protect biodiversity in Arctic and Subarctic regions.

DAMOCLES will also contribute significantly to the objectives of the European Environmental Technologies Action Plan, as well as to the objectives of the European Strategy for Environment and Health by reinforcing competitiveness. DAMOCLES will contribute to the implementation of socio-economic assessments and tools and management practices in phase with the future orientation of the European Union strategy for sustainable development at the enlarged EU level by the inclusion of two new member states (Poland and Estonia) in addition to eight other European member states and at the world level due to an extensive international cooperation with the US and the Russian Federation. DAMOCLES will be a main vector for developing international cooperation and achieving common strategies to respond to global change issues.

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# ATTENDEES

## Downslope processes, deep ventilation and meridional overturning circulation

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The processes governing the continental shelf break and deep ocean interactions are crucial to an understanding of the global climate system. In particular, downslope processes, deep ocean ventilation and meridional oceanic overturning circulation control the main exchange between the Southern Ocean and the Atlantic, Indian and Pacific Oceans. However, the Southern Hemisphere is often given too little weight in our analyses and this leads to an underestimation of the role of these processes in global climate evolution at the right time scale.

### IMPORTANT PHYSICAL PROCESSES

The thermohaline cell (THC) of the global ocean is the major mechanism contributing to control the global radiation budget, leading to major climatic changes (Bigg & al., 2003). The classical view of this circulation is that deep convection processes during winter of either polar hemisphere produce dense, cold, saline waters that flow towards the equator and slowly well up. This global circulation also acts as an important control on nutrient circulation and hence on biogeochemical aspects. Even if this general picture is still accepted, all of its components are undergoing significant change, particularly the THC engine. The convection arm of the THC is driven, in fact, by two mechanisms. One is buoyancy loss at the sea surface in the open ocean caused by cooling (Marshall and Schott, 1999; Gascard & al., 2002). The second mechanism acts through densification by salt release during sea ice formation or sub-ice shelf accretion, typically on the continental shelf. Dense plumes are formed and then slide down the continental slope. This process occurs all around the Antarctic coast (Orsi & al., 1999) and particularly in the Weddell and Ross Sea, to form the majority of Antarctic bottom water, that later spreads out into every major deep basin.

During the last decade, some PNRA (Programma Nazionale Ricerche in Antartide) and USAP (United States Antarctic Programme) expeditions focused on mesoscale processes along and across the Ross Sea continental shelf break. The major efforts were to study the interactions between overflow process and the incoming Circum-polar Deep Water (CDW). However, the influence of the new shelf water production mixing across the shelf break, and the Antarctic Bottom Water (AABW) formation, as well as its influence on the Antarctic Circum-polar Current (ACC) and the Southern Pacific arm of the global THC, are crucial to understanding global climate variability. Besides, past data analysis showed climatic change over several decades (Jacobs & Giulivi, 1998, 1999), acting on critical salinity values of the thermohaline structure of the Ross Sea that could, therefore, have consequences both on the AABW formation and on the global circulation.

Focused on temporal ranges of $10^1$ - $10^2$ years, new studies (Italian Polar DOVE Project) explore geochemical signals 'fixed' in mineral (e.g. calcium carbonate) or proteic skeletons of selected organisms, mostly benthos. The new studies also address water masses, as well as the whole data set of physical and biological observations. The water variability in water masses is indeed tied to variations of their attributes (e.g. salinity and temperature) which later become geochemical signals that can be coded once incorporated by tracing organisms. Isotopic and elemental chemistry of carbonate, whether formed as the shell of an organism or through abiotic chemical reactions, captures a record of the temperature and chemistry of the fluid from which it was formed; as such, carbonate chemistry serves as an important proxy for deciphering the earth's history. In near shore waters of the Ross Sea, one of the most conspicuous carbonate building organisms is the endemic scallop *Adamussium colbecki* (Chiantore et al., 2001). This bivalve is not the only useful organism to be checked as a proxy to evaluate oceanographic variability within a polar context. In fact, it is important to recognise other organisms equipped with a calcareous skeleton along the track of Antarctic shelf water flow. In particular, stable isotope profiles of shell carbonate have recently been applied to identify the bivalve's annual growth pattern, as well as those of other Antarctic invertebrates (e.g. Marshall et al., 1996; Brey and Mackensen, 1997). Stable oxygen ratios ($\delta^{18}O$) are inversely related to temperature. Hence lower $\delta^{18}O$ characterises shell parts deposited during spring/summer, whereas higher values correspond to parts formed during autumn/winter.

From the oceanographic point of view, the Victoria Land area, near Terra Nova Bay (TNB) where *Adamussium* are present in large number, is characterised as a source of HSSW dense enough to flow northward and trigger downslope processes to the abyssal depths. Moreover, it also ventilates the Ross cavity, contributing to Ice Shelf Water (ISW) formation. These are super cold waters, characterised by a temperature below the surface freezing point, originating below the Ross Ice Shelf (RIS). The interaction leading to the melting and freezing in different areas produces plumes that outflow in particular positions along the RIS edge. This process can trigger important exchanges between the open ocean, interacting with the atmosphere, and the ocean cavity, which can have a longer memory of past conditions. The AABW production becomes, therefore, a critical factor in regulating the variability of a branch of the THC which regulates, and is also regulated, by the Earth's climate.

At the same time, in order to understand the dynamic behaviour of the interactions between the Ross Sea and the Southern Ocean, a globally nested, fully implemented dynamic-thermodynamic sea ice model (Regional Ocean Modelling System, ROMS) was implemented to explore the effects that decadal climate forcing variability may have on the general circulation of the Ross Sea, downslope processes and deep ocean ventilation. The adopted grid consists of 208 by 288 horizontal points (average horizontal resolution of 10 km) and 33 levels in the vertical. The area was modelled by means of a one-way nesting with a larger area model in order to receive appropriate boundary conditions. Preliminary results from a short retrospective period using ERA40 atmospheric forcing data have shown the formation of two strong tongues sinking from the continental shelf break off of Cape

Adare. Different dynamic behaviour was found in the correspondence of the small differences in water mass characteristics. While the saltier one, coming from Drygalsky Basin, was able to trigger a cascading a-geostrophic downslope event, falling 2 000 meters , the eastern one, a little bit less salty, exhibited a geostrophic adjustment reaching 800 meters in depth.

## THE NEED FOR THE NEXT STEP

At present, Southern Ocean processes are relatively poorly observed, described, simulated and understood. This is due to technological and logistical problems, but also we need long time series (multi centennial time scales) with high resolution (at least seasonal). The correct time scales of observations and modelling are urgently needed for the scientific community and also an integrated Observing and Modelling System will be an essential component for enhancing our understanding. Such a modelling system should focus on multi-decadal to centennial time scales but with a seasonal resolution.

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# The Southern Ocean: an integral part of the global climate system

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The Southern Ocean is an integral part of the global climate system through its roles in the meridional oceanic overturning circulation, in the global radiation budget and in the uptake of $CO_2$. Ice-shelf ocean interaction affects the ocean freshwater budget and has potential, through the restraint which ice shelves impose on discharge from the Antarctic ice sheet, to influence sea level. However, the large distance from the Southern Ocean to densely populated areas in the Northern Hemisphere often leads to an underestimation of its influence. The design and implementation of a Southern Ocean Observation System is urgently needed to improve understanding and the ability to forecast global change at multi-decadal to centennial time scales.

## SOUTHERN OCEAN PROCESSES

The Southern Ocean plays a significant role in global climate. Heat loss to the atmosphere and fresh water gain by precipitation and melting of icebergs and shelf ice, as well as differential formation and melting of sea ice, determine the stability of the water column. Enhanced sea ice formation in polynyas on the Antarctic continental shelf forms deep and bottom waters which are dense enough to sink to the abyssal depths and drive the descending branch of the global meridional overturning circulation. An ascending branch of the present day meridional overturning circulation is also located in the Southern Ocean where upward sloping surfaces of constant density reach from the deep to the upper ocean layers. These processes are related to the Antarctic Circum-polar Current (ACC) by a balance of wind forcing, eddy formation and stratification. South of the ACC, Circum-polar Deep Water penetrates into the sub-polar gyres and supplies heat and salt into intermediate layers which reach the surface mixed layer in the Antarctic Divergence through mixing. The ACC, the largest ocean current on Earth, provides a link between the other major ocean basins. The large seasonal variability of Antarctic sea ice extent affects surface albedo and the global radiation budget. But heat flux from the ocean limits the thickness of Antarctic sea ice, and the sea ice characteristics that result from this have consequences for the ocean atmosphere exchange of trace gases (including $CO_2$) and heat.

The Southern Ocean contains a highly diverse ecosystem which is at present only slightly exploited. On decadal to centennial time scales, global climate change is affected by Southern Ocean processes, and climate change in turn affects the physical and ecological conditions in the ocean.

The flow of ice from the Antarctic sheet into the ocean occurs mostly in ice streams which feed into floating ice shelves. It is still unclear to what extent the ice shelves buttress the ice flow from the continent to the ocean and hence the discharge of grounded ice: this may be a major control of the amount and speed of sea level rise. The fate of the ice shelves depends on both surface conditions and ocean interaction at the underside of the shelf. Both melting and refreezing processes occur beneath ice shelves, although melting dominates and is a major factor in the eventual loss of ice from the ice sheet. In a warming world, the warming ocean might dominate processes of ice shelf stability. Increased freshwater input to the ocean from ice shelf and iceberg melt will also affect ocean stability and the overturning circulation. Potential changes to ice melt due to global warming require thorough investigation. The sudden collapse of the Larsen B Ice Shelf on the east of the Antarctic Peninsula had effects on both glacier discharge and on the ocean circulation. There is also renewed concern about the stability of the West Antarctic Ice Sheet (WAIS). The WAIS may respond dynamically to even a small additional ice melt, with accelerated glacier discharge leading to a dramatic global sea level rise of several metres.

## THE DESIGN OF A SOUTHERN OCEAN OBSERVATION SYSTEM

At present the Southern Ocean is relatively poorly observed. This is due to both the technological challenges of observing a vast and partly ice covered ocean, and the small number of coastal states that directly adjoin the ocean. Consequently, Southern Ocean conditions are still not well represented in global observations and modelling. Future changes to the climate system, and their impacts can only be properly assessed in the global context, and the Southern Ocean gap in the global coverage of observations has to be closed. A Southern Ocean Observation System (SOOS) is required one that makes appropriate use of new technologies (autonomous observation platforms, sophisticated new satellite systems, etc.) and methods have to be found to apply these technologies to provide sustained observations, integrated with a true comprehensive hierarchy of nested models.
The Southern Ocean Observation System is urgently needed because there are indications of recent changes in the region. For example, the near-surface Sub-antarctic Mode Water, which lies north of the Antarctic Circum-polar Current, has warmed since the 1960s, and Southern Ocean mid-depth waters have also warmed in recent decades. There is also evidence of change in Antarctic Bottom Waters with decreases in salinity over the last four decades in the Ross Sea and in the Australian-Antarctic Basin Antarctic Bottom Waters. These changes need to be observed more accurately and investigated to develop a sound basis for understanding and for prediction. A Southern Ocean Observation System will be an essential component of an Antarctic observation system.

Measurements and models to assess Southern Ocean processes are only in their infancy. Comprehensive measurements of ocean properties, including sea ice and ice-shelf ocean interaction, are required at spatial and temporal resolution adequate to detect regional and seasonal variations respectively. These must be made in combination with high resolution modelling of the ocean circulation. Together these will allow identification of the impact of global scale variations on the Antarctic region, and the feedback of Southern Ocean changes to the global system. Measurements have to include remote sensing and insitu methods, and some key areas have yet to be determined. The efforts undertaken during the International Polar Year 2007/2008 will provide a platform on which we can design and implement a Southern Ocean Observation System that will provide observations into the future.

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# Multi-decadal ozone and UV climate in the European Arctic

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## INTRODUCTION

The atmospheric ozone layer protects all life on land from lethal solar UV radiation. Its thickness – which is equivalent to its shielding function depends on geographical location, as well as atmospheric chemistry and dynamics. After the late 1970s, a dramatic seasonal attenuation was observed in the polar regions – first in Antarctica (Farman et al., 1985), and later in the Arctic (e.g., Hansen et al., 1997, Rex et al., 1997) – which was ascribed to the man-made release of chlorofluorocarbons in the atmosphere. The large natural variability, both on a seasonal and an inter-annual scale, and its possible contribution to long-term trends, was not investigated before the end of the 1990s. For this purpose, multi-decadal measurements series, which were started before the era of large-scale CFC emissions in the early 1970s, are of great value. Combined with meteorological observations (cloud cover), they also can be used to derive long-term UV climatologies by means of radiation transfer modelling (e.g. Engelsen et al., 2005).

## THE DATA SETS

The total ozone series from Tromsø and Svalbard belong to the longest data series of this parameter in the world and are the longest from the polar regions. The Tromsø series, based on Fery spectrograph and Dobson spectrophotometer, was started in summer 1935 and was continued almost uninterrupted until the summer of 1972. It was re-started in 1985 and continued until 1999. Since then, it has been continued at the nearby site of Andøya with a Brewer instrument. The complete dataset was re-analysed and homogenised (as far as possible) in recent years, and investigated by means of multi-linear regression (Hansen and Svenøe, 2005). The much more fragmented Svalbard series stretches from 1950 to 1968 (Vogler et al, 2006) and again from 1984 until today.

In order to derive UV climatologies, one ideally needs daily values of total ozone and cloud coverage. In the case of the Tromsø series, almost complete time coverage was achieved for total ozone by including satellite data (BUV, TOMS, ODIN) and ground-based data from Murmansk in the 1970s. A gap in the Svalbard data could not be filled in the same way; data are missing from 1973 to 1978. Cloud data (visual cloud fraction in octals) were taken from Skrova, Lofoten, Norway, as an example of a North-Norwegian coastal site, and from Hopen Island, Svalbard, as a typical high Arctic site. An empirical calibration of the calculated UV daily doses was performed by comparing them with measured doses in 1997. A more comprehensive description of the method is given in Engelsen et al. (2005). The UV climatology for Svalbard is only preliminary, as it does not yet include a proper representation of surface albedo. Figure 1 shows, as an example, UV-B and

UV-A monthly doses at Skrova, as well as total ozone for April, while Figure 2 gives April mean noon dose rates for Hopen Island.

## DISCUSSION AND OUTLOOK

Both sites are inside the region where severe Arctic ozone depletion occurs in some years. The month of April is most sensitive from an ecosystem point of view, as some of the most important processes, e.g. the algae bloom and the Northeast Arctic cod spawning take place in this period. At the same time, the sun reaches an elevation at which the UV radiation may have a significant impact, especially if the ozone layer is strongly attenuated due to chemical ozone destruction. This occurred, among others, in the years of 1993, 1995, 1997 and 2000.

Figures 1 and 2 show that although the ozone layer development has been similar at the two sites, with an overall negative trend in spring, the UV trends are different. In northern Norway, both UV parameters have had a positive trend in the last sixty years, most pronounced in the UV-B spectral interval which is due to the decrease in total ozone. But also the UV-A dose, which is mainly influenced by cloud cover, has shown a statistically significant increase.

At Hopen Island, the positive UV-B trend to be expected from the decrease of total ozone is more than compensated by a marked increase of cloud cover, so that the UV-B trend is slightly (not statistically significant) negative. The UV-A trend, on the other hand, is very significantly negative, with all-time low values occurring after the year 2000. This trend may continue or even increase, as the sea ice coverage in the area around Svalbard has decreased dramatically in recent years.

However, also at Hopen Island, occasionally high UV-B levels occur, such as in 1997, when the stratospheric polar vortex persisted until the end of April. In northern Norway, the highest doses occurred in 1993, 1997 and 2000, years with severe ozone depletion and a higher number of days with little cloud coverage.

Future work will focus on an improvement of the radiation modelling tool to include a proper representation of surface albedo and multiple scattering effects which can be significant in the Arctic. We would also like to focus on studies of 'hot spot' events, i.e. years with especially high radiation levels compared with minimum radiation level years, to better quantify the potential influence of radiation, in combination with other pressure factors, such as climate change, on Arctic ecosystems.

**Figure 1. Monthly UV-A (dotted line) and UV-B doses for April, based on cloud data from Skrova and total ozone data from Tromsø. Thin lines: linear trends. UV-A divided by factor 500. Red line: total ozone (x 600).**

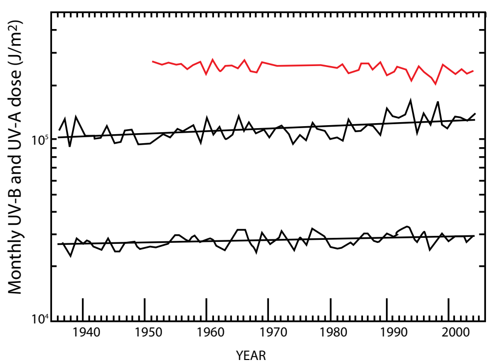
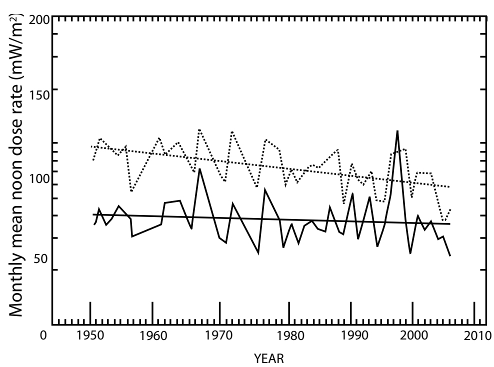



**Figure 2. Monthly mean UV-A (dotted line) and UV-B noon dose rates for April, based on cloud data from Hopen and total ozone data from Longyearbyen/Ny-Ålesund. Thin lines: linear trends.**



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# *ACCO/Net — Arctic Coastal Observatory Network — a truly international EU-led effort to investigate the physical and social impact of climate change on Arctic coasts*

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Human habitation, migration and resource use in the north occurs mostly along the Arctic coastline. This environment is sensitive to changes in sea level, sea ice and air, and the thawing of permafrost. Coastal erosion, often exceeding 1m/yr (Lantuit and Pollard, 2007) has been shown to threaten northern communities' infrastructures, and to contribute significantly to the Arctic Ocean carbon budget (Rachold et al., 2000). Resource access and availability are directly impacted by these changes as well. The ACCO/Net project is a timely contribution to the study of coastal erosion along permafrost coasts, aiming at gaining information about one of the longest stretches of coastline in the world, yet one for which studies and funding have been scarce. Researchers from seven countries are working along the entire circum-polar Arctic coastline to establish a network of observatories to monitor changes in the Arctic coastal zone. This includes monitoring changes in coastal erosion, sea ice cover, wave action and the temperature and response of the permafrost. ACCO-Net efforts during IPY create a baseline for future coastal monitoring.

## RATIONALE

The coastal zone is the interface through which land-ocean exchanges in the Arctic are mediated and it is the region of most high-latitude human activities. The coastal margin hosts a complex interaction of marine, terrestrial and atmospheric processes that are extremely vulnerable to predicted environmental changes and anthropogenic stresses.

These high-latitude coasts are typically dominated by permafrost and suffer from rapid erosion with serious implications for ecosystems and communities (Arctic Climate Impact Assessment (ACIA) – key finding #5). Furthermore, changes in inputs of water and constituents (nutrients, sediments, dissolved inorganic matter and contaminants) from major Arctic rivers have the potential to fundamentally alter biogeochemical cycling and productivity in the coastal zone and in the Arctic marginal seas (continental shelves).

Longer term changes in the Arctic coastal zone include the inundation of the land surface following glacial cycles. As a result, relict permafrost underlies large areas of the current Arctic Sea shelves, although little is known about its distribution and state. Gas hydrates are stabilised by the permafrost, which may additionally serve as a cap on onward migration of gas through the sediment. It appears that near-shore processes, such as bottom-fast ice formation, are critical in determining changes in permafrost temperature and degradation due to salt water penetration (Rachold et al., 2007).

Changes in the Arctic coastal zone, including coastal erosion and riverine fluxes, will not only affect regional biological and human systems, but are also likely to influence the global system. For example, degradation of coastal and offshore permafrost may lead to the release of greenhouse gases (GHG), and increases in freshwater inputs may alter regional as well as large-scale ocean circulation and climate patterns. To detect and quantify trajectories in coastal/shelf systems, their components and transformations must first be monitored.

A coordinated monitoring programme incorporating diverse regions and providing site-specific, fine-scale baseline and time-series data will yield maximum value, facilitating local and circum-Arctic studies, such as validation of multi-scale biodiversity and coastal community models.

## ACCO/NET

To address these issues, an internationally coordinated circum-Arctic network of coastal and marginal sea observatories (42 key sites including deltas and estuaries of major Siberian and North American rivers) was established within the IPY 2007-2008 framework based on ecoregion representation criteria and on keysites established under the Arctic Coastal Dynamics (ACD) programme. The sites will be loci for multi-disciplinary, multi-resolution studies set within a broader eco- and socio-regional frame of reference and will include sensitive areas with varying degrees of human impact. Site investigations will be coordinated with local communities and will build upon existing monitoring programmes and data availability. In particular, ACCO/Net will build upon a successful application at the European Space Agency, providing high resolution imagery from its 42 sites across the Arctic. It will be integrated within the International Permafrost Association (IPA) and IPY data management systems.

**Arctic Coastal Observatory Network spatial distribution. The 42 coastal sites are part of the successful ESA ACCO/Net IPY application.**

ACCO/Net is also striving to involve the next generation of European scientists by relying on the Permafrost Young Researchers Network (PYRN), the largest young researcher network in the world of cryospheric science, to provide a continuum between young and senior scientists. The 42 coastal sites are part of the successful ESA ACCO/Net IPY application.

## CONCLUSION

While coastal erosion on permafrost coasts is a topic of prime importance because of its direct physical and societal impacts (removal of churches, schools in communities, threats to industrial infrastructures) as well as its significant contribution to the global carbon cycle, it remains a largely unstudied and unfunded topic in the research realm because it falls under several science fields (geomorphology, oceanography, modelling, social science, etc.).
We therefore strongly advocate raising the profile of fields of science that focus on the impact of climate change on polar regions, because these impacts act as considerable feedback sources for the climate system.

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# On the amplified Arctic warming

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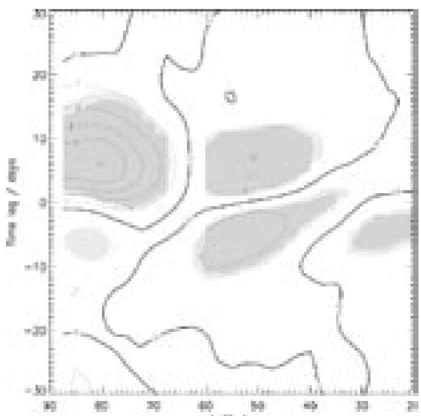
Arctic temperatures are increasing at a rate about twice that of the global mean temperatures (cf. e.g. Serreze and Francis 2006). Several hypotheses have been put forward to explain this so-called Arctic amplified warming (e.g. ACIA 2004), however, there is still no consensus to what feedback mechanism is primarily responsible. One important reason for this lack of understanding is a paucity of observations, especially of the vertical structure of the Arctic atmosphere and of processes involving clouds.

## 1. WHERE AND HOW IS THE ARCTIC WARMING?

**Figure 1. Zonal means of the regressions of the SAT field on the ANET across 60°N at different time lags. The regressions have been scaled by the standard deviation of all regressions. Light and dark shading indicates significance on a 99% and 99.9% level, respectively**



A number of hypotheses have been put forward to explain the Arctic amplified warming (e.g. ACIA 2004). With the exception of one, changes in atmospheric meridional heat transport associated with changes in the global atmospheric circulation, these hypotheses all relate to processes at the surface: sensitivity to lower troposphere stability, small surface evaporation, heat fluxes from the ice-free ocean etc. The most widely spread hypothesis is that of the so-called snow-and-ice albedo feedback. In this, a warming reduces the surface albedo by melting of snow and ice, which increases absorption of solar radiation and causes an enhanced warming at the surface. A particular problem when evaluating these hypotheses is the lack observations, especially in the central Arctic, prohibiting an analysis of the spatial structure of the Arctic warming and cause-and-effect analyses. We thus know very little about how the warming is distributed, horizontally and in particular in the vertical.

Advanced reanalysis data provides a means around this limitation. Using data from the ERA-40 reanalysis (Uppala et al. 2005) we study trends in Arctic temperature as a function of the meridional Atmospheric Northward Energy Transport (ANET, Graversen 2006). Figure 1, as an example, shows the regression of the near Surface Air Temperature (SAT) on the meridional energy transport across 60°N for the period 1979-2001, at different time lag. It is clear that enhanced energy transport in the atmosphere is followed by elevated SAT in the Arctic north of that same latitude, some 5 days later. It is worth noting that the warming through this process is distributed throughout the Arctic including the central Arctic Ocean. This is in contrast to that which can be associated with the Arctic Oscillation (AO, Thompson et al. 2000), which is mainly confined to the northern parts of the continents, mostly over northern Europe and Siberia. Moreover, the increasing trend in AO during the late 20th century has been broken and replaced by more neutral values since the late 1990s, while the ANET continues to increase. It is also worth noting that nothing restricts the impact of meridional energy transport to the surface; one may as easily expect to find the associated warming effects in the free troposphere.

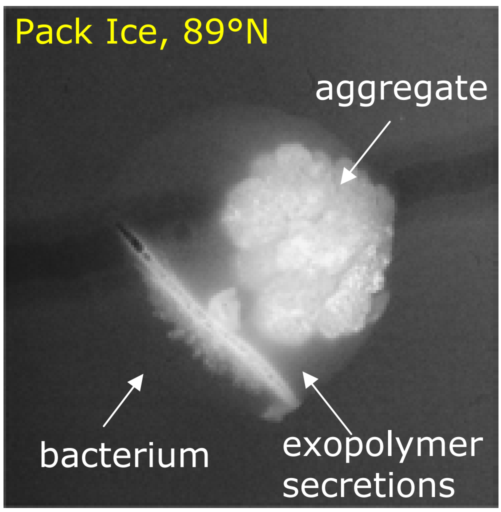
## 2. ARCTIC SUMMER CLOUDS

Trend analysis shows that during some seasons, as much as 15-20% of the Arctic warming can be attributed statistically to the increased atmospheric meridional flux of energy across 60 °N. Thus while changing large-scale atmospheric circulation can explain part of the Arctic amplified warming, there is still a need for further feedback mechanisms to explain the entire warming. Feedback effects from clouds remain one of the most important but also difficult issues in understanding the Arctic climate system. In the summer Arctic, persistent low-level stratocumulus clouds dominate (Intrieri et al. 2002; Tjernström et al. 2004). In contrast to mid-latitude stratocumulus, these clouds have a warming influence on the surface (Tjernström 2007). While reflecting solar radiation their albedo is similar to that of the surface, but they do increase incoming longwave radiation at the surface. Thus even large changes in the surface albedo due to the melting of the sea ice will not necessarily affect the radiative forcing of the system as a whole. Only a few percents increase of the cloud albedo is sufficient to offset changes in the system albedo due to melting pack ice. It follows that small changes in the radiative properties of the clouds may be critically important to the Arctic climate.

Such changes can come about due to changes in cloud microphysics. Each cloud droplet is initiated as a small aerosol particle, called cloud condensation nuclei (CCN). Due to the isolating effects of sea ice, reducing natural production of aerosols from the ocean surface, and the remoteness of the area, reducing impacts of anthropogenic aerosols at least in summer when solar radiation is important, summer clouds in the Arctic have relatively low cloud droplet number concentrations (Heintzenberg et al. 2006) and thus a low albedo compared to similar clouds at lower latitudes: few large cloud droplets generate a lower albedo while many, and consequently smaller, droplets give brighter clouds, with a higher reflectivity.

We have found a previously unknown natural source of aerosols in the central Arctic Ocean. We found biological material in aerosols, coming from the surface film on the water in leads within the melting pack ice (Figure 2, Leck and Bigg 2005). These particles are presumably injected into the atmosphere as film drops. When becoming airborne they are comparatively large and can act as CCN relatively directly; they also provide surface area for condensation of oxidation products from dimethyl sulfide advected from the open ocean to the south (Lohman and Leck 2005). While other factors may control particle mass, these particles control the CCN number concentration and thus the optical properties of clouds. This may provide a biogenic feedback: as the ice melts in a warmer climate, biological activity becomes larger and therefore the local CCN production. This could provide a potential negative feedback on climate change.

**Figure 2. Electron microscope picture of biogenic aerosol particle from the open water of a lead in the pack ice.**



## 3. SUMMARY

Arctic climate change is faster than for any other region on Earth, but in spite of significant attention over the last decades, we still do not understand well the reasons for the apparently high climate sensitivity of this region. There are at least two important reasons for this. First, there is a lack of high-quality monitoring observations of the whole system; for large parts of the Arctic observations are only carried out at the surface and the network is not very dense. Second, several feedback mechanisms appear unique to the Arctic, and there is a need to better observe these in order to build a sufficient understanding to include these in our climate models. Both these tasks have to be addressed in an environment that presents particular technical and logistical challenges for any kind of observation.

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Polar Environment and Climate

# 3. Future climate & modelling

## *REPORT from CHAIRS*

# *Report from the session on future climate & modelling*

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Models are necessary to make projections of future climate change in polar regions and for predicting climate effects on living conditions, animal life, and vegetation. Models incorporate a range of processes representing the current state of understanding of the science. All the existing climate models include at least a minimal representation of physical processes, such as the horizontal and vertical transport of heat and water, the formation and melting of sea and land snow and ice, the radiative properties of the earth surface including the clouds, greenhouse gases, and aerosols. Some of the newest climate models also include a representation of atmospheric chemistry, particularly the transformation of greenhouse gases and the evolution of stratospheric ozone. Finally, only about ten coupled models have included an interactive carbon cycle. Most of the more complex biological and soil processes are entirely missing.

Whereas climate models reproduce the global trend in surface variables reasonably well (e.g. temperature, winds, precipitations), they are difficult to evaluate in polar regions. Observations are typically much shorter and the coverage far less in polar regions, spanning at most a few decades, compared to over 150 years for direct surface temperature measurements at the global scale. Furthermore, polar regions show much interannual and decadal variability because of the presence of ice and snow cover, which makes the detection of trends more difficult.

The session on future climate and modelling conveyed a general impression that coupled models currently include only an incomplete representation of polar processes, and that they are not adequately evaluated in polar regions. The processes which need to be considered or improved include (i) the dynamical changes in ice and snow and how these can potentially accelerate global warming, (ii) the feedbacks with the biosphere and soils, particularly regarding emissions of greenhouse gases from frozen soils, and (iii) the representation of natural variability which can then be extracted from the climate projections to improve estimates of human-induced trends. However, the processes above are only partially understood, and further theoretical developments or experimentation are needed. It was pointed out that the potentially important effects of the Greenland Ice cap have not been included in the models so far.

As long as the models cannot be better constrained by observations in polar regions, it will be difficult to say if the representation of polar processes in models is complex enough to accurately project future changes. To improve model evaluation, both the mining of past data and the deployment of instrumentation to capture current changes are needed.

Climate changes are enhanced in polar regions because of the interactions of the ocean-cryosphere-atmosphere system. Thus the influence of polar regions on global climate can be large. Coupled models would improve both their regional and global projections of climate change by improving their representation of polar regions, including its physical, chemical, and biological processes.

## SPEAKERS

# Ranges of uncertainty in polar climate over the past and coming decades

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Estimates of past and future climate are inherently uncertain for a number of reasons, some of which are most acute in the polar regions. This paper presents a discussion of estimates of the uncertainties in our estimates of past and future climate. This discussion is centred around computer models of the climate system, which are an essential tool for these estimates. The concentration is on temperature, partly because it is a very relevant measure of polar climate, and partly because it is the most studied quantity; uncertainties in estimates of changes in other variables tend to be considerably larger. Uncertainties in Arctic climate do not appear to be large enough to mask a recent and future warming, while the situation is more ambiguous over the Antarctic where observational coverage is very sparse.

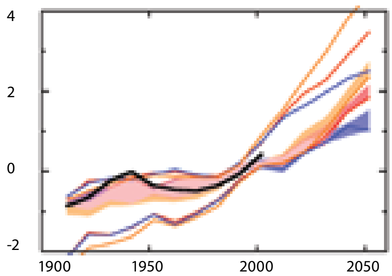
### OBSERVING CLIMATE

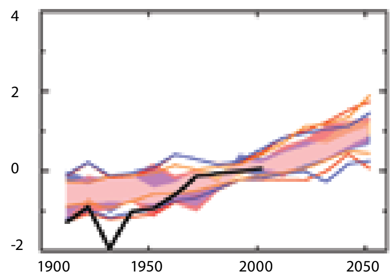
What we have been observing over the past century is not the climate but rather the weather, i.e. the particular trajectory our world has taken in the past and current climate space (Allen, 2003). Time averaging can reduce the noise if we are concerned about long term mean climate change but not if we are concerned about more rapid changes, after a volcanic eruption, for instance, or about variability.
Additionally, our past observations are incomplete, especially over the polar regions. For instance, only about 20 meteorological stations have been recording temperatures south of 60ºS since 1960 (Brohan et al., 2006). This issue is illustrated in Figure 1. The red lines show an estimate of the climate from model simulations if data is taken from the simulations only when and where observations exist, while the yellow lines show the estimate if all data is taken. This not only produces uncertainty in our knowledge of observed past climate change, but also in our projection of future change because our current point of reference is not clear. By the 2050s the difference between these two definitions affects warming estimates in the Arctic by 0.5-1.0ºC.

### MODEL FORMULATION

We must use numerical models of the climate system both to project future climate changes and to understand past changes. These models solve equations representing physical (and increasingly chemical and ecological) processes of the atmosphere, ocean, sea ice, land ice, land surface, and vegetation on a global spatial grid at consecutive moments in time. Some processes are not fully understood, while other processes cannot be fully resolved by models using current computing resources; thus, they must be represented in a simplified way. Some uncertainty in the use of such simplifications is captured in the differences between the simplifications

**Figure 1: Time series of decadal average temperatures over the Arctic (left, north of 60ºN) and Antarctic (right, south of 60ºS) over the 1907-2056 period. Anomalies in ºC from the 1977-2006 average are shown. The black line denotes observed values (from the HadCRUT3 dataset of Brohan et al., 2006, http://www.hadobs.org). The pairs of coloured lines denote the approximate 5th-95th percentile ranges of 21 simulations from 8 models (from the WCRP CMIP3 multi-model database, https://esg.llnl.gov:8443/index.jsp). The red and yellow lines show data from historical and SRES A1B scenario simulations, with data used for the red lines being masked according to the availability of observations in the HadCRUT3 dataset (with perpetual 2006 coverage into the future) while the data used for the yellow lines is not masked. The blue lines show data from historical and SRES B1 scenario simulations masked according to the observations. Shaded bands are identical to the line pairs except that data is restricted to 5 simulations from the MRI-CGCM2.3.2 model.**




used by the various models around the world. Unfortunately though, we have no rigorous way of knowing if the range of simplifications spanned by current models truly encapsulates these uncertainties. Fortunately, large- scale spatial and temporal patterns of temperature changes appear quite robust across models, allowing the application of observational constraints on the less robust amplitudes (Stott et al., 2006); how far this extends to smaller spatial scales and other variables is actively being investigated.

The issue of model formulation is particularly important for the polar climates because processes important for the evolution of ice and its role in climate, such as leads, crevasses, and melt puddles, are only metres across. Such features can dramatically alter the radiative, energy, and moisture properties of the surface. We can see this importance in Figure 1. The coloured bands represent the range of 5 simulations from one particular climate model only, identical otherwise to the ranges marked with like-coloured line pairs. Over the Arctic, the bands from the single model cover only a small portion of the ranges covered by all of the models.

## EXTERNAL FORCING

A number of factors have been and will be affecting global and local climates. Uncertainties in some of these, such as historical changes in atmospheric concentrations of greenhouse gases, are well constrained (Ramaswamy et al., 2001). Others are not so well known, however. Because various modelling groups use various reconstructions of these past external forcings, some of the uncertainty is represented in the ranges shown in Figure 1.

The selection has not been coordinated across modelling groups though, so the sampling is probably biased.

In the future, how political, economic, and technological advances will translate into emissions is poorly understood. Figure 1 shows the spread of climate model simulations following two popular 'business as usual' scenarios of future greenhouse gas and sulphate emissions. Differences in the warming do not become substantial for another few decades. None of these simulations include the effects of sporadic volcanic eruptions, leading to an underestimate in the width of the future climate plume.

## INTERPRETATION

Finally, there is the question of how to interpret the output from climate models. The useful output has a course spatial resolution. Nesting a higher resolution regional model inside the global model alleviates the problem, but still questions remain for instance on how a model's interpretation of precipitation compares with a station's interpretation. Statistical downscaling is another option, but it depends on remaining within the confines of past climate.

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# *Climate variability and climate change in the Arctic region*

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Human-induced climate change is projected to become particularly severe in the Arctic, mainly because of the many non-linear (and strengthening) feedbacks within the ocean-cryosphere-atmosphere system. At the same time, and probably for the same reasons, the Arctic climate shows strong natural variations in time scales from years to decades. It is also likely that multi-decadal and longer variability modes exist, but it is difficult to quantify those because of the relatively short and incomplete records from instrument readings.

It is possible that in the near future, the combined effect of global warming and a positive phase in the natural variability may impose hitherto unknown stresses and threats on the Arctic communities, infrastructure and biodiversity. It is, therefore, of critical importance to reduce the uncertainty of future climate projections, to understand the mechanisms behind the natural climate variations, and to assess whether and to which extent the natural variations may be altered in a warmer climate.

Furthermore, changes in the Arctic may also influence the climate globally, and particularly in the northern hemisphere. Such an influence may take place through atmospheric teleconnections or through oceanic processes. For the latter, southward advection of fresh water from enhanced precipitation and melting of snow and ice plays a major role.

The presentation will focus on the ocean component of the northern high-latitude climate. The implications of both poleward heat flux anomalies, originating from variations in the strength and extent of the North Atlantic sup-polar gyre, and fresh water anomalies originating from the Arctic, will be discussed. In addition, changes in temperature, sea ice extent, sea level pressure, sea level, etc. will be given for a business-as-usual climate scenario that goes beyond the 21$^{st}$ century, illustrating the effect of the positive climate feedbacks in the region.

The presentation is partly based on the EU-funded project *DYNAMITE* .
http://dynamite.nersc.no

# *Modelling climate variability and climate changes in the Southern Ocean*

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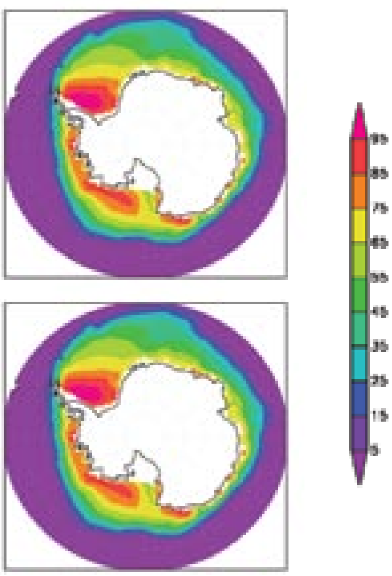
Averaged over all the model simulations performed with atmosphere-ocean general circulation models (AOGCMs) for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4), the current climate is reasonably well reproduced (e.g. Arzel et al. 2006, Lefebvre et al. 2007, Figure 1). This shows that there is apparently no systematic bias in the models. However, this averaging procedure hides the errors from individual models that are quite large in this region. In particular, the majority of the models present strong regional biases, overestimating the ice extent in some regions of the Southern Ocean and underestimating it in others.

**Figure 1. (a) Observed annual mean ice extent over the period 1979-2004 (Rayner et al. 2003 and updates); and (b) Same for the average of 16 AOGCMs**

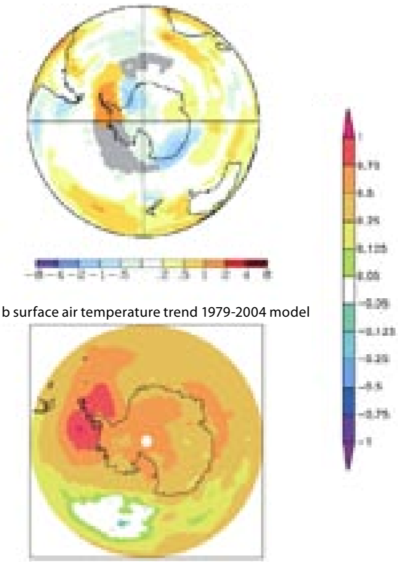
a

b



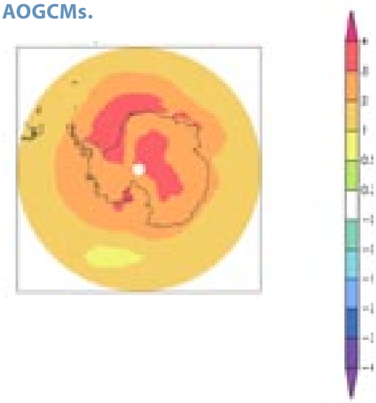
Over the late 20th century, the multi-model average simulates a stronger warming around the Antarctic Peninsula compared to other regions, which is in qualitative agreement with observations (Figure 2). This is probably related to the positive trend in the Southern Annular Mode (SAM) index over the 20$^{th}$ century, in both observations and in the multi-model average (see for instance Gillet and Thompson, 2003, Arblaster and Meehl, 2006, Miller et al. 2006). The simulations also generally display a decrease of the ice extent in the Southern Ocean over the 20$^{th}$ century (e.g. Arzel et al. 2006). Because of the large inter-annual variability, the trend is generally not significant if only 30-year time series are analysed. Model results are thus consistent with the absence of any trend in the extent of Antarctic sea ice observed over the years 1978-2004, corresponding to the period for which we have good observation data with which to compare model. On the other hand, the decreasing trend of ice extent becomes clear longer term in the majority of the models. Longer time series of ice extent would thus be of particular interest for a relevant model data-comparison and to precisely analyse the role of the various processes responsible for the observed stability of the ice extent in the Southern Ocean during the past several decades.

**Figure 2. (a) Observed surface temperature trend (K) integrated over the period 1979-2004 (http://data.giss.nasa.gov/gistemp/, Hansen et al., 1999); (b) Same for the average of 16 AOGCMs.**




At the end of the 21st century, all the models simulate a clear warming and a decrease of the annual mean ice extent, ranging from less than 1 $10^6$ $km^2$ to more than 5 $10^6$ $km^2$ for scenario A1B. In those projections, the amplitude of the seasonal cycle of the ice extent tends to increase in the Southern Ocean, although this increase is less strong than in the Arctic. Despite the simulated positive trend in SAM during the 21st century (e.g. Miller et al. 2006), no regional warming around the Antarctic Peninsula is seen in the multi-model average projected temperature. The maximum warming is indeed located over the continent and over the Weddell Sea (Figure 3). In this latter region, the warming is associated with a large reduction of the ice cover in the multi-model average. Another large reduction of the sea-ice cover can be found in the Amundsen-Bellingshausen Seas. Individual simulations generally display larger disparities between the responses of the various sectors of the Southern Ocean. However, no robust regional signal could be found in the various models. As a consequence, at this stage, the more or less annular temperature rise and decrease of the ice extent as given by the multi-model average should be considered as the most likely projection of future changes in the Southern Ocean.

**Figure 3. Difference in annual mean surface temperature (K) between the period 2071-2100 and 1979-2004 in scenario SRES-A1B. averaged over 16 AOGCMs.**



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# Future changes in snow, ice and frozen ground — a modelling challenge

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Although polar climate conditions have been monitored and studied with great enthusiasm and increasing frequency since the times of the heroic exploration expeditions, there are still many aspects of the polar climate which are less well observed and understood when compared to the temperate climate. Most of this discrepancy is due to the remoteness of the regions to most humans and certainly due to the harsh climatic conditions themselves, which still challenge field activities and the generation of reliable long term observations. With the dawn of the satellite era this changed somewhat, but even when observed from space the polar regions are well known to offer special problems related to the interpretation of remotely sensed data. Given this, it comes as no surprise that modelling of these conditions is a challenge in itself, yet even more so, if projected changes due to global climate change are to be modelled with credibility in these cold areas. The question is, however, could we model polar climate reasonably well even if we had good measurements and reliable long time observations of everything we needed for model validation? A simple answer cannot be given right away, but perhaps we would be able better to identify why our efforts are often facing large discrepancies between observed and modelled conditions. Part of the challenge actually comes from the fact that polar climate is synonymous with periods exhibiting extreme cold conditions and a very pronounced seasonal cycle illustrated by the contrasting conditions between the dark and long polar winter night and fascinating bright polar summer. The difficulty comes from this strong seasonality involving the phase transition of water from liquid to solid form and vice versa. Water in the climate system is in itself a challenge to model with credibility everywhere, but when it comes to the strong feedback processes involved in the phase transition coupled to the dynamic climate system consisting of atmosphere, hydrosphere, cryosphere, ocean, and biosphere this becomes an almost insurmountable challenge.

Modelling climate change has traditionally been looked at as a so-called delta change approach: we model the present climate state and then we make a simulation of the future, either for a new equilibrium state or with a transient change, in which all the time lags are included, at least in principle. The next step is to compare the climate of the two periods and analyse the difference. This is an approach which works well for most regions of the globe, and it has the virtue that many systematic model biases tend to cancel out this way. A good example is the relatively good agreement between coupled GCMs in simulating the global temperature under the assumption of a particular future emission scenario. When normalised to a common period, the systematic errors do cancel at the planetary scale. In the polar regions, however, this is less obvious. The amplification of global warming in the Arctic is the result of a non-linear feedback from reduction in snow cover and sea-ice retreat, which allows the 'white stuff free' surfaces to absorb substantially more incoming solar energy. Therefore, great accuracy is needed in simulating present day conditions of snow and ice in order to give credible information about the likely change in a warmer world. In other words, if the model has too much sea ice or snow on the ground for present conditions, the signal of warming is likely to be much larger than in a model with less ice and snow, if their climate sensitivity is comparable. This indicates that an uncritical use of all available GCMs for climate change studies in the Arctic is problematic. The fidelity of the model in the Arctic must be acceptable if such exercises are to make any sense.

Recent observations, as well as modelling efforts, indicate that polar climate variability and change on a century long time scale need to include processes that so far have been more or less neglected in climate models. Ice sheets, such as in Greenland and Antarctica, are exhibiting changing behaviours, e.g. fast moving ice streams, that seem to indicate that these processes cannot be ignored anymore in order to have a reasonably complete description of polar climate, and models therefore need to address this. Regions covered by permafrost are not well-described by climate models that only include a shallow soil layer rarely deeper than 3-5 metres to interface with the atmosphere. Soil processes in permafrost soils may need to be described to a much greater physical depth in order to address the phase transition of water, when infiltrated in complex soil textures. Last, but not least, the carbon cycle in the polar regions and in the Arctic in particular is only starting to be understood at the process level, and there is a long way before we can claim that models are giving a fair representation of what really happens. However, in this case we certainly need an even better understanding of the carbon cycle itself, before the models can become truly useful.

# 4. Session on human and wildlife health

# *REPORT from CHAIR*

## *Session on human and wildlife health*

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The morning session addressed an array of interrelated topics on human and wildlife health, on fertility, on waterborne or airborne contaminants present in the diet and on mammal borne zoonoses. Whenever relevant, the topics were related to climate change.

### THE PRESENTATIONS

The first presentation was by *Pál Weihe* and *Philippe Grandjea*n and treated *Human Implications from Exposure to Mercury and PCBs in the Arctic*. The examples were mainly drawn from studies on the Faroe Islands. In the Arctic and Sub-arctic regions, humans are more exposed to mercury and to PCBs than anywhere else in the world, in particularly so when traditional food plays an important role in the diet. For more than twenty years studies of Faroese child cohorts have been carried out. The studies document that harmful effects from mercury are irreversible to the exposed persons. In particular, the central nervous system suffered permanently in areas like memory, attention and language. The project has a high media coverage and is followed with great interest by the population.

Then followed a presentation of *Northern Aspects of Mammal Borne Zoonoses* by *Heikki Henttonen* who based his presentation on research on Nordic reindeer herding and rodents as carriers of zoonotic infections to man. Reindeer are of huge local importance economically as well as socio-culturally. Reindeer are also vulnerable to many illnesses and parasite attacks, some of which are transmitted to their herders. Studies so far show that the recent years' increase in temperature influences the Arctic landscape and the composition of animals – like the recent documented change in rodent dynamics. The increasing temperatures not only invite new diseases and parasites, but stimulate prolonged cases of already existing diseases.

The third presentation was by *Pim Leonards* and dealt with *Exposure of Brominated Flame Retardants in the Arctic Food Chain*. Some BFRs are persistent, lipophilic, toxic and bio-accumulate. Moreover, their presence is increasing in the aquatic environment. A comparison of BFR concentrations in the marine system from The Netherlands to Spitsbergen shows a decrease in concentration the further north samples were taken, but the later years have seen a growing amount of BFRs – also in the northernmost regions. It also appeared that some animals like polar bears are able to degrade some of the BFRs in their thyroid system. The paper suggested that further research on food, genetics and reactions to pollutants should be initiated.

Jens Peter Bonde & Gunnar Toft gave the last paper in the morning session. This paper was on *Environmental Contaminants in Polar Regions and Human Reproductive Health*. The presentation referred to comparative studies of the influence of persistent organochlorine pollutants on human reproductive powers. The regions involved were Greenland, Sweden, Poland and Ukraine. The focus of the studies was couple fertility and male reproductive functions. The comparisons revealed a remarkable difference between, on the one hand, Inuit men and, on the other, the Swedish, Polish and Ukrainian men with regard to sperm chromatin integrity and sperm DNA damage. Here the Inuit appeared to be more robust to PCB exposure. The results so far called for further studies of genetics and diet.

## TOPICS FOR A FUTURE RESEARCH AGENDA

Common to all four papers was the demonstrated move forward from the traditional single-string cause-effect analysis. All speakers pointed to the need for more encompassing research questions.
Among the research questions for a future research agenda the following five topics were singled out:

- The interrelationship between genetics and diseases.
- Human and wildlife/domesticated animals' response to pollutants and in particular studies on pollutants' capability to affect health and fertility. This topic should be closely monitored in time covering several generations.
- Impact of contaminants on immunity.
- Dynamics in interactions: climate change versus diseases, parasites and the like.
- Pollutants' interaction: how do pollutants interact with each other? What are the effects of mixtures of contaminants in live organisms (whether human, birds, fish or other animals).

The listed questions are not confined to polar studies, contamination and climate change is an emerging issue and the questions are of global relevance. All four presentations identified urgent research needs.
Their questions for the future research agenda do contain huge cutting edge research potential due to the *focus on the interplay of multiple factors* and to the implicit invitation for the *establishment of synergy between the sciences*.

## SPEAKERS

# Human health implications from exposure to mercury and PCBs in the Arctic

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Several industrial pollutants from far away sources reach the Arctic and Sub-arctic regions and accumulate in human food. While the extent of this pollution is being evaluated, research on the potential adverse health effects has lagged behind. Assessment of the long-term consequences requires prospective studies with sophisticated clinical examinations and confounder control.

We have chosen to carry out studies in the Faroes, because some of the population is highly exposed to food contaminants from the tradition of eating pilot whale meat (methylmercury) and blubber (polychlorinated biphenyls, PCBs, and other persistent lipophilic compounds). The pilot whales, which the Faroese have been eating for centuries, migrate far in the oceans and feed on species from the food webs that have now been contaminated with a variety of industrial chemicals. The Faroese, who eat a traditional diet, are thereby exposed to certain substances much in excess of that to which other Europeans are exposed.

Assuming that the foetus is particularly sensitive to the effects of methylmercury, we collected blood and cord tissue, as well as the mother's hair, in connection with more than 1000 deliveries in 1986-1987. The analyses showed that about 15% had mercury levels higher than the limit, which was considered safe, according to the WHO at the time. At the age of seven years, the children were examined by an international team of researchers, with the support of the EC. The results showed a connection between the prenatal exposure to methylmercury and deficits in the child's memory, attention, language and other mental functions (Grandjean et al., 1997). Thus, what was previously thought to be a harmless exposure to mercury during pregnancy in reality has a negative effect on the children's development. At the age of 14 years, the entire cohort was re-examined to determine the possible persistence of negative impacts on the central nervous system. The effects had not disappeared and must now be considered permanent. This research has inspired a downward revision of exposure limits and also a recommendation from EFSA to minimise mercury exposures.

In 1994, a new study of newborn babies in the Faroes was initiated. This time the aim was to carry out a detailed study of whether PCBs affect children's development. By analysing blood from pregnant women, blood from the umbilical cord and breast milk, an understanding of the PCB exposure of the foetus was obtained (Steuerwald et al., 2000). The children's development was monitored closely in annual examinations, again with the support of the EC. So far the children have been examined thoroughly up to the age of 10 years, with a battery of neuropsychological tests, physical examination, various neurophysiologic measurements. The results are in the line of the previous finding in the first cohort.

A third cohort of 650 children was established in 1998-2000. This study also focuses on mercury and PCB exposure, but in addition aims at examining harmful effects on the immune system. Preliminary results from this study, and supporting data from the previous cohort, indicate that PCBs have a negative impact on the immune system, so that antibody concentrations after vaccinations are negatively correlated to PCB exposure (Heilmann et al., 2006).

## MAIN CONCLUSIONS

In the Faroes study, methylmercury appeared to be a much stronger neurotoxicant than did PCB, but a weak tendency towards PCB neurotoxicity was seen in children who at the same time had a high prenatal exposure to methylmercury (Grandjean et al, 2001). Also, in the second Faroese cohort, decreased neurological optimality scores were seen at increased methylmercury exposures, while PCB did not have an independent effect (Steuerwald et al. 2000). In conjunction with other evidence and descriptive studies of human mercury exposure in the Arctic, these findings indicate that methylmercury is an important neurotoxicant at levels exceeded in several regions of the Arctic.

PCBs act as a weaker neurotoxicant, but exposures are associated with decreased postnatal growth, perhaps through joint effects with methylmercury (Grandjean et al., 2003). The adverse effects on immune functions may be related to the dioxin-like effects of some PCBs, and effects of clinical relevance seem to occur at present exposure levels in the Arctic, where PCB concentrations have not yet decreased.

Because these food contaminants occur along with essential nutrients in seafood, attention must also be paid to the fact that some adverse effects may appear to be quenched by the beneficial influence of healthy (though polluted) foods. When such benefits are taken into account (Budtz-Jørgensen et al., 2007), the adverse effects appear to be even greater than previously reported. Our findings illustrate that seafood contaminants should be looked at conjointly, and that the health benefits of seafood ought to be optimised by avoiding the pollutants.

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# *Northern aspects of mammal-borne zoonoses*

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In this talk I will concentrate on terrestrial mammal-borne zoonoses and, separately from that, on some aspects of reindeer health, all affected by the environmental change in the north. Small rodents (voles and lemmings) are the dominant mammal group at northern latitudes. Their dynamics are characterised by strong, often cyclic fluctuations. Voles and lemmings, often called arvicoline rodents, are known carriers and reservoirs of several viral, bacterial and parasitic zoonotic infections to man, including *Nephropathia epidemica* (NE), a mild form of hemorrhagic fever with renal syndrome, poxviruses, tularemia, yersinias, *Echinococcus multilocularis*, etc.

The dynamic patterns of rodent-borne zoonoses in humans often mirror those of their reservoir species. On the other hand, rodent dynamics are affected by many environmental factors. Seasonality, the snow quality, the simple structure of animal communities, and habitat homogeneity or heterogeneity all affect the rodent dynamics. All these factors are also prone to environmental change. Accordingly, clear changes in rodent dynamics have been observed in Northern Europe, as well as in the patterns of rodent borne zoonoses in humans. The more stable rodent dynamics may, on the one hand, reduce the incidence of directly transmitted viral and bacterial diseases in man, but may, on the other hand, increase the risk of the spread and establishment of parasitic diseases like alveolar echinococcosis in Northern Europe.

Reindeer husbandry differs considerably among Nordic countries, and this may affect the reindeer health problems experienced in different countries. Many of the reindeer parasites have complicated life cycles through intermediate hosts. Climate change can affect the development rates of intermediate stages of several parasitic species harmful to reindeers, thus increasing the total parasitic burden. In addition to the accelerated development rates of already existing parasites, recent evidence suggests that new parasite species, like filarial nematodes, have spread north, possibly through the climate-induced changes in the occurrence of the host insect species.

# Exposure of brominated flame retardants in the Arctic food chain

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Brominated flame retardants (BFRs) such as diphenyl ethers (PBDEs) and tetrabromobisphenol A (TBBPA), are widely used as flame-retardants mainly in buildings and electronic equipment and in textiles (Darnerud et al., 2001; de Wit 2002). The annual global production of BFRs has been estimated to be about 150 000 tons. PBDEs are lipophilic, stable compounds with a low biodegradation profile. As a result, these compounds accumulate in biota, and are widely found in the food chain depending on the aquatic environment, but also in humans (Law et al., 2006; De Wit et al., 2006; De Boer et al., 1998; De Boer et al 2003, Sellström, 1998). Over the past decades, PBDE levels have been steadily increasing in marine mammals, birds and fish. In the Canadian Arctic, increasing concentrations were found in ringed seal (9-fold increase between 1981 and 2000) and beluga (de Wit et al., 2006; Muir et al., 2004; Law et al. 2003; Ikonomou et al., 2002). Recent data also showed that the levels of another brominated flame retardant, hexabromocyclododecane (HBCD), increased in seals in North America (Stapleton et al. 2006), and in porpoise from the North Sea (Law et al., 2006).

In 2001, the European project FIRE, consisting of 19 partners, was started with an integrated approach of directed toxicological studies and exposure assessments to characterise the emerging human and wildlife health risks from BFRs by endocrine disruption. PBDEs, TBBPA and HBCD have been identified as potential endocrine disrupters. One of the aims of the project was to investigate the aquatic wildlife exposure, and to provide information on the food chain transfer of BFRs from water, sediment to invertebrates to predators (fish) and fish-eating top-predators (tern, seal and polar bear), and provide information on the spatial distribution of BFRs, including the Arctic. Information on levels in marine biota from the transect, The The Netherlands (Western Scheldt, Wadden Sea) to Norway (Froan, Oslofjord) to Bear Island and Spitsbergen, was gathered. The Arctic was selected, as it will act as reference site, since the pollutant levels in the Arctic should be much lower than in the North Sea and Skagerrak. The Western Scheldt estuary (Netherlands) was selected as this location is situated near industrial activities, including BFR industry and users of BFRs.

The FIRE project showed that the BFR levels in biota are linked to the sources and use of BFRs. Increasing concentrations are found in marine mammals, bird eggs and fish, with decreasing latitude (Sørmo et al.; Jenssen et al. 2007). The levels in mammals and birds from the Arctic were low compared to the temperate regions. For zooplankton, cod, and seals, levels generally decreased by one order of magnitude from the Skagerak Sea in the south to Spitsbergen in the Arctic. For terns (Arctic and Common), far fewer differences were seen between populations, most likely because they are being exposed during migration. Substantially elevated levels of PBDEs and HBCD in common terns from the Western Scheldt suggest their high exposure and the bioaccumuation of these compounds at their breeding grounds. Most of the PBDE and HBCD biomagnify in the food chain of ringed and harbour seals (Sørmo et al., 2006). For the polar bear food chain only one of the PBDEs (BDE153) biomagnified in a polar bear, which is probably due to its ability to metabolise most of the PBDEs. Levels of PBDEs in polar bears from Spitsbergen are among the highest reported (De Wit et al., 2006), and are comparable to the levels found in east Greenland and southeast Baffin.

Although PBDEs and HBCD are present in the Arctic, the levels of these compounds are much lower than along the temperate regions, and much lower than e.g. PCBs. However, temporal trends show that concentrations are increasing in the Arctic.

## ACKNOWLEDGEMENTS

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# Biopersistent organochlorines in diet and human fertility: epidemiological studies of time to pregnancy and semen quality in Inuit and European populations

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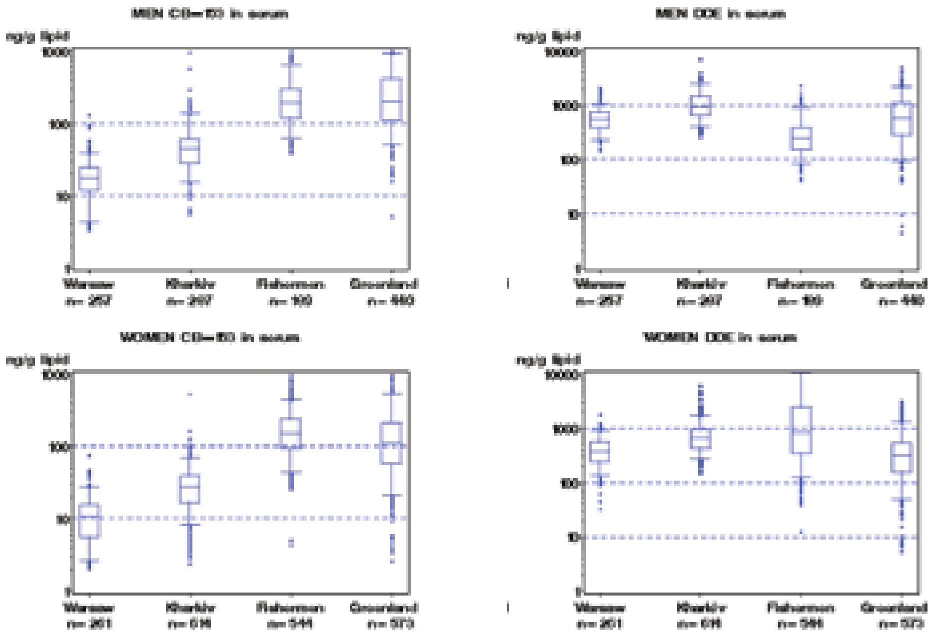
Inuendo studies are an EU Fifth Framework Programme RTD project, that examine reproductive toxicity of dietary persistent organochlorine pollutants (POPs) in polar regions and European countries. Couple fertility and male reproductive function were investigated in four regions, Greenland, Sweden, Warsaw and Kharkiv. Pregnant women and their partners were consecutively enrolled during antenatal visits except for Swedish fishermen and their partners, who were recruited separately. Time-to-pregnancy interviews were obtained from 2 269 women, blood was sampled in 1 992 women and 1 172 men, and a subset of 798 men provided a fresh semen sample. Serum concentrations of an indicator of polychlorinated biphenyls (PCBs) [2,2´,4,4´,5,5´-hexachlorobiphenyl (CB-153)] and 1,1-dichloro-2,2-bis (*p*-chlorophenyl)-ethylene (DDE) were measured in both genders. Xenobiotic transactivation of the estrogen (ER), androgen (AR) and aryl hydrocarbon (AhR) receptor was measured ex-vivo by CALUX assays in a subset of 362 men.

Male reproductive function was evaluated by reproductive hormones in blood and a range of sperm characteristics (count, morphology, motility, chromatin and DNA integrity, pro- and anti-apoptotic markers and Y/X chromosome ratio) together with biochemical markers of the epididymal and the accessory sex gland function.

*Exposure levels.* The median serum concentrations of CB-153 and DDE in the four regions spanned more than one order of magnitude (Figure 1). Agonistic and competitive xenobiotic transactivation of the ER, AR and AhR differed between regions. Antagonism of the ER and competitive enhancement of the AR resulting in a xenobiotic ER/AR-balance towards higher androgenicity was seen to a higher extent among Inuits than in the European regions. Agonistic AhR transactivation was detected in almost all samples. Median 2,3,7,8-tetrachlorodibenzo-p-dioxin toxic equivalents (TCDD TEQ) values ranged from 200 pg/g lipid among Inuits to 310-430 pg/g lipid in the other regions. Inuit samples exhibited high competitive enhancement of the AhR while the European groups exhibited high AhR competitive antagonism. The xenobiotic receptor activities were not or only weakly related to the selected POP markers.

*Consistent and coherent corroborating results.* Male and female serum concentrations of POPs were related to reduced fertility among Inuit couples. In all regions decreasing progressive sperm motility with increasing CB-153 serum concentrations was observed. Similar associations between CB-153 and neutral-α glucosidase point to post-testicular effects on epididymal function that may explain reduced sperm motility. Effects were most pronounced in men with CB-153

**Figure 1. Lipid adjusted serum concentrations of CB-153 and DDE in men and women in four regions (median, 25/75 and 5/95 percentiles, min/max)**



blood levels exceeding current levels in the general European population, but the data demonstrated no clear no-effect threshold. In addition, the study revealed a remarkably high level of sperm chromatin integrity and low level of sperm DNA damage among Inuit men that may explain why Inuits may escape the rather strong PCB related effect on sperm chromatin found among Caucasian men.
*Consistent refuting results*. Serum concentrations of DDE and xenobiotic steroid receptor activities were not related to female and male fertility. Furthermore, blood levels of POP markers and xenobiotic receptor activities in serum were not related to sperm count and morphology and no evidence was found that POPs interfere with the regulation of sperm apoptosis.

*Other findings*. The study revealed several associations between POP blood levels and male reproductive hormones as well as Y/X sperm chromosome ratio, but strong heterogeneity between regions complicates the interpretation. Some associations may be related to heterogeneous exposure profiles and others may appear because of multiple comparisons, confounding or artefacts of the study design.

*In conclusion,* the study indicates that POPs in the male adult may interfere with his reproductive function without major impact on fertility or sperm counts in European populations. PCBs seem more to blame than DDT. No-effect thresholds cannot be established. Findings provide limited evidence that xenobiotic disruption of endocrine regulation is at stake but do not exclude mechanisms related to receptor function. The study does not address the effects of fetal and childhood exposures.

The following issues emerge directly from this study as major research questions the answers to which would advance our understanding of reproductive risk related to dietary xenobiotics:

*Fetal exposure*. The risk for subfertility and other reproductive disorders including female reproductive function in relation to fetal and early postnatal xenobiotic exposures. Epidemiological follow-up studies linking reliable markers of fetal exposures with reproductive function in male and female offspring are needed. Such studies must rely on biobanks established more than 20 years ago to be efficient within a reasonable time period.

*Genetic reproductive polymorphisms*. Investigations of genetic polymorphisms of genes regulating reproductive function may help improve our understanding of the apparently favorable aspect of reproductive function among Inuits, and examination of gene-environment interactions may be crucial to distinguish causal from spurious associations in environmental epidemiological research.

*Protective dietary factors*. Studies of dietary factors such as micronutrients and polyunsaturated fatty acids may be of greater importance than studies of cardiovascular and metabolic diseases, and may be part of the explanation that Inuits seem better protected against some reproductive toxicants

## POLICY IMPLICATIONS

The demonstration of reproductive effects related to adult POP exposure of this study should be taken as a warning that humans may also be at risk from even trace amounts of persistent xenobiotics. The results reinforce the need for stringent regulations to better protect people from reproductive hazards and to prevent development of reproductive impairment. Counselling of the public should balance the reasons for concern and the need for stringent regulations with the reassuring findings of no major impact on fertility, the health promoting ingredients of marine diet and the risk related to intake of an industrially refined diet. The main importance of this project is to add to the credibility of claims that xenobiotics in trace amounts may indeed play a role for reproductive function and thus contribute to the attention and priority from regulating bodies that are called upon. Unfortunately, the project does not provide clues as to involved cellular mechanisms. Such clues could establish a rational basis for the development of additional reliable screening of xenobiotics. But the results stress the need to include reproductive endpoints in any array of outcomes that need to be evaluated before new chemicals are allowed onto the market and the public is widely exposed.

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Polar Environment and Climate

# 5. Research infrastructures

# REPORT from CHAIRS

## Session on research infrastructures

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Undertaking research in the harsh polar environments of both the Arctic and the Antarctic requires a level of logistic and infrastructure support considerably greater than that required for most other regions of the Earth. A high proportion of the polar research budget is allocated to logistics. Often, the investment required to implement and maintain such infrastructure is beyond the capacity of a single nation, and increasingly, polar infrastructure is shared between consortia of national operators. The International Polar Year 2007-2008 provides an opportunity to enhance scientific collaboration between institutes and countries and to share logistic support requirements for polar research. Many of the challenges of polar science also require development of innovative new research tools to access areas such as the abyssal ocean beneath multiyear sea ice, or the bedrock surface beneath the ice sheets. Sophisticated and quantitative new satellite remote sensing systems, together with innovative automated *in situ* observational platforms, provide a means of ongoing monitoring of all components of the polar environments, although ground-truthing is more difficult than in most regions. Also required is the infrastructure to effectively harvest, archive and distribute the data from such observational systems.

### OVERVIEW OF THE SESSION

The presentations in this session exemplified different categories of major research infrastructure required to support present and future polar research.

Major infrastructure investment is required in new technologies and large capital equipment such as ships, satellites and polar research stations. These resources are extremely expensive to both construct and operate, particularly for one nation alone. The example of a new generation of a polar research ice breaker, able to undertake deep-sea drilling and a range of other research functions year-round in ice-covered oceans, is given by Thiede at al. (this volume). Such a facility could only be funded and operated at optimal efficiency by a consortium of polar institutions from European nations.

The Svalbard archipelago has been used as a high latitude observational site since the first IPY and, with its easy accessibility by commercial air transport, it has more recently received increasing attention as a site for international polar research cooperation (Ørbæk, this volume). In particular, the research infrastructure at Ny-Ålesund includes the facilities of more than ten different nations, with considerable multidisciplinary capacity. Such concentrated research infrastructure is ideal for developing partnerships to undertake the interdisciplinary process studies proposed as part of IPY 2007-2008 and beyond (e.g. studies of total ecosystems, or links between the different parts of the earth system).

The presentation by Viisanen and Paatero (this volume) illustrates the type of infrastructure and collaboration necessary to establish an integrated large-scale observation system – in this case for atmospheric dynamics, radiation, aerosol and trace gas composition. These observation systems require station and instrumental facilities plus measurement protocols and standards, and mechanisms for data verification, management and exchange.

In both polar regions, the enhancement of observation networks requires not only the establishment of stations at new sites but also the re-establishment and rejuvenation of parts of networks that have degraded over the past decades.

## ISSUES FROM THE ROUND TABLE DISCUSSION

Infrastructure requirements are properly driven by science priorities but, in many cases the latter have long lead times for implementation and must be developed in parallel with ongoing research. Proper long-term foresight and planning of polar research priorities is hence of critical importance. Infrastructure covers a continuum of scales, at all levels of resource required to support priority research. Widespread low-level facilities may be required to support some of the priority areas, not just 'big-ticket' and high profile items.

The following issues were discussed at the round table.

IPY 2007-2008 has fostered a range of proposals to develop new observation networks. More consideration is required on how these networks will be maintained into the future to leave a true legacy of IPY. Networks for monitoring atmospheric chemistry were given as one example of an important requirement that is not necessarily guaranteed in the future. Monitoring networks are built around national facilities, but the EU has a role to play in supporting national initiatives, and in helping develop the partnerships that build the best and lowest cost monitoring programmes.

IPY 2007-2008 has also led to an unprecedented sharing of polar research infrastructures between nations. Again, consideration needs to be given as to how this can be maintained and enhanced beyond IPY. This should include not only cooperation between European nations, but also other nations active in polar research.

Data management, archiving and access are part of infrastructures. Are we doing enough, not only within individual projects, but also to link across projects? Can we develop better electronic networking of polar scientists to facilitate the exchange of ideas, plans and data, and to reduce travelling?

The Arctic has a direct impact on the nations and peoples of the European Union, and it is also far more accessible than the Southern Hemisphere polar regions. But global linkages within the total earth system require comprehensive observations and thorough knowledge of the Antarctic and Southern Ocean, regions where networks and understanding are frequently more rudimentary than in the Arctic. There needs to continue to be a balance of European research in both polar regions.

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## SPEAKERS

# Need for novel research approaches, infrastructures and technologies for the exploration of the polar environments

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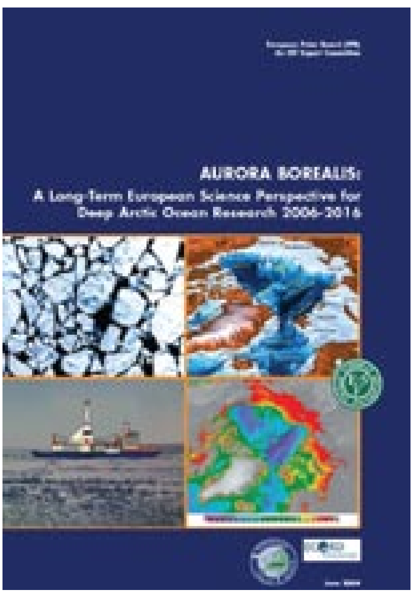
### INTRODUCTION

Research in the extreme environments of the high latitudes, both on land and in the sea, cannot be conducted without novel and state of the art technology which will require major investments, both in terms of generating new 'tools', as well as maintaining and improving existing infrastructure. Arctic research infrastructure in its widest sense falls under the umbrella of FARO (Forum of Arctic Research Operators), Antarctic infrastructure falls under the umbrella of COMNAP (Conference of Managers of National Antarctic Programs). They aim to encourage, facilitate and optimise the logistics, use and development of infrastructure and support for scientific research in the polar regions. Here we will highlight deficits in polar research infrastructure and propose ways to remove these deficits. These research infrastructures will include unmanned observational systems (marine and terrestrial), polar stations on the polar land areas, drifting stations, ships (mainly icebreakers), airplanes and satellites.

**Figure 1: Long-term Science Perspective for AURORA BOREALIS developed by 20 European Countries (http://www.esf.org/esf_publications_list.php?language=0&section=4&category=6&type=2).**




Major infrastructure items in many cases are too expensive, complicated and/or technically demanding to be run as national facilities. Schemes will have to be developed to establish international consortia to generate and manage large-scale international polar research infrastructure.

Polar research, both on land and in the sea, cannot achieve the needed progress without novel and state of the art technologies and infrastructure. In addition, we have the obligation to equip the upcoming young and courageous generation of polar researchers with the most modern and safest research platforms the 21st century can provide. This effort will require major investments,

both in terms of generating new 'tools', as well as maintaining and improving existing infrastructure. The upcoming IPY with its attempts to coordinate and foster cooperation on an international level in an unprecedented way, therefore, offers a unique chance for a leap of progress in our understanding of polar processes and their dynamics with their influence on the adjacent continents and the global environment.
There are many different novel tools presently being developed for polar research, but here we will concentrate on the one that is currently most high profile, namely the planning for a new research icebreaker, with an all season endurance capability in permanently ice-covered waters and with the capability to carry out deep-sea drilling in ice-covered deep-sea basins.

## THE AURORA BOREALIS PROJECT

Polar research and, in particular the properties of northern and southern high latitude oceans are currently a subject of intense scientific debate and investigation, because they are (in real time) and have been (over historic and geologic time scales) subject to rapid and dramatic change. Polar regions react more rapidly and intensively to global changes than other regions of the earth. News about the shrinking of the Arctic sea ice cover, potentially leading to an opening of sea passages to the north of North America and Eurasia, on the way to a 'blue' Arctic Ocean, as well as about the calving of giant table icebergs from the ice shelves of Antarctica, are examples of these modern dynamics.
It is still unclear how many of the profound changes in all parts of the Arctic are natural fluctuations or are due to human activity. Since these changes occurred over several decades, long time data series of atmospheric and oceanic conditions are needed to understand and predict future developments. Despite the strong seasonality of polar environmental conditions, research in the central Arctic Ocean up to now could essentially only be conducted during the summer months, when the Arctic Ocean is accessible to the currently available research icebreakers.

Many nations have a particular interest in understanding the Arctic environment, with its potential for change because highly industrialised countries reach into high northern latitudes and Europe and North America are influenced by and interact with the Arctic environment (Fig. 1). In addition, considerable animate and inanimate resources are found in the Arctic Ocean, its deep-sea basins and their adjacent continental margins. Modern research vessels capable of penetrating into the central Arctic are few. A new state-of-the-art research icebreaker is therefore urgently required to meet the needs of polar research and to document the multi-national presence in the Arctic. This new icebreaker would be conceived as an optimised science platform from the keel up and allow the conducting of long, international and interdisciplinary

**Figure 2: Initial design of the Aurora Borealis (© AWI).**

expeditions into the central Arctic Ocean during all seasons of the year.

Global climate models demonstrate the sensitivity of the polar areas to changes in forcing of the ocean and climate system. The presence or absence of snow and ice influences global heat distribution through its effect on the albedo, and the polar oceans are the source of dense, cold bottom waters, which influence thermohaline circulation in the world oceans. This global conveyor is a major determinant of global climate.

In spite of the critical role of the Arctic Ocean in climate evolution, it is the only sub-basin of the world's oceans that has not been sampled by the drill ships of the Deep-Sea Drilling Project (DSDP) or the Ocean Drilling Program (ODP) and its long-term environmental history and tectonic structure is, therefore, poorly known. This lack of data represents one of the largest gaps of information in modern earth science, and is also a problem in the field of hydrocarbon exploration. Therefore, the new research icebreaker AURORA BOREALIS (Figure 2) should be equipped with drilling facilities to meet the needs of the IODP (Integrated Ocean Drilling Program) for a "Mission Specific Platform" to drill in deep, permanently ice-covered ocean basins. The icebreaker must also be powerful enough to remain stationary against the drifting sea ice cover and will have to be equipped with dynamic positioning technology. The first successful attempts at scientific deep-sea drilling in the central Arctic were carried out during the ACEX expedition in summer 2004, and had an important European input.

AURORA BOREALIS will be a novel research icebreaker with no national or international competitor because of its:

- drilling capability;
- sophisticated modularised mobile laboratory systems allowing mission-specific laboratory selections;
- moon pools for drilling and for the deployment of Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV) for sub-ice surveys;
- propulsion and dynamic positioning systems;
- capability for polar expeditions into high latitude ice-covered deep-sea basins even during the unfavourable seasons of the year.

The vessel will be a powerful research icebreaker with 44 000 tons displacement and a length of 196 m, with 50 megawatt azimuth propulsion systems and a deep drilling capability for use in extreme conditions water depths in excess of 4 000 metres. It will have high ice performance to penetrate autonomously into the central Arctic Ocean with 2.5 m of ice cover, during all seasons of the year.


**Figure 3: ESFRI Roadmap 2006 of the European Commission (http://www.eubuero.de/arbeitsbereiche/infrastrukturen/esfri/Download/dat_/fil_2076).**

| | Projects (in alphabetical order per discipline) | Estimated Construction Cost (M€) * | First possible operations for users | Indicative Operational/ Deployment Cost (M€/year) |
|---|---|---|---|---|
| Environmental Sciences | AURORA BOREALIS | 360 | 2010 | 18 |
| | EMSO | 150 | 2011 | 20 |
| | EUFAR | 50 - 100 | 2007 | 2 - 4 |
| | EURO ARGO (GLOBAL) | 76 | 2010 | 6 |
| | IAGOS-ERI (GLOBAL) | 20 | 2008 | 6 |
| | ICOS (GLOBAL) | 255 | 2010 | 13 |
| | LIFE WATCH | 370 | 2014 | 70 |

An efficient use of the new research icebreaker requires the formation of a consortium of European countries and their polar research institutions to ensure a high quality of science and efficient utilisation of the research vessel throughout all seasons of the year. Extensive and well-developed Arctic research programmes exist in several European countries, particularly in the Scandinavian countries, Russia, and Germany. In each individual country, different organisations or working groups are present, with diverse structures and impacts in their home countries. The construction of AURORA BOREALIS, as a joint European research icebreaker, would result in a considerable commitment of the participating nations to coordinate and expand their polar research programmes in order to operate this expensive ship continuously and with the necessary efficiency. If AURORA BOREALIS is eventually established as a European research icebreaker for the Arctic, European polar research will be strengthened. Europe will contribute to meeting the Arctic drilling challenge within IODP and retain its top position in Arctic research. However, in the long-term, the AURORA BOREALIS will also be used to address Antarctic research targets, both in its mode as a regular research vessel as well as a polar drill ship.

## PERSPECTIVES OF THE AURORA BOREALIS PROJECT

The German Science Council evaluated the AURORA BOREALIS project in May 2005 and recommended the construction of the research icebreaker in 2006. Since March 2007 the German Federal Ministry for Science and Education (BMBF) has been funding a portion of the preparatory work for AURORA BOREALIS. In this project, the final engineering work for the development of the vessel is carried out under coordination of the AWI and the University of Applied Sciences in Bremen. Additionally, the engagement of the European Science community will be promoted by organising workshops in different European countries to discuss science plans and technical requirements for the AURORA BOREALIS.

The European Commission identified the project for the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap (Figure 3). The Commission assigned the highest scientific priority to development of this large-scale infrastructure for basic research in Europe. A European consortium of 16 institutions, funding agencies and companies from 11 European nations including Russia has already formed to develop management structures for this unique facility and to implement it into the European Research Area.

# Atmospheric observatories at Pallas-Sodankylä and Tiksi as examples of the IASOA project

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The International Arctic Systems for Observing the Atmosphere (IASOA, www.IASOA.org) is an International Polar Year (IPY) Activity (#196) that was formally endorsed by the IPY committee in November 2005. IASOA is coordinated by the United States National Oceanic and Atmospheric Administration (NOAA). This activity seeks to enhance and integrate measurements of the Arctic atmosphere on an international scale by coordinating the activities of seven atmospheric observatories in Alaska, Canada, Greenland, Spitsbergen (Svalbard), Sweden, Finland and Russia. The IASOA key science questions focus on efforts to understand the processes driving Arctic weather and climate within the larger (marine, cryosphere, biological and terrestrial) system. The primary activities involve combining the resources of intensive super-site observatories, distributed networks, and campaigns and innovative technologies to provide a comprehensive Arctic observation system. The primary mission is to understand change and the relative effects of natural and anthropogenic effects well enough for the global community to plan mitigation and adaptation strategies. In the following, the activities and plans at two of these sites, Pallas-Sodankylä in Finland and Tiksi in Russia, are described.

The first meteorological observations in Sodankylä, northern Finland were made during the First International Polar Year in 1882-1883. Regular aerological observations at the Arctic Research Centre of the Finnish Meteorological Institute (FMI-ARC) have been conducted for over 60 years constituting one of the longest upper atmosphere meteorological observation data series north of the Arctic circle. Since 1994 the FMI's Pallas-Sodankylä site has been one of the 22 global stations of the World Meteorological Organization's Global Atmosphere Watch (GAW) programme. This is globally the most important international network to monitor greenhouse gas and aerosol concentrations, ozone, ultraviolet radiation, certain reactive gases and precipitation chemistry which are the priority issues of the GAW programme.


Upper-air weather, ozone, aerosol and radioactivity soundings are made at Sodankylä, as well as several ground-based and ground-level measurements: spectral UV radiation, airborne radioactivity, climatological and other meteorological parameters, total ozone column, deposition of acidifying compounds (e.g. sulphate), and aerosol optical depth. Carbon dioxide flux between a pine forest and the atmosphere is also measured. The FMI's northernmost weather radar is situated on the top of Luosto fell 25 km south of FMI-ARC. The range of the radar covers most of northern Finland.

Most of the tropospheric air composition and related meteorological measurements are made at Pallas. The measurements include:

- reactive gases (ozone, sulphur dioxide and nitrogen oxides);
- greenhouse gas concentrations (carbon dioxide, methane, nitrous oxide and sulphur hexafluoride);
- carbon dioxide flux between a spruce forest and the atmosphere;
- methane and carbon dioxide flux between a wetland and the atmosphere;
- aerosol particle number concentration and size distribution;
- PM10 particle mass concentration;
- aerosol scattering coefficient;
- black carbon;
- volatile organic compounds (ethane, propane etc.);
- inorganic compounds (sulphate, nitrate, gaseous ammonia and particle-bound ammonium, sodium, calcium etc.) in the air and precipitation;
- stable isotopes.

Over the last 10 years the data obtained at Pallas-Sodankylä have been used over 70 peer-reviewed articles, including three in *Nature* and *Science*, and over 200 other publications.


The NOAA, with the support of the National Science Foundation (NSF), is currently upgrading the climate observatory near Tiksi, located close to the delta of Lena river in northern Siberia, in collaboration with the Russian authorities, e.g. Roshydromet and the government of the Republic of Sakha (Yakutia). The research of the NOAA will focus mostly on climate processes involving the surface radiation balance as affected by clouds and aerosols, cloud microphysics, satellite validation, circulation patterns, snow and sea ice, etc.

The work plan at Tiksi proposed by the FMI consists of four research topics on atmospheric observations which will complement the other observations at the site. The FMI is planning to start research in cooperation with the other IASOA partners on four activities: 1. atmospheric concentrations of greenhouse gases; 2. carbon dioxide and methane exchange between tundra ecosystems and the atmosphere, 3. aerosol properties relevant to radiative forcing, 4. atmospheric concentrations of heavy metals and PAH compounds. Tiksi will efficiently fill the 'black hole' of atmospheric circumpolar monitoring activities in the vast area between northern Finland and Alaska.

# Research and research infrastructures in Svalbard during the International Polar Year(s)

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The Svalbard archipelago is a unique research platform in the European Arctic with its easy accessibility and well-developed infrastructure, despite its remote high latitude location at 74º N - 80º N. It has a very favourable geographical location for research in the fields of upper atmosphere and space physics, biology, geology and geophysics, and especially in environmental research such as climate change, long-range transportation of pollutants, ecology, and ocean-atmosphere interactions. Global warming with increased climate variability, stratospheric change and contaminants that range over long distances, presents multiple challenges to Arctic ecosystems that add to the already harsh environments with their large natural variability. This is due to the fact that these key environmental factors are amplified in the Arctic, forced by natural and anthropogenic variability (ACIA 2004; AMAP 2003; WMO 2003). Svalbard is also uniquely located under the polar cusp and the dayside auroral oval with direct optical view along the magnetic field lines to the interplanetary space, where the solar and terrestrial magnetic field lines are being reconnected.

Svalbard was used as a research platform already during the first international polar year (1882–83), with a Swedish research expedition at Kapp Thordsen conducting observations covering meteorology (temperature, wind), earth magnetism and astronomy. A Swedish expedition also made meteorological observations from Svalbard (Nordenskiöldfjellet) during the second International Polar Year (1932-33). During the International Geophysical Year (1957–58), two new research stations were established on Svalbard, Kinnvika and Hornsund. These stations, together with the other established research sites and communities on the archipelago, will together provide an impressive research contribution to the International Polar Year 2007-2009 from Svalbard. This includes the Ny-Ålesund international research station, participation from more than 10 permanent research stations of different nations and a large multidisciplinary research programme. The research activities carried out in the Russian settlement of Barentsburg will set up new measurement acitivites, and the Svalbard Science Center in Longyearbyen with the University Center (UNIS), the Eiscat Svalbard Radar and the Norwegian Polar Institute will provide extensive logistic support, continuous monitoring activities and education programmes during the IPY.

Over the past 10-15 years, Svalbard has been the object of increasing international interest. This talk will give an overview of the contemporary and historic research issues, infrastructure and activities that make Svalbard one of the leading research platforms in the Arctic, at the start of the International Polar Year 2007-2009.

## *ATTENDEES*

# *International Partnerships in Ice Core Sciences (IPICS) and the future of European ice coring*

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Ice cores have been a cornerstone of global change research in recent decades. Europe has been at the forefront of this science, particularly through the GRIP and EPICA projects funded by the EU and national agencies. A new international grouping, IPICS, has charted a plan of four priority science projects for the next decade or more of ice core research. These proposed projects would each contribute unique and important data to understanding how the earth works, and to improving the accuracy of forecasts. This paper summarises those projects and discusses some of the organisational and funding issues involved in such ambitious and high-profile projects.

### ICE CORES IN GLOBAL CHANGE RESEARCH

Ice cores provide information about past climatic and environmental conditions on time scales from decades to hundreds of millennia. They contain direct records of atmospheric composition, complementing other palaeoarchives that define the terrestrial and marine realms. They occupy a central role in global change and earth system science, because they provide key datasets that characterise changes over the industrial period and over the timescales of multiple glacial-interglacial cycles. They have, for example, clearly demonstrated the close coupling of past climate and greenhouse gas concentrations and the occurrence of abrupt climate switches.

European nations have played a particularly prominent role in ice core studies over several decades. Complementary skills (in logistics, ice drilling, analysis and interpretation) have evolved through a series of collaborations, of which the most prominent have involved multiple national agencies and institutes, European Union funding, and organisation on a European scale through the European Science Foundation (ESF). In the early 1990s, a consortium of eight European nations was successful in reaching the base of the Greenland ice sheet in the Greenland Ice Core Project (GRIP) that provided the clearest view of the interactions within the earth system during the last glacial cycle. This work acted as a strong motivator not only for later palaeoclimate projects, but also for work aimed at understanding the stability of thermohaline circulation.

During the last decade, a consortium of ten European nations, supported under successive Framework Programmes, completed two ice cores to bedrock in Antarctica under the European Project for Ice Coring in Antarctica (EPICA, see extended abstract by D. Raynaud in this volume). It has provided what will certainly become iconic diagrams of changing climate, greenhouse gases, and other environmental parameters over 800 000 years, as well as more detailed records of shorter periods. It has already produced several much-cited and high-profile scientific papers (e.g. EPICA Community Members 2004, 2006), and has made a strong impact on the European public. No single nation had the capacity, expertise, or funding to attempt such a project alone: this was a very clear achievement made possible only through a combination of EU and national funding, and collaborative methods of working developed over two decades or more.

## THE FUTURE OF ICE CORING: IPICS

The success of the previous projects, as well as other activities in the climate and earth system realm, have raised new questions that can be very well-addressed by analysing further ice cores. Recognising the key role that international collaboration has played so far, and also understanding that the cost and scope of such projects demand coordinated international efforts, the international ice coring community decided to join together to define its priorities for the next decade and beyond and then find ways to realise them. International Partnerships in Ice Coring Sciences (IPICS) has developed as a group of scientists, engineers and drillers from 20 nations, including all the major ice coring teams. It has held two meetings, the first near Washington, supported by the US NSF, and the second in Brussels, supported by the European Polar Consortium (EPC). As a result of these meetings, IPICS has identified four ambitious priority projects, each aimed at providing answers to big questions in earth system science. These projects have been described in a series of white papers that can be viewed on the IPICS website, hosted by the IGBP PAGES office, at **www.pages-igbp.org/science/initiatives/ipics/** . A fifth paper discusses the strategy for maintaining expertise and improving the technology in ice drilling and related areas.
The four priority projects supported by IPICS are:

- 'The oldest ice core: A 1.5 million year record of climate and greenhouse gases from Antarctica'. The aim of this project will be to extend the existing 800 000 year record through the mid-Pleistocene transition (when the glacial-interglacial cycle shifted to its present 100 000 year period from the previous 40 000 years). In particular, this work will show whether changing background levels of $CO_2$ were responsible for the change in the way the climate worked.
- 'The last interglacial and beyond: A northwest Greenland deep ice core drilling project'. The aim will be to finally retrieve a complete record of the last interglacial. Because this period was probably 3-5º warmer than the present, it represents a key target for assessing whether estimates about the fate of the Greenland ice sheet and the Arctic under a future warming climate are accurate.
- 'The IPICS 40 000 year network: a bipolar record of climate forcing and response'. This network of cores from around Antarctica and the Arctic will show the spatial and temporal pattern of change during major climate reorganisations: the end of the last glacial period, and the rapid Dansgaard-Oeschger events. This will provide a strong test of the ability of models to assess the climatic effects of such changes.
- 'The IPICS 2k Array: a network of ice core climate and climate forcing records for the last two millennia'. This network of cores, collected wherever a suitable ice mass exists in the world, will be a contribution by the ice core community to multi-proxy climate assessments of natural variability in recent centuries, such as the ones used by successive IPCC (Intergovernmental Panel on Climate Change) reports.

## NEXT STEPS AND EUROPEAN INPUT TO IPICS

Based on the very strong partnerships and infrastructures developed in previous proposals, Europe is in a very strong position to play a leadership role in many aspects of IPICS. Indeed, sub-groups of European nations have already started work on the 40 000 year array, by drilling cores in Antarctica at Berkner Island and Talos Dome. In addition, numerous European nations are planning to participate in the Greenland interglacial project (now known also as the NEEM project) which is already deep into a planning phase under the guidance of Danish scientists. The intention is to start the NEEM project during the International Polar Year (IPY) using national funds. The EPC involvement in the IPICS process offers mechanisms for coordinating a European input to each project where necessary. The oldest ice core project, in particular, will call for an extensive phase of geophysical survey (probably during the IPY) followed by the challenging task of drilling at such a remote site. A pan-European (and ideally European Union) funding input to what will inevitably be an even wider consortium than that of EPICA will certainly be essential for the success of this project (as for the others); it is likely to be another flagship project with a very high scientific return and public profile.

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# 6. Natural and socio-economic impacts of climate change

# REPORT from CHAIRS

## Session on natural and socio-economic impacts of climate change

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The fact that there are still considerable gaps in our knowledge about the effects of climate change on biota and societies was the principal message of the session. We understand the process of climate change and are able to make predictions about future developments with some reliability, but we have little knowledge on how to translate these predictions into scenarios about the changes in biota and societies.

Corinne Le Quéré (British Antarctic Survey, Cambridge, and University of East Anglia, UK) presented the results of a study on the impact of climate warming on the $CO_2$ sink and the marine ecosystem in the Southern Ocean. She explained the possible changes in the $CO_2$ pump and the effects on the biogeochemical cycles in the Southern Ocean. She finished her lecture with two items we have to address urgently:

- The quantification and understanding of carbon sinks in the ocean and on land;
- The quantification and understanding of the complex interactions between these carbon sinks.

Terry Callaghan and Christer Jonasson (Abisko Scientific Research Station, Abisko, Sweden) presented results of their studies on the impact of climate change in European Subarctic ecosystems, including a projection of future impacts on these systems. They stressed the need for long-term experiments and observations in order to develop scenarios for the developments in ecosystems in general as a result of global warming. Funding is too often focused on short-term studies. The onset of the International Polar Year has been instrumental in the development of consortia to revisit old study sites in order to record changes in the tundra ecosystem as well as the development of consortia which study environmental baselines, processes and changes. A number of these consortia comprise scientists as well as indigenous people. One of the important legacies of the International Polar Year would be the extension of these studies into long-term monitoring programmes.

Elisabeth Vestergaard (University of Aarhus, Denmark) explained that climate change causing temperature increase in Arctic areas would lead to dramatic changes in socio-economic relationships in the region. The consequences of climate change can be both negative (loss of traditional livelihoods such as hunting and fishing) but also positive (transport and resource extraction). She explained that, because of these consequences, we need to revise our research agenda and focus on studies on:

- Ethical questions (activities and costs)
- Strategic questions (how to deal with future changes)

- Interdisciplinary and international studies (including all stakeholders)

Lars Otto Reiersen (Arctic Monitoring and Assessment Programme, Oslo, Norway) also on behalf of Odd Rogne and Grete Hovelsrud reported on the follow-up of the Arctic Climate Impact Assessment (ACIA). The report was published in 2004 and by now all working groups of the Arctic Council have implemented or will implement projects on their own or in collaboration with international organisations. The different research projects will cover a wide range of subjects from field observations to the assessment of socio-economic developments. The speaker stressed that the Arctic should be a priority for the European Union and that the EU should support research, monitoring and changing infrastructure in relation to climate change.

## SPEAKERS

# Impact of climate change on Southern Ocean sink for $CO_2$ and marine ecosystems

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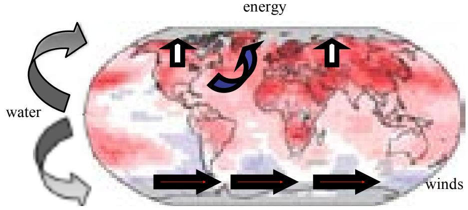
Marine ecosystems (here referring to plankton assemblages) play an important role in climate because they maintain the atmospheric concentration of $CO_2$ at 200 ppm lower than it would be in the absence of sinking organic matter in the ocean. Marine ecosystems also form the base of the marine food chain and thereby influence the availability of food resources. Thus, changes in their structure or turnover rates could have implications for other ecosystems.

Changes in the structure of marine ecosystems could be triggered by changes in the environment in which they live, such as changes in climate and ocean circulation, temperature, nutrient supply from wind-driven upwelling, ocean acidification, ice melting, and grazing pressure from human activities (Figure 1). Observed environmental changes over the past half century have been particularly large at high latitudes, yet their individual and combined impact on marine ecosystem structure is unknown.

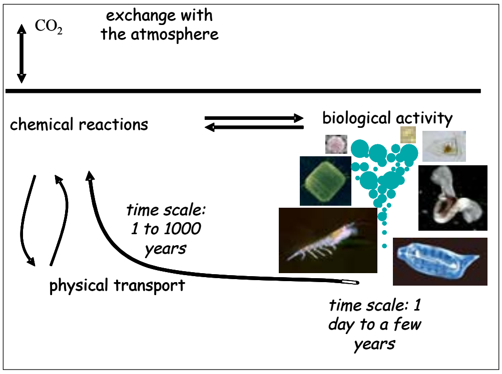
**Figure 1. Observed warming trend during 1979-2005 (Trenberth et al., 2007) and schematic of observed and projected changes in the climate system which may influence marine ecosystems and the carbon cycle.**




The structure of marine ecosystems is a result of complex interactions between the primary producers, which take up ~50 PgC ($10^{15}$g of carbon) per year, and the remineralisers (bacteria, archaea, and zooplankton) which degrade that organic matter (Figure 2). The complexity arises from the fact that the remineralisers are active both at the surface, where they degrade 80% of the organic matter which is then free to go back to the atmosphere, and at the sub-surface where they degrade the remaining organic matter. Because the sub-surface is essentially isolated from the atmosphere for decades to hundreds of years, a small change in the turnover rate of primary producers versus remineralisers can lead to a large and non-linear change in the way the $CO_2$, nutrients, and food are recycled.

The different plankton types which compose marine ecosystems react differently to environmental changes. The small organisms such as bacteria and micro-zooplankton (unicellulars) react most to changes in temperature. Organisms which form hard shells of calcium carbonate such as coccolithophorids or pteropods react most to ocean acidification. The largest zooplankton such as krill are most influenced by fisheries. Thus environmental changes will have an impact on the capacity of the ecosystems to transport carbon to the deep ocean, but we do not know the amplitude of this impact. What we do know however is that this impact will be felt instantaneously because the turnover time of ecosystems is very fast in the ocean compared to the circulation time of the ocean (Figure 2).

**Figure 2. Schematic of the role of marine ecosystems in the global carbon cycle. If the activity of marine ecosystems completely ceased, atmospheric $CO_2$ would increase by about 200 ppm.**




The combination of large and potentially abrupt changes in the climate system, modifications of top-down pressure by zooplankton resulting from human activities, and the non-linear response of marine ecosystems suggests that there may be sensitive areas in ecosystem ecology that we should closely monitor, or potentially dangerous climate regimes or human activities that we should carefully avoid. However, the existing knowledge is fragmented, the model developments are not guided by theory, and there are few connections between either the models or the theory and the observations.

The state of knowledge in modelling of marine ecosystems is in its infancy (Le Quéré et al., 2005), and requires a much larger knowledge and understanding of the various rates of plankton activity, and of the current state of marine ecosystems. The recently well-documented shift in polar winds in the Southern Ocean has apparently led to changes in ocean circulation, air-sea $CO_2$ fluxes, and marine productivity, and is threatening to accelerate the detrimental consequences of surface ocean acidification (Le Quéré et al., 2007). As environmental changes are projected to continue this century, further changes in marine ecosystems and their consequences for atmospheric $CO_2$ are to be expected.

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# Current and projected impact of climate change on landscapes and ecosystems of the European sub-Arctic

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## BACKGROUND

Arctic landscapes and their ecosystems are experiencing several rapid environmental changes; increased habitat fragmentation, increased UV-B radiation, and climatic changes (ACIA, 2005). In the European Subarctic, where mean annual temperatures have been close to 0°C, recent warming has resulted in some dramatic changes. At Abisko in northernmost Sweden, environmental monitoring started almost 100 years ago, generating some of the longest records for the Arctic and, within the past 20 years, a unique suite of manipulation experiments has been developed that explore the likely future responses of ecosystems and biodiversity to changes in climate (Cornelissen *et al.,* 2001; Semerdieva *et al.,* 2003; Van Wijk *et al.*, 2003; Walker *et al.*, 2006). Biogeochemical cycling, particularly of methane and carbon dioxide, has been documented from plot to catchment scales (Friborg, *et al.*, 1997; Christensen *et al.*, 2004, in press; Johansson, T., 2006; Johansson, T. *et al.*, 2006).

## CLIMATIC CHANGES

Mean annual temperature has risen by about 1°C since 1913 (Holmgren and Tjus, 1996) but the trend is non-linear: there was a cooling in the 1970s and mean annual temperatures have just recently exceeded the warming that occurred in the 1930s. There has been a long-term increase in snow depth of between 20 - 30 cm since 1913 (Kohler *et al.*, 2006). Surprisingly, there is no significant trend in the onset or thawing of a winter snow cover although analyses of growing season length based on days with temperatures above 0°C have shown an increase of about 3 weeks since 1913 (Holmgren and Tjus, 1996).

According to a range of regional climate models, driven by various emission scenarios, mean annual temperature is expected to rise by 2.7 to 3.6°C by 2080 and precipitation by +18 to 27% (Saelthun and Barkved, 2003).

## IMPACT OF CLIMATE CHANGES ON THE LANDSCAPE SCALE

The landscape surrounding Abisko contains discontinuous permafrost at low elevation (Åkerman, 1991; Johansson, M. *et al.*, 2006). Within the past decade, permafrost has disappeared from several mires in the northern parts of Sweden (Åkerman and Johansson, M. *In prep.*) and Finland. This has resulted in water logging, change in vegetation and increases in methane emissions (Christensen *et al.*, 2004; Johansson, T. *et al.* 2006;).

Long-term observations of ice dynamics on lake Torneträsk (10 km long, 70 km wide) show a decreasing trend of ice duration of about two weeks since 1913, resulting from both later freeze-up and earlier break up. Ice thickness has decreased by more than 5 cm in 50 years.

## IMPACT OF CLIMATE CHANGES ON ECOSYSTEMS AND BIODIVERSITY

During the past century, shrubs above the altitudinal tree-line have increased their altitudinal range and the subarctic mountain birch forest tree-line has increased in altitude (5 m per 10 years and 40 m per °C summer temperature increase) (Hållmarker, 2002). Forests have increased in density near Abisko and in northern Norway. Such changes are expected to increase atmospheric $CO_2$ sequestration but also decrease albedo.

Intensive studies at the Stordalen mire in the late 1960s and early 1970s, and again within the past five years, have identified major vegetation changes associated with thawing discontinuous permafrost and increased extent of wetlands (Christensen *et al.*, 2004; Malmer *et al.*, 2005; Johansson, T. *et al.*, 2006; Johansson, T., 2006). Plant communities of dry, nutrient poor areas are decreasing while communities of wet depressions are increasing.

Periodic events occur that have major ecosystem effects and could potentially lead to step-changes in vegetation. The autumn moth caterpillar (*Epirrita autumnata*) defoliates vast areas of mountain birch forest and ground vegetation when it reaches outbreak proportions. A major control on population growth is death of eggs during cold winters: warmer winters are expected to lead to greater outbreak frequencies and intensities. At the same time, this effect can be counteracted by other abiotic and biotic factors, e.g. higher densities of insect enemies (Neuvonen *et al.*, 2005). An outbreak in 2004 converted areas of birch forest that are normally significant sinks for atmospheric carbon into a small source during the growing season (Johansson, T., 2006). The carbon sink functioning of the Torneträsk catchment as a whole has been shown to be extremely sensitive to such impacts on the birch forest (Christensen *et al.* ,*in press*).

Changes in vertebrate populations are occurring, such as decreases in Arctic fox, increases in moose and changes in the population cycles of small rodents. However, these changes are difficult to attribute to climate changes alone.

Understanding future changes in ecosystems and biodiversity requires experiments and modelling. An application in the LPJ-GUSS dynamic vegetation model to the Barents region has quantified the rate of change in vegetation throughout the area. Range extensions of coniferous and broad-leafed forest have been projected for the north and in the Scandes Mountains by 2100. However, surprising reductions in the extent of shrubs and increases in tundra were projected: these trends reflect the geography of the Barents region in which areas for shrub expansion in the Scandes are restricted in extent while there are areas of polar desert open to colonisation by tundra vegetation in the extreme north (Wolf *et al.*, *in press*).

Experiments that to some extent simulate future climates show that warming in summer leads to increased shrub and grass growth, but species impoverishment and decreased abundance of mosses and lichens (Cornelissen *et al.*, 2001; van Wijk *et al.*, 2003), an important winter food for reindeer. After 20 years of climate manipulation, changes in the dominance of species in communities have been reported and the loss of some species. However, few, if any, immigrant species have colonised the plots.
Experimental increases in UV-B radiation and $CO_2$ concentrations have lead to relatively minor changes in biodiversity and ecosystem processes although significant changes have occurred in soil microbe communities, nutrient cycling, nitrogen fixation and insect herbivory due to chemical changes induced in plant tissues (Buck and Callaghan, 1999; Johnson et al., 2002; Semerdieva et al., 2003; Solheim et al., 2002).

## FUTURE RESEARCH, MONITORING AND IPY

Existing networks such as SCANNET (Scandinavian and Northern European Network of Terrestrial Field Bases; Callaghan *et al*., 2004) have been used to develop consortia within the International Polar Year (IPY). Key to the European Subarctic are "Back to the Future" in which old study sites are to be revisited and recorded for future visits, and ENVISNAR (Environmental baselines, processes, changes and Impacts on people in subarctic Sweden and the Nordic Arctic Regions). Some of these projects bring together scientists and indigenous peoples.

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# Man and Climate Change — a call for a new research agenda

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The Arctic and sub-Arctic are very sparsely populated regions. The population which inhabits these northernmost areas of the world is estimated to be around 3.5 million people. Less than a million of these inhabitants are categorised as indigenous populations. The population growth in these regions is declining overall, although a few areas have seen a small increase.[1]

## SOCIETY AND ADAPTABILITY

In the Arctic and sub-Arctic areas, a climate change with rising temperatures would have dramatic socio-economic and cultural consequences for the regions – as also documented in several recent data collections and analyses, see, i.e. the reports from the *Arctic Climate Impact Assessment* groups (ACIA)[1]. The indigenous populations will be particularly vulnerable as herding, hunting and fishing constitute their primary livelihood. To mention just a few examples: increased temperatures have consequences for the vegetation and thus for both domesticated as well as wild animals. Marine mammals depend on ice-covered sea for hunting and breeding, and will thus be affected by a thinning of the ice, etc. New species and new illnesses will move in to fill the ecological niches created by the change in climate.

If the preconditions for their livelihood disappear, the people concerned will not just face a relatively benign situation in which they have to adjust to changing circumstances. The consequences are of a much more radical order. The local populations could easily be forced into a situation in which they face the loss of tradition and of socio-cultural identity, as well as a likely collapse of social structures.

The research agenda should reflect that both negative and positive consequences of climate change in the Arctic influence the livelihood of humans. In particular, foresight studies and socio-economic modelling that analyse multiple scenarios should be developed in order to furnish all stakeholders involved with an understanding of the consequences to society of climate change. The studies would then supply society with possible strategies on how to adjust to future environmental changes in the Arctic.

Society's ability to adjust to changed circumstances is a crucial variable in foresight studies. Why do some societies adjust or adapt better than others? And are there any differences in society's capability to adapt when comparing primary producers and consumers – like herders, hunters and fishers – with modern society's response to changing circumstances?

These questions are not answered in this paper, but they should be part of a future research agenda dealing with society and climate change. Instead, two short examples from East Siberia illustrating the *society and adaptation capacity question* will be presented.

In the 18th and 19th century Sojots and other Altaic[2] speaking nomadic groups from Mongolia and China were gradually forced up north into eastern Siberia by other groups. The Sojots were horse riding people, herding sheep and goats. The majority of these people adjusted quickly and in all ways to the local conditions following the example of the local reindeer herders. Horses, sheep and goats were replaced with reindeer.

However, some of the last newcomers to the North did not follow this pattern. These tribes – who originated south of the earlier groups – maintained their horses. The more north they came the more inadequate were the conditions for horse keeping. As a result, a main part of work effort became devoted to tending the horses. They would have to grow fodder for the horses, carry them out to the fresh grass in spring when the horses were too weak to walk themselves – in short, the largest expenditure in the society's calorie budget was connected to horse keeping.

What was going on? Why did these tribes demonstrate such an apparently irrational behaviour?

The first groups were examples of *successful adaptation to changed circumstances* as they replaced horses and sheep with reindeer. The question is whether the tribe which did not adapt to changing circumstances was unsuccessful or not?
What mattered to the first groups was to be nomadic herders. Replacing horses, goats and sheep with reindeer was a practical act which did not disrupt their conceptual universe and the constituent values in society, they were still nomadic herdsmen.
The group which maintained their horses was partly successful, too, though they did not adapt to the change of environment. What constituted society to this people was not the nomadic life form *per se*. What mattered was to be horsemen. Horses gave society cohesion and could therefore not easily be replaced with reindeer. The symbolic value of horses was higher than practical circumstances.
The above examples serve to illustrate that societies are multi-facetted. What at a first glance might appear as an irrational response to challenges, might be the only answer, lest the pillars of values which structure society should collapse. The acknowledgement of the constituent values in society has to be integrated as an element in socio-economic modelling and in foresight studies

Adaptation to a changing environment might have an impact on very different levels. This paper focuses on societies and change; among other important focus points, we find health and environmental change. A 'successful' adaptation to changes in environment and livelihood can in fact turn out negative as we see in several examples when for instance a traditional diet is replaced with a modern diet. Food adaptation can be a matter of centuries and even a matter of genetic selection; therefore, the introduction of a new diet might provoke diet related illnesses like diabetics. And the rejection of an adaptation or incapability to adjust to changed circumstances might result in the extinction of entire populations.

## CHOICES, SCIENTISTS AND SOCIETY

A new research agenda which focuses on the interrelationship between man or rather between society and climate change implies that a number of initial questions – some from the scientific level and others from the political and societal level – are raised.
Among the initial questions from *the scientific level* we find the following:

- What is the current state of knowledge?
- What is the worst case scenario?
- What to do? Formulation of research strategies
- Are there more choices? Formulation of scientifically based recommendations

Some corresponding questions from *the political & societal level* are:

- Which choices to make for adjusting society to changing conditions?
- What sort of society do we want in the future?
- And at what cost?

**The table below lists the background conditions for posing questions on change and society:**

> There are changes in society as well as in the environment which happen and over which we have no influence at all.
> There are changes which can be influenced.
> There are changes to which societies or individuals can adapt.
> There are changes to which societies or individuals will not adapt.
> There are choices to be made by societies or individuals.
> Choices today are of consequence to future choices.

There are choices to be made and, at the same time choices have consequences for future choices – this leads us back to the previously-mentioned research agenda questions.

## CHOICES DETERMINE THE FUTURE – FROM QUESTIONS TO RESEARCH

Some of the major elements in the new research agenda are the acknowledgment of different levels of responsibility. End users, society in this context, are not to be seen or to act as end recipients, but as primary decision makers. End users decide on a future society and scientists prepare scenarios. This clear division of tasks requires the partners to meet in a dialogue which furnishes the end users with high-level insights into possibilities and consequences. The scientific input to society is consequently the base upon which society chooses its future development.

## STEP ONE – ETHICAL QUESTIONS:

- What sort of society/societies and human activity do we/the stakeholders want in polar regions?
- What quality of life do the stakeholders want for the future generations in polar regions – both indigenous and other population groups?
- And at which cost? That is, human costs, social costs, environmental costs etc.

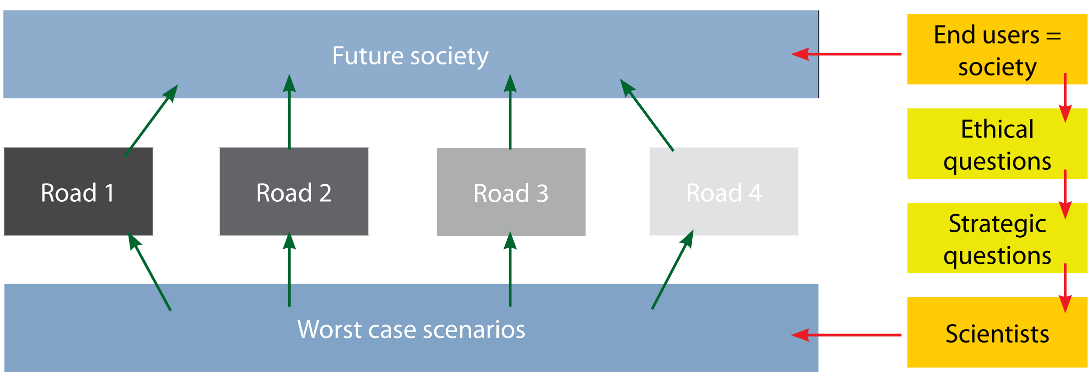
*These discussions take place at the political/ societal level.*

In order for society to reach its goals, some strategic questions have to be clarified.

## STEP TWO – STRATEGIC QUESTIONS:

- How will we/the stakeholders achieve the wished for future development of society and human activity in the polar regions?
- Which roads to travel in order to achieve the goals?

**These discussions take place between parties from the political and the scientific level.**



## STEP THREE – RESEARCH AGENDA:

- Multidisciplinary in order to 'attack' the research questions from as many angles as possible.
- Research is to be carried out at the international level to improve synergy in research
- Further development of foresight studies and modelling as tools in the science-society dialogue.

*Discussions here take place at the scientific level*.

In the new research agenda, the first questions to pose come from society itself. The questions are fundamental to society as they treat issues of an ethical nature. The questions deal with society's expectations and demands for the future. Ongoing dialogue with the scientific world ensures that society is sufficiently prepared to make decisions and well aware of the consequences. Foresight studies and modelling are some of the most essential scientific inputs for researchers to bring into the dialogue with society.

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1 See ACIA Scientific Report. Table 1.1. Country population data. Cambridge 2006:14. Some examples: Russian Arctic population declined from 1,999,711 persons according to the 1989 estimate to an estimated population of 1,535,600 in 2002 whereas some of the Canadian territories saw a small increase.

2 See ACIA Scientific Reports 2006 and earlier.

3 Languages belonging to the Turquoise languages group.

# *Arctic Council follow up work of ACIA*

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The Arctic Climate Impact Assessment (ACIA) was presented to the Arctic Council in 2004. At the Arctic Council meeting held in Salekhard in October 2006, the follow up work to be taken on by the Arctic Council and its working groups was discussed and approved. All working groups under the Arctic Council, AMAP, SDWG, CAFF, PAME, EPPR and ACAP, will implement projects either on their own or in cooperation with other international organisations.

The focus of the projects will cover a wide area from physical observations to assessments of the socio-economic consequences of climate change. The following are a few examples of initiated projects. One project initiated has invited international organisations to work together to establish a sustained observation network (Sustainable Arctic Observation Network, SAON) for research and monitoring of climate change and its effects on Arctic ecosystems and humans. Other projects aim at documenting currently observable physical, chemical and biological effects, downscaling of models to sub-regions and local areas, and preparing a better budget for carbon storage and flux in the Arctic.

The current status of vulnerability and adaptive capacity of Arctic communities in the context of climate change will be assessed in a project, and this project shall identify gaps in knowledge relevant to research and policy, based on analyses of information about previous and current research, and reports. The project includes comparative case studies across the Arctic nations on selected topics, such as sustainable energy and water.

Two ongoing assessments are examining shipping and oil and gas activity in the Arctic, and part of these assessments cover socio-economic aspects and effects due to climate change. The results of several of these projects will broaden our knowledge base, increase our adaptive capacity and provide useful information in linking the Arctic to global issues.

The presentation will provide an overview of the current and planned projects and will explore how these may be linked to other international initiatives.

## *ATTENDEES*

# *Potential of the study of Antarctic birds for assessing climate change in the Antarctic Peninsula*

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A short description of the climate change process shows that the average temperature of the Earth's surface has been increased 0.6ºC since the 19th century. The effects of climate change on living organisms can be predicted in four aspects: physiology, distribution, phenology and adaptive modifications. Long-term studies have shown that the temperature increase is associated with a decrease in size and body condition in several ungulate species or a decrease in the melanism frequency in beetles, for instance. Several plant and animal species have changed their phenology, mainly advancing it, as a response to temperature increase.

Birds are good models to study the effect of climate change on animals because they are the most studied group. The great amount of knowledge about avian biology should allow us first to understand the effects of current changes, and then, more interestingly, to make predictions about future effects under the scenario of temperature increases. Several studies have shown, for instance, that both the arriving and the breeding date of migrating birds have advanced (Both & Visser, 2001). There are also changes in the distribution of several organisms, increasing their range (e.g. Carrillo et al., 2007). Physiological changes such as body mass decline have also been reported (Yom-Tov, 2001).

Antarctica and, specifically, the Antarctic Peninsula have suffered from faster and higher temperature increases than anywhere else in the world, with an increase of temperature of 0.56ºC per decade over the year and 1.09ºC per decade in winter (Turner et al. 2005) in the last 50 years. The effects of this climate change have been described as a surface reduction of glaciers and a reduction of spring and winter sea-ice extent (Smith et al., 1999) which involves a reduction in the abundance of krill as well (Atckinson et al., 2004) and, consequently, can affect the levels of their vertebrate predators (Fraser and Hoffmann, 2003). In fact, such effects have been detected in penguins, in which two contrasting habitat species such as Adélie penguin (sea-ice dependent) and Chinstrap penguin (sea-ice intolerant) seem to have changed population abundance in the mid-Western Antarctic Peninsula (Fraser et al. 1992). However, opposite results for the Adélie penguin has been found in Eastern Antarctica where a reduction in sea-ice extent seems to have influenced an increase in its populations (Jenouvrier et al., 2006). Changes in phenology in Antarctic birds have also been reported showing the general pattern that birds breed later (Barbraud and Weimerskirch, 2006). However, few studies have paid attention to changes in physiology due to climate change and few have dealt with description of geographical variations in several parameters aiming to establish a baseline for future comparison under the climate change scenario (Barbosa et al., 2007).

Despite the fact that the Scientific Committee of Antarctic Research (SCAR) has recommended increases in the research effort in the context of climate change as 'the detection of biological changes should be an essential part of the Antarctic Strategy on Climate Change', the information we have currently about climate change effects on Antarctic fauna and on Antarctic birds in particular is very fragmented. For instance, the aspects most studied, such as population changes, have been mainly carried out in penguins and only in a few places. There is little information about other Antarctic species such as petrels, albatrosses and skuas, or even about other characteristic penguin species like the Emperor penguin. We have seen before that the interactions between climate, sea ice, krill and population trends in penguin populations are complex (Forcada et al., 2006). Therefore, more places and more species should be monitored to have a general picture on climate change effects. Other aspects linked to climate change such as the study of the prevalence and expansion of diseases and parasite infections and how species can respond are now in the early stages. It should be noted that it has been hypothesised that a temperature increase will produce an increase in the distribution range, abundance and/or virulence of parasites and pathogens (Shutherst, 2001). This can also be enhanced by the likely increase in the arrival of exotic species to Antarctica carrying new pathogens, if environmental conditions are ameliorated. Moreover, other questions such as the effects of UV radiation through the ozone hole on Antarctic penguins or other birds remain to be studied (Karentz and Bosch, 2001), and a delay in the recovery of the ozone hole is predicted due to interactions with climate change (Shindell and Grewe, 2002).

## CONCLUSIONS

Birds inhabiting Antarctica offer an excellent opportunity to assess the effects of climate change.

- They would allow studying the effects in an ecosystem with a simple trophic web based on a main prey, the krill, which is clearly affected by the rise in temperatures and that affects population trends in top predators.
- This should allow building predictive models that can help to understand changes in other more complex ecosystems.
- Antarctic birds can be used as sentinels to monitor aspects derived from climate change such as the expansion of diseases, emerging of new diseases, effects of the expected increase in contamination due to the release of pollutants from glacier melting and to assess the effects of UV radiation in a climate change scenario on vertebrates.
- For developing of this potential, a research net of research teams should be created which takes active advantage of the infrastructure of each country in Antarctica. With at least 8 countries with complementary and highly specialised research teams involved in the investigation of Antarctic bird ecology, the European Union has great potential to achieve those tasks.

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# Antarctic marine biodiversity challenged by global change: the CAML/SCAR-MarBIN benchmark

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There is now undisputed evidence that climate change and modifications of the Earth system occurs, at faster rates in the polar regions. Among the many consequences we will be facing, the loss of biodiversity is probably of highest concern. CAML and SCAR-MarBIN are striving to provide the baseline information needed to assess the potential impact of climate change on Antarctic marine biodiversity. Through strong science plans, efficient data management and an unprecedented collaborative research effort within the IPY framework, CAML and SCAR-MarBIN intend to provide to scientists, environmental managers and decision-makers a sound benchmark against which future changes can reliably be assessed. This paper gives a brief description of the project's synergies.

The Southern Ocean, covering about 35 million km$^2$ and comprising about 10% of the world's oceans, is thought to play a vital role in maintaining the conveyor system of ocean currents, in which a key element is the extent of annual sea ice. The production of ice is matched by the production of deep Antarctic bottom water – cold, hyper-saline dense water which descends to the ocean abyss as it moves northwards. This water rises in the northern hemisphere where its nutrient and oxygen-rich water refreshes and supports life in the photic zone. The Antarctic Circumpolar Current, flowing from west to east around the Antarctic continent, has isolated highly-adapted planktonic and shelf/slope benthos systems from invasions, at least since their establishment some 34 million years ago.

Southern Ocean (SO) pelagic ecosystems have been studied since the early days of Antarctic exploration, stimulated particularly by the needs of the whaling industry. Likewise, some terrestrial and shallow marine benthic habitats around Antarctica, notably parts of McMurdo Sound and the Peninsula region, have been investigated thoroughly. These studies have revealed that marine biological communities in the more accessible parts of the Antarctic exhibit some very distinctive features, including endemism, gigantism, slow growth, longevity and late maturity. Moreover, adaptive radiations in shallow-water ecosystems have generated a considerable amount of novel biodiversity in some animal taxa. The deeper parts of the Southern Ocean exhibit some unique environmental features: in particular, the continental shelf is very deep, typically around 500 m water depth and the water column is isothermal. In addition, much of the world ocean's deep water originates in the Weddell Sea through thermohaline circulation. The vastness of the ocean surrounding Antarctica and the challenge of conducting research from icebreaking research vessels in ice-covered waters necessitates a very high level of international collaboration.

The International Polar Year (IPY) provides the context for the collaboration and SCAR (Scientific Committee on Antarctic Research) provides the broad-scale international interest in the project.

The Census of Antarctic Marine Life (CAML)/ SCAR Marine Biodiversity Information Network (SCAR-MarBIN) synergy provides the means to significantly advance our understanding of the biodiversity, evolution and biology of this vast and fascinating region of earth. The closely related IPY project ANDEEP-SYSTCO (SYstem COupling in the deep Southern Ocean) is designed to study processes in different realms of the biosphere in Antarctica and uncover how these systems are linked to each other (atmospheric-pelagic-benthic coupling processes). It will also represent a leap forward in this respect.

The CAML Science Statement sets out what is known about the Southern Ocean, what is not known and where the biggest gaps in knowledge may be found. It details a number of research questions for each biological realm which will help describe the value of the ecosystem services that the Southern Ocean freely provides to our societies. CAML/SCAR-MarBIN will assist with the description of the global significance of the Southern Ocean, and determine to what extent it is challenged by climate change.

To build a picture of the biodiversity of Antarctic waters, CAML and SCAR-MarBIN integrate knowledge across all habitats and all forms of Antarctic marine life. To fulfill this objective, the projects utilise currently un- and under-worked taxonomic collections and attempt to give access to these taxonomic data entered into world databases, in addition to purpose-designed field studies.

Existing databases offer valuable information on Antarctic species of particular taxonomic groups, but coverage is generally limited to those groups. In order to integrate and optimise the use of existing data, SCAR-MarBIN and CAML have been endorsed as parts of the new SCAR-EBA (Evolution and Biodiversity in Antarctica) programme, and as prominent projects of the International Polar Year (IPY).

In all realms of the Southern Ocean, CAML and SCAR-MarBIN will integrate studies of the diversity, abundance and distribution of marine life, and widely disseminate these results. Studies of the biodiversity of marine organisms, coupled to sound data management and dissemination will bring a better understanding of how life has evolved in the marine environment of the Antarctic, and how it can potentially respond to change. By building bridges between different research disciplines and international programmes, CAML and SCAR-MarBIN will provide a legacy of knowledge for future generations.

## RELEVANT LINKS

**CAML: http://www.caml.aq**
**SCAR-MarBIN: http://www.scarmarbin.be**
**SCAR: http://www.scar.org**
**IPY: http://www.ipy.org**

# Current French Ichthyological research in the Antarctic Ocean: present programmes and perspectives for the IPY

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In the past 40 years, French ichthyological research has been highly active through many campaigns in the Southern Polar region, in the sub-Antarctic sector mainly (Marion-Dufresne I and La Curieuse campaigns) but also more recently in the Weddell Sea (EPOS), Ross Sea (Franco-Italian collaborations and foremost around Terre Adélie (ICOTA). Kerguelen Islands have provided a reference zone located outside the Polar Front, but close enough to provide highly meaningful comparative material. The material collected during these campaigns has been used in numerous studies following the progress of techniques and equipment, and brought valuable insights on the evolution and the functioning of the polar ichthyofauna. The south polar ichthyofauna is particularly interesting because it has a high proportion of endemic species and groups, much higher than in the north polar waters. Among these, the Notothenioidei contain 122 species of Antarctic and sub-Antarctic species, that is, 46% of the actinopterygian fish species for 90 % of the fish biomass of the Antarctic continental shelf and upper slopes. Some notothenioids present unique adaptations to the extremely cold waters isolated by the circumpolar current, like a complete loss of hemoglobin (Channichtyidae) or the acquisition of anti-freeze proteins. This group is a well-known example of adaptative radiation in an extreme environment, but many other teleost fish species from distant groups also possess interesting characteristics and have been studied in order to better understand the formation of complex fauna and ecosystems isolated around the Antarctic continent.

## PRESENT PROGRAMMES

One of the main programmes has been the IPEV (Institut Polaire Français Paul-Emile Victor) sponsored ICOTA (Ichtyologie Cotière en Terre Adélie) that has been running since 1996. The programme has received complementary financial support from the CNRS, MNHN, University Paris VI and Université du Littoral Côte d'Opale. The current programme includes many complementary aspects and approaches in the search for an integrated comprehension of the South Polar system, an understanding that is essential for the detection or even prediction of possible changes in the fauna and ecosystems due to climate and environmental modifications.

## SYSTEMATICS AND EVOLUTION

The knowledge of local fauna has progressed tremendously but remains incomplete and requires additional sampling since it has been poorly investigated under 200m depth. The study of all other aspects of Antarctic fish biology relies on a sufficient overall understanding of their systematics, and the existing gaps in our knowledge can lead us to overlook or misinterpret other results. Several aspects still warrant in-depth study and specimen collecting campaigns.

The comprehensive description of all the species occurring in this environment is a prerequisite, but the limits of several groups are not yet well understood, in the genus *Trematomus* for example. Thus, each taxonomic unit (species, subspecies, population, etc.) must be clearly characterised since they may show different resistance and adaptative capacities to environmental changes. Overlooking these differences can lead us to miss radical changes and replacement of one population or species by another. Observing and recording such changes is fundamental for the use of species as bio-indicators, an approach that has proven very fruitful in coral reef ecosystems. Another point is the taxonomic identification of larvae that is vital for ecological studies, but not yet fully possible.

Lastly, the determination of evolutionary relationships between species is still under study and, necessary for the interpretation of the emergence of all adaptations and the building of ecosystems.

## ECOLOGY

The ecology research programme concentrates on the characterisation and modelling of the notothenioid habitats, exploring how individuals choose their habitat by study of their localisation, trophic strategies, and searching to establish ecophysiological adaptatibility and its links with the distribution of the species.

The Antarctic shelf is quite unique as it is deep and cut by innershelf depressions either open to the oceanic zone or closed by a sill. These depressions create habitat fragmentation for the sedentary fish species. Another particularity resides in the areas disturbed by iceberg scouring. Such disturbances affect the benthic fauna but also the demersal fish communities by changing habitat and prey availability. Finally, the hydrology and ice conditions are very important for the cryopelagic species (living near the sea ice) but also for the bentho-pelagic fluxes. Some species adapted to the natural ice disturbances. This adaptability might explain the success of these species in the colonisation of the Antarctic shelf. To explore these questions, four techniques are being used:

- Survey observations by classical methods (fishing) and underwater observations by ROV: behaviour and species distribution characterisation
- Habitat modelling
- Trophic ecology using mainly stable isotopes
- Life history traits

This survey will provide the data necessary for any attempt to predict or mitigate dramatic changes that could have a feedback impact on predator-prey relationships, fisheries or even on climate changes themselves through their influence on the food chains.

## PERSPECTIVES FOR THE IPY

The current programmes have already yielded interesting results on some essential points, but they also progressively reveal new areas where research and collection is absolutely needed.

The IPY 2007-2008 is an extraordinary opportunity for enlarging the study while the changes to the Antarctic climate are still not too important. Under the umbrella of the CoML (Census of Marine Life) Antarctic division (CAML), the SCAR (EBA) and for the IPY, the Australian Antarctic Division (AAD), the Institut Paul Emile Victor (IPEV) the National Institute of Polar Research (NIPR) and the Tokyo University of Marine Science and Technology (TUMSAT), a collaborative effort between Australia, France and Japan has launched a three ship campaign around Terre Adelie for the Antarctic summer 2007-2008. The collecting opportunities will be outstanding and allow pelagic and benthic investigations in rarely collected areas from 200 – 1000m depths, with a wide range of fishing gears and suitable laboratory equipment. The results will be directly integrated in international collaborative data assembly projects, like the Scar-MARBIN, the Barcode of Life Project, and FISHBASE. An outstanding effort at outreach and education towards the public and French, Japanese and Australian schools will be performed, during the campaign itself, as well as in the ensuing months. French ichthyological research in Antarctica is partly funded by IPEV for field work, while laboratory research funding is for now mostly provided by the home institutions of the scientists. The extent of future financial supports (French National Research Agency, European subsidies, etc.) will determine the speed of processing and analysis, as well as the extent of some of the studies.

## CONCLUSION

Our knowledge and understanding of the ichthyofauna of the Antarctic region has already benefitted from the new molecular and technological advances. But time is also running short: the polar ecosystems are among the first strongly hit by global climate changes, and we still do not possess a meaningful baseline to which we could compare future states of the systems to detect changes in faunal composition and ecosystems. Even our knowledge of actinoperygians, a highly visible group of economic importance, and one of the most comprehensively studied groups in Antarctic waters, is still incomplete. The gaps in our understanding could have dramatic results in the interpretation of research to come, and for future decisions regarding the conservation and management of both polar regions, whether at national or at European level.

# *EBA: Evolution and biodiversity in the Antarctic. The response of life to change — An overarching SCAR-IPY programme*

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The 2004-2013 SCAR Programme Evolution and Biodiversity in the Antarctic. The Response of Life to Change (EBA) so far includes close to one hundred teams from the vast majority of the SCAR nations (including most, if not all, European countries). EBA will act as a major route for *(i)* new SCAR members (e.g. Malaysia, Ukraine, Czech Republic), *(ii)* those with reduced logistics and funds, *(iii)* nations that have not traditionally engaged in polar research, *(iv)* students. Students will receive first-hand experience and training in logistics, such as resource planning, sampling technologies, etc, and will continue their polar education at their home institutions. They will form the next generation that continues the development of polar biology. EBA will foster undergraduate and post-graduate education.

EBA will explore the evolutionary history of modern Antarctic biota, examine how biological diversity in the Antarctic influences the way present-day ecosystems function, and thereby predict how the biota may respond to current and future environmental changes. For the first time, it will integrate the major realms of Antarctic biology (marine, terrestrial, freshwater) into a cohesive picture. EBA will advance evolutionary and ecological theory using organisms and model systems. Latitudinal gradients (e.g. ICEFISH; Victoria-Land Transect; IBMANT collaboration between European and South American countries on evolutionary connections between the Antarctic and South America) require extensive international collaboration.

The programme will include sub-Antarctic islands, nunataks, and stretch across the Southern Ocean down to the deep ocean and the shelves. Extensions to the Arctic are envisaged (Svalbard, Greenland, circum-Arctic). EBA is based on national funding sources, and will seek support from other funding agencies (e.g. EC FP7).

The broad objectives are: *(i)* to compare evolutionary adaptations to the Antarctic in a range of organisms, and determine general principles; *(ii)* to link with geoscientists to establish more clearly the evolutionary history of the Antarctic biota; *(iii)* to explore patterns of gene flow and determine their consequences for population dynamics; *(iv)* to identify patterns and examine diversity of organisms, ecosystems and habitats, together with the ecological and evolutionary processes that control these; *(v)* to study the impact of past, current and predicted environmental change on biodiversity and the consequences for Antarctic marine, terrestrial and limnetic ecosystem function.

The science extends over an entire biome on Earth. By comparing the outcome of similar evolutionary processes over the range of Antarctic environments, fundamental insights can be obtained into evolution and the ways in which life responds to change, from molecular to whole-organism levels, and ultimately at the biome level. The Antarctic environment offers a unique opportunity to address these questions following an inter- and multi-disciplinary approach: a pre-requisite for understanding the structure and functioning of the earth system. The goal of studying evolution, biodiversity, ecology and population dynamics will use the synergy of anatomy, physiology, biochemistry, biophysics, molecular biology, cytogenetics, taxonomy, morphological and molecular systematics, life-history strategies, phylogeny. With these backgrounds, EBA will provide a broad view of biogeographical distribution and biochemical processes. Advanced techniques (in particular at the molecular level) will be widely used to detect, determine and describe genetic signatures (DNA and RNA), biomarkers (lipids, carbohydrates, proteins) and biological index species.

EBA will liaise with the relevant physical, geological and historical disciplines to ensure use of the most recent data and insights in interpreting the biological results: plate tectonics, climatology, glaciology, geophysics, oceanography, palaeontology, glacial features, etc. The tectonic, climatic and glacial evolution of Gondwana offers a powerful opportunity to advance our knowledge of how evolutionary processes are related to the physical setting. Sampling sites will be identified and subsequently used to track changes in biodiversity. Collections will be made available to the scientific community and deposited in museums. Genomic resources, e.g. specimens, bulk DNA from a wide range of habitats, PCR-based clone libraries, meta-genomic libraries will be available to polar biologists. Establishing cross-linkages with the SCAR programmes (ACE, AGCS, SALE) is ongoing. EBA is related to other activities: e.g. CAML, ICEFISH, ANDEEP-SYSTCO, MarBIN, CLICOPEN, HABIPOL, HERMES, CCAMLR and IAI. Most of these programmes will outlive IPY. EBA will run three types of workshops: *(i)* thematic, fostering cross-disciplinary interactions (e.g. with ACE, AGCS and SALE); *(ii)* interaction with non-polar experts in evolutionary biology; *(iii)* integrative, for the polar community.

The EBA web site will be used for data management, ensuring data release and metadata support. Marine and terrestrial data will be integrated into the MarBIN and RiSCC databases, respectively. Genomics, proteomics, sequences and other data will flow into Genebank, SwissProt, etc. The site will serve as gateway for the general public, including young generations, to increase awareness of polar and global environments; it will serve as a forum to discuss schedules and outcomes, deposit data to share, offer/request laboratory uses, etc. Conferences, seminars and workshops will be scheduled to disseminate knowledge to children/teachers, because EBA has direct relevance to issues of increasing importance to the general public such as global change.

EBA will leave a legacy of evolutionary and biodiversity information, which is the hallmark of IPY. The science plan will make a significant contribution to IPY by elucidating the evolutionary response of organisms, populations and communities to environmental change. It will address the impacts of climate change on species biodiversity, adaptation, and also depletion of fisheries in the Southern Ocean. It will contribute to our understanding of the effects of such changes by investigating the severely restricted acclimatory responses available to high latitudes. It will contribute to the development of a baseline understanding of sensitive ecosystems, one against which future changes in species distribution and survival may be evaluated judiciously.

We will conclude with a short overview of ICEFISH (International Collaborative Expedition to collect and study Fish Indigenous to Sub-Antarctic Habitats). It is one of EBA's activities, aimed at understanding the fish biogeography, evolution and adaptation along the latitudinal gradient that extends north of the Antarctic. As an intermediate geographical system between the polar extremes, the Subantarctic fish fauna will provide vital information pertinent to a global synthesis of the characteristics of marine ecosystems. In a world experiencing global climate changes and loss of biodiversity, the Antarctic and the Subantarctic offer natural laboratories for understanding the evolutionary impact of these processes. Research integration has been limited, largely due to lack of access to sub-Antarctic fishes. In particular, species of the dominant suborder notothenioidei are critical for a complete understanding of the evolution, population dynamics, eco-physiology and eco-biochemistry of their Antarctic relatives, and are an important sentinel taxon for monitoring the impacts of climate change on biodiversity and community dynamics in the Southern Ocean. ICEFISH is designed to fill these critical gaps in our knowledge. The activity will be wide-ranged: *(i)* systematics and evolutionary studies; *(ii)* life history strategies and population dynamics; *(iii)* diversity and biogeography; *(iv)* physiological, biochemical and molecular-biological studies; and *(v)* genomic resources. Cruises, encompassing the South Atlantic, South Pacific and South Indian Ocean sectors constitute the first comprehensive international survey of the sub-Antarctic marine habitat. During the first cruise (17 May–17 July 2004), extensive fishing was performed in the South Atlantic sector: Burwood Banks, Falkland/Malvinas, Shag Rock, South Georgia, South Sandwich Islands, Bouvetøya, and Tristan da Cunha, at depths ranging from tidepools to the abyss. The next cruise will sample the sub-Antarctic Pacific sector, including Campbell and Scott Islands, Antipodes, Auckland, Macquarie, and Balleny Islands. It is an integral component of EBA (which covers all Antarctic organisms), CAML (Census of Antarctic Marine Life), CCAMLR, etc. These IPY activities have a very wide scope, and ICEFISH addresses an important theme common to all. In the ICEFISH web site **(www.icefish.neu.edu)** there are educational programmes directed to kindergarten through high school students (an "Ask a Scientist" email applet permits students to communicate with ICEFISH scientists as the cruise progresses). During ICEFISH, scientists will illustrate their field of research to young students, who will receive first-hand experience and training and continue their polar education by analysing cruise samples at their home institutions. These efforts will increase interest and the number of researchers in polar science as well as the number of expeditions, and will thus stimulate policy decisions on polar programmes. ICEFISH has direct relevance to global change.

# FP7: Research on climate change in polar environments must include effects on biota of both polar regions

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Polar biology is on the threshold of a revolution based on new technologies (e.g. genomics, proteomics), which will greatly enhance our knowledge of polar ecosystems and their *biodiversity*. The broad biological approach (e.g. physiology, ecology, molecular biology, biochemistry, phylogeny) allows researchers to monitor the impact of changes on polar species, on their adaptation and capacity to cope with ongoing climate changes and survive. In global terms, polar research is advancing at a fast pace, and the contribution by European biologists is very significant.

High atitude communities are a reservoir for a rich ensemble of species, many new to science. However, (due to the delicate physiological and ecological equilibria which are the price to achieve adaptation to extreme conditions), there is reason to think that they might be highly sensitive to even small climate changes, either natural or anthropogenic. Therefore, comprehensive baseline studies and biodiversity observatories are essential to further document and reliably monitor changes. The ambitious task of covering the biodiversity and biology of northern and southern polar environments is fundamental to answering questions that will help to predict the effects of climate changes, as a first step to counterbalancing their impact. e.g.: what are the differences and similarities of the adaptive strategies developed in each polar environment? Are organisms more vulnerable to climate change, due to their limited capacity to adapt to environmental variability? Are they able to cope with anthropogenic impacts, such as ozone depletion or pollution?

Loss of biodiversity and habitats, and changes in the rates of basic ecosystem processes, will be experienced everywhere on Earth, but in particular in the polar habitats. The protection of biodiversity along the whole evolutionary scale is a *top priority* for science and its funding sources, such as FP7. The G8+5 Potsdam meeting (March 16th, 2007) issued a statement underscoring the global economic significance of biodiversity, that it requires more extensive research, and that the abundant biotas of extreme environments such as the polar regions are particularly relevant.

Research covers the range from molecules to communities and ecosystems, in the marine, terrestrial, limnetic realms and the cryosphere (sea ice, snowpack, glacial ice and permafrost). For instance, cryoconites (miniature ecosystems within melt holes in surface ice) might be more abundant than currently realised and substantially change the N and C budgets of the glaciers. In a geographical context, latitudinal environmental gradients within and between the two polar environments and surrounding sub-polar habitats have proved to be invaluable for ecology, physiology and biogeography, and could be used more extensively to address key questions of response to change.
*Trans-disciplinarity* is another key strategy. Research in atmosphere physics, oceanography and sea ice in relation to the carbon cycle, for instance, should take into account the potential effects on living organisms and ecosystems and recognise that these same organisms and ecosystems can and do influence these same physical and chemical phenomena (contributions to biogeochemical cycles: e.g. carbon sequestration and release, a possible feedback loop between DMS production and cloud formation, etc) It is impossible to study climate change without considering life as a primary component. In fact, it is reasonable to foresee that models that neglect biology will miss important processes. A crucial step for integration and synergy with the other disciplines is the search for cross-links. SCAR (Scientific Committee on Antarctic Research), with its calendar of meetings aimed at establishing linkages among its five main programmes (EBA, ACE, AGCS, SALE and ICESTAR), which cover all of Antarctic science, is indeed a good model; groups such as IASC (International Arctic Science Committee) and AOSB (Arctic Ocean Science Board) have a similar role in Arctic Science. SCAR will produce a study on Antarctic Climate Change and the Environment (ACCE), to assess the climatic and environmental changes that are taking place across the Antarctic and Southern Ocean and to present projections on how the environment may evolve over the next century. Antarctic meteorology, oceanography of the Southern Ocean, biogeochemistry, ice sheet and shelves, ice caps and glaciers around the Peninsula and sub-Antarctic islands, sea ice, frozen ground environments, terrestrial and marine biota, will all be duly considered, and will represent a Southern Hemisphere equivalent of the Arctic Climate Impact Assessment (ACIA), produced in 2004 by IASC and the Arctic Council. ACIA research clearly indicates the vital importance of integrating biological research with physical and chemical studies of the changing polar regions.

In this framework, in addition to the balance between life sciences and the suite of other disciplines, it is also essential to reach a proper balance between Arctic and Antarctic research. Because of geographical, political and economic reasons, the former may seem more 'visible' for the EC, but the latter has a fundamental role in influencing the earth's climate. It is worth mentioning that both SCAR and IASC are planning mutual participation in their respective conferences, clearly showing that the bipolar approach to science is both reasonable and necessary.

The occurrence of the International Polar Year (IPY) 2007-2008 is a timely and extremely important occasion, not to be missed, to link up with the most important, ongoing Antarctic programmes in biological sciences (EBA, ICEFISH, CAML, SCAR-MarBIN, etc). Not unexpectedly, the focus of these programmes is the study of biodiversity. There are direct links to the global programme CoML

(Census of Marine Life) and its constituent Arctic programmes, whilst projects such as MERGE-IPY links microbiological studies across both polar regions. Also within IPY, in the multi-disciplinary setting afforded by SCAR, links will be established with geosciences, atmospheric and other physical sciences (e.g. ACE, AGCS).

Research on the effects of climate change on the biota of the Arctic and Antarctic regions is of the utmost importance for understanding the impact of such changes on the earth system. Now that polar research is increasingly turning bi-polar, scientifically important outcomes for global science would significantly suffer if funding agencies, such as FP7, did not also integrate funding for biologicaly-oriented research in the Arctic and the Antarctic.

# At-sea distribution of seabirds and marine mammals in the Greenland and Norwegian seas: impact of extremely low ice coverage

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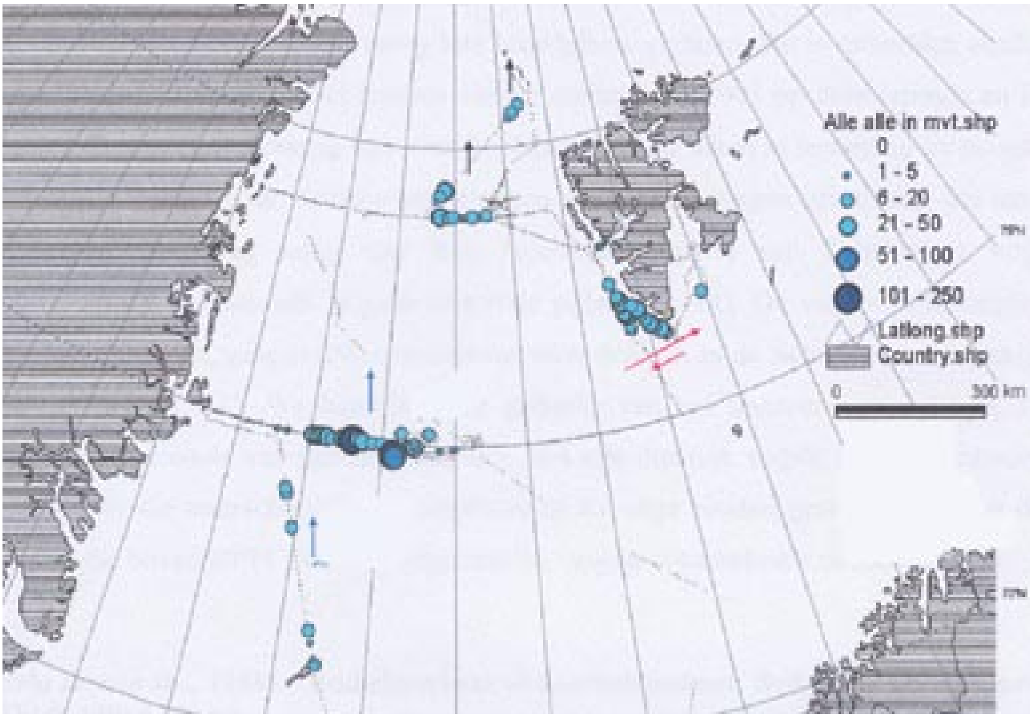
**Figure 1: Observations of moving little auks *Alle alle*: North from Jan Mayen to the pack ice, and to and from the breeding colonies around South Spitsbergen.**




At-sea distribution of seabirds and marine mammals was quantified in July-September 2005 on board the *RV Polarstern*. As a consequence of both the long-term decrease of pack ice coverage in the Arctic, as well as severe North Atlantic Oscillation in 2005 (NASA, last visited 2006), ice coverage was the lowest ever recorded in the region (Figure 1).

## RESULTS AND DISCUSSION

During more than 1 000 half-an-hour transect counts, a total of 16 000 seabirds were recorded, belonging to 24 species, 315 cetaceans (9 species), 250 pinnipeds (5 species), and 15 polar bears *Ursus maritimus*.

The most striking observations, in comparison with numerous studies by the same team (see synopsis in Joiris, 2000) concern the main alcids: little auk *Alle alle* and Brünnich's guillemot *Uria lomvia* on one hand, and polar bear and its main prey the ringed seal *Phoca hispida* on the other.

Little auks were leaving their Jan Mayen breeding grounds, and moving north by the thousands, probably in order to reach their feeding grounds at the ice edge, looking for zooplankton. Due to the huge distance between colony and feeding grounds, they apparently failed in their breeding season: all were obviously flying north (fig. 1), before the end of the breeding cycle. A similar, albeit more limited, situation was observed for the Brünnich's guillemot.

Density of polar bears and ringed seals, on the contrary, was very high in the SW part of the study area, along the 75°N transect. This does not, however, correspond to an increase of populations, but to local concentration on the limited ice edge.

## CONCLUSIONS

On the basis of these observations, one can foresee the following consequences of a further decrease in Arctic pack ice:

- Marine mammals do not seem to be strongly influenced by retreating pack ice: depending on the ice edge, they should be able to adapt to the new conditions and show a more northern distribution, as long as, of course, there remains a significant pack ice coverage in the region.
- Colonial seabirds on the contrary depend on terrestrial breeding grounds, while their main feeding grounds (alcids) are situated at the ice edge. In order to feed their chicks at the colony, they must be able to travel to the feeding grounds and back in a reasonable time. This apparently became impossible for the southern Jan Mayen colony in 2005, and might in future happen to the huge breeding colonies on Spitsbergen as well.

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NASA

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# Importance of insect herbivory for structure and functions of forest ecosystems in changing climate

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The potential effects of changing climate on plant-herbivore interactions have received substantial attention, but several crucial problems remain to be explored. In this short report, we identify the most critical data gaps that need to be filled in order to reliably predict the future effects of insect herbivory on terrestrial vegetation by using biogeochemical ecosystem models.

## INSECT OUTBREAKS AND ENDEMIC HERBIVORY

Herbivores can consume a large proportion of primary production, contributing to regulation of plant productivity in many environments. However, actual loss in plant biomass and subsequent decrease in productivity are documented only for relatively rare situations–mass occurrences (outbreaks) of insect herbivores. Shortage of data on consumption of plant biomass by low-density herbivore populations (termed endemic, or background, or nominal herbivory) was identified long ago as an issue (Schowalter et al. 1986), but still little is known about the importance of the endemic herbivory for vegetation and for ecosystems in general.

The few available estimates on the amount of foliage routinely removed by insect herbivores (not accounting for the loss of plant biomass due to sap feeders) vary between 1 - 16% (Kozlov 2007, and references therein). Although these relative figures seem minor, the *absolute* values are indeed large due to high plant biomass in forest ecosystems. Importantly, the amount of biomass removed by herbivores changes with climate: foliar losses of white birch, *Betula pubescens* Ehrh. due to endemic herbivory increased in Northern Europe from 1-2% at 70°N to 5-7% at 60°N, and this pattern was best explained by mean temperatures in July (Kozlov 2007). The General Ecosystem Simulator demonstrated that the predicted temperature increases are likely to enhance the impact of insect herbivores on white birch. Losses of birch foliage in some parts of the Barents Sea region can increase by 4-5%, resulting in reduction of the leaf area index, total biomass and productivity. These relatively minor changes, accumulating over decades, may lead to substantial effects on vegetation structure (Wolf et al., 2007). However, due to shortage of experimental data, this temperature-driven conclusion is made under a non-realistic assumption that $CO_2$ elevation will not modify consumption of birch foliage.

Three data sets need to be combined to reliably predict the effects of endemic herbivory on vegetation structure and ecosystem parameters in a changing climate by using dynamic ecosystem models: (1) Both densities of insect herbivores and the amount of plant biomass consumed by these insects (including sap feeders) need to be monitored for principal forest-forming trees along latitudinal transects in Northern Europe; (2) Effects of chronic low-level herbivory (5-10% defoliation) on growth (productivity) of these trees should be investigated by manipulative studies, because most experiments conducted so far have concentrated on the effects of acute plant damage (25-100% defoliation); (3) The combined effects of elevated $CO_2$ and elevated temperature on the behaviour of insect-plant systems need to be explored, as described below.

## COMBINED EFFECTS OF ELEVATED $CO_2$ LEVELS AND ELEVATED TEMPERATURE

While observations along natural climatic gradients do not allow exploration of $CO_2$ effects, most manipulative studies of plant and ecosystem responses to carbon dioxide enriched atmosphere ignore the effects of temperature elevation. In particular, the conclusion that herbivores will consume a larger proportion of plant biomass in a $CO_2$ enriched atmosphere (Lincoln et al., 1993) was not verified under simultaneous temperature increase. We have identified only 42 studies that have explored the effects of elevated $CO_2$ and elevated temperature, both alone and in combination, on the plant biochemical and morphological traits (that reflect host quality for herbivores) of 31 species (Zvereva & Kozlov, 2006).

We discovered three types of relationships between $CO_2$ and temperature elevation: (1) responses to elevated $CO_2$ do not depend on temperature (foliar nitrogen, C/N ratio, leaf toughness, phenolics in angiosperm leaves); (2) responses to elevated $CO_2$ are mitigated by elevated temperature (foliar sugars and starch, terpenes in needles of gymnosperms, insect performance); and (3) effects emerge only under the combined action of elevated $CO_2$ and elevated temperature (foliar nitrogen in gymnosperms; phenolics and terpenes in woody tissues). This result in particular indicates that conclusions of $CO_2$ elevation studies cannot be directly extrapolated to a more realistic climate change scenario. The predicted negative effects of $CO_2$ elevation on herbivores are likely to be mitigated by temperature increase (Zvereva & Kozlov 2006). Thus, additional studies involving combination of $CO_2$ increase with other factors, primarily temperature, are necessary to improve predictability of the models.

We have identified only seven studies that had explored the combined effects of elevated $CO_2$ and elevated temperature on the performance of insect herbivores (Zvereva & Kozlov, 2006); most conclusions on the potential effects of climate change on insect-plant interactions are based on changes in plant chemistry. Although they often allow prediction of herbivore response, quantitative relationships between changes in insect performance and changes in host plant quality are not evident. Moreover, different guilds of herbivores respond to $CO_2$-mediated changes in host plant chemistry in different ways and responses vary from negative to positive. Therefore, the direct evaluation of the performance and measurement of biomass consumption by herbivores from different feeding guilds on plants subjected to elevation of both $CO_2$ and temperature, cannot be replaced by analysing plant chemistry (Zvereva & Kozlov 2006). Moreover, exploration of population-wide effects requires studying of three-trophic-level systems, which would allow accounting for both bottom-up (from host plant) and top-down (from natural enemies) impacts regulating herbivore population dynamics.

## ADAPTATIONS TO CLIMATE CHANGE

Although evolution by natural selection is a pertinent force to consider even at the time scale of contemporary climate changes (Berteaux et al., 2004), none (to our knowledge) of the models exploring the potential effects of climate on insect-plant interactions consider the possibility of the rapid evolution of either plant or insect populations. These evolutionary processes may be driven by both direct (elevated temperature and elevated $CO_2$ concentrations) and indirect (altered biotic interactions) impacts of the rapidly changing environment (Parmesan 2006). Therefore, innovative studies addressing this problem are badly needed to produce more reliable predictions on the consequences of the expected climate change for ecosystem structure and functions, as well as to develop adaptation strategies and mitigation measures.

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# Access and conservation of polar bacterial diversity, and the impacts of climate changes

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A number of IPY projects address the microbial diversity in polar regions, a quite recent research topic that is gaining momentum with the realisation that a lot of organisms are still to be discovered, that their adaptations are worthy of study and that they can be expected to contain biotechnologically interesting molecules. Moreover, microbial communities play a major ecological role and it is probable that they will be impacted by climatic changes, and thus could be used as indicators. It is our opinion that the EC should think about integrating these research topics in its polar programmes.

Our proposal on polar bacteria diversity is part of the integrated and interdisciplinary IPY project entitled 'Microbiological and Ecological Responses to Global Environmental Changes in Polar Regions' (MERGE, 2007-2008 Coordination Proposal No. 55). MERGE is an umbrella hosting a number of transnational activities planned for the International Polar Year, involving 81 scientists from 22 countries. Three main themes will be addressed: 1) Diversity and biogeography of polar prokaryotic and eukaryotic organisms; 2) Food webs and ecosystem evolution; 3) Linkages between biological, chemical and physical processes in the supraglacial. The major purpose of the MERGE umbrella is thus to provide and expand the chances for sharing/exchanging/offering data, samples, logistics, expedition opportunities, field facilities, laboratories and analytical instruments between the research themes. Particularly notable is the expertise developed by participants in 'contamination-free' sampling and the isolation of ice-borne microorganisms.

## ACCESS AND CONSERVATION OF POLAR MICROBIAL DIVERSITY

In the context of MERGE, our proposal focuses on the taxonomical, genetic and metabolic diversity of heterotrophic and photoauthrophic bacteria isolated from terrestrial, freshwater and marine polar ecosystems, including cryoconites, benthic mats (in lakes, melt waters and the marine littoral), sea ice, crusts on rocks and soils, volcanic springs, and endolithic biota. This activity will include the conservation *ex situ* of the isolated strains, of their metabolite extracts and of their genetic material. Phylogenetic and population genetic methods are being used to assess the present status of Antarctic and Arctic microbiota with the aim of tracking the effects of past and present environmental and human changes in the polar regions. Molecular-genetic and genomic approaches, in combination with monitoring studies in selected areas, will reveal how key organisms have co-adapted to the extreme polar environment and how they respond to inter-/intra-annual environmental changes such as light, climate, temperature, and nutrient concentrations. In addition to classical microbiological methods, we propose to study and exploit the metagenome of these communities in order to access the diversity of functional genes from uncultivated micro-organisms.

## PREVIOUS, PRESENT AND FUTURE ACTIVITIES AND COLLABORATIONS

The team of Flavia Marinelli at University of Insubria intends to widen knowledge on the presence and distribution of heterotrophic bacteria, with particular attention to actinomycetes, in terrestrial, freshwater and marine, sea-ice, and rock samples from Arctic and Antarctic ecosystems. Previous experiences on the microbial mats sampled during EU project EU MICROMAT BIO4-CT98-0040 (Biodiversity of microbial mats in Antarctica) in 23 Antarctic lakes, which deeply vary in salinity, ice cover, light intensity, sea water inlets, wind driving mixing, etc., have led to the recurrent identification of ubiquitarious heterotrophic psychrotolerant bacterial taxa and of endemic psychrophilic cyanobacteria. The heterotrophic and photoautotrophic bacteria isolated by MICROMAT partners, have also been screened for biotechnological and pharmaceutical purposes. As of this writing, we have already identified several interesting metabolites produced by Antarctic actinomycetes. Thanks to the collaboration with the team of Dr. Annick Wilmotte, at the University of Liege, we had also the opportunity to investigate the metabolic and genetic diversity of 60 Antarctic cyanobacteria, many of them being novel species or species endemic to Antarctica. We plan to continue these activities on the novel strains, which will be isolated from Arctic and Antarctic samples collected during IPY, and to isolate and purify secondary metabolites endowed of interesting anti-infective and anti-cancer properties.

On the same polar microbial communities, the team of Maria Luisa Tutino at the University of Naples will apply a combination of molecular approaches, such as genomics, metagenomics and metabolic screening. The sequencing of a significant number of polar-derived DNA fragments, combined with phylogenetic analysis approaches, will help in assessing the microbial diversity of selected sampling sites. This programme will take advantage of the availability of a still unique gene-expression system which uses an Antarctic Gram-negative bacterium (*Pseudoalteromonas haloplanktis* TAC125) as host for the recombinant protein production. Indeed, the construction of 'shuttle' metagenomics libraries, i.e. metagenomics collections that can be replicated either in the usual bacterial host (*E. coli*) or in the psychrophilic host *Pseudoalteromonas haloplanktis* TAC125, will give the unique possibility to carry over the functional screenings (metabolic or activity tests) of the encoded psychrophilic (and possibly also thermal labile) proteins at low temperature, i.e. in temperature conditions more physiologic than those achieved by using the mesophilic *E. coli*. *Pseudoalteromonas haloplanktis* TAC125 was selected by a European consortium to be the first Antarctic bacterium to be sequenced, and the team of Maria Luisa Tutino has been deeply involved in PhTAC125 genome annotation and functional characterisation.

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# Coping with cold. The evolution of hemoglobin in fishes living at polar latitudes

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In the biosphere, organisms have succeeded in adapting to a variety of environmental conditions. The diversity of life forms suggests that adaptation has been reached by species in all regions of the Earth. The cellular macromolecules, proteins and nucleic acids are very sensitive to environment perturbations. Temperature, hydrostatic pressure, medium cellular composition and oxygen availability may profoundly affect cell physiology. Adaptation implies keeping the structural and functional features of the cellular biochemical constituents and an adequate level of energy turnover in response to variable environmental conditions. Certainly, temperature is the most important physical factor affecting life (di Prisco and Verde, 2006b; Verde et al., 2006b).

The recognition of the important role of the polar habitats in global climate changes has awakened great interest in the evolutionary biology of the organisms that live there, as well as the increasing threat of loss of biological diversity and depletion of marine fisheries. These organisms are exposed to strong environmental constraints, and it is important to understand how they have adapted in order to cope with these challenges and to what extent these adaptations may be upset by current climate changes (di Prisco and Verde, 2006a).

Research on polar teleosts is providing important insights into the molecular mechanisms of protein thermal adaptation, conceivably reflecting differences in palaeogeography (di Prisco at al., 2007).

Here we summarise recent advances in our knowledge of the structure, function and evolution of the oxygen-transport system, in particular hemoglobin (Hb), in polar fish. Particular attention is devoted to molecular phylogenies based on Hb genes of Antarctic and Arctic fish involved in cold-adaptation. Molecular phylogeny has revealed different adaptive scenarios in the two polar regions.

The Arctic and the Antarctic differ by age and isolation of the respective marine faunas. Antarctic fish are highly stenothermal, in response to stable water temperatures, whereas Arctic fish are exposed to seasonal and latitudinal temperature variations. The knowledge of the mechanisms of phenotypic response to cold exposure in species of both polar habitats offers fundamental insights into the nature of environmental adaptation (Verde et al., 2002; Verde et al.,2004)

Proteins, e.g. Hb, are highly responsive to temperature, and their structure and function mirror the thermal conditions encountered by species during their evolutionary histories.

Notothenioidei, the dominant suborder in the Antarctic, have evolved reduction (and even elimination in the icefish family) of Hb concentration and multiplicity, perhaps as a consequence of the stability of temperature and other environmental parameters. The coastal waters of Antarctica are cold and oxygen-rich. The metabolic demand of polar fish for oxygen is relatively low, the solubility of oxygen in their plasma is high, but the energetic cost associated with circulation of a highly corpuscular blood fluid is large. With the selective pressure for erythrocytes and oxygen carriers relaxed and with the cells posing a rheological disadvantage in the temperature-driven increase in blood viscosity, notothenioids have evolved reduced haematocrits, Hb concentration/multiplicity and oxygen affinity (Verde et al., 2006c).

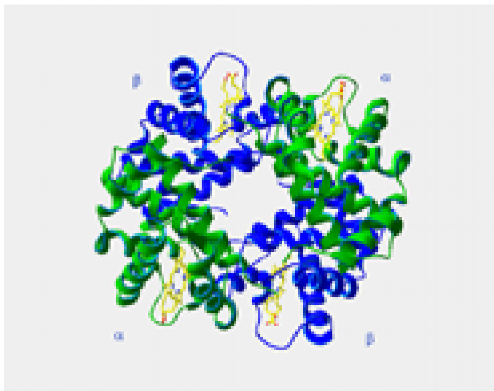
In contrast, similar to other acanthomorph teleosts, the Arctic ichthyofauna, thriving in a more complex and variable oceanographic system, maintained higher Hb multiplicity and a globin system with high diversity, helping fish to deal with environmental changes and metabolic demands. For instance, although the presence of multiple Hbs may be regarded as a plesiomorphic feature secondarily involved in temperature fluctuations, it may allow higher total concentration in the erythrocyte through selective expression (Verde et al., 2006a).

The amino acid sequences used to gain insight into the evolution history of $\alpha$ and $\beta$ globins of polar fish have clearly shown that Antarctic and Arctic globins have different phylogenies. It appears that the selective pressure of environment stability has allowed the phylogenetic signal to be maintained in the Antarctic sequences, while variations in the Arctic would tend to erase this signal. As a result of isolation, notothenioids acquired a completely different genotype with respect to other teleostean groups, and in phylogenetic trees the globin primary structures are clearly grouped in two clades (Verde et al., 2007).

Considering the amount of information available on cold adaptation, the study of fish adapted to the extreme conditions of the polar seas will allow us to gain invaluable clues on the development, impact and consequences of climate and anthropogenic challenges, with powerful implications for the future of the Earth.

New information, including the choice of suitable target species, long-term data sets and the concerted efforts from international multidisciplinary programmes, will help us to identify the responses of vulnerable species and habitats to climate change. This preliminary step is required to establish efficient strategies aimed at neutralising threats to biodiversity: in particular, before they become hopelessly irreversible, those which are essentially driven by anthropogenic contributions. It will not be an easy task, but in the fertile scenario of polar research this demanding challenge is well worth pursuing.

**Structure of Pseudaphritis urvillii Hb 1 (G. Barbiero, unpublished), built by homology modelling using the programme MODELER.**



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# The challenge of the human dimension in climate change research

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Humans are different from many other components of terrestrial and aquatic ecosystems in their intellectual capacity for making cultural, social, and emotional choices in contrast to or overruling the laws of nature or pure economics. Nonetheless, it is these aspects that have a crucial impact on the future of humankind in a changing climate. Research on the 'human dimension' of climate change is still in its infancy. Aspects such as the perception of climate change and local responses of resource users are studied by a small group of insiders with limited funding, whose results are hardly considered in large-scale modelling or projections. Even the economic impact of future climate change is barely understood, although it has an important impact on the future of humankind.

One problem of the human dimension in climate change research is that human behaviour is difficult to incorporate into quantitative models. Patterns of human decision-making are so complicated and depend on so many variables that any model attempting to predict them becomes unmanageable. Data in human dimension research are often qualitative and impossible to consider beyond a descriptive narrative. Even in those cases where human behaviour can be linked to quantitative data, for example in economic modelling, model performance and predictive capacity is hampered by the fact that rational economic choice is only one among numerous variables influencing people's decision-making.

Considering the complications of incorporating the human dimension, it has often appeared that the most efficient way to proceed is with predictive models of physical climate change that operate implicitly, as if humans do not exist, as was pointed out in a recent IPCC report (Science Daily 2007, April 6).

It should be noted that the importance of the human dimension in climate change research is not relative to population densities or percentages. Paradoxically, it seems to be well accepted that the extinction of the polar bear as a result of climate change would be a key loss to biodiversity, while the threat to numerous indigenous subsistence livelihoods seems to get less public or research attention, even though such endangered communities in the Arctic are important components of circumpolar and global cultural diversity. In addition, we acknowledge that the majority of Arctic residents today are immigrants to the North or their descendants. Studying the social impacts of climate should therefore include the majority of non-indigenous northerners, without neglecting the particular needs of indigenous minorities. Mineral resource extraction, the growing indigenous international agency, and - since 2006 - the International Polar Year (IPY), have brought a whole wave of publicity for human issues in the Arctic, which led to a new discussion about the definition of the human dimension in the North. Notably, the 'human' topic of the current IPY includes not only indigenous but all human societies as a focus of research (Hovelsrud & Krupnik 2006).

Therefore we argue for the inclusion of the human dimension into climate change research as a component of complex integrated impact assessment. We have identified the main challenges for such an integration firstly by applying the key theoretical concepts to both natural and social sciences, namely human vulnerability, resilience and adaptation; secondly, by bridging the gap between quantitative and qualitative approaches; thirdly, by linking scientific and traditional ways of knowing, acknowledging the particular needs and value of indigenous communities without ignoring the majority population; and fourthly, by taking into account regional particularities.

The future impacts of climate change predicted vary greatly, depending on which climate model is used to predict changes. They also vary in the present, depending on a number of factors such as the particular development chosen in the region, the economic, social and cultural orientation of the human population, its relative income, national composition, density and interaction with its environment. Differences in the above-mentioned factors could potentially determine the level of vulnerability of a community to climate change, and its potential for successful adaptation. For example, climate change will have a different impact in indigenous communities with subsistence economy than in big industrial cities. It will also matter whether these communities are located, for example, in Norway or in the Russian North, with their different levels of economic development and technological base. This shows how complex and dynamic the relationships between different variables in interactions between humans and the ecosystem are.

We therefore suggest amending and operationalising the key concepts in climate change research using regionally adapted concepts, focusing on three main sectors:

1. Human-nature relations in the broad context. The major challenges facing the human dimension in climate change research in the North, like elsewhere, are intimately bound up in the wider contexts of four main spheres:

   a) political: national, regional, local aspects: the questions of national strategy and policy decision;
   b) socio-cultural: perception, cultural change, demographic processes, local response of communities;
   c) economic: extraction and management of mineral and marine and terrestrial resources, indigenous economies, subsidy regimes, tourism, costs of adaptation;
   d) legal: property rights, human rights, minority law, international law, e.g. law of the sea.

- A holistic approach to understanding the connections of people with their environment incorporates these four spheres and can serve as a basis within the conceptual framework of assessing the human implications of climate change.

2. Anticipation versus prediction. In most cases, the complexity of socio-cultural-economic systems makes any prediction as part of a model highly unreliable and only possible under a largely unjustifiable simplification of future scenarios. Instead, as we move from pure research to the application of what we have learned, perhaps we should think in terms of anticipating what may happen, rather than predicting what will happen (Huntington, 2002:xxvi). Anticipation is a more pro-active concept that is based on the predictive capacities of not only models but also of real people with real experiences of the land. Intimate experience and practices of humans on the land enable them to share the atmosphere and join in the state of their environment. This brings about another sphere of predictive capacity that can be used in adaptation processes.

3. Regional specifics and place-based methods. Integrated models of climate change should pay greater attention to developing place-based methods. Scale is crucially important when incorporating humans into the research focus (cf O'Brien et al 2004). These regional particularities are relevant for the human population of different geographical areas (coastal, low-lying, permafrost areas, urban, rural), for high risk areas, and for areas with indirect impact. There is already a big demand for developing practical guidelines for adaptations to climate, and actors as diverse as industrial companies, insurance businesses and indigenous communities need reliable statements about the current and possible future impact of climate change in their specific areas of operation.

In spite of recent efforts to incorporate the human dimension into climate impact assessment, we note still many limitations. One is the fragmentation of research into individual projects where members have to worry about new funding applications that draw the researchers' attention away from still-ongoing projects. Another limitation is the focus on impact assessment 'from outside', based on an assumption that scientifically trained experts from the south know better how to do this research than local residents with a generation-long experience of life in a changing Arctic environment. Future research might therefore consider different funding systems and more participatory methods.

We also emphasise that research should consider not only the threats but also the opportunities of climate change, such as potential reductions in heating expenses, increased growth rates of commercially usable plants, and benefits for tourism in northern regions as a result of a warming climate.

Finally, it is worth remembering that there are sources of social change other than a changing environment, and sources of environmental change other than climate (Huntington 2002: xxvi). The latter constellation in particular is important for the population in the Russian North, where a sudden change in policy or economic turbulence can have effects of an order of magnitude higher than climate change and in a fraction of the time needed (Rees et al forthcoming 2007). The challenge for polar social scientists is to bring the relevance of their results for climate change research and for the social understanding of the dynamics of the ecosystem to a broader audience, including natural scientists and decision-makers.

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*Polar Environment and Climate*

# 7. Public outreach, education and policy makers

# REPORT from CHAIR

## Session on public outreach, education and policy makers

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A number of observers and professionals feel that within the field of environmental issues, there is a significant gap between the knowledge in the research community and in the general public. Climate change and polar research are two of the areas where this can be seen.

The 7th session of the Symposium on 'Public outreach, education and policy makers' provided a great opportunity for the participants to familiarise themselves with initiatives from different types of organisations addressing this issue. Each described its activities and future plans, and identified the challenges ahead.

From the experiences that were presented and shared with the audience, it became obvious that communication to and with the public on climate and environmental issues is both crucial and complex. Crucial for the future of the planet; complex due to the multiple factors involved in scientific forecasts, the sometimes contradictory points of view expressed by media and scientists and the change in behaviour it requires from members of the public. The latter are interested in learning, forming and building on their opinions, yet a bit worried about the consequences for their daily lives. Eva Jonsson, of Teknikens Hus, stated: 'Climate change is for real and it is happening now, and it is possible to live a good life with less use of the earth's resources.'

To achieve the objectives of communicating to a large audience in professional and relevant ways, two major recommendations were brought forth:

One 'horizontal' recommendation states that all research activities should include public communication of their work and findings to the public in an accessible and interesting way, on a very large scale. Communicate to many, on a variety of subjects.

The second 'vertical' recommendation recognises the depth of the subject to be communicated and its complexity, and therefore calls for the need to test methods and approaches for communicating to the public. As these issues are difficult to translate into activities that are meaningful and appealing to the public, they must be done by professionals, who communicate science on a full-time or regular basis, such as science centres and museums, specialised foundations or research institutions that have developed knowledge in science communication. As one of the speakers Walter Staveloz, ASTC, mentioned, 'one needs sound and interesting science to be the base of the project. The science and the phenomena must be relevant to society; the techniques put in place must appeal to people's emotions and the most advanced technologies are needed to help deliver the results within an international framework.'

Networking and sharing experiences are essential for these goals. Participants encourage and ask for more collaboration between universities / research organisations and science centres / museums, as well as for the training of researchers and university students in science communication. Existing resources' websites should be disseminated and reinforced.

## PROJECTS PRESENTED

The International Polar Foundation showed their rich SciencePoles website and their numerous public outreach activities on polar research. The IPF seeks to bring about a keener appreciation of the role of science, and in particular scientific research in the polar regions, to facilitate the dialogue between the scientific community and society. It provides new tools for the dissemination of research findings to the wider public:

- The new 'Zero Emissions' Princess Elizabeth Antarctic Research Station;
- The DAMOCLES European exhibition on the EU-supported research project in the Arctic;
- Popular multi-lingual interactive CD-ROMs, international educational projects and tools; and the future Polaris Climate Change Observatory.

Anne Henderson-Sellers from the World Climate Research Programme caused a stir during the Symposium by demonstrating how forceful we have to become if we want to get the right messages across. Key Performance Indicators (KPI) should be developed and used to identify critical success factors in science communication.

Walter Staveloz, Association of Science-Technology Centers showed three examples of new science communication actions that aim to successfully respond to the elements at stake.

'Live from the South Pole with Japanese Astronomer M. Mohri' connected three science centres (Miraikan-Tokyo, Questacon-Canberra and MST-Bangkok) to the Japanese Research Station on Antarctica for a dialogue between Dr. Mohri, Director of Miraikan Science Center in Tokyo and researchers.

With 'Digging in people's picture archives to illustrate climate change', Prof. Primack of the University of Boston has compiled scientific descriptions of nature in Massachusetts, starting with the groundbreaking work of Thoreau, and has collected archives of the botanical garden, amateur scientists and photographers. He concluded that both techniques give comparable results, an increase of the average temperature in this area of about 1.5°C over the last 150 years. In cooperation with the ASTC-IGLO (www.astc.org/iglo) project and the science centre of MIT, the public is now invited to dig in their archives or take pictures of specific spots indicated by Prof. Primack to continue the work on a much larger scale. The MIT museum will create an exhibition on the basis of this unique citizens research partnership.

## ILLUSTRATING THE PLANET'S ALBEDO

On 1 March 2008, a worldwide action on the planet's albedo will be held. Young people from schools and science centres will make 20 large white surfaces with cardboard boxes, thus creating 20 imaginary new polar surfaces. NASA's Goddard Earth Observatory, participate in the project and the satellite will allow the measurement of the sun's reflection, showing that the larger the surface of the polar ice caps, the smaller the rise in global average temperatures.

# SPEAKERS

## Bridging the science society divide

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The International Polar Foundation (IPF), recognised by Royal Statute as a public utility organisation in 2002, was created with the aim of providing a novel interface between scientific research and society at large. The IPF seeks to bring about a keener appreciation of the role of science, and in particular scientific research in the polar regions.

The International Polar Foundation has been created to facilitate the dialogue between the scientific community and society. Researchers in the polar regions have been actively trying to fill in the gaps in knowledge to address the uncertainties surrounding the pace and direction of change related to global warming. These activities will intensify during the International Polar Year 2007-2008.

The polar ice caps of Antarctica and Greenland yielded, after painstaking research, the evidence that finally established the causal link between human-related carbon dioxide emissions, mean surface temperature, and climate change. Accelerated warming, in turn, would unlock the millions of tonnes of fresh water held in the ice caps, causing sea levels to rise.

Meanwhile, the Arctic sea ice, which has the dual function of an early warning system (being particularly sensitive to warming trends on the planet), and a reflective shield, keeping in check any acceleration of the warming process, is also in decline. Observed loss of sea ice extent is preoccupying the scientific community.

In light of the potentially devastating outcomes related to warming at high latitudes, it becomes crucial that scientific research aimed at throwing light on these phenomena should continue, and that the latest findings are brought into the public domain.

The IPF has set out to support the efforts of the international scientific community by providing new tools for the dissemination of research findings to the wider public, through the leveraging of support for research infrastructure and activities, and by promoting the International Polar Year 2007-2008.

Some IPF activities: in support of scientific research activity are presented here:

- The new ‘Zero Emissions’ Princess Elizabeth Antarctic Research Station;
- The DAMOCLES Over Europe Exhibition on the EU supported research project in the Arctic;
- Educational and outreach activities: popular multi-lingual interactive CD-ROMs, international educational projects, novel educational tools, support to the IPY Office and outreach from Polar research activities;
- The future Polaris Climate Change Observatory;
- The SciencePoles web site.

# Polar climate challenge: Role of global environmental research in communication and outreach

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In the light of rapid and acknowledged environmental change in polar regions coupled to the widespread interest in the issue of global warming, I seek to engage those attending the symposium in consideration of the question: 'How can environmental research (& researchers) better inform the public, enhance education and influence policy?' This question is surely one of the immediate and important challenges of today.

Many research questions are known and these include:

- What will be the magnitudes, patterns and rates of change in the polar regions on seasonal to century timescales in the 21st century?
- What will be the major socio-economic consequences, either direct or occurring through feedback loops, on the climate system?
- What is the contribution of glaciers, ice caps and ice sheets to changes in the global sea level on decadal-to-century time scales? How can we reduce the current uncertainties in these estimates?
- What will be the nature of changes in sea ice distribution and mass balance in both polar regions in response to climate change and variability?
- What will be the impact of changes in the polar regions on atmospheric and oceanic circulation?
- What is the likelihood of abrupt or critical climate and/or earth system changes resulting from processes in the polar regions?

The difficulties facing researchers and programmes which aim to 'delver value' are also well-known and include: (i) the differing time scales (of research, media and policy); (ii) language and translation conflicts (among researchers, the public and the sources they access); (iii) research & sponsor priorities, reward, incentive structures; (iv) manipulation: real or perceived; (v) the difference in demand for standards of evidence; and (vi) failure of decision making – new knowledge linkage. The World Climate Research Programme (and similar organisations) face real challenges as we try to prioritise research to deliver benefits.

This paper reviews some success strategies for better coherence between research and public awareness, education and policy development.

# *Extreme science communication: how IPY can revamp science for the public*

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The IPY has ignited not only a great number of research project ideas, but has also stimulated a variety of education and outreach ideas. It is fair to say that this might become the world's biggest science communication effort on one single topic ever. The only comparable events might be the 1999 solar eclipse, but because of its nature and despite the intensive use of information technology, it was not a worldwide event. The IPY might become one, and the official launch that takes place on 1 March will give an indication of the impact of the IPY education and outreach, as we will be able to count the number of schools and science centres in the world that have launched a virtual balloon using Google Earth as their kick-off signal.

We will need to wait for the end of the IPY to fully understand why the poles have created such an interest among educators and science communicators. We can, however, guess some of it: the poles are considered part of the world heritage and are universal in nature; they are still inaccessible for most of us and carry some kind of adventurous ideal and, ultimately, they tell us a lot about the world we live in. These are all elements that are a good basis for innovative science communication programmes.

This presentation will show three examples of new science communication actions that are building up to respond to these elements and be successful with the public.

## LIVE FROM THE SOUTH POLE WITH JAPANESE ASTRONOMER M. MOHRI

Three science centres (Miraikan-Tokyo, Questacon-Canberra and MST-Bangkok) have connected with the Japanese Research Station on Antarctica where Dr. Mohri, Director of Miraikan, the Science Centre in Tokyo, had a dialogue with researchers about the specific atmospheric conditions on the South Pole. At some point, Dr. Mohri addresses the fact that while he is talking, we do not see the condensation of his breath. The question to the audiences: why is this? In preparation for this question a protocol for experimentation using aerosols in the different participating museums has been set up and the dialogue between Antarctica and the audiences aims at explaining the phenomenon by combining the experiment on the pole and a similar experiment performed by the partner institutions.

## DIGGING IN PEOPLE'S PICTURE ARCHIVES TO ILLUSTRATE CLIMATE CHANGE

Prof. Primack of the University of Boston has compiled scientific descriptions of nature in Massachusetts, starting with the groundbreaking work of Thoreau. In addition to that, he has collected archives of the botanical garden, amateur scientists and photographers. He compared the results and came to the conclusion that both techniques give comparable results, an increase of the average temperature in this area of about1.5 degrees Celsius over the last 150 years. In cooperation with the ASTC-IGLO **(www.astc.org/iglo )** project and the science centre of MIT, the public is now invited to dig in their archives and even make pictures of specific spots indicated by Prof. Primack in order to continue the work on a much larger scale. The MIT museum will create a new exhibition on the basis of this unique citizens-research partnership.

## ILLUSTRATING THE PLANET'S ALBEDO

One of the main elements that link polar research to our daily lives is the question of the changing climate. A crucial element in understanding that is the albedo. Our partner in IGLO, the IPF, has suggested creating an event where children would be asked to form large white surfaces by bringing together cardboard boxes. They would then measure the impact of these newly created imaginary poles. We have picked up that challenge. Indeed if we can show that the bigger the poles surface the better we can keep the planet from heating that would be a perfect combination in the context of the IPY. However, it is a technical challenge. Thanks to our collaboration with NASA's Goddard Earth Observatory, we have been able to identify the satellite and the conditions under which this can be successful. Now, we have the solution and will perform a worldwide action on the albedo on 1 March 2008, on the occasion of the first anniversary of IPY. At 20 locations all over the planet, students and science centres will create the white spots that will enable us to make precise calculations of the sun's reflection.

These three examples should help us to understand why we can speak about extreme science communication; we need sound and interesting science to be the base of the project. The science and the phenomena must be relevant to society; the techniques put in place must appeal to people's emotions; we need the most advanced technologies to help deliver the results; and we need an international framework: an IPY and a network like ASTC.

# *Grasping climate — a science centre grip on global warming*

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## GRASPING CLIMATE – AN EU-PROJECT

In 2001 the Swedish government presented a proposition the aim of which was to assemble all the Swedish, EU and international climate-policy related measures in a single national climate strategy. The objective was to bring about an active climate policy that would involve the entire society.

The proposition pointed to the climate issue as one of the largest global environmental problems. The necessity of making individual efforts – not least among young people – was emphasised, as was the importance of international cooperation.

The emphasis on the role of youth and the importance of international cooperation was what induced the Norrbotten Energy Network (NENET), which is one of more than 250 local and regional energy-efficiency offices in the EU, to contact the region's science centre, Teknikens Hus, in Luleå.

The idea was that NENET, with its expertise and international and national networks in the field of energy and environment, and Teknikens Hus, with its experience of public exhibitions and learning activities for children and adults, should combine their resources in a joint climate initiative.

Eventually, the ideas were formulated in a joint project application to the EU ALTENER programme. By then, two other partners – the National Energy Foundation (NEF) in the UK and Rhônalpénergie-Environnement (RAEE) in France – had joined the project, which was given the name 'Grasping of climate' (in Swedish 'Klimatgreppet'). Teknikens Hus assumed the role of project coordinator. In England the project was conducted under the title 'ACT' (Act on Climate Today!), while in France it went under the title 'CLIMATTITUDE'.

The project was carried out during the period January 2003-June 2005, a total of 30 months, and contained the following:

- Teacher training programme, seminars and lectures;
- Interactive exhibition, 'Grasping of climate – a sunny story';
- Interactive drama, 'The earth – our only one', for students age 10-18;
- Pedagogical activities for students age 10-18, both in Teknikens Hus and as out-reach programmes;
- An inspirational guidebook for teachers, 'Grasping of climate'. Downloadable at **www.graspingclimate.net** , in Swedish, English or French.

The project reached 1 000 teachers and 22 000 students in direct activities. The duration of the project was two and a half years, and during this period Teknikens Hus and the exhibition had more than 100 000 visitors. Even since the project's official ending, the number of persons that have been reached by the project has continued to increase. Many have read the inspirational material for teachers produced within the project. We recently had to print a second edition. But the most important increase is through visitors to the exhibition 'Grasping of Climate – a sunny story'. After being on display at Teknikens Hus the exhibition has been touring Swedish science centres and other institutions, as of today reaching more than 200 000 visitors. It has become one of the greatest successes in the history of Teknikens Hus and is booked years in advance. The project was also acknowledged as an example of 'good practice' by the European Commission: **http://www.managenergy.net/products/R1329.htm**

In 2002, when we started planning the project Grasping of Climate, there was little or no public debate about ongoing climate changes. Al Gore had not started making movies and there were no big headlines about threatening climate catastrophes. Researchers, however, knew a lot more than the man on the street. Today, everyone, including officials in the White House, have grasped that there is something going on.
Science centres around the world play a vital role when it comes to transforming research data and new scientific knowledge into public understanding. The science centre is a venue for students, teachers and families – a venue where everyone can explore, reflect and learn. In order to cope with the big global issues about sustainable development, we believe it's crucial to 'get everyone on board' and boost both understanding and the willingness to act.

## FUTURE PLANS – NETS

Grasping of Climate made it clear that many teachers wish to penetrate deeper into the climate issue. Therefore a continuation of the project is being planned, via a new educational project with demanding qualitative goals and a focus on developing the competences of the participating teachers. In the new project, NETS (Network of European Teachers for Sustainability), international exchange experience will be an important element. The teachers who participate in the project will gain enough competence, self-confidence and insight to be able to continue to develop teaching in the climate sphere after the project is completed. The aim is to obtain the long-term value of education yet also provide the students with the tools and the confidence they require in order to be able to perceive, understand and manage the climate and other complex survival issues, with a strong belief in the future, both in their own everyday life and in their future choice of profession.
The project will run for 30 months with an estimated start in September 2007. In Sweden , there are three partners; Teknikens Hus, the University of Linköping and the Norrbotten energy network (coordinator). Furthermore, the project has partners in the UK, France, the Czech Republic, Greece and Bulgaria.

## A NEW EXHIBITION ON POLAR RESEARCH

During the International Polar Year, IPY 2007-2008, Teknikens Hus will cooperate with The Swedish Research Council in order to produce a new, interactive exhibition:
*Cold Poles – Hot Stuff, research in the Arctic and Antarctic regions*. The exhibition will open at the Swedish embassy in Washington DC, House of Sweden, on 10th of April. From late June 2007 the exhibition will be on display at Teknikens Hus and then from late fall on tour in the Nordic countries. The exhibition emphasises the importance of research in the Arctic and Antarctic regions, not least when it comes to global warming.

## TEKNIKENS HUS, www.teknikenshus.se

Teknikens Hus, the House of Technology in Norrbotten, is one of the oldest and the northernmost science centre in Sweden. It is located close to the Arctic Circle. Teknikens Hus is a non-profit foundation that opened in 1988. The permanent exhibition is based on the natural resources we have in the region; forests, mines and rivers, and the technology we use to transform them into paper, steel and electricity. The technology of everyday life is also in focus, ranging from dishwashers to cars and aeroplanes. We also rent temporary exhibitions or build them ourselves, in order to highlight current issues, for example global warming, the International Space Station, etc.

Teknikens Hus is a resource centre for all the schools in the region, for students as well as teachers: we do out-reach programmes, teacher networks, training for teachers-in-service and teacher education. We have a close co-operation with the local university, Luleå University of Technology. Teknikens Hus attracts more than 100 000 visitors every year.

# ATTENDEES

## Journey into the heart of the climate machine

**Michael Pitiot,**
**Tara Expéditions and MC4 films, Paris, France**
**michael@taraexpeditions.org**

**Tara Arctic base camp, winter 2006-2007.**

At a time when information is mainly conveyed through images, not being present on screens restricts the impact that the scientific community can have on the general public. Yet, to turn the scientific researcher into a modern hero without distorting his speech remains without a doubt the major challenge of the scientific movie genre. However, Tara Expéditions and DAMOCLES, with the assistance of the film company MC4, are confident that they can rise to this challenge.

### A SCIENTIFIC FEATURE MOVIE ON PACK ICE

TARA Expéditions and DAMOCLES are in the process of making a 90 minute movie named 'Journey into the heart of the Climate Machine'. This full-length documentary is centred on the drift of the Tara ship that has been converted into a permanent Arctic base at the service of the European scientific consortium DAMOCLES. The movie aims to lead the audience through a scientific odyssey so as to discover the 'climate machine'.

Science, nature, International Polar Year, environmental future, but also European scientific programmes are all themes featured in this movie that will be shot in high definition. The director, Emmanuel Roblin, a specialist in nature films, has chosen to show science on the move, science that does not lapse into conveying gloom and doom but brings a positive and documented vision. Designed for the main television channels,

**Tara Arctic base camp, winter 2006-2007.**

the wealth of events contained in such an expedition and the human adventure remain at the heart of the movie. Roblin has been careful to make a movie that remains accessible to the general public.

The production of the movie has been entrusted to several professionals in the trade: the movie company MC4 and its producer Jean-Pierre Bailly have been chosen to be associate producer. With more than 800 movies produced for television and the movies, the company also has good expertise on science, nature and exploration. The ARTE TV channel will be its first broadcaster in 2008, as well as the RTBF and TSR channels. This campaign is being executed by the Dutch film distributor 'Off The Fence' in Amsterdam. The task is to ensure that the movie is broadcast in all of Europe and adapted for the American, Japanese, Chinese and Middle East markets. The broadcasters within the main markets will officially be disclosed in the course of 2007. A DVD version as well as a VOD (Video on Demand) broadcast will complete the campaign.

With this campaign, the movie developed by DAMOCLES and TARA Expéditions can expect to reach between 200 and 300 million viewers according to estimates.

## TOWARDS A NEW GENERATION OF SCIENTIFIC MOVIES

Even though the technical challenges in making the movie were particularly great, the biggest accomplishment of 'Journey into the heart of the Climate Machine' lies elsewhere: to make a lasting impression on the general public by turning scientists into modern heroes, but to do so without distorting their speech. This feat can make one smile, but in a world influenced by the media and especially by the influx of images that originate from the television networks and even from the movies, the share of messages devoted to scientific research remains quite modest. This can be attributed to the esoteric character of the scientific manner of speech that many media think is meant only for specialised publications. The scientific contribution thus remains at the margin of the main mediums used by society to understand its surrounding world. Among other consequences, this isolation minimises the importance of science and weakens public funding dedicated to research.

As such, the movie, more than any other support, can be an efficient ambassador. Easy to disseminate in the world, the movie as a medium can have an important public impact and reinforce the communication and the identity of a federation such as the European Community.

Finally, the scientific film is a perennial tool. It can live for ten years or more. Ample time for the hypotheses put forth in the movie to be validated.

**Stills from the Tara movie teaser:**




# 8. Agenda

International Symposium

# *Polar Environment and Climate: the Challenges*

***European Research in the context of the International Polar Year***

http://cordis.europa.eu/sustdev/environment/ev20061023.htm

***Venue: Royal Museum for Natural Sciences***
***Rue Vautier, 29***
***1000 Brussels***
www.naturalsciences.be

# *Monday 5th March 2007*

**9:00-9:30** **Registration**

**9:30-9:45** **Welcome and opening remarks**

*Commissioner for Science and Research* ***Janez Potočnik***
*(European Commission)*

**9:45-11:15** **General Session on IPY and Environment & Climate in the Polar Regions**

***Chairs: Manuela Soares (European Commission) and Jean-Claude Gascard (U. Pierre Marie Curie, Paris)***

**9:45** **Peter Lemke** *(Alfred Wegener Institute, Bremerhaven)*

***Observed changes in snow, ice and frozen ground***

**10:05** **Dave Carlson** *(International Polar Year)*

***Success measures of the International Polar Year — European and international opportunities and challenges***

**10:25** **Ola Johannessen** *(Nansen Environmental and Remote Sensing Center, Bergen)*

***Climate and environmental change in the Arctic***

**10:45** **Carlo Alberto Ricci** *(European Polar Board, European Science Foundation and U. of Siena)* **and Paul Egerton** *(European Science Foundation, European Polar Board & European Polar Consortium, Strasbourg)*

***European strategic frameworks for research in the Polar Regions***

**11:05** **Elisabeth Lipiatou** *(Directorate Environment, DG Research, European Commission)*

***Polar environment and climate: European research in the Seventh Framework Programme***

# 11:15-11:40 Coffee break

# Climate system Research

## 11:40-13:00 Session 1: Past climate

*Chairs: Hugues Goosse (U. Catholique de Louvain) and Tavi Murray (U. Wales, Swansea)*

**11:40 Dominique Raynaud** *(CNRS & U. Joseph Fourier, Grenoble)*

*The Antarctic ice core record: a useful archive for a better understanding of our climate and environment*

**12:00 Keith Briffa** *(U. East Anglia)*

*Dendroclimatological evidence of Arctic temperature changes through recent Millennia: current evidence and research prospects*

**12:20 Naja Mikkelsen (***Geol. Survey of Denmark and Greenland***)**

*Past climate variations around the Arctic on millennial to multi decadal scales: marine and terrestrial evidence (presentation not available)*

**12:40 Danny McCarroll** *(U. Swansea)*

*Past and present response of the northern forests to changes in atmospheric carbon dioxide concentrations*

# *13:00-14:00 Lunch*

## 14:00-16:05 *Session 2:* Present changes and observations

***Chairs: Cynan Ellis-Evans (British Antarctic Survey) and Jan Piechura (Institute of Oceanology, Polish Academy of Science)***

**14:00 Markus Rex** *(Alfred Wegener Institute, Bremerhaven)*

***Polar stratospheric ozone loss - Current understanding and links to changes in climate***

**14:25 Klaus Dethloff and Annette Rinke** *(Alfred Wegner Institute, Potsdam)*

***Observed and modelled polar climate: regional feedbacks and global links (presentation not available)***

**14:50 Bob Dickson** *(Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Suffolk)*

***The poleward spread of warmth through subarctic seas: achievements and challenges***

**15:15 Christoph Heinze** *(U. Bergen)*

***Carbon cycling at high latitudes - bottleneck for anthropogenic $CO_2$ and precursor for ocean acidification***

**15:40 Jean-Claude Gascard** *(U. Pierre et Marie Curie, Paris)*

***Is the Arctic Sea-Ice going to disappear in summertime in a foressable future?***

## *16:05-16:40 Coffee break*

**16:40-18:00** ***Session 3:*** **Future climate & Modelling**

***Chairs: Corinne Le Quéré (British Antarctic Survey and U. East Anglia) and Peter Aastrup (U. Aarhus)***

**16:40 Dáithí Stone** *(U. Oxford)* **Ranges of uncertainty on polar climate change over the past and coming decades (presentation not available)**

**17:00 Helge Drange** *(Nansen Environmental and Remote Sensing Center, Bergen)*

***Climate variability and climate change in the Arctic region***

**17:20 Hugues Goosse and Wouter Lefebvre** *(U. Catholique Louvain)*

***Modelling climate variability and climate change in the Southern Ocean***

**17:40 Jens Hesselbjerg Christensen** *(Danish Meteorological Institute)*

***Future changes in snow, ice and frozen ground - A modelling challenge***

## *18:30-20:30 Evening drink*

***Mobile exhibition of DAMOCLES to be launched***

# Tuesday 6th March 2007

## Cross cutting sessions

### 9:00-10:20 Session 4: Human and wildlife health

*Chairs: Elisabeth Vestergaard (U. Aarhus) and Tuomo Karjalainen (European Commission)*

**9:00** **Pál Weihe and Philippe Grandjean** *(Faroe Islands Hospital System and University of Southern Denmark)*

*Human health implications from exposure to mercury and PCBs in the Arctic*

**9:20** **Heikki Henttonen** *(Finnish Forest Research Institute)*

*Northern aspects of mammal borne zoonoses*

**9:40** **Pim Leonards** *(Free University, Amsterdam)*

*Exposure of brominated flame retardants in the Arctic food chain*

**10:00** **Jens Peter Bonde and Gunnar Toft** *(Aarhus University Hospital)*

*Environmental contaminants in Polar Regions and human reproductive health*

## 10:20-10:45 Coffee break

**10:45-11:45** ***Session 5:*** **Research Infrastructures** *(organised in cooperation with the Research Infrastructures Unit)*

***Chairs: Ian Allison (Australian Antarctic Division) and Terry Callaghan (Royal Swedish Academy of Sciences, Abisko)***

**10:45 Jörn Thiede** *(Alfred Wegner Institute, Bremerhaven)*

***Needs for novel research approaches, infrastructures and technologies for the exploration of the polar environments***

**11:05 Yrjö Viisanen and Jussi Paatero** *(Finnish Meteorological Institute)*

***Atmospheric observatories at the Pallas-Sodankylä and Tiksi as examples of the IASOA project***

**11:25 Jon Børre Ørbæk** *(Norwegian Research Council)*

***Research and research infrastructures in Svalbard during the International Polar Year***

**11:45 – 13:05** ***Session 6:*** **Natural and Socio-economic impacts of climate change**

***Chairs: Ad H.L. Huiskes (Netherlands Institute for Ecology) and Antonio Tovar Sánchez (IMEDEA, Baleares)***

**11:45 Corinne Le Quéré** *(British Antarctic Survey, Cambridge, and U. of East Anglia)*

***Impact of climate change on Southern $CO_2$ sink and marine ecosystems***

**12:05 Terry Callaghan and Christer Jonasson** *(Royal Swedish Academy of Sciences, Abisko)*

***Current and projected impacts of climate change on landscapes and ecosystems of the European Subarctic***

**12:25** **Elisabeth Vestergaard (U. Aarhus)**

***Man and climatic change - a call for a new research agenda***

**12:45** **Lars Otto Reiersen** *(Arctic Monitoring and Assessment Programme, Oslo)*

***Arctic Council Follow up work of ACIA***

## 13:05-14:00 Lunch

**14:00 – 15:20** ***Session 7:*** **Public outreach, education and policy makers**

***Chairs: Elisabeth Lipiatou (European Commission) and Catherine Franche (European Network of Science Centers and Museums, Brussels)***

**14:00** **Nighat Johnson-Amin** *(International Polar Foundation, Brussels)*

***Bridging the science society divide***

**14:20** **Ann Henderson-Sellers** *(World Climate Research Programme, Geneva)*

***Polar climate challenge: Role of global environmental research in communication and outreach***

**14:40** **Walter Staveloz** *(Association of Science-Technology Centers, USA)*

***Extreme science communication: how IPY can revamp science for the public***

**15:00** **Eva Jonsson and Olle Nordberg** *(Teknikens Hus, Luleå)*

***Grasping climate — A science centre grip on global warming***

## 15:20-15:50 Coffee break

**15:50 – 17:30** ***Session 8*** **Round table**

***Reports from sessions by chairs and discussion on future perspectives and research needs***

**17:30-18:00** **Closing Remarks**

***Zoran Stančič, Deputy Director General, DG Research, European Commission***

**18:30** **End of the Symposium**

***Organised by***

***Climate change and Environmental Risks Unit — Environment Directorate — DG Research***

***Scientific Officer: Damien Cardinal***

***Secretariat: Conchita Menendez-Garcia***

***Tel. +32 2 296 3234***

***rtd-climate-change@ec.europa.eu***

# 9. List of Participants

# *Polar Environment and Climate: The Challenges*

*European Research in the context of the International Polar Year*
*Royal Institute of Natural Sciences, Brussels, Belgium*
*5-6 March 2007*

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