Implementation plan
February1996

IASC Working Group on Arctic Glaciology

Mass balance of Arctic Glaciers and Ice sheets in relation to the Climate and Sea level changes (MAGICS)

EXECUTIVE SUMMARY

Introduction and Key science questions

Arctic ice sheets and glaciers play an important role in the climate system and thus also have a fundamental impact on society. Glacier variations affect global sea level on timescales as short as decades. The sensitivity of Arctic ice caps and glaciers also suggests that they may provide an early warning of climatic shifts. The Greenland ice sheet is by far most important for sea level change, but the smaller glaciers and ice caps will give the first detectable response. Recent ice cores from Greenland indicate highly unstable climate during interglacial periods. The studies also indicate close links between ice masses, rapid iceberg and meltwater production and the ocean and atmospheric circulation. This has wide implications about future climate evolution and impacts on the environment at different scales.
The objectives of the study of arctic glaciers and ice sheets are:

- to predict the change in ice volume in the Arctic that may occur in the next decades to several centuries as a result of possible climate change for different climate scenarios
- to give input to the estimate of future rate of sea level change
- to measure and predict freshwater input to the sea from melting of glacier ice
- validate and provide data to GCM-models
- to reconstruct the past, Holocene climatic variations in the Arctic

Scientific approach

The principal points of the proposed scientific programme are:

- To determine the present geometry of the Arctic ice masses and their rates of change.
- To determine mass balance components and their altitudinal and regional variations in relation to climate.
- To evaluate the physical controls on the dynamics, spatial extent of ice streams and outlet glaciers, and switching between different flow regimes.
- To reconstruct climate variations from ice cores and other sources. ICAPP - Ice core Circum-Arctic Paleoclimate Programme - is a part of this approach. The program has already started under the IGBP - PAGES umbrella.

Action required from IASC

- encourage a bipolar approach, sponsor of a joint IASC/SCAR workshop in 1996

- funding a state of art report
- encourage joint projects between IGBP and IASC, i.e. ICAPP under PAGES
- funding of core group activity
- support and lobbying of future IASC-projects in funding agencies

Linkages within IASC and beyond

The Mass Balance projects give input to several other programmes. Glaciers, Ice caps and Ice sheets mass balances are important parts of the global sea level response. Fresh water input to the marine environment has an impact on the marine biology and the ocean drift systems. Increased melting will also influence the environment on ice-free land areas. Further deep and shallow ice-core drilling will enhance knowledge of the regional variability of past climate, as well as the poorly known spatial and temporal distributions of the precipitation in the Arctic.

Thus the studies will give input to:

- IASC-projects: 1.2 BASIS, 1.3 BESIS, 2.2 Terrestrial Ecosystems, 3.1 Arctic Marine Systems
- other international programs: IGBP - PAGES, WCRP - ACSYS, GCOS, QUEEN
  And on different levels also to SCAR-projects, EISMINT and ICSI

Users/funders

The users are on different levels in the international community:
IPCC, Governments, Other research groups as mentioned above, offshore activity, water management, insurance companies.

Projected timetable

The research projects defined under scientific approach are on different levels and thus different time scales are required. There will be many subprojects, some of them are already well prepared and ready to go. Other projects need an organising period of a couple of years to define key areas and methods. Some projects will be of monitoring type that requires remeasurements for instance every five years to detect changes. Others, like the ICAPP ice core drilling project can be implemented during a few years. ICAPP has already started and is ready to continue.

After a five year period the whole project should be restructured and evaluated.

Next step

In the coming year 1996 the first steps to a circumarctic program will be taken through:
1. Continuation and further development of the ICAPP ice core program.
2. Three planned workshops:

- A first joint IASC/SCAR workshop. This will be the first bipolar approach with the objectives to look at the Glaciers, Ice caps and Ice sheets mass balances contribution to the global sea level change. The workshop will be arranged in Norway in June in connection with an international conference on Changing Glaciers. The workshop will be co-sponsored by WCRP and ICSI.
- The Sixth workshop on mass balance of the Greenland ice sheet and related topics will be held at Geological Survey of Denmark and Greenland (GEUS) in Copenhagen, 22-23.

January,1996. The idea is to extend this well established workshop to cover the entire Arctic region and later make this into Arctic Glaciology workshops or symposia.
- Annual Meeting of the WG on Arctic Glaciology in the autumn 1996. Themes will be the running implementation plan, update the plan, initiate new projects, promote effective information exchange of running projects, initiate and discuss international co-operation.

The prospects for MAGICS are good because:
- the topics are not covered by another program
- there is international interest in many countries
- the infrastructure is already there
- it is a bipolar approach and
- the time is right and mature to make this a part of WCRP.

INTRODUCTION

Arctic ice sheets and glaciers play an important role in the climate system and thus also have a fundamental impact on society. Glacier variations affect global sea level on timescales as short as decades. The sensitivity of Arctic ice caps and glaciers also suggests that they may provide an early warning of climatic shifts. The Greenland ice sheet is by far most important for sea level change, but the smaller glaciers and ice caps will give the first detectable response. Recent ice cores from Greenland indicate highly unstable climate during interglacial periods. The studies also indicate close links between ice masses, rapid iceberg and meltwater production and the ocean and atmospheric circulation. This has wide implications about future climate evolution and impacts on the environment at different scales.

A number of international projects and programmes have focused on global climate change problems. Those with strong relevance to the cryosphere are described later, for instance the IGBP- PAGES and the WCRP - ACSYS programs. Both programs state that if we want to explain former and future climate we need to improve our knowledge of the present role of Arctic ice masses in the climate system.

The IASC **Working Group on Arctic Glaciology** intends to link and coordinate projects from different countries concerning ice masses in the Arctic and the group has proposed a Scientific Programme in Arctic Glaciology.

The objective of the plan presented here is to propose how the science plan for Arctic Glaciology can start to be implemented over the coming years.

Terms of reference for the IASC Working Group on Arctic Glaciology:
- The aim of the working group is to initiate scientific programs and international co-operation between glaciologists and climate modellers to develop the understanding of arctic land ice and its role in global climatic and environmental changes.

The working group should strive to achieve this aim by:
- Promotion of effective information exchange in Arctic glaciology including contacts with other scientific communities
- Initiation of symposia and workshops

- Initiation of a scientific planning process leading to an Arctic glaciological research programme
- Revision and review of existing and planned research programmes
- Advising IASC on glaciological matters

SCIENTIFIC PROGRAMME

Introduction

The scientific programme on Arctic Glaciology should include glaciologists from the countries involved in IASC, address Global Change aspects of glaciers in the Arctic, and combine field studies, remote sensing and modelling.

The IASC Working Group on Arctic Glaciology will promote a balance between research on the Greenland ice sheet and on smaller Arctic ice caps and glaciers. Because of its size and the length of its stratigraphic record there must be a strong research focus on the Greenland ice sheet, but it is important to promote a circum-Arctic perspective on all Arctic glaciers and their role in Global Change.

The principal goals of the proposed scientific programme are:

- to predict the change in ice volume in the Arctic that may occur in the next decades to several centuries as a result of possible climate change for different climate scenarios
- to give input to the estimate of future rate of sea level change
- to measure and predict freshwater input to the sea from melting of glacier ice
- validate and provide data to GCM-models
- to reconstruct Holocene climatic variations in the Arctic and put present ice melt and fresh water flux into a Holocene context by integrating ice core paleoclimate records.

The goals will be approached through the following main scientific research tasks:

- To determine the present geometry of the Arctic ice masses and their rates of change.
- To determine mass balance components and their altitudinal and regional variations in relation to climate.
- To evaluate the physical controls on the dynamics, spatial extent of ice streams and outlet glaciers, and switching between different flow regimes.
- To reconstruct climate variations from ice cores and other sources. ICAPP - Ice core Circum-Arctic Paleoclimate Programme - is a part of this approach. The program has already started under the IGBP - PAGES umbrella.

The goals fall within the domain of the plan "Global Change studies in the Arctic" prepared at the IASC-organized "Planning Workshop on a Regional Research Programme in the Arctic on Global Change" held in Reykjavik 22-25 April, 1992. They are related to sea-level change and a circum-Arctic approach to climate change.

Background and relevance to global change

The Greenland ice sheet contains sufficient ice to raise world sea level by about 7 m if melted completely and the contribution to sea-level rise of the small glaciers in the Arctic and Subarctic areas (about 2/3 of the total small glacier area in the world) would be about 0.2 m. Although Greenland is the main fresh water reservoir, the smaller glaciers and ice caps are not the least important, because climate change will be detected first at small glaciers and ice caps. If temperature rises, the small glaciers will melt first and both contribute to sea level rise and add fresh water to the ocean in specific areas.

Beyond the direct effect of melting ice on the sea level there are equally important indirect effects on other components of the climate system. It has been shown by general ocean circulation models that the surface freshwater balance strongly influences sea surface salinity and temperature, and as a consequence global thermohaline circulation. The circulation of the North Atlantic is especially sensitive to such changes. Since variations in sea surface temperature influence the fluxes of heat and freshwater to the atmosphere they can directly feed back on the accumulation on ice sheets themselves. Thus, changing ice masses must not be considered in isolation but be understood as an active key component in the climate system. Beyond ice sheet models that are necessary to understand the flow dynamics of the ice masses, a suite of coupled models is required to assess the effects and estimate the magnitude of feedbacks between ice sheet, ocean and atmosphere.

The uncertainty in identifying the causes of the sea-level rise over the past century, and in forecasting future changes, stems in part from the incomplete knowledge of the mass balance of the world's ice masses. Lack of continuous observations are the main cause of uncertainty.

Most of the smaller Arctic ice masses exist at higher air temperatures than those of Antarctica. Therefore the Arctic ice masses will probably lose mass in a warmer climate and cause the sea-level to rise, in contrast to Antarctica where ice masses are expected to increase. Further, as many of the Arctic ice masses are temperate they are expected to show a more rapid response to climatic change than Antarctica ice masses. Circumpolar studies of Arctic glaciers are thus likely to give an early warning of climate change.

The ice masses have undergone considerable changes over geological time. For the Greenland ice sheet, several processes in the ice sheet-lithosphere system, notably glacio-isostatic adjustments and the effect of temperature change on ice viscosity in the deeper layers, have long response times. It is likely that the ice sheet is still reacting to the glacial-interglacial transition some 10,000 years ago. Thus the contribution to recent sea-level changes is both a combination of a long-term trend and the response to changing mass balance on the century time scale. It is unlikely that this long-term response causes the ice thickness to change by much more than 1cm/year.

The surging of many glaciers in the Arctic is important for Global Change. Surges are not directly forced by contemporary climatic variations, and they transport large ice masses to lower elevations, thereby causing increased melting and fresh water input into the ocean.

Sediment-cores from the North-Atlantic sea bed indicate rapid climate oscillations during the Pleistocene, e.g. periods with massive iceberg discharge and meltwater/sediment fluxes into the ocean (Heinrich events). These events may be connected to large scale changes in the oceanic circulation in the north Atlantic region and have most probably disturbed the atmospheric circulation pattern. Recent ice core analyses from the European Greenland Ice coring Project (GRIP) and the US core GISP2, show similar, extremely rapid, climate oscillations during glacial and during transition periods to the interglacial with extremely short time scales of a few years to decades. The triggering mechanism of these oscillations is not known, but instability of the ice cover and subsequent large surge-events influencing ocean circulation are important candidates.

The North Atlantic sector is a crucial area. Most of the water mass exchange between the Arctic and lower latitudes occurs there. It is a location of high latitude heat and moisture exchange from the ocean to the atmosphere. It is also a zone in which the major sea ice fluctuations occur. Water masses formed here influence the structure and circulation of the oceans on a global scale, and it has been shown that the North Atlantic may be a control point for switching between different regimes of transport of heat towards the high northern latitudes. Glaciers or small ice caps in Svalbard, Franz Josef Land, Novalya Zemlya, Northern Scandinavia, Iceland and on the east coast of Greenland are all potentially important locations for studies that can contribute to a better understanding of the climate in the North Atlantic.

Climate changes as rapid as those envisaged over the next century will have prefound effects on Arctic ice masses: increased melting at lower elevations and probably increases in precipitation at all elevations. *Predicting the net effect on sea level of those changes is the prime goal of this programme*

Scientific approach

1. To determine the present geometries of the Arctic ice masses and their rates of change.

The shape of an ice mass and its evolution in time is important because it is a measure of the mass balance and an important constraint for the surface and initial boundary condition of ice sheet models;

Until recently, ice-surface topography was derived from ground surveys, aerial photogrammetry and airborne radar altimeter data. Errors were large. Beginning in 1978, satellite radar altimetry data have been used to reconstruct a smoothed version of ice-surface topography over parts of the Greenland Ice Sheet with slopes less than about 1:100. Ice thickness has, and is, measured by surface and airborne radio-echo soundings. The accuracy is approximately 5-10 metres. A major improvement here, as for nearly all quantitative remote sensing techniques, is the recently developed ability to determine the aircraft trajectory very accurately (~10 cm) using the Global Positioning System (GPS) technique.

What do we know?
The overall geometry of the larger Arctic ice masses is known at a course spatial resolution to a few tens of metres in elevation and thickness, and to about 1 km or better in horizontal location. The high elevation, smoother parts of the Greenland ice sheet have been mapped by satellite radar altimetry to a vertical accuracy of a few metres.

We still do not know whether the largest Arctic ice mass - the Greenland Ice Sheet - is growing or shrinking. Repeat surveys along the EGIG transect are still under analysis, and repeat surveys by satellite radar altimetry suggest a thickening of the ice sheet south of 72^{o}N. This is, to some extent confirmed by comparing aircraft data with earlier surface measurements using Doppler satellite technique. Definitive estimates must await repeated radar and laser altimetry surveys separated by several years.

What do we need to know?
1.The change in the volume of Arctic terrestrial ice, with the Greenland Ice Sheet as highest priority. In addition to long term trends, we need the seasonal cycle and the interannual variability of ice surface elevation.
2. Surface and bed topography of marginal parts of Arctic ice caps and the Greenland Ice Sheet, where slopes are highest.
3. Crustal vertical movement beneath the Greenland Ice Sheet.

2. To determine Arctic glacier mass balance components and their altitudinal and regional variations in relation to climate.

In addition to the annual mass balance, the observation of individual components, the accumulation and ablation, is necessary to understand how glaciers respond to climate variability and change.

Better knowledge of the mass balance components is also critical for evaluating the overall impact of the mass balance change and thus understanding its contribution to sea level changes. The main components are surface net accumulation, melting, and iceberg discharge (when glaciers terminate in the sea). Additionally any melt increase has important consequences for the change in sea-ice formation and will influence thermohaline circulation and marine biology. The change of meltwater is also important for water management. Presently for only 12 Arctic glaciers separate accumulation and melt observations are carried out as a part of net mass balance measurements. These glaciers are all between Alaska and Svalbard and none in the Russian Arctic. Only two of these glaciers are calving.

Although spot measurements in the field are conventional in the mass balance measurements the regional estimation of the mass balance components would be the most important information. The accurate estimation of the surface accumulation and ablation is best determined by a combination of spot measurements and satellite survey techniques. Spot measurements (snow pits, shallow cores and stake observations) have been made for more than 50 years, but coverage is still inadequate in many areas and only few measurements are available on long-term changes in mass balance components. The most useful direct application of remote sensing is satellite altimetery at the end of accumulation and ablation periods.

Internal accumulation by refreezing meltwater has been known already for some time to form a significant portion of the accumulation. It is, however, evaluated only at a few spots as superimposed ice or refreezing meltwater in firn. The knowledge of this component is presently missing for the entire circumpolar glaciers.

In this context also the meltwater discharge is important. It is observed only for several glaciers in Scandinavia and one in Svalbard.

The importance of calving as an ablation mechanism can be seen from the fact that roughly half of the ice-loss from the Greenland ice sheet is contributed by calving. There are, however, only two glaciers with direct observation of the calving rate. Calving rates are determined by measurements of the thickness and ice-flow velocity at the calving front. Systematic measurements of the calving in the entire arctic basin is urgently needed. The application of SAR data will substatially support the estimation of the present calving rate. It is also necessary to study the mechanism of calving, in such a manner that an appropriate parameterization can be used for climate models.

Field studies of mass balance and associated meteorological elements must be carried out by including the atmospheric boundary layer. Only through this sort of investigation it is possible to integrate the case studies into climate models.

To implement the described investigations, new methods should be actively developed. Ground based remote sensing techniques are successfully used to map temperature regime, snow cover and albedo on glaciers. Future developments in satellite techniques for all weather conditions are eagerly awaited.

The high resolution climate models (GCM as well as HIRLAM) have been proven to be a powerful tool for simulationg accumulation and ablation, especially under the future climate conditions. To fully exploit the models capability *it is highly desirable to build a comprehensive climatological and glaciological data bank for the circumpolar Arctic.*

What do we know?
-Mass balance componenet data for some glciers have been recorded for up to 50 years from the Arctic. Some smaller areas are very well documented, other areas are poorly known.
-Glacier front positions are documented since the end of the Little Ice Age, or data can be obtained, from a large part of the Arctic.
-The general recession and shrinkage of glaciers in the Arctic during the 20th century is basically a response to the post Little Ice Age climate warming and many glaciers still have a negative mass balance.
-At present there is no general trend in the mass balance records of Arctic glaciers, though on a regional scale trends have been identified.

What do we need to know?
-the mass balance components of glaciers along the Russian Arctic
-the mass balance components of Greenland outlet glaciers
-the existing mass balance measurements must be continued in order to obtain longer homogeneous time series.

3. To identify and evaluate the physical controls on the dynamics, spatial extent of ice streams and outlet glaciers, and switching between different flow regimes.

A large portion of the ice leaving Arctic ice caps is discharged through outlet glaciers, which in some cases are fed by ice streams originating far inland. These glaciers play an important role in the mass balance and the potential response to changing climate. Mapping of these glaciers and description of their motion patterns is incomplete.

We know that some outlet glaciers appear to move at high speeds continuously. Others are known to switch between normal slow states and fast surge states. Such surges are not forced directly by climatic variations, but they transport large masses of ice to lower elevations and thereby cause increased melting. We know that internal deformation, basal sliding, bed deformation, and side shear are all important physical controls on the dynamics of ice streams and outlet glaciers. Moreover, there is strong evidence from marine sediment records for massive outbursts of ice from Northern Hemisphere mid-latitude ice sheets into the ocean during the last glacial period that had a pronounced effect on the climate in the Atlantic region.

Although there is a growing understanding of the mechanisms of slow and fast motion and how a fast motion is initiated or ended, we do not know how this applies more generally to Arctic glaciers, i.e. what are the relative importance and roles of internal deformation, basal sliding, bed deformation, marginal shear and how these relate to sub-glacial topography. We do not know the amount of basal melting from Arctic floating ice tongues. Neither do we know how changing climate and sea ice cover affect glacier flow regimes, and to what extent changes in Arctic terrestrial ice covers affect the climate of the North Atlantic region, and how that feeds back to surface processes.

Knowledge of the current state of the Arctic ice masses and predictions of future states are limited by these deficiencies. Whithin the next five years, significant progress can be achieved as regards delineation of the boundaries and speeds of ice streams and outlet glaciers. Ice surface and bed topography of selected glacier basins can be mapped. Studies of basal melting of floating ice tongues and of the blocking ability of semi-permanent sea ice covers with respect to disintegration of floating ice tongues can be conducted. Altogether, such studies will significantly increase our understanding of the physical controls on the dynamics of ice streams and outlet glaciers. Whithin a 5-year time frame, significant improvement of the hierarchy of ice-dynamic models and their incorporation into full climate models can also be expected.

Data on topography and ice dynamics can be obtained by various methods, but remote sensing by radar altimetry, laser altimetry, radio-echo sounding, and SAR interferometry from airplanes and satellites will play the dominant role. Understanding the mechanisms of fast motion will also require sub-surface observations: bedrock topography, hydrological conditions, basal temperature regime and the distribution of subglacial sediments in order to define thermal and structural patterns near the base where fast motion originates. Progress will require a combination of remote sensing of basal conditions (e.g. radar or seismic methods) and direct access through drill holes. Changing sea ice and glacier ice extent can be mapped by using aerial photographs and satellite images.

In a broader context, physical controls on the dynamics of ice sheets extend to the other components of the climate system, as was recently shown using simplified models (bing-purge process of ice sheet collapse as a possible cause of Heinrich events). The input of large amounts of freshwater from melting or surging ice sheets changes the surface properties of sea water. Slight perturbations can lead to significant changes of the deep (thermohaline) circulation of the ocean due to the presence of instabilities. These changes may include simply a shift in location or a reduction or even complete shutdown of deep water formation. As a consequence, the meridional transport of heat to the high northern latitudes by the ocean is altered rapidly. Coupled to the atmosphere via ocean-atmosphere fluxes, the meridional flux of heat and moisture to the ice sheet, i.e. accumulation, are expected to be influenced in turn. This clearly calls for efforts that embed the knowledge of ice sheet dynamics into a framework encompassing all interacting components of the climate system. This is best done by using a hierarchy of coupled models.

What can be done within the next decade?

Within five years:
1. First estimate of the volume change of all major Arctic ice masses over the 5-year period. This estimate will be accurate to a few centimetres equivalent ice thickness over the total period. This volume is less than the approximately 20 cm accuracy of ''spot'' elevation derived from airborne laser altimetry, because errors for individual transects should be independent.
2. Accurate surface (by laser altimetry) and bed topography (by radio-echo soundings), along transects of most major ice caps and glaciers, and along transects of all major drainage basins of the Greenland Ice Sheet.
3. Development of ice sheet models of increasing complexity and their coupling to climate models.

Within ten years:
1. Volume changes of all major ice masses for a ten year period, with detailed information on seasonal cycle and interannual variability of the last three to four of the years.
2. Accurate surface topography of all major ice masses(from satellite laser altimetry) at 300-meter spacing along satellite tracks, with an across-track separation less than 1 km near 84^{o}N, increasing to less than 4 km at 60^{o}N.
3. Detailed bed topography of selected Greenland drainage basins and outlet glaciers.
4. Vertical crustal motion at three or more locations around the Greenland Ice Sheet, based on up to ten years of continuous GPS measurements. Accuracy will be on the order of 1-2 mm/yr.
5. Validation of these models using paleoclimatic and present data and application to estimate future ice sheet mass balance and sea level rise.

4. To reconstruct the Holocene climatic variations in the Arctic from ice cores and other sources.

Ice core Circum-Arctic Paleoclimate Programme (ICAPP), a joint PAGES/IASC project.

Mass balance data collected in the circum-Arctic region over the past 25-50 years show no signs yet of the expected warming. These data are necessarily restricted in their time span. Therefore an Ice core Circum-Arctic Paleoclimate Programme (ICAPP) has been established. ICAPP aims to extend the glacier (climatic) record back over tens of thousands of years into the last ice age. While the Greenland ice sheet has, and still is, providing high resolution climatic records from ice cores drilled through over 3 km of ice to bedrock, there has been no concerted effort until now to coordinate an ice core programme on icecaps in Arctic Canada, Svalbard and the Russian Arctic Islands. Valuable paleo-climate information has come from cores drilled by Canadian Government agencies on Meighen, Devon and Agassiz ice caps in the Canadian Arctic Archipelago. These have shown that there have been substantial changes

within the Holocene. These changes are much more pronounced than those shown by the Greenland ice-sheet records, particularly the recent Summit (GISP2 and GRIP) cores which show a remarkably stable Holocene climate compared to the glacial period. The Svalbard records provided by Japanese and Russian cores, either cover short time periods or have time gaps in them created by negative balances at the drill sites during past warm periods. Cores from Severnaya Zemlya suffer the same problems although that from the Academy of Sciences ice cap does appear to penetrate Pleistocene ice. The same core also demonstrates the same persistent cooling trend from 10 ka to present as found in the Canadian cores and in the core from the local Renland ice cap in Central East Greenland.
An ongoing investigation of existing ice core data in the circum-Arctic region outside Greenland suggests that most of the ice caps in the Russian Arctic and on Svalbard may have melted completely in the early Holocene and have reformed in the last few thousand years. Recent results from ice core and other studies on the local Hans Tausen ice cap, eastern North Greenland shows that this was also the case for that ice cap. The only absolute dating in any of these cores supports this hypothesis. As far as the Canadian Arctic is concerned, only the larger ice caps survived throughout the Holocene. However, the fairly uneventful Holocene record from Summit (GRIP & GISP2) shows little evidence for such a Holocene glacial history. However, in a paper "Greenland palaeotemperatures derived from GRIP bore hole temperature and ice core isotope profiles", Tellus, in press by S. Johnsen et al., it is shown that when corrected for surface elevation changes, the Holocene climatic optimum shows up also in the Summit isotopic record. The basic disagreement between the Greenland and 'small ice-cap' cores demands further examination. This is particularly true considering that the extremely important new Greenland cores may become the standard climatic index in the future. New cores from the circum-polar Arctic ice caps are needed to resolve this problem.

Global ocean/atmosphere coupled climatic models predict North-east to be a region of high climatic variability and sensitivity. This was the background for initiating the "Hans Tavsen Ice Cap Project - Glacier and Climate Change Research, North Greenland" (1993-1997). The main goal of the project is to investigate the present and past climate, and glacier dynamics of North Greenland by means of ice core records, ice margin studies, ablation-climate studies, and glacial geological studies.
Collaboration and linkage with ICAPP should be intensified.

In 1996 a joint Japanese-Canadian-Russian drilling project is planned to be carried out in Severnaya Zemlya.

Ice core records from the Canadian ice caps also suggest that deglaciation in the Canadian Arctic was more complete during the Eem interglacial than at any time during the present (Holocene) one. Pre-Eemian ice is not evident in any of the Canadian cores. Detailed information about the Pre-Eemian climate is only available from the recent deep Greenland cores. Ice cores from Penny Ice Cap in Canada and Academy of Sciences ice cap in Severnaya Zemlya would provide valuable additional information as to the extent of deglaciation in the Eem interglacial.

Other sources of Holocene climate data are found in Arctic environments with alpine glaciers, e.g. tree rings, moraines, other glacial landforms, and sediment rate records from pro glacial lakes. A dendro chronology can be established using fossil trees buried in bogs and lakes. In Arctic environments, not too far from the present tree-line, logs can be found originating from warm periods during the Holocene when the tree limit extended further north and up to a higher elevation. In Siberia old trees are found along gullies cut into the permafrost. At present dendro chronologies exist for the last 3000-4000 years in Scandinavia. These records will most likely be extended to cover the entire Holocene within a few years. There is also a good potential to establish a Holocene chronology for parts of Siberia.

Moraines in front of non-surge type glaciers might be used as indicators of cold periods. An advancing glacier often buries organic matter while forming its frontal moraine. Dating of such moraines gives a record of when, and in favorable situations how long, periods with a climate favourable for glacier growth have occurred. Other glacial landforms may also be used to describe the thermal condition existing within past glaciers giving a qualitative measure of the climate.

Information on variations in sedimentation rate in proglacial lakes is very useful for climatic reconstructions. During warm periods the organic content is high and during cold period the minerogenic part is large both in relation to the organic part and overall.

All methods used to study Holocene climatic variations in the Arctic are indirect measurements. Thus, in order to transfer paleo records from ice cores, tree-rings or sediment cores to a climatic record, the present relation between the processes of interest and the climate must be studied in situ.

THEMATIC RESEARCH TASKS

Background

Ongoing projects on mass balance and related topics around the Arctic gives the fundamental background for the future research.
Such programs can be on national level as for example running mass balance programs in Russia, Scandinavia, Greenland, Canada and Alaska. There are also running bilateral or international programs that gives an excellent underpinning for future cooperation.
Some ongoing activities can be mentioned as examples:
- The french-norwegian project on monitoring present and recent past mass balance in Svalbard funded by French-Norwegian-Foundation and the Norwegain and French Polar Institutes.
- The bilateral projects between UK and Russia on Franz Josef Land (1993-1996) funded by INTAS and on Severnaya Zemlya (1996-1998) funded by UK (NERC) on investigations of the form and flow of of the ice masses. This project will include a comprehensive airborne radio-echo sounding program in 1996.
- The USA-Russian deep drilling project on Franz Josef Land, Graham Bell Ice Dome (1996-1998) funded by NSF.
- The ‘‘Hans Tausen Ice Cap project - Glacier and Climate Change Research, North Greenland" funded by the Nordic Environmental Research Programme (1993-1997) launched by Nordic Council of Ministers (NMR) with participation from Denmark, Island, Norway and Sweden, and the project "Mass Balance and Dynamics of North-East Greenland Ice Margins and Sensitivity to Climate Change", a sub-project under the project "Climate change and Sea Level" funded by the EC 4th Framework Programme "Environment and Climate" (1996-1998). The "Climate Change and Sea Level" project has participation from Denmark, France,

Germany, Italy and UK. The sub-project on North-East Greenland is a collaboration between Denmark and Germany.
- The Japanes arctic drilling program conducted under Japanes Arctic Glaciological Expeditions (JAGE) has carried out core drillings down to a depth of maximum 200 meter on ice caps in Norway, Greenland and Svalbard in the period 1987 - 1995.

Shallow ice cores

Shallow ice cores (less than 50 m) can be analysed to study the accumulation rate during the last 200 y. The idea is to study reference horizons and annual layers by isotope studies, as well as sea salt input variations, ice facies zone shifts, volume of summer melting water production, stable isotope composition, unique temperature distribution in glacier bodies, natural and industrial pollution. Also radioactive elements due to the Chernobyl accident and/or atmospheric nuclear tests conducted in 1961-62 may be used to measure the net accumulation.

Such studies have been conducted and are planned to be conducted as a part of other projects. For instance work by Ohio State University in Franz Josef Land has recovered and analysed cores up to 25 m in length, which show a clear stratigraphy, and Laboratorie de Glaciologie in France has dated layers based on tracers of the Chernobyl accident in 25 ice cores in Svalbard.

Ice margin dynamics

Rapid climate oscillations both during glacial and interglacial periods have been connected to large scale changes in the oceanic circulation in the North Atlantic. The triggering of these oscillations is not known, but ice-sheet instability (surges) causing massive iceberg discharge and meltwater flux into the ocean (Heinrich events) may have had an important influence. At present, the largest land-ice masses in the North Atlantic region are found in East Greenland. Glacier-dynamics studies carried out during the EC EPOCH and ENVIRONMENT programmes suggest that North and North-East Greenland ice sheet outlets are potentially unstable. Possible influence of glacier disintegration (iceberg discharge) on past North Atlantic ocean circulation and climate, requires that it is important to study the variation of present North-East Greenland floating ice margins, focusing on the environmental conditions which determine their existence, and the possible changes that will result in their disintegration/advance. A study of the interactions between climate, glacier mass-balance and dynamics, sea- and fjord ice extent, and glacio-isostatic rebound may contribute to a better understanding of important processes behind the rapid climate fluctuations in the past. The fact that GCM model studies predict North-East Greenland to be a region of high climatic variability and sensitivity, also under present conditions, further stresses the importance of such a study. An equally important aspect of the study is related to the discovery by ERS-1 SAR imagery of a large fast-flow ice stream which clearly originates well into the ice sheet, some 550 km from the coast. Due to this feeder ice stream, dynamic instability (a surge), or climatically induced changes of glacier dynamics, might propagate far into the interior of the ice sheet, and consequently, have a significant influence on the mass balance of a large sector of the North Greenland ice sheet.

The Project "Mass Balance and Dynamics of North-East Greenland Ice Margins and Sensitivity to Climate Change" will focus on the study of the environmental conditions, which determine the existence of the present North-east Greenland floating glacier tongues, and the changes that will result in their disintegration/advance. The project comprises studies of bottom melting, surface mass balance and ice dynamics. The methods to be used are hot-water drilling through the glacier, collection of climate and mass-balance data and measurement of glacier flow and deformation, using GPS and satellite SAR interferometry. Stability conditions of the floating ice margins will be studies in the short and long terms. The relation between ocean-sea ice-glacier interactions will be mapped to elucidate possible break-up mechanismes of the ice tongues based on aerial photos and satellite imagery. Long term ice-margin variations will be documented based on quaternary geological information and dating of ice transported biogenic material.

The Greenland studies should be coordinated with related studies in other parts of the high Arctic, e.g Svalbard, Franz Josef Land, Severnaya Zemlya.

Remote sensing

Air photoes is by far the most precise remote sensing tool. Frequent photo coverage is expensive and cover small areas compared to satellite images, but repeated air photography should be considered for some selected areas. That gives precise data for mass balance changes, geometry changes and dynamical changes.
Airborn radio echo-sounding, as well as other active and passive measurements in different bands should also be used and developed.

A synoptic approach using satellite imagery and appropriate analytical methods is required in order to provide estimates of key parameters linked to glacier mass balance, so that the sensitivity of Arctic ice caps to climate change can be assessed. In order to obtain quantitative mass balance data from satellite imagery it is desirable to distinguish between glacier ice, superimposed ice, firn and snow, as well as to identify the position of the transient snowline in late summer. One major problem is due to the fact that the dynamic scale of reflectance of the uppermost few centimetres of an ice surface is very sensitive to the weather conditions prevaling before any field or satellite measurement. Reflectance measurements do not allow to discriminate unambiguously between all various snow and ice facies and between different states of surfaces. But, one way to solve the problem is to discriminate the diverse facies from field observation and then to extract the variable contribution of the weathered uppermost layer in order to recover the signatures of the underlying surface. Synchronized characterization of the different kinds of observed surfaces and of the atmosphere above them may allow calibration of satellite measurements recorded at the same time. A multi-sensor approach should be used including Landsat (TM and MSS), SPOT visible/near-infrared and ERS-1/2 synthetic aperture radar (SAR) imagery as well as future high spectral resolution instruments. Such investigation will require a development of reflectance models, in situ measurements, and development of experimental devices for validation.

Expected results can be produced on: (i) the average position of the transient snow line on glaciers which can be used for estimations of the mean equilibrium line altitude (ELA) on a large number of glaciers, and (ii) the interannual variability in elevation patterns, linked to shifts in meteorological parameters. The multi-sensor approach is important in the solution of this problem, and is also significant in terms of assembling the full range of spatial and temporal coverage that is required.

Interferometric analysis of pairs of ERS1/2 SAR images has the potential to yield accurate and detailed glacier velocity and strain fields, if it is controlled accurately using known surface points. The interferometry may permit ice flow measurements in the centimeter range, discriminating between slow and fast flowing glaciers and detection of the early stage of glacier surge. Digital terrain models available from several Arctic ice masses provide ideal test sites. This method holds considerable potential for the synoptic measurement of glacier and ice cap velocities. It will provide a valuable tool in testing the output (e.g. in terms of predicted velocity fields calculated using finite elements) from numerical models of Arctic ice masses against independently derived observational datasets.

Modelling

A distinction should be made between (i) ocean-atmosphere or climate models, (ii) energy and mass balance models and (iii) ice-flow models. The climate models are needed to generate the boundary conditions for the ice flow models where the most important boundary condition is the mass-balance pattern over the entire ice mass. The most crucial aspect of new ice-flow models is a successful treatment of fast flowing outlet glaciers and their role in the overall dynamics of the ice caps.

Energy balance modelling, including degree-day models, of mass balance and the response of glaciers in terms of thickness and terminus position is a first step of mass balance studies. This modelling should include both the possible effects of natural variability (e.g. the Little Ice Age epoch), and the glacier and sea-level response to greenhouse warming.

The climate and ice models must be validated by known past and present configurations as well as by transient events identified by, for example, glacial geological studies. Field and satellite data will provide the boundary conditions and the present ice-sheet configurations for such validation experiments. Input to sophisticated ice-sheet models should span the period from the last glacial maximum to the present and, to be credible and applicable for projections into the future, the models must be able to reproduce this period accurately.

Past and future predictions: Time dependent numerical modelling of the Weichselian (and Würm / Wisconsin) ice masses.

Recent and future: Energy balance modelling and degree-day models of the mass balance of Arctic glaciers combined with dynamical models provides a quantitative method of assessing their sensitivity to climatic shifts. Such models calculate the components of ice surface energy balance, takes meteorological data, the area distribution with altitude of the ice mass, and parameters defining the global radiation as input values. Meteorological data for the modelling will come from records at several Arctic stations.The energy balance and degree-day models can be linked to numerical ice-flow and thermomechanical ice-sheet models which calculate time-dependent changes in glacier geometry, outlet glacier flow and calving rate using mass balance information derived from the energy or degree-day balance models. This coupling allows the next iteration of the models to take account of changes in ice surface morphology.

It should also be noted that the general shape of the glacier equilibrium line across the high Arctic is of utility in three-dimensional numerical modelling studies of the long-term response of these ice masses to climate change

Another type of modelling is to simulate the influence of growing and disappearing ice domes on the temperature and precipitation fields on local and regional scales. The urgent task is the glacier-sea water interactions: ice calving, floating parts etc. Besides, the modelling of different flow regime shifts is also very important from theoretical and practical applications.

Field program

The continuation of long time series of mass balance monitoring programmes into the coming years when global circulation models predict a warmer climate will be a special challange. World Glacier Monitoring Services points on this in their recommendation for future activities.

Large areas in the Arctic lack information about the status of the ice masses. Until now glacier mass balance data from selected areas of the Arctic show no signs of the expected warming due to anthropogenically-induced climate change; there are no signs of *increased* melting of the glaciers in the Arctic and no significant trend in the existing mass balance series. An enchanced global warming would be reflected in Arctic ice masses by changes in their mass balance, surface melting, and physical characteristics like internal temperature, flow regime and geometry. Therefore, it is essential to improve the knowledge of the Eurasian Arctic ice masses as indicators of climate change, and **timely to establish a network of key areas** for detection and monitoring of future changes in Arctic ice masses due to climate change. This requires an extensive monitoring program, using *in situ* and *remote sensing* **measurements**, for defining their present state and for evaluation of future behaviour based on the physics of glaciers. At the same time it is important to improve our knowledge of how the Arctic ice masses have been affected by climatic fluctuations in the recent past.

Only very few areas of the high Arctic have detailed mass balance time series over a number of years. Such data exist mainly from the west coast of Spitsbergen and from the Canadian high Arctic (Meighen Ice cap, Devon Island Ice Cap). Some information is now available from more sporadic investigations in the Russian high Arctic, Severnaya Zemlya and Franz Josef Land. The Russian High Arctic archipelagoes are some of the least known areas on the northern hemisphere. Information from this area is therefore important for the general knowledge about the Arctic environment and especially in the global change context. Some selected ice masses should be studied from the High Arctic Eurasian archipelagos of Novaya Zemlya, Severnaya Zemlya, Franz Josef Land and Svalbard. This information should be be put into a broader context and linked to the existing data from areas that have been studied through some years.

In order to enable a systematic collection of basic data on a wide range of Arctic ice masses it is important to coordinate the studies on a multinational level.

It will be important to improve methods of in situ and remote sensing techniques for future monitoring of changes in the Arctic ice masses.

The studies should determine mass balance components and their altitudinal and regional variations in relation to climate, and also determine the present geometries of the Arctic ice masses and their rates of change. This will require direct mass balance observations, but also involve methods to derive information and application of SAR multi-pass coherence images in detection of glacier facies properties. Extracted information includes dry and wet snow zones, zones of superimposed ice in large ice fields. Geometry change investigations will require use of different methods by use of air photos and satellite images in digital photogrammetry together with field investigations of geometry and dynamics by kinematic GPS-positioning of stake profiles and by use of airborne laser altimeter profiling. Monitoring should not be restricted to ice masses terminating on land because calving flux from tidewater glaciers may be very important and should be studied.

Shallow core drillings should be used to establish accumulation rate changes. On glaciers without routine mass balance measurements the average ELA can be observed using either high resolution radar or to measure concentration of radioactive fall outs. In ablation area, the fall outs are concentrated in a layer at the glacier surface (ice surface just below the winter snow) while in accumulation area, radioactive peaks are found at greater deepths and are associated to a lesser fall-outs. The radar method is used by several groups and the latter is used by Laboratoire de Glaciologie in Grenoble.

Accurate determination of ice-sheet and ice cap geometry and geometry changes serves several purposes: 1) Locating ice divides for establishing drainage patterns. 2) Providing short wavelength topography, i.e. surface undulations and roughness, indicative of fast-flow regions/ice streams. 3) Providing background for sophisticated use of other remote sensing methods, e.g. SAR interferometry. 4) Providing background for mass- and energy balance models. 5) Direct observation of ice surface elevation (ice volume) change.

As regards point 4) listed above, a study of the mass balance of selected sectors of the Greenland ice sheet revealed that the applied topographical model with a spatial resolution of about 10 km does not resolve the topography accurately enough to ensure that low-elevated surfaces of narrow fjord glaciers with a potentially high melt-rate contribution are properly accounted for, thus resulting in a substantial under-estimation of the loss by melting. Moreover, detailed mass balance measurements on the Greenland ice-sheet margin show a distinct pattern depending on local surface topography. Modelling of these patterns also presupposes knowledge of the detailed ice margin topography. This calls for high-resolution topographical models of ice masses, particularly of their margins, which for the Greenland ice sheet alone have an extent of more than 200,000 km2. The required accuracy and resolution (1 kilometre or better) can probably be obtained only by intensive airborne laser altimitry measurements.

Workshops

1) A first joint IASC/SCAR workshop on Glaciers and Mass Balance and Sea level Change will be organised in conection with the IGS-symposium on Changing Glaciers in Fjaerland, Norway, in June 1996. The themes will be:

-How are the mass and volume of ice sheets changing with time.
-What are the present and predicted mass input to large ice sheets from the ocean.
-What is the present day output from the ice sheets.
-Improved estimations of the contribution of smaller glaciers and ice caps.
-What is the likelyhood of a significant increase in the sea-level-rise rate caused by a massive outflow of ice from the West Antarctic ice sheet.

2) The Sixth workshop on mass balance of the Greenland ice sheet and related topics will be held at Geological Survey of Denmark and Greenland (GEUS) in Copenhagen, 22.-23. Jan.,1996. This workshop is the sixth in a series of workshops that have been held regularly since 1990 with 20-30 participants.

It is proposed to extend the "workshop-area"to the entire Arctic region, and turn these workshops into Arctic Glaciology workshops (or even symposia) as counterparts to the institutionalized International Symposia on Antarctic Glaciology.

3) Annual Meeting of the WG on Arctic Glaciology

As a part of the implementation of the Science Program proposed by the WG an Annual Meeting of the WG would be a useful tool to conduct the plan.

The main task of the meeting should be:

- discuss and update the running implementation plan,
- initiate new projects
- promote effective information exchange of running projects.
- Initiate and discuss international cooperation.
- Initiate symposia and workshops

A two-days meeting in late autumn or early winter is recommended.

Annual IASC fundings should be applied for support of the Annual meeting.

LINKAGE TO OTHER IASC AND INTERNATIONAL PROGRAMMES

There are already some globally coordinated reserach programmes in place partly dealing with cryospheric aspects. The programmes are on different levels. The linkages are illustrated in the figure below.

Linkages between internationally co-ordinated programmes related to the cryosphere in some different perspectives.
Abbreviations: IASC -Working group on Arctic glaciology - Mass Balance of the Arctic ice masses (IASC-MB), Working group on glaciology within Scientific Committee for Antarctic Research - Mass Balance of Antarctic ice masses (SCAR-MB), Arctic Climate System Study (ACSYS), Climate Variability and Predictability (CLIVAR), Past Global Changes (PAGES), and Ice Core Circum-Arctic Paleoclimate Programme (ICAPP).

The most relevant ones for this IASC initiative are the International Geosphere-Biosphere Programme (IGBP) sponsored by ICSU and the World Climate Research Programme (WCRP), jointly sponsored by WMO,ICSU and UNESCO´s IOC. But also the Global Climate Observing System (GCOS) is of relevance here. In order to avoid duplicating and to encourage cooperation the links to the following projects of IGBP and WCRP will be described:

-PAGES (Past Global Changes), a core project of IGBP, on paleo-studies of the global environment;

-ACSYS (Arctic Climate System Study), a 10 year project (1994-2003) of WCRP mainly devoted to sea-ice processes in, and fresch water export from the Arctic Ocean;

-CLIVAR (Climate Variability and Predictability) focussing on the understanding of natural climate variability on time-scales from a season to centuries and climate prediction to the extent possible, including antropogenic influence.

IGBP - the International Geosphere-Biosphere Programme, asked IASC in 1991 to work out a regional research programme on global change for the Arctic. IASC established a Global Change Working Group which in turn asked different working groups to develop specific scientific pojects. One of these subgroups is devoted to Arctic Glaciology. The IGBP core project PAGES (Past Global Changes) has also developed implementation plans for many

components including transects from the Arctic to the Antarctic. One sub-project is named Ice Sheet Mass Balance and Global Sea-Level Change and is of special interest here. Two tasks of this project are the study of ice sheets and sea level during the last 2000yrs and the response of ice sheets to external forcing in order to substantially reduce the uncertainties in the mass balance of the major ice masses of the Earth and to better understand the current rate of sea level rise. The extraction and the study of shallow ice cores to study the accumulation rate during the last 200 yrs is one proposed step in this subproject.
Therefore close co-ordination of both projects, the IASC initiative on the mass balance of glaciers and ice-sheets and PAGES is needed. In discussions with the designated chairman of the PAGES Scientific Steering Group (SSG), Prof. Bradley, the WG on Arctic Glaciology agreed that ice core-studies within ICAPP will be conducted jointly with PAGES and that continuous close cooperation is needed because of the intertwined time-scales in mass budget studies of larger ice bodies. This will best be handled by a joint working group and invitations of a representative of the SSG of the neighbouring project to all SSG meetings.

CLIVAR (Climate Variability and Predictability) is the youngest element of WCRP and has a clear but difficult and far reaching goal: to understand and predict to the extent possible climate on timescales up to decades. For this it needs data on the variability of the Arctic Ocean sea-ice and ice-masses on land, i.e. the mass-budget studies on time scales up to many decades are a necessary input for coupled modelling studies and model validation.
Thus CLIVAR expects the input from the ice mass budget study of IASC.

ACSYS (The Arctic Climate System Study) is the Arctic research project of WCRP. This programme focuses on sea-ice processes in the Arctic Ocean to answer two related questions:
1) Is the Arctic climate as sensitive to global change as models seem to suggest?
2) What is the sensitivity of global climate to Arctic processes ?
ACSYS also links these processes to the hydrological cycle in the Arctic region. Since the variation of fresh water input to the Arctic Ocean is caused by changes in the mass balance of the glaciers and changes in precipitation and river run-off the spatial and temporal distributions of the precipitation (mostly in solid form) in the Arctic have to be known better as well as the fresh water release from Arctic ice masses as a result of climate variability and change. Thus, one of the ACSYS objectives is to initiate a long-term climate research and monitoring programme for the Arctic Ocean.

The Scientific Goals of the Working Group on Arctic Glaciology are the urgently needed terrestrial part to the mainly oceanographic ACSYS project.

Contacts to the International ACSYS Project Office in Oslo which is located in the Norsk Polarinstitutt as the IASC secretariat are already close and should be developed further through the involvement of the scientific steering groups of both projects.

GCOS (Global Climate Observation System) is a joint initiative of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the UNESCO, United Nations Environment Programme (UNEP), and the International Council of Scientific Unions (ICSU). They provide an international forum for the development of a comprehensive long-term observing system that will improve our understanding of the climate.

One of the objectives for GCOS is to provide the observations required to meet the needs for Climate system monitoring, climate change detection and response monitoring especially in terrestrial ecosystems and mean sea-level.
GCOS and the Global Terrestrial Observing System (GTOS), have developed the Terrestrial Observation Plan for Climate Observations. The objective is to detect status and trends in global ecosystems with high sensitivity, to document, quantify and map changes of global ecosystems and to provide data needed for modelling of global climate change.
The cryosphere is one selected area of this plan in which interactions between the cryosphere and the climate system should be studied.
Mass balance of glaciers, ice caps and ice sheets are important for global sea level changes and fresh water input to the global ocean as well as the environment on ice-free land. Any new observing system developed within this IASC initiative is thus a potential contribution to GCOS.

SCAR- Scientific Committee on Antarctic Research - Working Group on Glaciology.
The IASC council has agreed that bi-polar cooperation should be further developed The working group shall establish ties to the World Glacier Monitoring Service (WGMS), the Scientific Committee on Antarctic Research (SCAR) and the SCAR Working Group on Glaciology. The IASC Working Group on Arctic Glaciology would be the Arctic counterpart to the respective SCAR Working Group.
As a first step a joint IASC/SCAR workshop on glaciers and mass balance will be organized with co-sponsorship by WCRP.

QUEEN (Quaternary Environment of the Eurasia North) is a recently approved 5 year project of the European Science Foundation (ESF) starting in 1996. The aim of the programme is to understand environmental change, and the growth and decay of ice sheets, over the Eurasian Arctic, for the last 250,000 years. The linakge between ice-sheet fluctuations and the sedimentary record on the Eurasian continental margin of the Arctic Ocean, including the Russian North, will be a particulalr focus for the study. Numerical reconstruction of ice sheets through time will also form a part of the project.

ICSI/WGMS (World Glacier Monitoring Service)

Data on mass balance will be distributed both by the World Glacier Monitoring Service in Switzerland, and by the working group. A data bank for Arctic mass balance data will be established and data will be distributed either by publications or by Internet.

EPICA (European Program on Ice Core drilling in Antarctica) is a long term (~7 years) deep ice core drilling project in Antarctica to derive high resolution records of climate and atmospheric composition through several glacial-interglacial cycles. The ESF project is designed to complement the highly successful central Greenland projects and it will allow extension and full documentation of the East Antarctic record so far essentially limited to the analysis of the Vostok core. To achieve EPICA's goals, it will be necessary to drill at two sites, both to achieve the required resolution on different timescales and an adequate continent-wide perspective. EPICA is now funded by the fourth framework within the European community.
A first test of the drill took place on the Hans Tausen ice cap in north Greenland during 1995 and a second test will be carried out north of Summit in Greenland in 1996. The latter project

is called Nordgrip and will hopefully add new data to solve the discrepancy between the ice cores GISP and GRIP.

EISMINT (European Ice-Sheet Modelling Initiative)

Following an ECOPS sponsored workshop held in Cambridge, April/May 1991, a programme was submitted to the ESF General Assembly in October 1992. Phase I was approved for launching in January 1993 for an initial period of three years. The ESF Executive Council approved in November 1995 an extension of two years to the EISMINT programme.
The aim with EISMINT is to increase our understanding of the role of ice sheets in the climate system by improving mathematical modelling in a number of key areas. These are the physical basis of modelling, provison of standard datasets, and intercomparison of models and results.

FUNDING SOURCES

EU-fundings

Joint european programs should be initiated and tried funded under the EU-framework programs, and especially under the EU-Environment 4th framework (1994-1998) and the next 5th framework.
The 4th framework focus in the working program on Environment and Climate on the consequences for the natural environment and monitoring of global change and climate research in the Arctic area.

It is important that the WG is active and give input to future plans as EU 5th framwork Working program.

Through the Eastern European linkage program initiatives should be taken to involve participants from eastern European countries to join EU-projects.

The Training and Mobility of Researchers program gives opportunity for exchange of people, students and researchers between different european countries.

National fundings

National research councils may have bilateral agreements between certain countries that can be used to develope projects, and to secure monitoring programmes providing data for short term research projects.

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