Federal Ministry
of Education
and Research

Rapid Climate Change in the Arctic

Polar Research as a Global Responsibility

Contents

Foreword

The cartographer August Petermann laid the cornerstone for German polar research at a conference of experts in Frankfurt about 150 years ago. One widespread theory at the time claimed that large parts of the Arctic Ocean were ice-free. Although it was later disproved, the hypothesis of an Open Polar Sea gave rise to numerous expeditions which laid the foundations for research into the Arctic.

Ever since, Germany has been committed in various ways to providing the international community with relevant data to gain an understanding of the climate system as well as with analyses of future developments for the polar regions. The Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) is Germany's national polar research institute. It falls within the remit of the Federal Ministry of Education and Research (BMBF) and was founded in 1980. The AWI conducts polar and marine research and coordinates Germany´s contribution as Consultative Party to the Antarctic Treaty. Apart from the Polarstern research and supply vessel, the AWI also operates other vessels such as the Heincke and Mya for conducting research in temperate zones as well as operating research stations in the Arctic and Antarctica and research aircraft. The Deutsche Forschungsgemeinschaft (German Research Foundation, DFG) supports polar research at universities under its priority programme "Antarctic research with comparative investigations in Arctic ice areas". The latest round of funding was launched in 2012 and will run until 2018. The BMBF is making a further 250 million euros available for Arctic research alone under the "Research for Sustainable Development framework programme" (FONA[3]) which was started in 2015.

Ice sheets and polar sediments are important climate archives for research. Climate change manifests itself more clearly in the Arctic than in any other place worldwide. The sediment and ice samples obtained by deep drilling allow the international science community to derive information on the cause-and-effect mechanisms of climate change. As an observer to the Arctic Council, Germany has always advocated supranational cooperation in research in order to prepare the ground for future-oriented and sustainable political decisions. As a partner without any claims to resource-rich Arctic territories, Germany can furthermore use its international renown in polar research to play an important role as a neutral observer.

German scientists and the BMBF can look back on many years of Arctic research cooperation with the Arctic states. This close international cooperation plays a central role in securing research access to Arctic regions. To this end, the Federal Government has established favourable conditions with its Guidelines of the German Arctic Policy.

In this current strategy paper, the German science community poses important questions to which Arctic research must find answers in the years to come. I wish the researchers all the best and every success in their efforts to gain a better understanding of the processes occurring in the polar regions and their relationship with the climate system.

Prof. Dr. Johanna Wanka
Federal Minister of Education and Research

Introduction

Polar exploration has a long and distinguished tradition in Germany. The Arctic and Antarctic have a unique genesis and serve as archives of Earth's evolution. The geological, biological and climatic processes that occur in these regions play an important role for global developments.

The rapid climate change in parts of the Antarctic and in the Arctic especially is giving rise to a broad range of pressing issues. These issues were revealed by numerous concerted research projects, particularly during the 2007 – 2008 International Polar Year. The present strategy paper addresses the new challenges brought on by changing environmental conditions in the Arctic and aligns Germany's Arctic research to the requirements of sustainable development.

The following topics have great social significance and global relevance:

- The past, present and future of climate change in the Arctic
- Contribution of the Greenland ice to sea level rise
- The decline in Arctic sea ice and the resulting feedback loop between atmosphere, ocean and ecosystems
- Permafrost and gas hydrates as unknown variables in the climate system
- Adaptation of polar organisms to changes in the Arctic environment
- The risks and opportunities of expanding commercial exploitation in the Arctic

This strategy paper addresses the main questions raised by the commitment of German Arctic research to sustainability. It also defines research goals based on the requirements set forth in the FONA framework programme of the BMBF[A], the European Union's (EU) "Arctic Communication"[B], the report of the "Earth System Science for Global Sustainability: The Grand Challenges," and the "Future Earth Initial Design Report" from the International Council for Science (ICSU)[C, D, E].

Sea ice drilling is used to measure the thickness of the ice and extract samples for ice analysis.

New aspects of German Arctic research include the development and use of innovative monitoring technologies, the development of better models for prediction and a network of reliable data archives.

A greater emphasis is also placed on socioeconomic questions relevant for the Arctic region and the effective transfer of knowledge to society [F].

Although this strategy paper and the following sections mainly deal with the Arctic, it should be noted that the Antarctic is just as important and is subject to practically the same amount of German research. This can clearly be seen in the German government's decision in 2009 to support the construction and opening of the Neumayer Station III in the Antarctic.

1. The Strategic Goals of Arctic Research

Due to climate change and geopolitical trends, the Polar regions are becoming increasingly the focus of scientific, political and economic interests. This applies to the Arctic in particular.

The Arctic sea ice is receding faster than climate models have predicted. What are the causes and consequences of these changes? This question presents an enormous scientific challenge considering that the central Arctic is still one of the least explored areas on the planet. All the data collected so far show that different areas and locations in the Arctic react differently to global changes.

Climate change is also opening up the Arctic to increased commercial use. This is causing widespread desires, which is why measured geopolitical action is urgently needed. Ensuring sustainable development requires comprehensive basic knowledge and a deep understanding of the key processes at work. This is critical since the risks for the Arctic ecosystem and society arising from climate change and commercial exploitation are largely unknown. The same applies to the feedback effects on the global climate.

Many countries are currently developing new research strategies and committing significant financial resources to expanding national research activities in the Arctic. This is not only the case for Arctic rim countries, but also for distant countries such as China, India or South Korea. The Arctic is also receiving more attention from the EU ("Arctic Communication") [B] and the International Council for Science ("Grand Challenges in Global Sustainability Research") [C, D].

The research is intended to inform society and policy makers so that the potential local and global consequences of climate change in the Arctic can be appraised. This will form the basis for sustainable development strategies on the national and international – and especially the European – level.

Thanks to decades of excellent scientific work in this area, German polar research enjoys an outstanding international reputation. The expertise gained so far must now be used to meet current challenges and promote even closer networking of national research with international partners.

Additional efforts are needed to master the tasks raised by the rapid changes in the Arctic. The BMBF has explicitly addressed these tasks in its FONA framework programme [A]. The programme recognizes the need

- to observe the changes in the Arctic in more detail,
- to measure the feedback effects of polar and global processes in the Earth system and
- to improve prediction models.

Video-controlled grab with extracted target sample on board the German research vessel Polarstern

2. Arctic Research: the Central Questions

Arctic research faces six central questions that lie at the core of two main tasks.

First: Arctic warming has been very high over the last few decades and the amount of ice on land and in the sea has declined significantly in that time. This not only affects the Arctic ecosystem and the living conditions of people in Arctic latitudes, but also the development of global climate patterns. In addition, there is a world-wide apprehension about a threatening rise in the sea level.

Hence the goal of research must be to observe and quantify these changes in detail and in real time. The underlying processes and how they interact with other areas on the planet must also be observed and analyzed. Only on this basis will we be able to predict future developments accurately.

Second: the largely unknown regions in the Arctic harbor untapped natural resources. Researching the risks and opportunities that arise from exploiting such resources will help ensure sustainable and environmentally friendly development in these regions. The research must also be in line with the socioeconomic interests of the Arctic states and of the local people.

Arctic warming is leading to degraded permafrost and increased erosion and ultimately the destruction of this frozen landscape.

2.1. The Past, Present and Future of Climate Change in the Arctic

The climatic and environmental conditions in the Arctic region and the habitats that have adapted to those conditions are the product of three million years of alternating cold and warm periods. Even before this time there were warm periods in the far North, as evidenced by the former presence of deciduous forests up to the 80 degrees latitude north. This climate development is documented in various deposits on the land and in the ocean. Ice cores taken from the Greenland ice sheet are high resolution archives of the past 120,000 year climate history of the region.

The current rapid climate change is being recorded by monitoring systems. It is known that quick climate changes occurred in the northern polar region in the past, some of which only lasted for a few years. Such developments are not isolated but rather connected to global developments by the atmosphere and the ocean, and thereby affect Europe as well.

In light of the current changes, it is clear that we need to gain a greater understanding of the dynamics of these natural processes. Only then will we be able to precisely determine the anthropogenic influence on current developments and more accurately predict future changes.

What is needed are comprehensive field studies, innovative reconstruction methods and monitoring systems (e. g. Satellite Remote Sensing) combined with advanced data analysis and numerical models for process analysis, reconstruction and prediction. The connection between atmosphere, biosphere, ocean, sea ice, ice sheet and land surface systems will play a key role in such studies.

Research Goals:

- Improve the understanding of the variability of the climate system in the past, present and future from a polar perspective
- Estimate anthropogenic influences

Main Questions:

- What did the Arctic climate and environment look like during the warm periods of the past, and how did they affect the atmosphere and ocean circulation?
- What are causes and time scales of the present climate fluctuations in the Arctic, and how are they influenced by mankind?
- What are the physical and biogeochemical conditions that lead to tipping points and hence rapid climate upheavals?
- How do the processes in the Polar regions affect the global climate?
- How do models have to be developed or improved in order to better understand the Arctic climate system and its interactions with the global climate?

Deep-water coral from a bottom sample near Spitsbergen

2.2. Contributions of the Greenland Ice Sheet to Sea Level Rise

The Greenland ice sheet and the Arctic glaciers and ice caps have lost mass at an accelerated rate over the last several years. This loss of ice mass contributes to an increasing but hardly predictable sea level rise. The loss can be attributed to stronger melting processes on the surface of the ice masses as well as to the higher flow rate in most of the outlet glaciers that drain the ice sheet.

Whereas the melting process is relatively easy to calculate, the causes for the rapid outflow remain mainly unknown. One popular hypothesis states that a greater amount of ice surface melt water is reaching the base of the ice sheet and accelerating the movement of ice there. A second hypothesis says that the subglacial melting of tidewater glaciers due to contact with warm ocean currents is responsible for the acceleration.

Both hypotheses need to be investigated and quantified in order to modify existing numerical models for ice dynamics. Only then can reliable predictions of future developments be made. In order for this to be achieved, a better understanding of ice dynamics since the peak of the last ice age about 18,000 years ago is also needed. Last but not least, we need access to the base of the ice sheet, a biotope that has never before been explored.

Research Goals:

- Analyze the mass balance and dynamics of the Greenland ice sheet via process studies and the development of models with the goal of predicting future sea level variations more reliably
- Determine those Arctic regions where receding ice cover offers opportunities for future human use

Main Questions:

- Which factors and processes (e. g. subglacial geology, ocean currents) affect the dynamics of the Greenland ice sheet?
- How can models for inland ice sheet dynamics be improved?
- How can global and regional changes in sea level be predicted more reliably?
- How did the ice recede since the last ice age and what can that tell us about current and future ice dynamics?
- How does a change in freshwater influx affect the ocean circulation systems?

2.3. The Decline in Arctic Sea Ice

The Arctic Ocean is covered by ice throughout the year, although the extent and thickness of the ice varies greatly depending on the season. Since the 1980s, the extent of the ice cover in summer has decreased by 35 percent. In 2013 the ice cover reached its lowest record since begin of satellite observation. This decline in sea ice is one of the strongest climate signals in the world. One of the known reasons for the decline is the increased oceanic and atmospheric heat input from the middle latitudes as well as internal feedback loops. However, it is not yet possible to make more accurate statements about the causes and the future developments.

Given its capacity to reflect sunlight, Arctic sea ice has a large effect on the radiation budget of the Earth. It also plays a critical role for the heat and gas exchange between the ocean and the atmosphere. The decline in sea ice therefore has consequences for the oceanic and atmospheric circulation far beyond the Arctic.

Sea ice also offers a habitat for a uniquely adapted flora and fauna. The ice affects all marine ecosystems because it controls the food supply to the deep ocean and the sea floor. The loss of thicker, multi-year sea ice is already resulting in species loss and changes in the biogeochemical cycles in the Arctic Ocean. It is predicted that the decline in sea ice cover will create additional risks for Arctic ecosystems, e.g. increased shipping and the development of marine areas and resources that so far have not been able be used commercially.

Research Goals:

- Deepen the understanding of the interaction between sea ice, ocean and atmosphere
- Predict sea ice developments and the effects of reduced sea ice cover on the climate, biogeochemical cycles and marine ecosystems

Main Questions:

- To what extent does heat entering the Arctic from the middle latitudes via atmospheric and ocean currents contribute to the decline in sea ice cover in comparison to the internal feedback effects that occur in the Arctic?
- How can we improve the seasonal and long-term predictions regarding sea ice development based on observations and models?
- What consequences does the loss of sea ice have for the carbon cycle and the ecosystems in the Arctic and Northern Hemisphere?
- How does the loss of sea ice affect the atmosphere, the biogeochemical and hydrological cycle in the Northern Hemisphere and the overturning circulation in the North Atlantic?
- How does the loss of sea ice affect the ecosystem of the Arctic deep sea?
- What are the socioeconomic consequences of these rapid changes?

2.4. Permafrost and Gas Hydrates as Unknown Variables in the Climate System

Terrestrial permafrost underlies a quarter of global land surface and can mostly be found in Polar regions, especially in the Northern Hemisphere. It is also assumed that there are large areas with submarine permafrost in the Arctic, the extent of which still needs to be determined.

Permanently frozen soil contains large amounts of carbon in the form of methane, carbon dioxide or organic carbon. In addition, carbon is stored in the marine gas hydrates of the Arctic continental margins and in the terrestrial gas hydrates beneath the permafrost. When permafrost layers thaw, the carbon is mobilized and greenhouse gases are released.

Thawing permafrost can also potentially lead to higher coastal erosion. In the worst case scenario the release of gas hydrates can destabilize continental margins. Thawing permafrost can cause major changes to the water balance, the biodiversity of Arctic terrestrial areas and the marine ecosystems. The effects of these changes on the climate and earth system and human living conditions are as yet not sufficiently known.

Rosette water sampler on board the German research vessel Polarstern

Ice floes in the Arctic

Research Goal:

- Gain a better understanding of how further warming will affect the carbon fluxes from terrestrial and marine permafrost, the stability of gas hydrates and the Arctic habitats

Main Questions:

- How have the natural dynamics and the extent of Arctic permafrost changed over the past few decades?
- What are the conditions under which submarine gas hydrates (or those trapped in permafrost) will become unstable?
- How much methane, carbon dioxide and nitrous oxide is released into the atmosphere from the terrestrial and submarine permafrost and from gas hydrates, and how can the resulting climate effects be predicted using suitable models?
- How will microbial communities change following the thawing of permafrost and the degradation of gas hydrates? What does that mean in terms of sources and sinks of climate gases from the permafrost?
- How does the thawing of permafrost affect regional living conditions?

2.5. Adaptation of Polar Organisms to Changes in the Arctic Environment

Over a period of millions of years the animals, plants and microorganisms of the Arctic have adapted to the environmental conditions in the Arctic, which are shaped by cold temperatures, ice and strong seasonal changes. These unique physiological and biological adaptations make Arctic organisms very sensitive to sudden and unusual changes in their habitat. Global warming, acidification and increased human activity in the Arctic will therefore have a massive impact on the viability and biodiversity of the affected ecosystems. Invading organisms from southern regions will be establishing themselves in the Arctic and there will be shifts in the local food cycles.

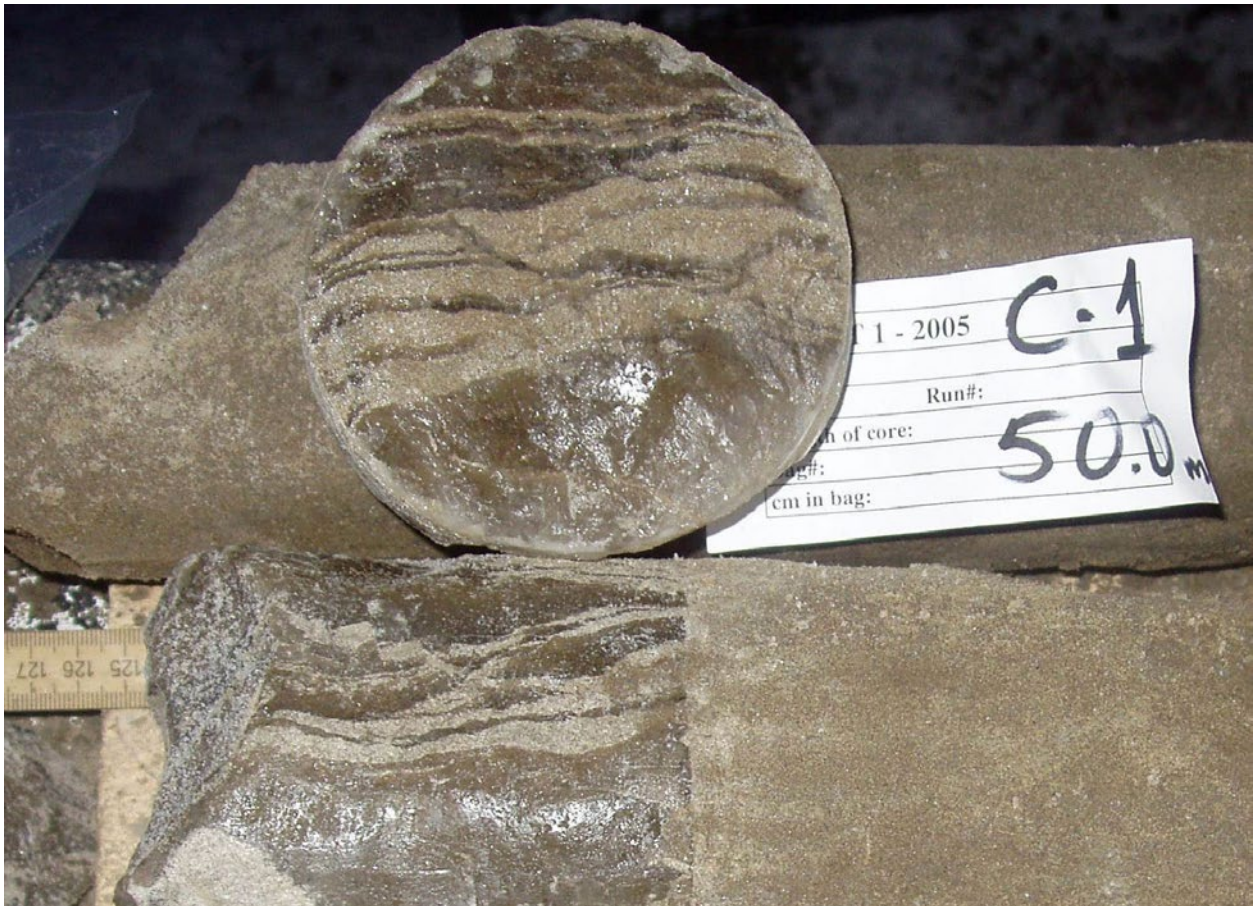
How that will affect the productivity of the Arctic ecosystems (e. g. the biological productivity of the Arctic Ocean or the biogeochemical cycles) is largely unknown, since we do not yet know enough about the Arctic biosphere. In particular, there is a lack of knowledge about the ecological communities and processes in the Arctic deep sea and the habitats in and below the ice sheets.

Research Goals:

- Gain a better understanding of the genetic and ecophysiological adaptations and survival strategies of Arctic species
- Predict how environmental changes affect biodiversity, food webs, productivity and ecosystem functions

Main Questions:

- How can Arctic organisms adapt to environmental changes, and how great is their capacity to adapt?
- Where will migrations of Arctic or invading species occur and what are the consequences of such migrations?
- Are there indicator species for the changes in the marine and terrestrial environments?
- Are there thresholds for temperature, acidification, sea ice cover and pollution which, once passed, will result in massive change of Arctic habitats?
- Where is biodiversity especially high in the Arctic? What factors support or endanger native biodiversity?
- How does submarine volcanic activity affect the habitats in the Arctic deep sea?



Detailed view of a core sample from the submarine permafrost: the core shows typical structures, which can also be found in terrestrial permafrost.

2.6. The Risks and Opportunities of Increasing Commercial Exploitation of the Arctic

Rapid climate changes in the Arctic will accelerate the economic development of the region, including the opening of new transport routes and the exploitation of living and mineral resources such as fish stocks, ores, gas and oil.

In order to guide this development in a sustainable manner, knowledge of the location, accessibility and scope of these resources as well as the overarching socioeconomic and political conditions of the region is essential.

The current state of knowledge is insufficient because of the difficult access to this part of the world. Geoscientific, climatic, biological and socioeconomic baseline studies, however, are contributing to overcome this obstacle. These studies provide a basis for the development of scenarios regarding commercial exploitation and its impacts on ecosystems and populations. Based on these scenarios, the risks and opportunities of commercial exploitation can then be assessed and recommendations for action be made.

Sustainable use also means resolving conflicts of interests, which is why responsible research must also address the political and legal mechanisms of mediation and their efficacy.

Sample of a sediment core from Lake Billyakh in the Verkhoyansk mountains of Eastern Siberia: the sample shows the contact area between the sediment surface and the overlying ground water.

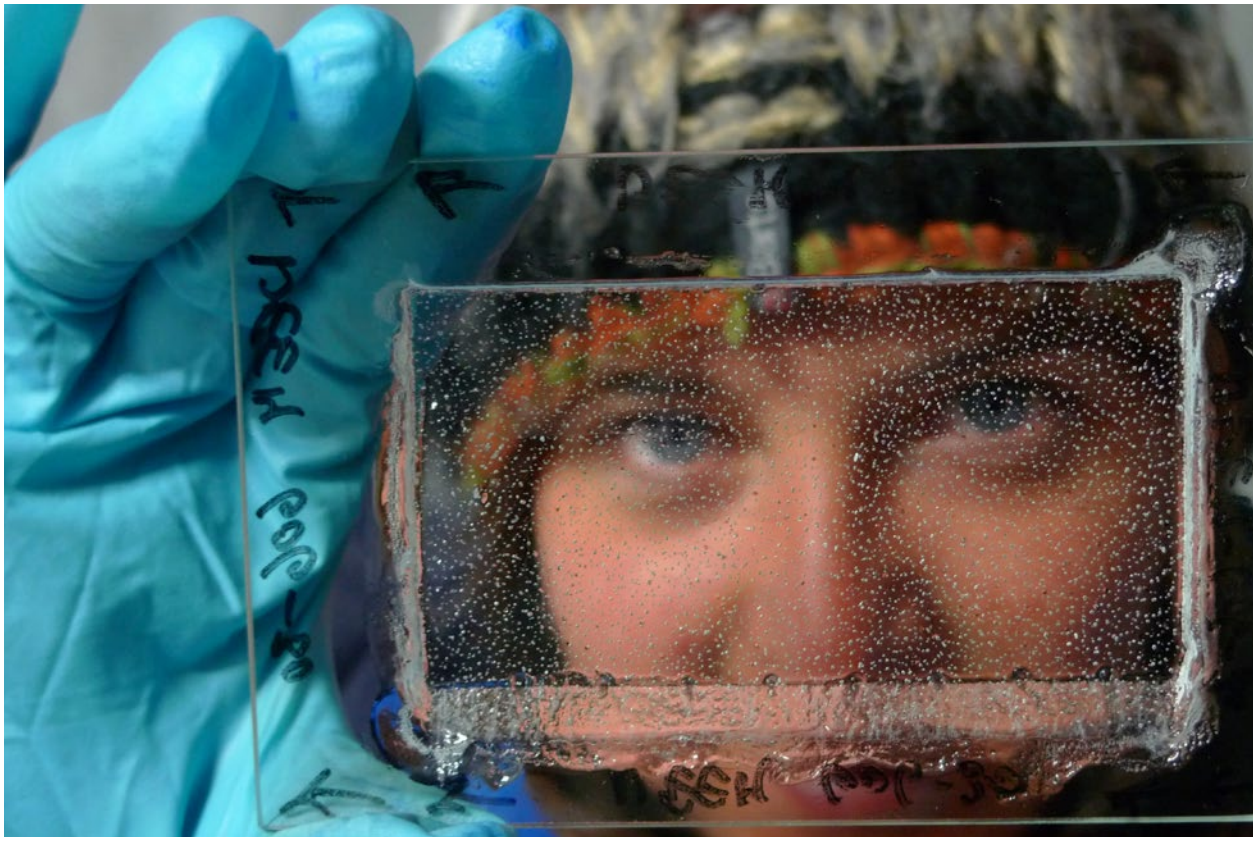
At the ice edge in the Kronprins Christian Land, northeast Greenland, at about 80 degrees north: the striped coloration of the ice is due to the massive amount of dust that was blown there during ice age and can now be found under the melting ice. Analyses of the stable isotope O-18 confirmed that the double-striped, brown-colored edge marks the boundary between the current warm period and the last ice age, which ended about 11,000 years ago.

Research Goal:

- Investigate the risks and opportunities of future human use of Arctic resources

Main Questions:

- What areas of the Arctic have economically viable resources, and how does rapid climate change affect the accessibility of those resources?
- How will local and international sociopolitical processes affect the possible exploitation of those resources?
- How will the ecosystem react to human interference, and can risk analyses be made regarding this topic?
- When and under what conditions will it be possible to use Arctic sea routes commercially?
- How can improved observations and short-term predictions be used to minimize the risk of maritime accidents and environmental damage?
- How will climatic, economic and political changes affect the living conditions, health, economic prospects and freedom of action among the residents of the Arctic?
- How can a sustainable use of resources be achieved?



The ice of the glaciers and ice sheet becomes more transparent as the drilling depth increases. Down to a depth of 1,000 meters the ice appears milky grey due to the presence of air bubbles. Below depths of 1,200 to 1,300 meters the ice is as clear as Plexiglas.

3. The State of German Polar Research

Polar research has a long tradition in Germany. It is supported by a well-coordinated network of various institutions and is conducted in both the Arctic and the Antarctic since the climatic and oceanographic processes at the poles are interlinked and their eco-systems exhibit similar characteristics.

Polar regions are extremely sensitive to climate changes. Phenomena such as declining sea ice cover, shrinking ice sheets or altered ocean currents have, in turn, a significant effect on global climate. For this reason German polar research is increasingly focused on gaining a better understanding of the fluctuations and forces that shape regional and global climate patterns.

3.1. The Partners of German Arctic Research

German polar research is based on three main pillars: universities, extramural research and businesses.

The AWI in the Helmholtz Association is of central importance. As part of its programme-oriented research activities, the AWI conducts internationally renowned interdisciplinary research in the Arctic and the Antarctic. The German Federal Institute for Geosciences and Natural Resources (BGR) investigates the structure and geological development of the continental areas and their borders. Within its institutional tasks, the BGR also addresses the estimation of polar resources.

Both institutes operate research stations, ships and airplanes and carry out multidisciplinary marine and terrestrial polar expeditions. They therefore have an infrastructure that university-based research can also benefit from.

Campaign for obtaining sediment samples at Noa Lake, Greenland

The institutes of the Max Planck Society and the Leibniz Association are also involved in specific research topics. Moreover, a large number of university institutes can look back on a long tradition of polar research.

German polar exploration is carried out by a well-coordinated network of different institutes. In 1992, the DFG established the German National SCAR / IASC Committee (Scientific Committee on Antarctic Research / International Arctic Science Committee). This committee plans and coordinates polar research activities at German universities together with the AWI and relevant federal agencies.

Comprising scientists from a wide range of fields, the German Society for Polar Research is an important instrument for interdisciplinary coordination and cooperation.

The BMBF and the Ministry for Economic Affairs and Energy (BMWi) support polar research through institutional funding. The BMBF also provides additional project funds, especially for Arctic research. The DFG funds Arctic research as part of its standard procedure and, to a more limited degree, through its priority programme "Antarctic Research with comparative investigations in Arctic ice areas".

The findings from polar research also find use outside the scientific domain. For example, the data is used by meteorological services, to assess claims under maritime law with respect to the "extended continental shelf", to evaluate resources, construct dikes (to protect against sea level rise) or for the calibration of satellite measurements. The data is also used for predictions of the regional effects of climate change.

Net-like structures from ice-wedge polygons lend an unmistakable shape to the permafrost landscape.

3.2. Regional Priorities of German Arctic Research

One focus of German Arctic research is the region of Spitsbergen and the Fram Strait, which is located between Spitsbergen and Greenland and acts as a gateway between the Atlantic Ocean and the Arctic Ocean. Research into terrestrial and marine habitats and long-term atmospheric studies are conducted at AWIPEV, the French-German Arctic research base in Ny Ålesund on Spitsbergen. Its name consists of the abbreviations for AWI and Institut polaire français Paul Émile Victor (IPEV). For over a decade the AWI has regularly carried out oceanographic surveys in the Fram Strait in addition to multidisciplinary experiments and measurements on the ocean floor at depths of 1,000 to 5,500 meters. The samples and studies conducted in the "Hausgarten" area off Spitsbergen

show that Arctic warming and receding sea ice are not only affecting the upper layers of the Arctic Ocean, but also the water temperatures and composition of deep sea communities. In 2007 research in the "Hausgarten" was expanded to include comparative studies in the shallow water areas along the Kongs Fjord on Spitsbergen.

Another key area for climate and permafrost research is the Laptev Sea together with the Lena delta (Samoylov research station) and the river system in the Siberian hinterland. Much of the sea ice for the Arctic Ocean is formed in the Laptev Sea. The ice enters the Norwegian Sea via the Transpolar Drift and thus influences our climate as well.

Under the Russian-German "Laptev Sea System" research programme, scientists from both countries have been conducting joint multidisciplinary expeditions and projects since 1991. This successful collaboration has become one of the key pillars of German Arctic research over the past 20 years and will be expanded through further cooperation in the future. Collaboration with Russian institutes also provides access to the Siberian sea and land areas.

Geological structures and magmatic activities are subject of circum-Arctic research. Among the research areas for geophysical expeditions on land or at sea are Yakutia, the Polar Ural, Spitsbergen, northern Greenland, the Canadian Arctic and the central Arctic Ocean, including the geographic North Pole.

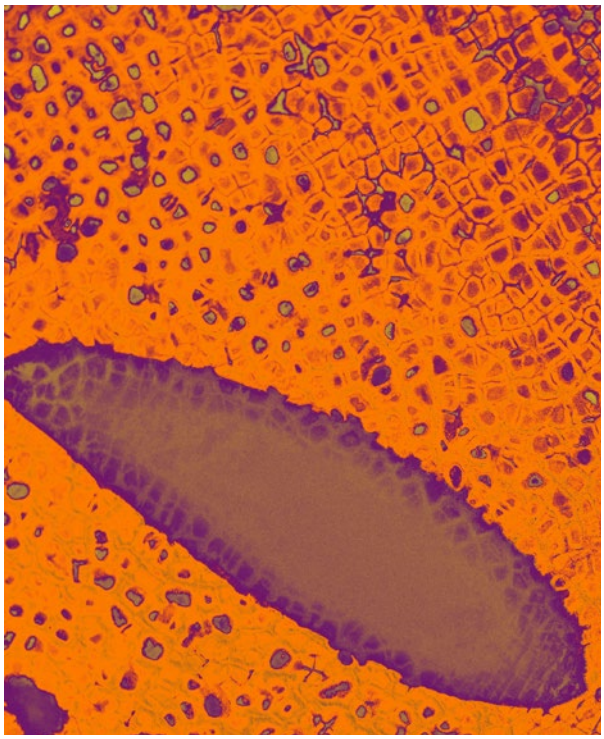
Meteorological and geophysical measurements as well as sea ice volume observations are conducted via aerial measurement campaigns in North American marine areas in close cooperation with Canadian partners. Special research topics are also being investigated through multidisciplinary programmes in other Arctic areas such as the Kamchatka Peninsula or the Elgygytgyn meteorite crater lake in north-eastern Siberia.

3.3. Positioning in the International Arena

Arctic research is an international endeavor. German scientists are involved or play a lead role in all relevant international polar research programmes. The office of the IASC, for example, is located in the AWI. German scientists are members of the European Polar Board, the Permafrost Association, and participate in IASC working groups.

Several German authors provided substantial cryosphere and biosphere contributions to the 5th Assessment Report of the Intergovernmental Panel on Climate Change [F]. German researchers also made significant contributions to the 2007 – 2008 International Polar Year.

The molluscan sea butterfly Clione limacina (maximum length: 70 – 85 mm) is often found in the upper layers of the Arctic Ocean.



Aerial image of the polygonal tundra on Samoylov Island (Lena Delta, Siberia): the colours have been artificially distorted to make some of the landscape structures (orange / reddish) and water-covered areas (from purple to grey depending on water depth) more discernible.

Research in the extreme Polar regions is subject to high logistics requirements, which is why international cooperation needs to be strengthened further. Arctic research involves important cooperative projects between German and international institutions and is supported by long-term objectives. Besides European partners, cooperation with the Russian Federation, Canada and the United States (US) is very important.

The European Polar Board of the European Science Foundation (ESF) offers a platform for coordinating the major European players in polar research. Numerous German scientists have taken on responsibilities in this organisation. As Europe is focusing on the Arctic, German polar research should assume a key role and is putting forward central issues within the EU Research and Innovation programme Horizon 2020. Further expansion of international, and especially European, cooperation is essential for the further development of Arctic research.

In spring 2010 geological services and research institutes agreed to jointly create a Tectonic Map of the Arctic (TeMAr). The initiative of the participating countries – Denmark, France, Germany, Norway, the Russian Federation, Sweden, the UK and the US – is providing impetus for assessing the potential of resources.

The future plans of the Integrated Ocean Drilling Program (IOPD) are reflected in the document “Scientific Drilling in the Arctic Ocean: A challenge for the next decades”. In this way additional climate change data and time series are to be obtained in the Arctic realm. The AWI maintains a data library with over 70,000 citable records from the Arctic which are used in international research projects. It thus offers excellent conditions for participating in data management activities in the context of large international projects, including, for example, the “Sustaining Arctic Observing Networks” (SAON) project initiated by the Arctic Council.

4. Implementation of the Arctic Research Strategy

Due to the rapid changes in the Arctic, the northern polar region has become the focus of scientific, economic and political interests. It is essential to reveal the risks and opportunities that such climate change creates. The EU has taken this up as a major topic for the future. The BMBF has identified the Arctic as one of the key regions for future sustainability research.

The present questions demand increased research efforts that go well beyond the activities pursued in the past. The involvement of university research partners needs to be strengthened in this regard. The Arctic research funded by the BMBF now focuses on projects that seek to ensure sustainability within the Arctic realm.

4.1. Sustainability Research

Known for its excellent potential in the above mentioned areas, German Arctic research is able to make significant contributions and to help overcome the new scientific and social challenges facing the Arctic region. This task is the focus of a number of new projects that are supported by external funding from BMBF Collaborative Projects, DFG projects, non-university research institutions, EU programmes and other funding sources.

Innovative monitoring systems and improved climate and ecosystem models will make it possible to more accurately predict future climate conditions. The collected data will provide the basis for suitable adaptation strategies and guidelines aimed at ensuring a sustainable exploitation of the Arctic region. The following points are highlighted in this respect:

- Studying the changes in the Arctic will enable researchers to more accurately estimate their effects on the regional and global climate in the next decades. Climate models can be greatly improved while minimizing uncertainties.

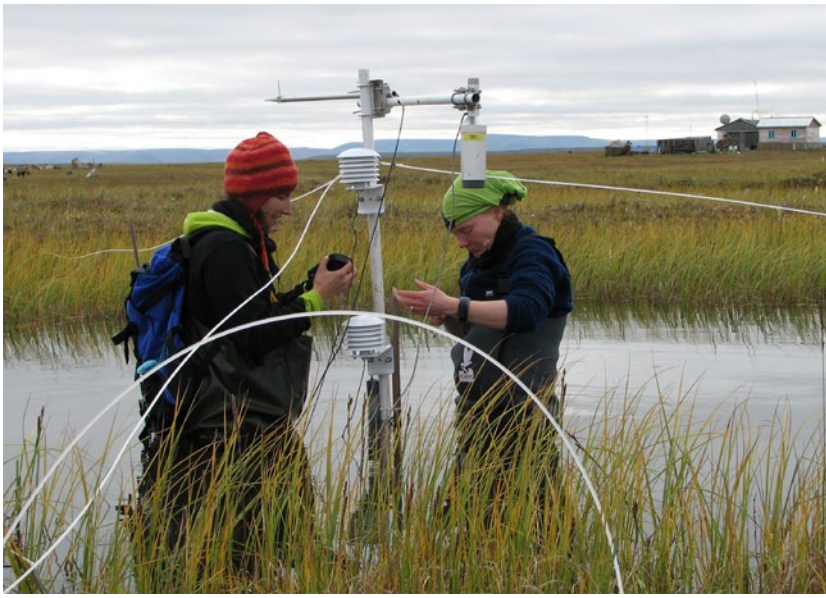
- The contribution of the melting Greenland ice sheet to sea level rise varies greatly. More accurate predictions of how much ice melt is contributing to sea level rise are necessary in order to determine its effects in different parts of the planet and to take appropriate protective measures.

- Severe changes in permafrost regions lead to higher erosion of the Arctic coasts, the release of climate gases from gas hydrates and profound transformations in habitats. Enhanced methods for monitoring and analyzing the relevant environmental factors will make it possible to detect potential dangers (e. g. the destabilization of gas hydrates) at an early stage.

- The increasing loss of sea ice can open up new shipping routes. Reliable models for sea ice forecasts will help secure the new shipping routes.

- The potential of the living or mineral resources of the Arctic Ocean can so far only be estimated insufficiently. One goal in this regard is to collect a reliable data basis that can be used to ascertain risks, to ensure sustainable use and to protect the environment.

- Climate change and the commercial exploitation of the Arctic will change the biological diversity of polar habitats. Research will help to identify sanctuaries for endangered endemic species and to develop protective measures. This will also allow for the sustainable management of living resources such as char and Arctic cod.



Alignment of sensors at an automated measuring station near the Samoylov station

Sea ice

4.2. Transfer of Knowledge to Society

The 2007 – 2008 International Polar Year saw a wide range of actions being taken to make polar research more accessible to the greater public [G]. School classes and teachers were involved in the research, for example. The successful collaboration between schools and research institutes is to be continued through the integration into suitable projects.

It remains an important task for university research institutes and non-university institutions to inform the public in a way that is both scientifically accurate and understandable for laymen. Only then will it be possible to raise social awareness regarding the current climatic changes and the associated economic and ecological changes.

The findings from polar research are critical for analyzing global and regional climate change. They were included in the 5th Assessment Report of the Intergovernmental Panel on Climate Change released in 2013 / 2014.

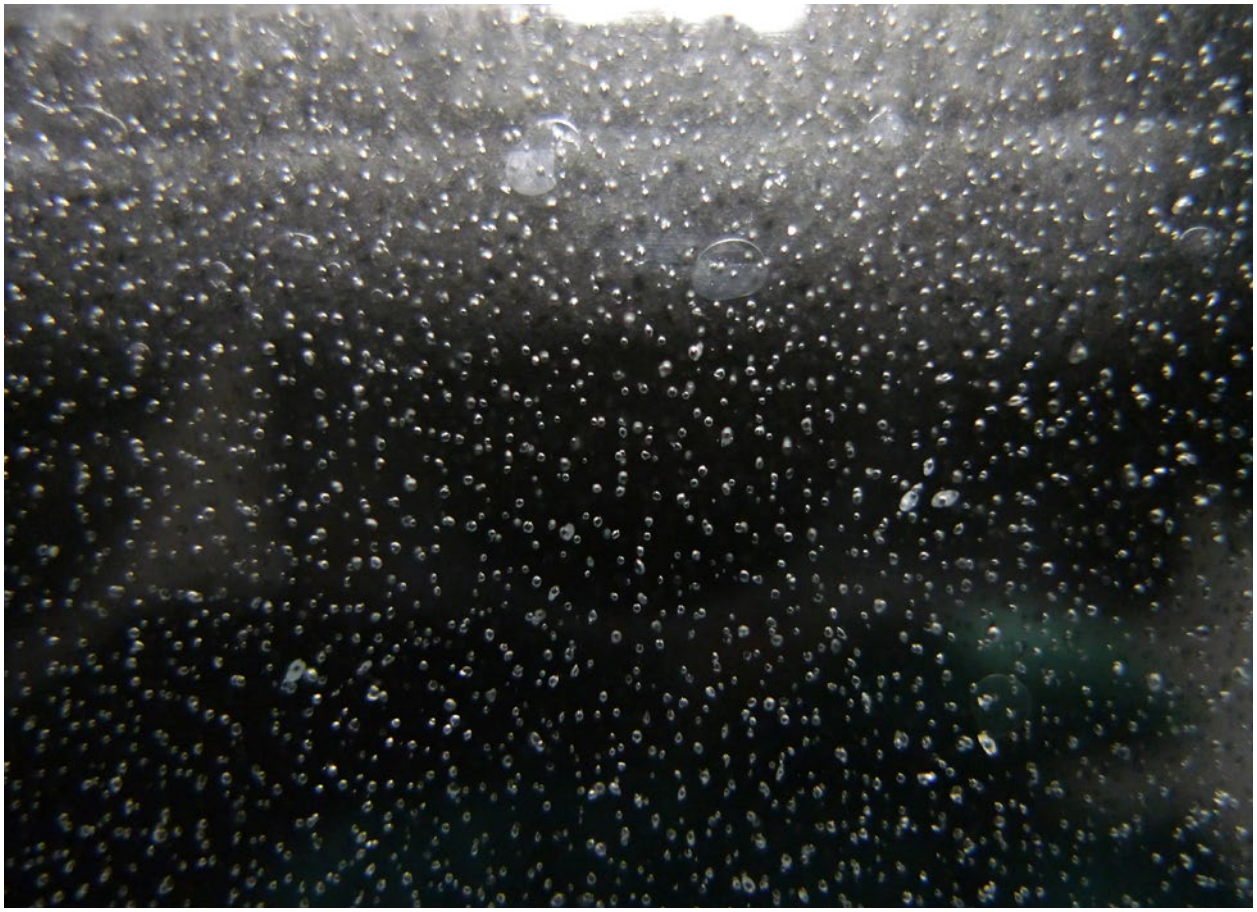
Analyses of cryosphere and sea level changes will be provided to both the IPCC and other committees. To this end a regional climate office was established at the AWI, which edits the data and responds to inquiries from the government, industry sector and the public. In order to widen these efforts, preparations are currently underway to create an "Earth System Knowledge Platform" in the Earth and Environment Research Field of the Helmholtz Association. This is being done in cooperation with the "Climate Service Center" of the BMBF.

One of the challenges in the next few years lies in relating scientific research findings to the socioeconomic aspects of climate change. When it comes to such interdisciplinary approaches, Germany still has some catching up to do. That is why greater collaboration should be established with national and international partners so that these issues can be addressed together.

4.3. Technology Transfer

Conducting Arctic research under the harsh conditions that prevail in the polar region requires advanced technologies and high safety standards (see box on page 21). The development of automated systems for monitoring and sampling under polar conditions provides new impulses for the maritime sector and offshore technology. There is also the expectation that new polar organisms will be found that may prove useful for biotechnology applications. Geophysical measurements in ice covered areas represent a technological challenge and are necessary to estimate resources.

These and other ways in which polar research contributes to the sustainable and responsible use of resources need to be strengthened in collaboration with industry. This also requires improved communication between partners from science and industry.



Air bubbles trapped in the Greenland ice sheets contain climate signals from past eras. Based on these archives it was possible to research climate periods that date back as far as 120,000 years ago.

Retrogressive erosion due to thawing permafrost in the ground, Herschel Island, Canada

Innovative technologies that are necessary to explore the Arctic

- Ice-breaking research ships that can be deployed at any time of the year
- Technologies for the extraction of core samples (from the ocean floor, Arctic ice sheets, deep permafrost sediments, gas hydrates in the continental margins)
- Technologies for analysing subglacial environments
- Autonomous measurement platforms for atmospheric research and small-scale meteorological monitoring networks
- Year-round autonomous observational and experimental platforms in the ocean with data communication
- Ocean observatories and underwater vehicles for working in the Arctic deep sea and below ice
- Remote sensing via satellites and aircraft that allows precise determination of Arctic inland ice masses and sea ice
- Complex coupled models for calculating and predicting climate, ice dynamics and sea level rise
- High computing capacity to allow the use of numeric models
- Analytical technology for genetic characterization and data archives for genetic information of specific Arctic organisms
- Pan-Arctic multidisciplinary databases and geographical information systems

4.4. Fostering Young Scientists

The German-Russian master's degree programme for applied marine and polar science (POMOR) is the outcome of a joint initiative of the Universities of St. Petersburg, Hamburg and Bremen, the AWI and the Helmholtz Center for Ocean Research Kiel (GEOMAR). POMOR has been carried out since 2002 in cooperation with the Universities of Kiel, Potsdam and Rostock, the Leibniz Institute for Baltic Sea Research in Warnemünde as well as the "Arctic and Antarctic Research Institute" (AARI) and "Otto Schmidt Laboratory for Polar and Marine Research" (OSL) in St. Petersburg.

Students spend the first two semesters in St. Petersburg and the third semester at one of the partner universities in Germany. POMOR leads to a Master of Science in Applied Polar and Marine Sciences.

The (OSL) is a modern research and education facility for polar geosciences, which is jointly operated by the AARI, GEOMAR and the AWI. A scholarship programme is available to support young scientists who are pursuing small research projects. The OSL is an important step on the way to German-Russian polar and marine research cooperation and serves as a new model for international cooperation projects.

The University Centre in Svalbard (UNIS), Norway, offers an international education and direct access to the Arctic environment. The world's northernmost higher education institution is located in the town of Longyearbyen in Spitsbergen and offers high quality courses in Arctic biology, geology, geophysics and technology to undergraduate, graduate and post-graduate students. German scientists are also engaged in these courses.

The Permafrost Young Researchers Network (PYRN) and Association of Polar Early Career Scientists (APECS) exemplify the development of interdisciplinary and international collaboration. Both organisations promote international exchange and support selected young scientists. Fostering young scientists in polar research demands a particularly strong interdisciplinary and international orientation. It is thus necessary to deepen the already good cooperation in education even further.

Notes

[A] Research for Sustainable Development – Framework Programme of the German Federal Ministry of Education and Research (BMBF), published by the BMBF, Division 721 – Basic Policy Issues Sustainability, Climate, Energy, Bonn, Berlin 2015, http://www.fona.de/mediathek/pdf/BMBF_FONA3_englisch_BARRIEREFREI_V01.pdf

[B] Communication from the Commission to the European Parliament and the Council: The European Union and the Arctic Region, published by the European Commission, Brussels 2008, http://eeas.europa.eu/arctic_region/docs/com_08_763_en.pdf

[C] Earth System Science for Global Sustainability: The Grand Challenges, published by the International Council for Science (ICSU) (2010).

[D] W. V. Reid et al.: Earth System Science for Global Sustainability: The Grand Challenges, in: Science 330 (2010), p. 916 – 917.

[E] Future Earth Initial Design: Report of the Transition Team. Paris: International Council for Science (ICSU) (2013).

[F] Contributions from working groups I, II and III to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), published by the Core Writing Team, R. K. Pachauri and L. A. Meyer, Geneva 2013 and 2014.

[G] Polar Science and Global Climate: An International Resource for Education and Outreach, published by Bettina Kaiser, Pearson 2010.

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