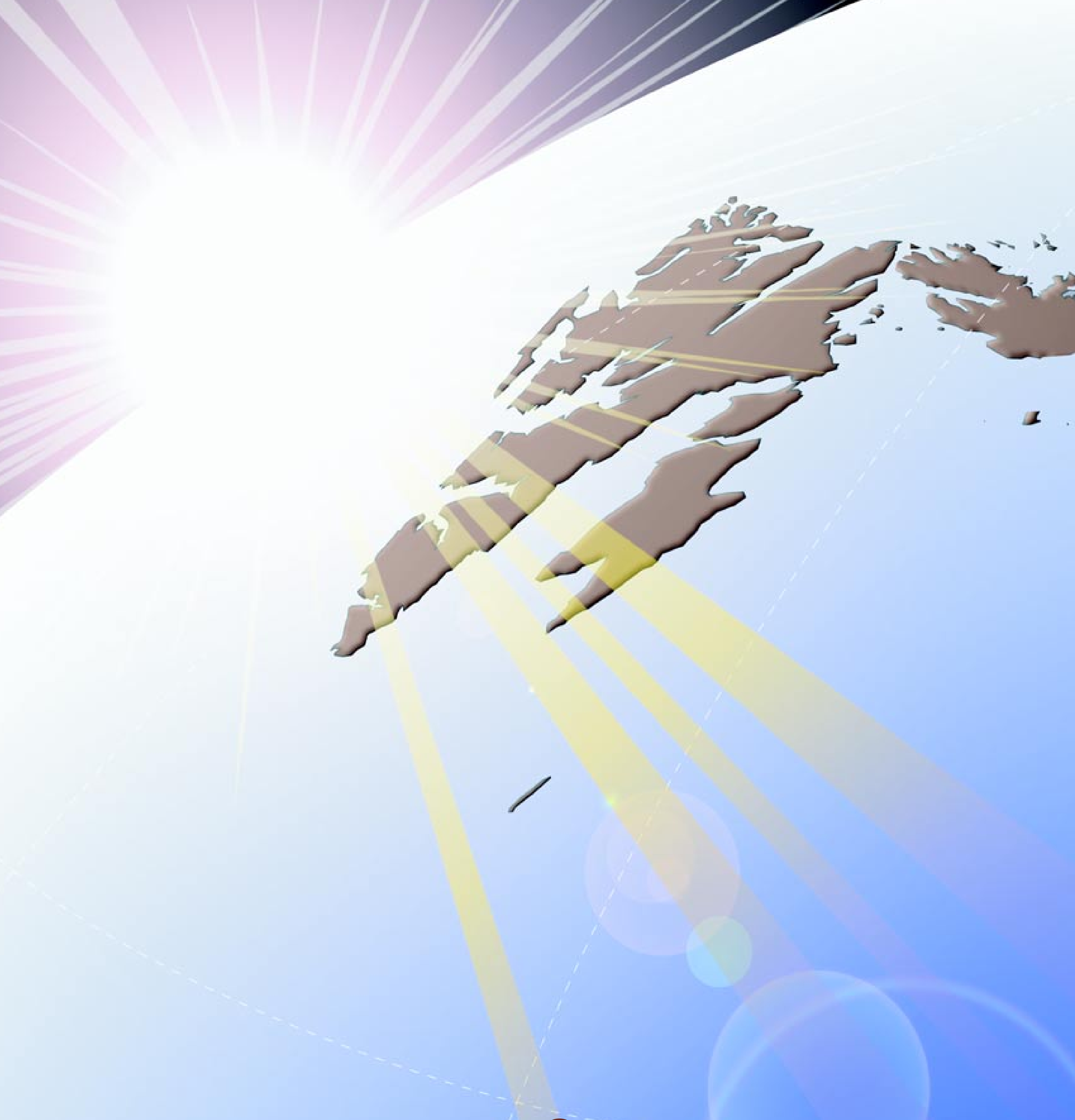

Opportunities for Collaboration Between the United States and Norway in Arctic Research

A Workshop Report

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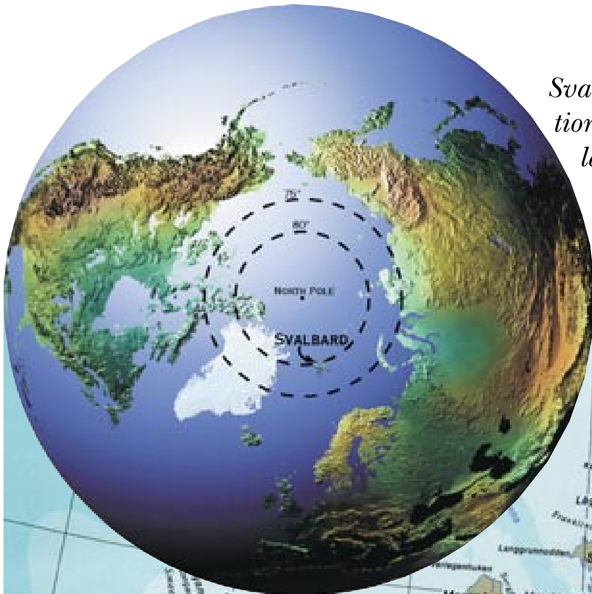


Svalbard is the location of some of the most northerly international research stations in the world. It is easily accessible by regularly scheduled commercial airline flights. (Globe by Mountain High Maps, modified by Sue Mitchell; map by Norwegian Polar Institute, 1983.)

Executive Summary

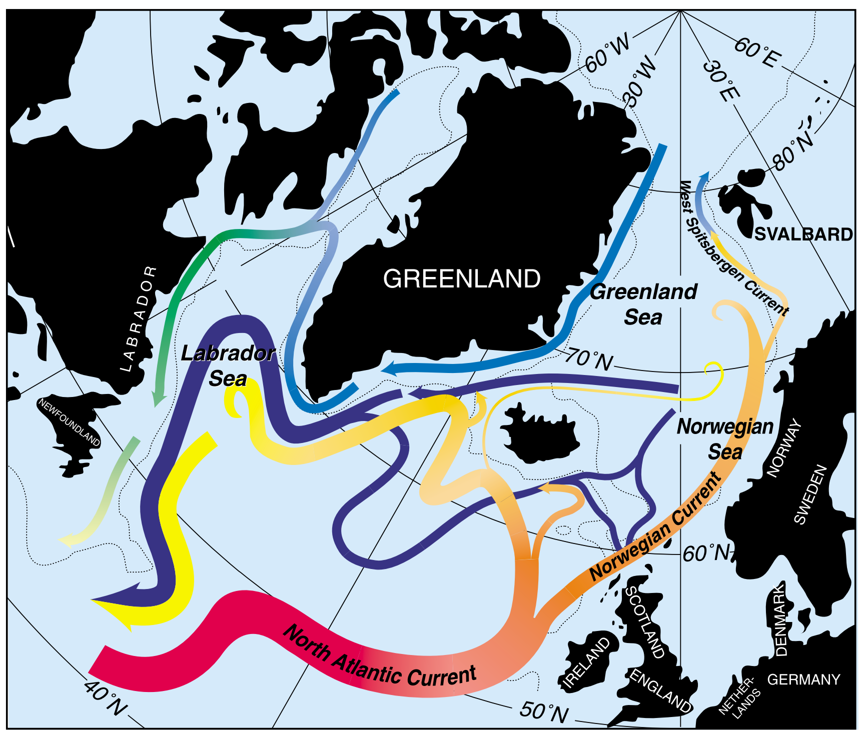
The Svalbard archipelago lies in the high Arctic between 74° and 81° N, midway between mainland Norway and the North Pole. The islands' abundant wildlife attracted whalers and trappers from a number of European nations beginning in the 17th century. Despite competing claims, the islands remained a no man's land until the Svalbard Treaty of 1920. The treaty, signed by 42 nations including the U.S., gave sovereignty over the islands to Norway and mandated that they remain demilitarized and that all signatory nations have equal rights to conduct business on Svalbard. Permanent Norwegian and Russian settlements developed on Svalbard in the 20th century to mine coal.

Since 1968, major Norwegian and international research efforts have been based in the archipelago. Svalbard is an excellent laboratory for studying the environment of the high Arctic because:

- Half of Svalbard's area is now protected as national park, nature reserve, plant protection reserve, or bird sanctuary.
- Svalbard's location offers access to Fram Strait, glacier fields, and other features that are important to global systems.
- It also contains relatively diverse animal and plant communities that are adapted to extreme latitude photoperiod and seasonality somewhat decoupled from extreme climate.
- Svalbard is the world's northernmost territory with modern research facilities and infrastructure.

In 1999, investigators from 14 nations conducted research on Svalbard, primarily based in Longyearbyen, the main municipality, and Ny-Ålesund, an international base for research in the natural sciences. The research effort in Svalbard is complemented by an educational program, University Studies on Svalbard (UNIS), a foundation which offers university-level courses in arctic sciences.

The Arctic is the first place that climate change is likely to be observed. The Arctic is experiencing significant change,

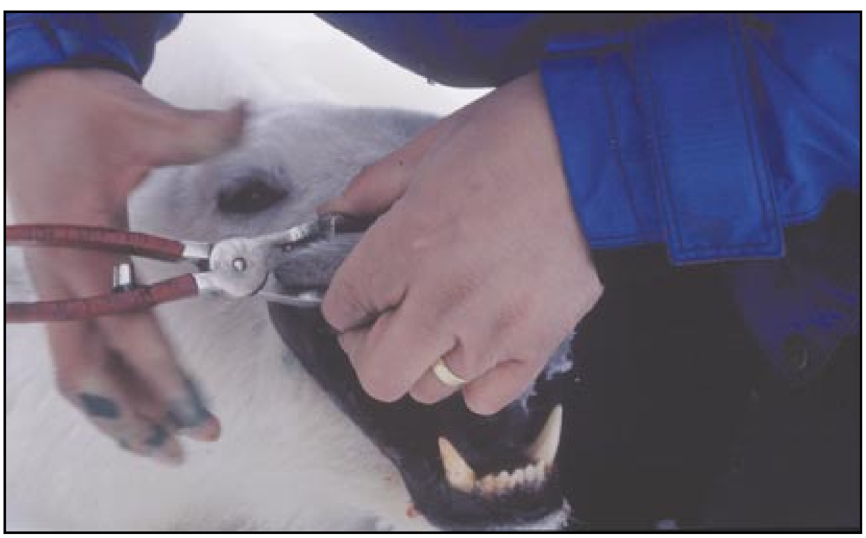


Currents in the North Atlantic. The West Spitsbergen current keeps western Svalbard considerably warmer than eastern Svalbard. From McCartney, Curry, and Bezdek, 1996.

which will have repercussions far beyond the region. Svalbard lies in the Atlantic portal to the circumarctic regions, at the northern end of the Gulf Stream's critical ocean/atmosphere heat pump. Shared scientific study of the Svalbard region, in the context of understanding past and present physical processes across the ocean/atmosphere/geosphere/biosphere system, is critical to understanding large climate and geophysical feedbacks on global scales (1996 IPCC Scientific Assessment). Svalbard is also the only readily accessible high-latitude site that underlies almost all geophysical phenomena triggered by interactions of cosmic particles with the Earth's magnetic field. In addition, like other Arctic regions, Svalbard is a "last frontier" for exploration and resource extraction, inviting northern engineering and comparative social science research.

As two of the eight arctic nations, Norway and the United States are major participants in circumarctic research and have complementary access and capabilities. The two nations have collaborated on many research projects in the past: The U.S. National Science Foundation (NSF) lists approximately 31 funded projects in Svalbard alone, and NSF has funded projects in other parts of the Norwegian Arctic. Other U.S. and Norwegian agencies also participate in collaborative research.

A multidisciplinary scientific workshop held on Svalbard August 16–19, 1999, provided an opportunity for American and Norwegian investigators to discuss a range of possibilities for enhanced collaborative research. This workshop was initiated to increase U.S./Norwegian collaborations in conducting arctic research and developing and using research infrastructure, collaborations which had decreased since the development of the European Union. Scientists from the U.S. will benefit from improved circumarctic access opportunities, ice-free ports, and modern logistical facilities at higher latitudes. Scientists from both nations will benefit from shared research goals, integration of findings, and joint use of facilities. Before the workshop, U.S. delegates solicited recommendations about collaborative research opportunities in Svalbard from their colleagues to provide a broad community perspective to the discussions.



Research in Svalbard includes work with polar bears. Here Dr. Andrew Derocher, Norwegian Polar Institute (NPI), tattoos the lip of a polar bear so that it can be identified if recaptured later. Tattooing is more reliable than ear tags and other devices that can get lost. Photo by Kit Kovacs and Christian Lydersen, NPI.

The major task for workshop participants was to discuss research needs and priorities and develop recommendations for potential collaboration and strengthened scientific cooperation on and around Svalbard. Participants from both countries recognized that the scope of potential research topics for U.S./Norwegian collaboration in Svalbard is necessarily expansive. The Svalbard region has a long tradition of interdisciplinary research, from studies of the cosmos to the sequestration of carbon in the polar marine food web. Workshop participants discussed several multidisciplinary questions appropriate for broader bilateral cooperation in Svalbard, including:

Iceberg in Kongsfjorden (King's Fjord) near Ny-Ålesund, a major site for international arctic research. Photo by Dag Hessen.

1. How will climate change be mediated by ocean processes and what will be the effect on carbon cycles?
2. How are mesoscale atmospheric circulations and ocean stratification affected by large exchanges of sensible and latent heat in the high-latitude North Atlantic?
3. How will climatic changes interact with stratospheric ozone dynamics and UV radiation?
4. How are soil thermal regime, carbon storage, and biological processes affected by climate change?
5. How can we exploit the synergistic co-location of powerful observational facilities of upper atmospheric processes on Svalbard to study how these processes affect consumer, business, and defense satellite communications?

In order to identify specific topics appropriate for U.S./Norwegian collaborative research efforts based in Svalbard, working groups were organized into five working groups, addressing studies in upper atmosphere; lower atmosphere; oceanography and geophysics; paleoclimatology; and biology.

Although a formal social sciences working group was not organized during the workshop, the U.S. delegation included several social scientists who worked with an informal network of international social scientists via e-mail to contribute social sciences recommendations to this report.

Spring research travel in Svalbard. Photo by Kit Kovacs and Christian Lydersen, NPI.

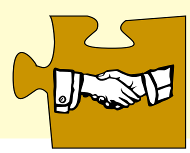
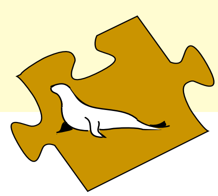
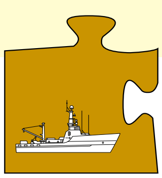
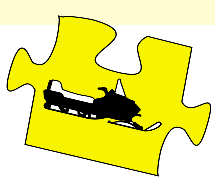
Recommendations

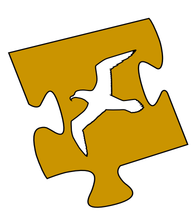
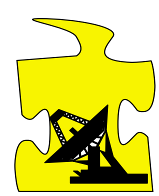
Multidisciplinary, international research cannot take place productively without many elements in their proper places: infrastructure, logistics, agreements between governments, funding, innovative ideas and research questions in many disciplines, and collaborative connections between individual researchers. Many recommendations for science priorities and improvements to logistics infrastructure were developed during this workshop and refined during the review process and are included in this report. A summary of the key science priorities and infrastructure recommendations is included here.

Collaboration and Improvements to Infrastructure

The United States and Norway should work together to:

- **Continue and expand the collaboration outlined in the "Statement of Cooperation Between National Science Foundation Office of Polar Programs and Norsk Polarinstitut, September 13, 1999," included in full in Appendix A (page 38).**
- **Establish a dedicated U.S. research station at Ny-Ålesund, including laboratory and storage space, necessary transportation and safety equipment for fieldwork, and permanent staff to fulfill sampling and data collection needs.**
- **Negotiate access for the USCG *Healy* to perform work in the Svalbard area, with ship time available on a regular, expanded basis.**
- **Plan and construct a new marine lab in Ny-Ålesund, through international cooperation.**
- **Upgrade outdated remote sensing facilities and electro-optical systems.**
- **Relocate and optimize EISCAT services.**
- **Upgrade SOUSY magnetosphere/stratosphere/troposphere radar on Svalbard.**
- **Establish a rocket launching facility at Ny-Ålesund.**
- **Develop methods to improve safe, expeditious, and cost-effective shipping for scientific equipment, supplies, and samples to and from Svalbard.**

Research Opportunities in Svalbard

General

- Synthesize research information on a circumarctic scale

The Changing Environment

- Implement a regional climate model for improving environmental management of the Svalbard area
- Study atmospheric contaminants, including persistent or toxic industrial compounds and pesticides, in snow and ice as in Canada;
- Investigate lipid metabolism in arctic food webs and its consequences for the transfer and accumulation of persistent and toxic organic compounds

Paleoenvironmental Studies

- Extract high-resolution paleoclimate information from marginal ice zones and shelves via longer sediment records, which will lead to the further development of proxies for sea ice, glacial, and meltwater variability from sedimentary and paleobiological records
- Continue glaciological and tide-water geological/oceanographic studies; measure sediment flux rates from different environments to help understand the stratigraphic record and quantify modern process studies, along with the role of subglacial processes on past events of paleoclimatic significance. Such work provides opportunities for remote sensing of ice flow and glacier dynamics
- Study ice core records from high-precipitation areas to evaluate late glacial/Holocene change for comparisons with Greenland and the Canadian Arctic
- Extrapolate shallow slope studies via programs similar to SCICEX, using ship-borne and submarine vehicles and geophysical instrumentation

Atmospheric Sciences

- Seek to understand the physics of air-sea-ice interactions, especially the importance of the West Spitsbergen Current and the historical fluctuations in the Arctic Oscillation and North Atlantic Oscillation
- Extend the field measurements of cloud-radiative interaction to an arctic region in which surface fluxes are much larger than in the SHEBA region and in which cloud-radiative interactions may be quite different from those in the central Arctic
- Study cloud chemistry and meridonal flux of contaminates along with vertical profiling of the atmosphere for study of climate and the carbon cycle
- Measure sea ice and ozone depletion trace gases using remote sensing and surface and aircraft-based measurements
- Study surface fluxes at marginal ice zones
- Expand programs for study of geophysical phenomena, including the auroral oval
- Study satellite communications and air density changes that contribute to satellite orbital decay
- Investigate meridonal transport of natural and man-made constituents and environmental meteorological effects (stratospheric warming)
- Use radar and optical methods to study arctic summer mesophere phenomena
- Analyze remote sensing data from SVALSAT in real time
- Study ozone concentrations and spatial variability through long polar night

Oceanography

- Determine the long-term variability of transport and water properties in Fram Strait
- Examine the effect on the Arctic Ocean of variability in Fram Strait transport and water properties, including possible feedbacks to lower latitudes
- Determine the role of Fram Strait in biogeochemical budgets of the Arctic Ocean, including their sensitivity to variability in the strait
- Investigate selected fjords and shelf regions in Svalbard as models for important processes on high-latitude shelves, including convection, the flux and transformation of carbon, nutrient cycling and primary productivity, and the role of terrestrial fluxes and ice on marine productivity

Earth Sciences

- Investigate unfrozen water and soil thermal processes in warm permafrost
- Study the effect of rain-on-snow events on soil thermal processes, soil chemistry, and ground ice development
- Measure deep permafrost temperatures as archives of paleoclimate
- Study the process of extremely well-developed sorted circles to establish dating control for Martian surfaces covered with similar features

Glaciology

- Initiate joint U.S.-Norwegian programs to study Svalbard's ice caps, either by innovative field programs or satellite remote sensing
- Investigate the role of alpine glaciers in Svalbard as cold traps of toxic contaminants that may be released into surrounding seas by climatic warming
- Perform process and comparative studies between western U.S. and Svalbard on rock glaciers

Biology

- Study extremophile biology and exobiology, especially in subglacial and marine sedimentary environments
- Examine high-arctic extremes in photoperiod and seasonality, decoupled from extreme high Arctic climate, including studies of sleep-wake rhythms, seasonal affective disorder, annual cycles of reproduction, growth, and molt
- Investigate physical and biological controls of biodiversity and ecosystem function on a spectrum of scales, ranging from prokaryotes to plants and animals, including life history and demography studies
- Study the influence of benthic community composition on sedimentary carbon and nutrient regeneration
- Analyze the effects of temperature anomalies, climate change, and increased UV radiation on arctic biota, both terrestrial and marine
- Extend the Circumpolar Arctic Vegetation Map (CAVM)

Social Sciences

- Survey the historical archaeology on the records of 400 years of human exploitation and exploration
- Prevent and predict site deterioration under the impacts of climate and tourism
- Compare human behavior and adaptation in extreme environments

Education

- Foster greater awareness of UNIS in the international arctic research community
- Encourage and support U.S. student participation at UNIS, including stipends for living expenses and transportation
- Support U.S.-Norwegian post-doctoral and faculty exchanges, using UNIS and programs at U.S. universities and research instutues
- Encourage American guest lecturers at UNIS by providing partial support for their participation

1 Research in Svalbard in a Global Context

Justification and Process

Scientific delegations from the United States and Norway participated in a workshop on arctic research opportunities and potential collaboration on Svalbard, 16–19 August 1999. Svalbard is notable as an arctic research platform because it is the world's northernmost territory with modern facilities and infrastructure and is optimally located for investigations of many important processes affecting the Arctic and the rest of the globe. The workshop was held partly in Longyearbyen, where several major research installations are located, and partly in Ny-Ålesund, where many international research stations operate.

The theme of the seminar was "Arctic Environmental Observatories: the Svalbard Model." This workshop was initiated in part by the Norwegian desire for increased collaborative research with the U.S. following the development of the European Union, and the corresponding desire of American scientists for improved access to circumarctic research opportunities, including ice-free ports and modern logistical facilities.

The workshop consisted of plenary sessions, several concurrent science sessions, and excursions to field sites. Participants were expected to represent their broad community and research interests, participate in discussions of collaborative opportunities, and assist with defining logistical support needs. Aspects of arctic policy and the history of arctic science were explored. For purposes of the working group discussions, participants contributed to one of four major themes: **global change, biodiversity, arctic atmospheric and space research,** and **social sciences and education.**

Neither the workshop themes nor this report are intended as a comprehensive listing of collaborative research opportunities between U.S. and Norwegian scientists. This report emphasizes research on Svalbard and not in the many other places where collaborations could occur. It necessarily focuses on the research questions discussed at the workshop and identified in the broad research community review of this document. This publication is intended to report on the workshop, to catalyze further discussions, and to advance recommendations for improvements in collaboration and infrastructure that would promote future research. It is not meant to exclude other research interests and, in fact, will ultimately advance much more extensive opportunities than can be described here.

Sparse tundra vegetation on Svalbard. Photo © Kit Kovacs and Christian Lydersen, NPI.

Relics of coal mining in Svalbard still remain, reminders of the impact of humans on the Arctic. Photo © Kit Kovacs and Christian Lydersen, NPI.

Current Arctic Research in a Global Context

The Arctic includes some of the most extreme environments on the planet. Radical changes in temperature and the amount of daylight alternately constrain and stimulate arctic terrestrial and marine ecosystems. The Arctic's physical and biological systems are regulated by processes that offer numerous opportunities for advancing basic knowledge. Many of these processes have been or are being investigated in the Svalbard area.

The Arctic and its residents appear to be particularly vulnerable to environmental, social, and economic changes. For example, climate model studies suggest that the arctic climate will react sensitively to global climate change (Manabe and Stouffer, 1994). Research results show that arctic climate and ecosystems are indeed changing substantially and that these changes are having impacts on people living in and outside the Arctic. The observed changes and the processes that cause them appear to be linked to changes in the whole Northern Hemisphere, involving physical characteristics in the atmosphere, ocean, and on land. Early indications suggest that the physical changes also are causing changes in the arctic biosphere.

Rapid changes also are taking place in arctic societies, especially in political and economic systems. Throughout the world, changes in markets for oil, minerals, forest products, and marine resources are having far-reaching consequences for subsistence and commercial activities (Chance and Andréeva, 1995). Increasing demand for "adventure tourism" is having an impact on arctic societies and on cultural and archaeological sites.

Current research in the Arctic increasingly takes an integrated, interdisciplinary approach to such regional and global problems. Major arctic research efforts are directed at investigating the Arctic as part of the global system, including:

- the role of the Arctic in global thermohaline circulation,
- sequestering of carbon in arctic environments,
- biological adaptations to high-latitude environments, and
- upper atmospheric processes in global change.

These investigations require geographic as well as disciplinary integration as researchers compare results from different locations around the Arctic. Scientific projects increasingly encompass the circumarctic region as a whole, requiring better year-round access to the Arctic and stimulating international collaborations. Expansion of current U.S.-Norwegian collaborative research efforts would improve documentation and understanding of the environmental changes that are already taking place, how they are impacting the human population, and how people living in the Arctic can adapt to these changes.

Arctic fox were trapped for furs on Svalbard, beginning in the 16th century. Photo © Kit Kovacs and Christian Lydersen, NPI.

Svalbard as a Research Platform

The Svalbard archipelago lies between 74° and 81° N latitude, east of northern Greenland. The seven large and many small islands cover a total of 62,000 square kilometers. Glaciers cover about two-thirds of the land, but the climate is relatively mild in comparison with other areas at these latitudes. Mean temperatures vary from –14° C in the winter to +6° C in the summer, with extreme readings of –47° C and 21° C in Longyearbyen. Svalbard can be characterized as an arctic semi-desert, with an annual precipitation of around 20 cm (Hanssen-Bauer, Solas, and Steffensen, 1990). The midnight sun can be seen in Longyearbyen from April 19 to August 24, but between October 28 and February 16 the sun does not appear above the horizon.

Coal is still mined in Svea on Svalbard. Photo © Kit Kovacs and Christian Lydersen, NPI.

Svalbard is underlain by permafrost that penetrates down to 200 to 300 meters below soil surface (Hanssen-Bauer et al., 1990), depending on the thermal forcing at the surface. During the summer the soil surface thaws, permitting plant and animal life in the upper 1 to 2 meters of the soil (Putkonen, 1998). The winter is commonly punctuated by warm intervals during which moist, warm Atlantic air sweeps over the area. This air mass produces heavy snow, slush, and rain as it converges with cold arctic air.

Some 165 species of plants have been identified on Svalbard, many of them flowering in fantastic displays of color. The largest bird colony in the North Atlantic is on Svalbard, with hundreds of thousands of pairs nesting in most years. The most common species are fulmars, auks, and kittiwakes. Reindeer and arctic fox are often seen around the houses. More than 2,000 polar bears roam the archipelago.

Beginning in the 16th century, several nations used Svalbard for whaling, fur trapping, and coal mining. The Svalbard Treaty of 1920 gave Norway sovereignty over the archipelago, and since the treaty was enforced in 1925, Svalbard has been part of the Kingdom of Norway. Half of Svalbard's area is protected as national park, nature reserve, plant protection reserve, or bird sanctuary. These reserves and the islands' more than 100-year history of scientific activity make Svalbard

Sampling tundra ponds in Svalbard. Photo by Dag Hessen.

an excellent laboratory for studying the environment of the high Arctic. Under the Svalbard Treaty, the archipelago is open to scientists from 42 nations, including the U.S. In 1999, investigators from more than 14 nations conducted research on Svalbard.

There are two main settlement areas on the islands: the Russian community of Barentsburg, which has a total of about 900 inhabitants, and Longyearbyen with its population of about 1,400. There are also small communities at Ny-Ålesund, Svea, and Hornsund and manned meteorological stations on the islands of Hopen and Bjørnøya.

Longyearbyen

Longyearbyen, the main municipality, is a modern town of about 1,400 year-round residents. Daily commercial airline flights connect it to mainland Norway. Longyearbyen offers researchers all transportation, telecommunication, and logistic services year-round. Amenities include a movie theater, shops, travel agent and tourist information, hotels, bank, first-class restaurants, a museum, a church, a library, and government offices. Longyearbyen is the site of several scientific installations and the University Courses on Svalbard (UNIS) educational program.

UNIS, a foundation established in 1993 by the Norwegian government in cooperation with Norway's four universities, offers university-level courses and performs research relevant to the high Arctic. Field courses are an important part of study at UNIS. Twenty-three instructors offer 35 courses in arctic geology, arctic geophysics, arctic biology, and arctic technology to students from 16 countries. Details on UNIS and research facilities in Longyearbyen can be found in Chapter 2.

Ny-Ålesund

The Norwegian government has designated Ny-Ålesund as an international base for research in natural sciences on Svalbard and as a center for Norwegian arctic research. Many of the research activities, coordinated by the Ny-Ålesund Science Managers Committee, continue year-round. All nonresearch activities in the area must pay due consideration to the needs of ongoing research.

Originally a coal mining community and one of the world's northernmost settlements (79° N latitude), Ny-Ålesund offers a variety of marine and terrestrial environments in the surrounding area and a well-developed infrastructure, including regular commercial air service and a modern harbor, making it an optimal base for conducting arctic research in many disciplines. The Ny-Ålesund International Research and Monitoring

Houses in Longyearbyen. Photo by Dee Boersma.

Facility includes research stations for Norwegian, German, British, Italian, French, and Japanese institutions, as well as the European Union's Large Scale Facility (LSF). The LSF includes facilities for:

- atmospheric climate and biological research, under the Norwegian Polar Institute Svalbard (NPI),
- atmospheric air research, under NPI and the Norwegian Institute for Air Research (NILU),
- ozone/stratospheric and climate research, part of the global Network for the Detection of Stratospheric Change, under the Alfred Wegener Institute for Polar and Marine Research in Germany, and
- space geodetic research, under the Norwegian Mapping Authority.

A new Norwegian Polar Institute research station in Ny-Ålesund, the Sverdrup Research Station, was inaugurated in August 1999. Russia and Poland also have research stations on Svalbard. Three research vessels operate in the area from May to September. The NPI offers logistics services to Norwegian researchers and to foreign researchers working under collaborative agreements. The Svalbard Science Forum (SSF), established by the Research Council of Norway, coordinates research facilities, the development of infrastructure, and information concerning research in Svalbard. Details on research facilities and coordination in Ny-Ålesund can be found in Chapter 2.

Ny-Ålesund. Photo by Dag Hessen.

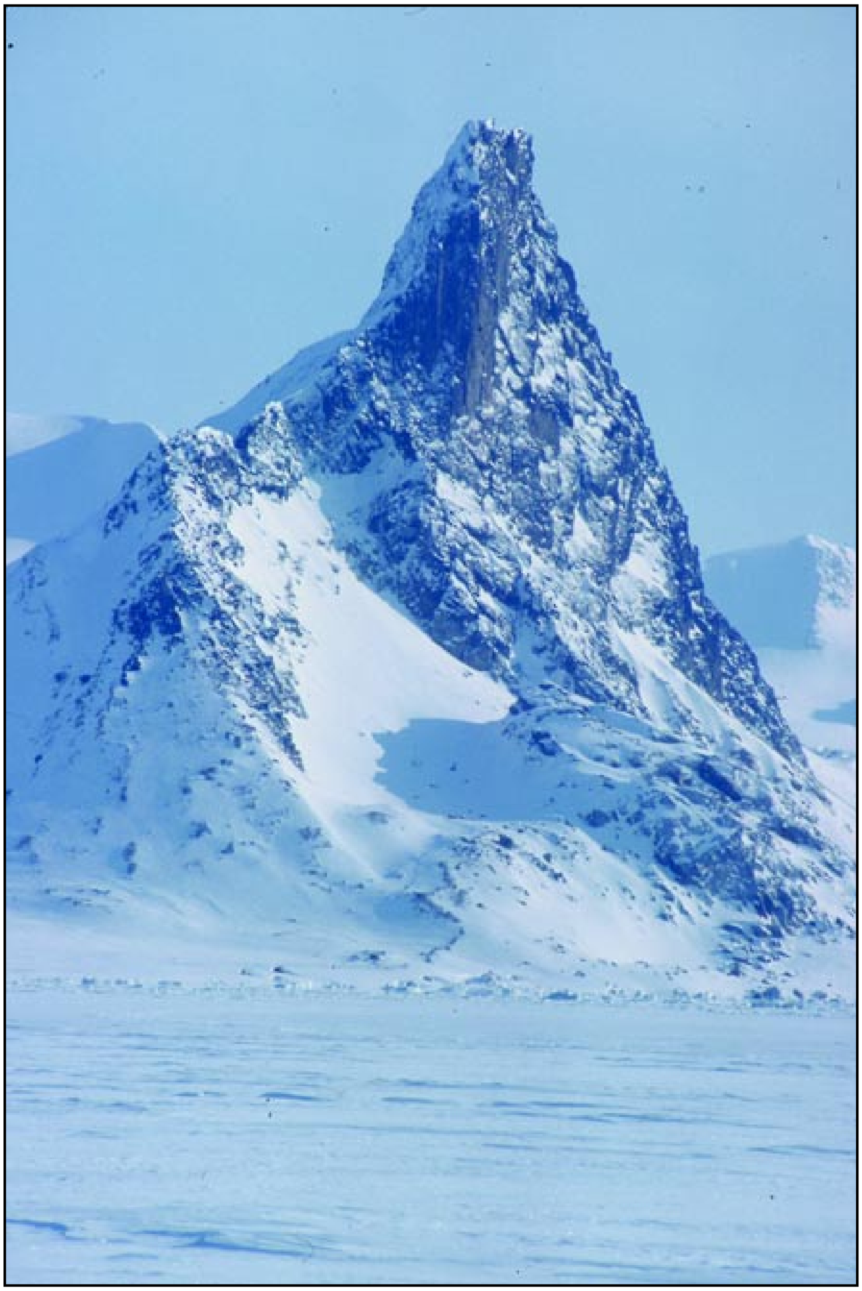
An aerial view of Ny-Ålesund, an active international science community, covered by early winter snow. Note the new pier that is able to accommodate large supply vessels. The road network is limited to the immediate vicinity of the settlement. Photo by Jaakko Putkonen.

Arctic Research Policy

Both the Norwegian and U.S. governments take active roles in the development of arctic research policies. The text of the 1999 Statement of Cooperation between the Norwegian Polar Institute and the National Science Foundation Office of

Polar Programs, initiated after the August 1999 joint workshop, can be found in Appendix A.

Increased U.S.-Norwegian collaboration in arctic research will promote common interests in the scientific issues related to the polar regions and will improve the availability of resources and infrastructure. While the bonds within the European science community have been strengthened as a result of the European Community and the EC funding agency, there is currently no corresponding funding to support U.S.-Norwegian scientific cooperation. Different factors have contributed to this situation, for example, the impact of the large European research and development programs, globalization of international research involving new regions, and a general decline in mobility of young researchers. Consequently, a long tradition of U.S.-Norwegian cooperation has been weakened. In this context, new opportunities are needed for collaboration in arctic research between institutions and individuals in the two countries. This initiative is intended to revitalize such cooperation in a broad range of scientific fields in the Arctic.



Svalbard has dramatic geology, much of it bare of vegetation. Photo © Kit Kovacs and Christian Lydersen, NPI.

Norwegian Arctic Research Policy

Strategic planning of Norwegian polar research is the responsibility of the Research Council of Norway. A National Committee for Polar Research, established by the Research Council is, in turn, responsible for the development of research strategy and for ensuring the best possible coordination of the resources with which Norwegian polar research is supported. A Norwegian national objective is that Svalbard shall be developed as an international platform for polar research where research activity shall be controlled by Norway in accordance with international agreements and current Norwegian legislation, and in particular, in accordance with Norwegian regulations for the conservation of the natural environment and cultural and historical monuments.

Approaching the glacier at the head of Kongsfjorden, the fjord near Ny-Ålesund. Photo by Dag Hessen.

U.S. Arctic Research Policy

The Arctic Research and Policy Act (ARPA) of 1984 recognized the inefficiencies in existing federal arctic research and the consequent need for improved logistical coordination and support. ARPA designates the National Science Foundation (NSF) as the lead federal agency for the development and support of arctic research policy. The U.S. Arctic Research Commission (USARC) and the Interagency Arctic Research Policy Committee (IARPC), both established by ARPA, are directed to develop and establish an integrated national Arctic research policy to guide federal agencies in their research programs in the Arctic, in cooperation with state and local governments.

Science Priorities for U.S.-Norwegian Collaboration in Svalbard

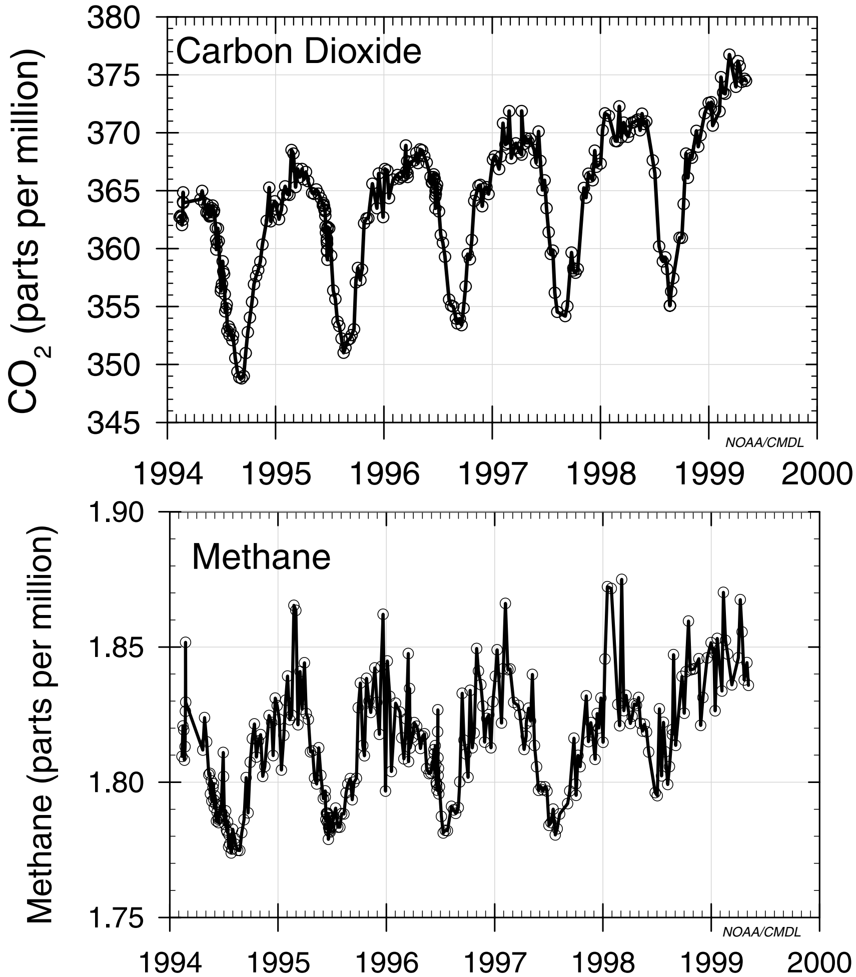
Participants at the August 1999 workshop discussed research needs and priorities and developed recommendations for potential collaboration and strengthened scientific cooperation on and around Svalbard. The multidisciplinary and disciplinary science priorities agreed upon are summarized here. Working group reports with more detailed information about specific discussions and recommendations can be found in Appendix B.

Multidisciplinary Themes

The scope of the potential research topics for U.S.-Norwegian collaboration on Svalbard is necessarily expansive. Workshop participants identified important research opportunities during discussions within disciplinary working groups (see page 14). In addition, during these discussions and in plenary session, workshop participants discussed several multidisciplinary questions appropriate for broader bilateral cooperation in Svalbard. Following the workshop, the co-chairs and the broad community review process further developed five of these overarching research areas, listed below:

How will climate change be mediated by ocean processes and what will be the effect on carbon cycles?

Large-scale oceanographic processes around Svalbard have profound impacts on both the regional and global climate: any major changes in conditions that have prevailed this century could be potentially devastating for North American and European communities. Biological systems may also influence these large-scale processes and have effects on the capture of CO_2 from the atmosphere through thermohaline circulation. These processes are especially important in the Fram Strait, requiring coupled efforts related both to atmospheric/ocean circulation models and biogeochemical studies focused on the interaction between element cycling and carbon dynamics and food web dynamics determining the transport of carbon. An international interdisciplinary program is needed to further studies of the marine carbon cycles and impacts of rapid climate changes on biological systems. Practical as well as scientific benefits can be expected through enhanced knowledge for fisheries and fish farming, contaminant transport and sequestration, and geophysical exploration and production. This supports cross-cutting research in such areas as marine productivity and trophic-level dynamics, carbon fluxes, vertebrate habitats, glacial hydrology, meteorology, and remote sensing. Direct information on natural climate variability in the Arctic is limited because the instrumental climate records of the region are relatively short. However, an understanding of this variability, which is essential to developing accurate predictions of future changes, can be extended into a longer term context by including evidence of past changes in the arctic climate



Weekly carbon dioxide (top) and methane (bottom) measurements made at Zeppelin Station above Ny-Ålesund up to mid-1999. The air samples are collected by the National Oceanic and Atmospheric Administration in collaboration with the Department of Meteorology, Stockholm University. The samples are analyzed in the NOAA Climate Monitoring and Diagnostics Laboratory in Boulder, Colorado, along with air samples from around the world. Annual variations related to seasonally varying uptake and emission are clearly observed. The Svalbard data collection, begun in 1994, forms an important arctic contribution to the NOAA global network that has recorded the increase in these greenhouse gases since the early 1970s. Figure courtesy of David J. Hofmann.

system inferred from proxy indicators: pollen records in peat deposits, delta O^{18} variation in glaciers, glacier melt layers, lake sediments, deep permafrost temperatures, and glaciation history based on terrestrial sediments.

The recently observed rapid changes in such variables as sea ice conditions and water column properties add urgency to the need for regional interdisciplinary studies of physical, chemical, and biological oceanography. The extent to which climate change and atmospheric CO_2 levels are modified by the ocean is strongly dependent upon the ultimate burial of surface-derived organic carbon in sediments. To quantify and characterize these processes requires a thorough understanding of the factors affecting primary productivity, carbon export from surface waters, and carbon transformations in sediments. While these changes are largely physical in origin, they have strong connections to biological and geochemical conditions and processes. Areas in which short-term changes can be anticipated and studied with modest investment include changes in tidewater glacier extent, fjord stratification, coastal erosion, and associated changes in primary productivity, plankton community structure, carbon flux and transformations, and nutrient element cycling. Such changes also may be reflected in marine mammal distributions.

International collaborations provide the immediate benefit of regional inter-comparisons as individuals with experience in Alaskan and Antarctic regions interact with experts in the European Arctic while studying in a new location. For example, in the Svalbard area the conditions of oceanography and meteorology are distinctly different from those of other polar sites, especially in terms of seasonality of insolation, water temperatures, and similar variables.

The excellent research support and logistics infrastructure and accessibility of study sites near Svalbard would make possible a unique series of year-round investigations of processes that have only been sampled in “snap-shots” at other polar locations. Export of carbon from the surface ocean and burial in the sediments is ultimately responsible for sequestration of atmospheric CO_2. Carbon production, transport, and burial may be decoupled in time and/or space; only by repeated thorough physical, biological, and chemical sampling at selected sites can the rates and natures of these transformation and transport processes be constrained effectively.

In addition, the increased recognition that the world ocean is itself a system of interacting subsystems means that understanding regional processes and their connection to larger scales is important. The world climate system is becoming better observed and understood, leading to the conclusion that climate variability and possibly climate change can occur rapidly and have profound influences. The Arctic is the site of much change today, and the proposed U.S./Norwegian collaboration is a useful step in understanding and predicting these changes and their impacts.

How are mesoscale atmospheric circulations and ocean stratification affected by large exchanges of sensible and latent heat in the high-latitude North Atlantic?

The ocean-atmosphere exchanges of heat and moisture in the subpolar seas near Svalbard are among the largest on the earth's surface. These fluxes may trigger significant responses in the atmosphere and the ocean. North Atlantic storm tracks and associated ocean temperature variations have historically been a topic of interest, and empirical studies of these associations date back to the early twentieth century. More recently, the existence of mesoscale atmospheric circulations such as intense vortices (polar lows) has been recognized, largely because of advances in satellite detection capabilities and the advent of mesoscale numerical modeling. In addition, aircraft data suggest that local mesoscale circulations such as low-level jets may develop near the ice edge due to the thermal contrast between the sea ice and the bordering open ocean. Feedbacks between these systems and the ocean are neither well-documented nor understood, despite the potential for significant modification of the upper-ocean stratification during high-wind events, especially where the ocean waters are delicately poised with respect to convection. Possible connections between mesoscale wind-induced mixing events and the "preconditioning" of the oceans for deep convection are poorly known. The potential for a role of mesoscale atmospheric events in upper-ocean ventilation introduces an attractive suite of possible scientific investigations focused on air-sea exchanges in the subpolar seas near Svalbard.

Because the potential importance of air-sea surface exchanges near Svalbard was identified by two different working groups (lower atmosphere, oceanography), this topic represents an important interdisciplinary theme that emerged from the workshop. It is noteworthy that the key processes and features involved in these exchanges are not resolvable in the global models typically used to simulate weather, climate, and the ocean circulation. Thus the optimum approach to an assessment of air-sea coupling will likely require a combination of in situ measurements and mesoscale modeling.

Because of its proximity to the North Atlantic ice edge and the areas of intense air-sea exchanges, Svalbard offers distinct advantages as a base for aircraft flights to sample the lower atmospheric fields (near-surface winds, vertical gradients of temperature and humidity) most relevant to air-sea coupling. Aircraft flights can also provide some information on upper-ocean stratification (by air-dropped expendible bathythermographs, for example). Remotely operated vehicles represent another sampling option, although this approach is still in its developmental phases. Coordinated aircraft-ship operations are also attractive, although the constraints imposed by planning requirements are more severe. A key objective of these field measurements would be an assessment of the oceanic response to surface exchanges that occur over periods in which atmospheric cyclones or other mesoscale circulations affect the marginal ice zone. Model experiments can then be focused on such periods to determine the adequacy of the models' surface flux parameterizations and of the air-sea coupling simulated by the models during specific episodes of air-sea exchange. Ultimately, the findings can be incorporated into the parameterizations used to capture the effects of mesoscale surface exchanges in the global models used for climate simulation.

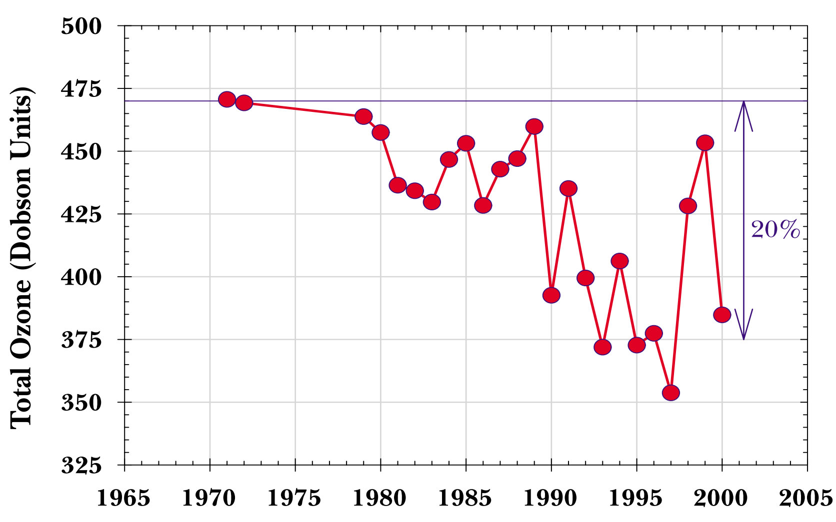
How will climatic changes interact with stratospheric ozone dynamics and UV radiation?

The atmospheric dynamics causing ozone anomalies and a springtime ozone depletion over arctic areas involve such factors as stratospheric cooling owing to increased temperatures in the lower atmosphere and changes in atmospheric water vapor (Kirk-Davidoff et al. 1999). These processes will have major impacts on springtime UV-radiation and could affect marine, freshwater, and terrestrial biota. Fluxes of dissolved organic carbon to marine areas could also change due to climatic changes, strongly affecting UV attenuation in arctic marine systems. These problems call for an integrated, multidisciplinary U.S.-Norwegian effort.

Increased UV radiation will have a disproportionate effect on arctic freshwater areas like those at Svalbard, which are particularly vulnerable due to their shallow and transparent waters (Hessen 1996, Hessen et al., 1999). Arctic marine areas are major feeding and breeding areas for large commercial fish stocks that could be harmed directly or indirectly via food web effects. Also the carbon uptake by algae could be impaired by increased levels of ultraviolet radiation. Climatic driven fluxes of dissolved organic carbon from Russian rivers could affect UV regimes over large areas in the Arctic (Opsahl et al., 1999).

How are soil thermal regime, carbon storage, and biological processes affected by climate change?

Climate change and soil physical, chemical, and biological processes have been extensively studied in the North American arctic; however, the environmental conditions there differ significantly from conditions in Svalbard. In Svalbard the snow pack is fairly thick and the winters are mild compared to North American winters. The



Average March total column ozone over the latitude band 63° N to 90° N, showing the increase in springtime ozone depletion in the Arctic in recent years. Figure courtesy of Dave Hofmann, NOAA/CMDL, from data obtained by NASA and NOAA satellite measurements since 1971 provided by Paul Newman, NASA/GSFC.

winters in Svalbard are punctuated by rain-on-snow events, which are uncommon in other Arctic areas.

Svalbard offers unique environmental conditions to study the heat flow and thermal processes in the soil. In large areas the influence of plants, including thermal insulation and transpiration, is negligible. The relatively warm mean winter air temperature (the mean of the coldest month, February, is –14.6°C), permits examination of latent heat effects and other nonconductive soil heat transfer processes that are much less evident at lower temperatures (Putkonen, 1998).

Soil thermal regime in Svalbard is not regulated by the thick organic layer often present in Alaska. The mild winter temperatures allow more accurate observation of soil unfrozen water, which vanishes in colder temperatures. The importance of this is that soil chemical and microbial processes do continue in subfreezing soil, in part fueled by the unfrozen water. Hence, instead of intuitive inactivity, the soil may be actively releasing or storing carbon through the cold period of the year.

Frost heave, which in part creates the extremely well-developed soil circles found in Svalbard, is enabled by water migrating towards the freezing front in the soil. Slow, prolonged soil freezing gives rise to the strong soil heave observed in Svalbard. Rain on snow generally occurs several times per winter. This warms the soil beneath the thick snowpack. Occasionally the water freezes on the soil surface in such large quantities that the ice shields the lichens, cutting off grazing animals from their food supply. In the past this has had drastic repercussions on the reindeer population near Ny-Ålesund.

Norwegian scientists have a long experience in plant biology and mammal research in Svalbard that together with U.S. soil physics, soil chemistry, and micrometeorological expertise would offer a good interdisciplinary platform for international collaboration, with possible comparisons between Alaska, Greenland, and Svalbard.

How can the synergistic co-location of powerful observational facilities of upper atmospheric processes on Svalbard be used to study how these processes affect consumer, business, and defense satellite communications?

Our planet is embedded in the outer reaches of the Sun's atmosphere, which expands at a very high velocity. This solar wind carries energy and momentum to the vicinity of the Earth. The Earth's magnetic field, which extends far into space, plays a crucial role in absorbing and directing this energy and momentum toward the atmosphere.

The polar cap region is the last remaining largely unexplored frontier for upper atmospheric science. The major interactions between the solar wind and the earth's environment take place at these high latitudes. For example, some solar storms create communication outages on both satellite and ground-based links.

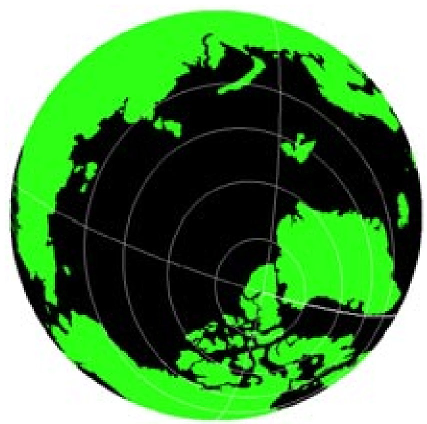
They may create surges on power lines that lead to power outages over very large portions of the world. They affect the resolution of our space-borne imaging systems and can severely degrade the accuracy of GPS navigation receivers. They can even lead to failures of semiconductor components on spacecraft and thus the failure of multimillion dollar sensing and communication platforms in space.

Most of the energy transfer to the Earth from the solar wind is accomplished electrically, and nearly the entire voltage associated with this process appears in the polar cap region, which extends typically less than 20° in latitude from the magnetic pole. The total voltage across the polar cap can be as large as 100,000 volts, rivaling that of thunderstorm electrification of the planet in magnitude. This polar cap electric field is the major source of large-scale horizontal voltage differences in the atmosphere. Moreover, the dynamic polar region accounts for a large fraction of the variability inherent in our upper atmosphere, variability due to chaotic changes in the solar wind magnetic field that produces large-scale restructuring of the cavity enclosing the Earth's magnetic field. This restructuring visibly manifests itself most clearly in the production of ionized plasmas and the associated distribution of aurora high over the north and south polar regions. In turn, the Earth's lower atmosphere (that part responsible for weather phenomena) undergoes variations in composition and dynamics influenced by these coupling effects through a complex and as yet not fully understood feedback system.

Presently, there are few observations of the upper atmosphere over the polar cap. Yet observations of this region are crucial because this is where the solar wind most directly couples with the Earth's atmosphere. Lack of polar cap observations represents the most conspicuous gap in our understanding of the Earth's upper atmosphere. A polar cap observatory such as Svalbard, suitably equipped with radar and optical instruments, will be able to determine the characteristics and variability of crucial terrestrial parameters while a number of satellite platforms record the variations in the solar wind and in the Earth's near space region.

From a more practical standpoint, the facilities at Svalbard can provide measurements needed for modeling and understanding the conditions in the space environment, called space weather, that influence the performance and reliability of space-borne and ground-based technological systems. Space weather storms can cause disruption of satellites, communications, navigation, and electric power distribution grids. Both the electric fields and particle precipitation in the polar regions are direct indicators of the state of space weather.

In addition to space science, the Svalbard facilities contribute important information to address critical problems in atmospheric sciences. For example, the highest clouds in the Earth's atmosphere (noctilucent clouds or polar mesospheric clouds) occur in the summer polar region, clouds which may never have formed before the emergence of widespread human habitation of



Magnetic latitude is critically important for ionospheric, auroral, and magnetospheric research. The north magnetic pole is currently located in northern Canada. Svalbard is at about 75 degrees magnetic latitude, just inside the poleward edge of the auroral ring. Thus Svalbard is well positioned to observe both the polar cap and the poleward edge of the auroral oval. Map contributed by Murray Baron, SRI, International.

the Earth. Understanding the complex interplay between lower atmosphere, solar wind, and local sources of energy and momentum in the tenuous upper atmosphere is an important challenge for atmospheric science in its attempts to understand and mitigate the significant, long term, and potentially deleterious impact of man on his environment.

Specific Disciplinary Topics

During the workshop, working groups were organized around studies in upper atmosphere; lower atmosphere; oceanography and geophysics; paleoclimatology; and biology. Working group participants identified specific topics important for U.S.-Norwegian collaborative research efforts based in Svalbard. These topics are briefly summarized here. Although a formal social sciences working group was not organized during the workshop, the U.S. delegation included several social scientists and, working with an informal network of social scientists, they contributed a social sciences section to this report. Other topics, while not adddressed within working group discussions, emerged during the process of review and comment by the research community. Research opportunities in such areas as permafrost, glaciology, soil energy budgets, and hydrology were enlarged upon during the review of this report and are included below. The complete working group reports can be found in Appendix B.

The workshop participants agreed that the training of young scientists and specifically UNIS student participation should be a central component of U.S.-Norwegian collaboration in arctic research activities on Svalbard. Opportunities for integrating research and science education identified by the workshop participants are summarized at the end of this chapter.

Upper Atmospheric Research

Upper atmospheric research encompasses investigations spanning the region of space from the upper stratosphere to the interplanetary medium. Observations made in the Svalbard ionosphere are traceable to processes several Earth radii away in the magnetosphere or even tens of Earth radii away at the magnetopause. Lower in the upper atmosphere, it is advantageous to study the high-latitude properties of the mesosphere such as the polar mesospheric clouds and ozone photochemistry. Many of the investigations possible in Svalbard have their counterparts in Antarctica, encouraging new studies of geomagnetic conjugacy and hemispheric asymmetries. There are distinct advantages to research on Svalbard, especially benefiting from the synergistic co-location of many powerful observational facilities. Potential opportunities include:

- expanded programs for study of geophysical phenomena, including the auroral oval since this is the only site for total darkness dayside observations;

- research related to practical applications, including consumer, business, and defense satellite communications and air density changes that contribute to satellite orbital decay;
- meridional transport of natural and man-made constituents;
- environmental meteorological effects (stratospheric warming);
- study of arctic summer mesophere phenomena by radar and optical methods; and
- study of ozone concentrations and spatial variability through the long polar night.

Needed investments in logistics and facilities to improve the capability in upper atmospheric research on Svalbard include:

- upgrades on outdated remote sensing facilities and electro-optical systems,
- relocation and optimizing of EISCAT services, and
- rocket launching facility at Ny-Ålesund.

Lower Atmospheric Research

Svalbard is the crossroads of atmospheric and oceanic fluxes between the Arctic and the North Atlantic, a crossroad that spans the temporal spectrum from short-term weather to long-term climate change. It remains one of the key sites for modern greenhouse gas monitoring. Moreover, the oceanic/atmospheric system differs radically from that in the central Arctic/Alaskan sector of the Arctic. Svalbard offers collaborative research opportunities, including:

- new possibilities for cloud-radiation research in a region with large surface fluxes of sensible and latent heat, which will offer a valuable comparison to programs in the Alaskan Arctic (SHEBA/ARM);
- new possibilities for studies of cloud chemistry and meridional flux of contaminants along with vertical profiling of the atmosphere for study of the climate and the carbon cycle;
- excellent staging point for remote sensing of sea ice and ozone depletion along with surface-based and aircraft-based trace gas measurements; and
- synthesis across strong gradients of surface properties.

Needed investments in logistics and facilities to improve the capability in lower atmospheric research on Svalbard include:

- building on existing instrumentation (mesophere-stratosphere-troposphere radar), and
- maintaining the Network for Detection of Stratospheric Change (NDSC) station for ozone depletion at Ny-Ålesund.

Oceanography and Geophysics

Svalbard is uniquely situated to provide access to the crucial communication between the Atlantic and arctic circulation systems and, by extension, the remainder of the global ocean. The key element of this communication is the advection by the West Spitsbergen Current of warm surface waters from, originally, the

Gulf Stream, via the Norwegian current to the Arctic Ocean. Increased heat in this current over the past decade appears to have caused the recent warming of the Atlantic waters at intermediate depth in the Arctic Ocean (Swift et al., 1997). Continued or increased advection of this heat increment into the arctic basin is expected to have significant effects on arctic sea ice and related phenomena, including the flux of freshwater through Fram Strait. Svalbard also provides excellent opportunities for study of seasonally ice-covered shelves.

Potential research areas include:

- careful monitoring of West Spitsbergen Current water properties and dynamics;
- continued simulations of the role of West Spitsbergen Current properties on Arctic Ocean circulation;
- analysis of historical fluctuations of the Arctic Oscillation and North Atlantic Oscillation as they have influenced Svalbard;
- studies of surface fluxes and mesoscale oceanography in the marginal ice zones;
- studies of marine biogeochemistry of the Greenland-Norwegian Sea-Fram Strait region and continued examination of the paleo-record in the sediments;
- studies of vertical mixing processes on seasonally ice-covered shelves;
- investigations of primary productivity and of carbon flux and transformations in both the water column and sediments, all as functions of flow regime, ice coverage, nutrient dynamics, and trophic structure; and
- investigations of glacial runoff and terrestrial inputs on carbon and nutrient dynamics and biological productivity.

Paleoenvironmental Research

The Svalbard region offers excellent opportunities for both marine and terrestrial paleoenvironmental research to understand the history of the ocean/atmosphere system on a variety of spatial and temporal timescales. Collaborative efforts should likewise meet scientific requirements for circumarctic synthesis and integration to "evaluate the impact and cause of climatic 'surprises' (i.e., unexpected, extreme and/or abrupt events) in North Atlantic and arctic climate system behavior" and "evaluate the realism of numerical models being used to predict future climate and environmental change on regional to global scales" (PARCS, 1999). The opportunities on Svalbard and in the circumarctic include:

- studies of lake sediment archives, geomorphology, permafrost processes, and arctic hydrology;
- studies of ice core records from high-precipitation areas to provide high-resolution proxy data to evaluate Holocene change for comparisons with Greenland, Russia, Alaska, and the Canadian arctic;

- studies of atmospheric contaminants (industrial compounds) in snow and ice as in other arctic regions, especially Canada;
- continued glaciological and tidewater geological/oceanographic studies;
- studies of sediment flux rates from different environments (including subglacial processes) to help in understanding the stratigraphic record and quantifying modern processes;
- extraction of high-resolution paleoclimate information from ice marginal zones and shelves via longer sediment records, leading to the further development of proxies for sea ice, glacial, and meltwater variability from sedimentary and paleobiological records; and
- extrapolation of shallow slope studies to continental slope studies via programs similar to SCICEX when opportunities arise.

Biology

The U.S. and Norway are responsible for managing large parts of the Earth's polar environments. Now it is more important than ever that tools for sustainable management of the polar environments are based on a sound scientific basis. By combining experience and scientific knowledge, the U.S. and Norway will be able to contribute significantly to the knowledge of basic biological processes specific to polar environments, as well as knowledge of how polar environments are affected by human activities. Such knowledge is vital for sustainable management in polar regions. Suggested opportunities include:

- studies related to extremophile biology and exobiology, especially in subglacial and other environments: that is, life-detecting exploration;
- studies of high Arctic extremes in photoperiod and seasonality, but decoupled from extreme high Arctic climate, including studies of sleep-wake and other circadian rhythms, seasonal affective disorder, and annual cycles of reproduction, growth, and molt;
- studies of physical and biological controls of biodiversity and ecosystem function on animal and plant species, including life history and demography studies;
- investigations of trophic and biogeochemical influences on ecological structure and biodiversity in water column and sedimentary communities;
- studies of effects of temperature anomalies, climate change and increased UV

A seal rests on an ice floe in Kongsfjorden, near Ny-Ålesund. Photo by Dag Hessen.

radiation on arctic biota, both terrestrial and marine;
- studies of lipid metabolism in arctic food webs and its consequences for the transfer and accumulation of persistent and toxic organic compounds; and
- extension of the Circumpolar Arctic Vegetation Map (CAVM).

Social Sciences

Svalbard's history and archaeological remains date exclusively within modern recorded history. No native population exists on Svalbard, nor has anyone found conclusive evidence of prehistoric occupation (Bjerck, 1999; Bjerck, in press). Historical remains include those from 400 years of human exploitation and exploration of the Arctic. These include:

- remains of European, Russian, and Scandinavian hunting operations covering four centuries; the scientific exploration revolution of the 19th and early 20th century and the former and current installations constructed for science research;
- high arctic mining;
- construction of a maritime transportation infrastructure in the high Arctic;
- military competition between the Allies and Nazi Germany during World War II; and
- the physical and social infrastructure of complex cultural relations between Russian and Norwegian settlements.

Russian Pomor cross, northeast Svalbard. Photo © Kit Kovacs and Christian Lydersen, NPI.

These sites provide several opportunities for research exclusively focused on Svalbard and for comparisons with Alaska and other arctic sites.

While social sciences were not a major focus during the workshop, Svalbard presents many opportunities for both regionally focused and comparative social science research in cultural and physical archaeology, the history of arctic exploration and exploitation, the effects of tourism, and the sociology of arctic adaptations. Some of these opportunities include:

- records of 400 years of human exploitation and exploration–historical archaeology;
- comparative studies of human behavior and adaptation in extreme environments;
- comparative analysis of national visions of the Arctic;
- cultural landscape of Svalbard; and
- prevention and prediction of site deterioration under the impacts of climate and tourism.

The following topics were not the focus of working group discussions during the workshop but evolved later during community review of this document. Other topics that emerged during the community review process were arctic engineering research and research in paleolimnology, both of which present opportunities for collaborative research, but which are not discussed here in detail.

Glaciology

Svalbard's glaciers and ice caps are particularly interesting. They are large enough to hold approximately 0.4 meters of sea-level equivalent which, if released to the ocean, would have a dramatic impact on low-lying coastal regions of the world, yet they are small enough that they react quite rapidly to changes in climate. Svalbard is located at the climatic boundary of the polar front. Any shift in the position of this boundary whould have a noticeable effect on the archipelago's glaciers and ice caps. Apart from a few small and medium-sized glaciers near Ny-Ålesund, most of Svalbard's large glaciers and ice caps have not been studied in any detail. Joint U.S.-Norwegian programs could make substantial progress in understanding these ice caps, either by innovative field programs or satellite remote sensing.

Calving glaciers at the Kongsfjorden (King's Fjord) near Ny-Ålesund. Photo by Jaakko Putkonen.

Permafrost

Permafrost underlies approximately 25% of the world's land surface, and it is widespread in high-latitude and altitude regions (Judge and Pilon, 1983). The widely discussed models for contemporary greenhouse-induced climate change generally predict that warming will be greatest in high-latitude regions (Budyko and Izrael, 1987; Maxwell and Barrie, 1989; Roots, 1989; Walsh, 1993; IPCC, 1996). This leads to the important expectation that current and impending climate change will alter the surface energy balance, the soil temperature, and hence the distribution of permafrost (Nelson and Anisimov, 1993; Riseborough and Smith, 1993).

The specific effects of macro-scale climate change on permafrost are not likely to be simple, because of the complex nature of the interactions between climate, microclimate, surface, and ground thermal conditions. Nevertheless, theoretical considerations suggest that relatively rapid changes may occur in the active-layer depth, defined as the depth of summer thaw, and in the distribution of warm permafrost near its southern limit. Changes in the depth of the active layer would have diverse and far-reaching implications, because all hydrologic, geomorphic, pedologic, chemical, and biological processes are sharply focused in this surface layer.

The anticipated increase in active-layer depth also would have direct societal consequences; increasing problems associated with frost heave and differential thaw settlement. Such problems include damage and increased maintenance costs for houses, roads, airports, and other structures; impediments to farming through thermokarst formation; and slope stability problems (*Permafrost Research,* p. 15, 1983; Judge and Pilon, 1983). In addition, increased active layer depth may influence regions far beyond permafrost areas, exacerbating greenhouse warming by releasing carbon dioxide and methane currently stored in permafrost to the atmosphere (Oechel, 1993).

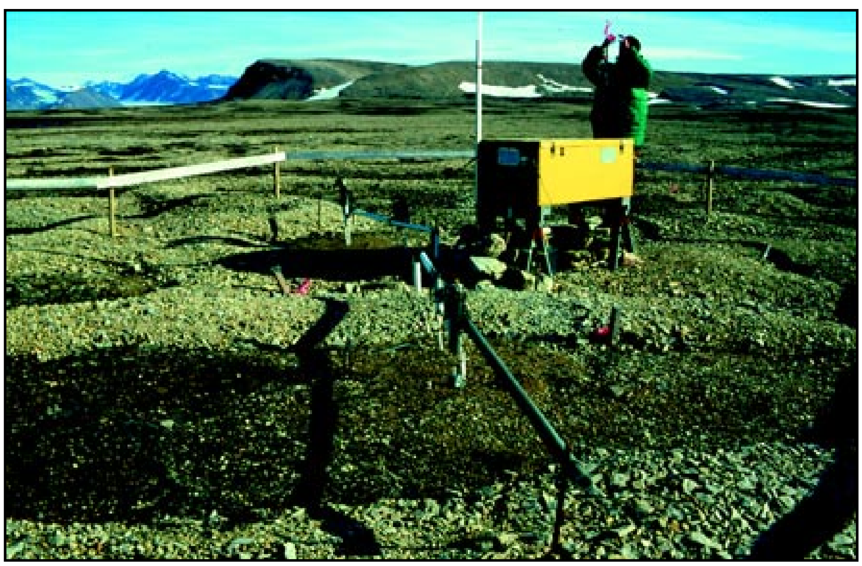
In contrast with the upper boundary of permafrost, which is defined by the depth of summer thaw, changes in the position of the lower boundary of permafrost will be generally unimportant for hundreds to thousands of years, due to the slow conductive transfer of heat (Osterkamp and Gosink, 1991). A virtue of this slow thermal response is that a direct archive of climatic events over the last decades and centuries lingers in permafrost temperatures.

In the presence of a changing climate, therefore, permafrost can play at least three important roles: (1) as a recorder of shallow ground temperature, stored in deep permafrost, (2) as an agent of environmental changes that affects landscapes and land-ocean and land-atmosphere interactions as well as ecological and human communities, and 3) as an amplifier of further climate change (Nelson et al., 1993).

Soil Energy Budgets

Determining the atmospheric and environmental factors such as duration of snow cover, snow thickness, frequency of rain-on-snow events, air temperature during winter and summer, and net radiation during summer that control the net energy budget of high-latitude soils today is an important future objective. This information is necessary to improve the interpretation of records of past soil temperatures and the assessment of the effects of upcoming climate change on the thermal regime of the active layer and permafrost.

The response of the soil energy budget to changes in environmental factors depends on both heat transfer through the snow/soil system and actual changes in the character and magnitude of external climatic forcings.



Strong freeze-thaw related frost heave is creating exceptionally well-developed soil circles in Svalbard. A University of Washington long-term research project is tracking soil thermal and physical changes to develop models of the self organization of the originally circle-free soil surface. Photo by Jaakko Putkonen.

Several aspects of this problem have been studied previously, including effects of snow cover on soil heat flow, soil heat flow in wet arctic tundra, soil and snow surface heat transfer, and rain-on-snow events. Almost all researchers have focused on relatively wet arctic or alpine tundra areas where the soil is covered by a substantial mat of organic material. This leaves the soil thermal regime of the vast high Arctic region, which is sparsely vegetated and relatively dry, largely uncharacterized.

A unique baseline of permafrost data already exists from Svalbard. A team from Quaternary Research Center, University of Washington, Seattle, has an ongoing project, initiated in 1984, to collect a diverse array of environmental variables over time. The main thrust of the research has been to characterize the physical properties and determining the heat and mass fluxes in the soil. Separate campaigns have addressed the issues of heat transfer between atmosphere and permafrost, soil carbonate dynamics, and paleomagnetic dating of permafrost terrain (Putkonen, 1998; Lovlie and Putkonen, 1996; Hallet and Prestrud, 1986; Sletten, 1988; Sletten and Ugolini, 1990). This field site is located in arctic desert (latitude 78°57'29"N, longitude 12°27'42"E), Broeggerhalvoya in western Spitsbergen, 10 km northwest of Ny-Ålesund, where the influence of plants, including thermal insulation and transpiration, is negligible. The relatively warm mean winter air temperature (the mean of the coldest month, February, is –14.6°C), permits us to examine latent heat effects and other nonconductive soil heat transfer processes that are much less evident at lower temperatures. For a description of the field site, see Hallet and Prestrud (1986).

Hydrology

In western Svalbard, the winter is commonly punctuated by warm intervals during which moist, warm Atlantic air sweeps over the area. This air mass produces heavy snow, slush, and rain as it converges with cold Arctic air. Liquid water delivered to the snow surface percolates through the snow pack and freezes at the soil surface. These events are important because significant energy can be delivered to the base of the snowpack, and hence confound the correlation between the air temperature and the temperature of the soil surface and permafrost. However, they are largely undetectable in air temperature records, because the increase in air temperature up to the freezing point is not correlated with the amount of precipitation (Putkonen, 1998).

Svalbard reindeer depend on the ability to dig through the snow to forage in the winter. Rain-on-snow events can create a layer of ice that makes this difficult. Photo © Kit Kovacs and Christian Lydersen, NPI.

Rain on snow is an important process prominent in western Spitsbergen but seldom observed in the North American Arctic. The midwinter rain events deliver a considerable amount of thermal energy through the snow pack to warm the underlying permafrost. The rain freezing at the soil surface can cover the moss and lichens with ice, making it difficult for reindeer to feed. Predicted arctic warming would likely increase rain-on-snow events in the North American Arctic, hindering the survival of caribou and other mammals dependent on access to vegetation through the winter.

Geomorphology

Svalbard offers important opportunities to study pingos that offer valuable information on groundwater dynamics, shifts in the flow conditions, and thaw depths. Rock glaciers are currently being studied in the western U.S. as a viable source of climatic proxy data. Due to the slower flow rate the ice in the rock glaciers may be substantially older than the ice in glaciers where the ice is subaerially exposed. Svalbard is known to have a rich variety of rock glaciers that are sparsely studied.

Hot (warm) springs on the west coast of Svalbard offer an unusual opportunity to study the possibility of life in extreme environments. Comparative studies are possible between microbial life in varying environmental temperatures and the genetic pressure and evolution that this has caused. Similar projects in Antarctica and undersea volcanoes are fueled by interest in the extraterrestrial life and the limits of life observed on our planet.

A University of Washington student studies the movement of soil by remeasuring markers placed on the soil surface several years prior. Involving students in research exchanges between the United States and Norway benefits students and faculty in both countries. Photo by Jaakko Putkonen.

Integrating Research and Education

Workshop participants recommended that oppportunities available through UNIS should be a central component of U.S.-Norwegian collaboration in arctic research activities. UNIS provides opportunities for student and faculty exchange, leading to cross-fertilization of ideas between U.S. and Norwegian institutions, of mutual benefit to both students and supervising scientists. Student participation in research also provides opportunities for long-term observations, important in calibrating paleoclimatic records and in improving our understanding of arctic processes. In this regard, the existing baseline of meteorological and other environmental observations in the Svalbard region (especially in Ny-Ålesund) is extremely valuable. U.S. universities have already participated by contributing to graduate teaching at UNIS and by exchanging graduate students, activities that should continue and increase.

Continuous measurement programs would benefit from an Internet interface designed for K–12 and university students. Video of the site and near real-time data could be quality checked, reduced, and downloaded to web sites for use in K–12, undergraduate, and graduate education. Units on arctic ecology using Alaska data sets could be expanded to include Svalbard, so comparisons of data from the western arctic to that from the warmer Svalbard region could be made directly. Special efforts should be made to develop units for use at Iḷisaġvik College, UNIS, and other arctic educational facilities that would use information from the entire region.

Use of UNIS by schools with NSF-funded arctic research programs should be encouraged. NSF also should consider a scholarship program for undergraduate and graduate students at UNIS that would cover airfare, tuition, and room and board. Consideration should be given to students intending to support NSF research programs as graduate or undergraduate research assistants. This would increase the maturity and experience of student assistants, and the productivity of NSF-funded research programs.

The UNIS facility could offer opportunities for postdoctoral research on Svalbard by U.S. students with reciprocal arrangements for Norwegian students in the U.S. It would be desirable to establish a postdoctoral program aimed at increasing the involvement of young American scientists in Svalbard science. Specific advantages for the U.S. polar research community include:

- UNIS students have the opportunity to do supervised fieldwork (ship and ice station based) under actual arctic conditions. Similar training in the U.S. is difficult and expensive.
- Contact among U.S. and European students early in their careers will build productive relationships among future polar researchers.
- The UNIS guest lecturer program provides convenient contact between U.S. researchers and their Norwegian counterparts.

General advantages for the U.S. Norwegian connection include:

- enhanced opportunity for short (1–2 semesters) student exchanges between U.S. and Norwegian universities;
- increased opportunities for post-doctoral and faculty exchange; and
- increased research collaboration.

Recommendations:

- U.S. support for UNIS student participation (stipend for living expenses and transportation),
- U.S. support for American guest lecturers,
- Foster greater awareness of the program among ARCUS institutions doing polar research, and
- Support U.S./Norwegian post-doctoral and faculty exchanges.

Illustration © Mountain High Maps, modified by Sue Mitchell.

Svalbard is an important part of a chain of research stations around the circumpolar Arctic. The major facilities supporting research in the Arctic include:

Canada*. The Polar Continental Shelf Project maintains two base camps in the Canadian Arctic,* ***Resolute*** *and* ***Tuktoyaktuk.*** *Scientists can use PCSP facilities and services on a space-available basis for nominal fees.*

Greenland. *Researchers can access logistical capabilities for research at* ***Thule, Kangerlussuaq, Summit,*** *and* ***Zackenberg.*** *The U.S. presence in Greenland is supported through an international agreement with Denmark.*

Norway*. In addition to the excellent research facilities on* ***Svalbard*** *in* ***Longyearbyen*** *and* ***Ny-Ålesund,*** *the University of Tromsø has extensive research facilities and a medical school.* ***Tromsø*** *is also the location of the EISCAT main radar station and the Polar Environmental Centre, which houses NPI and the arctic components of seven other Norwegian research organizations. The Polar Environmental Center has a total staff of about 250 people.*

Sweden. Abisko *Scientific Research Station is a year-round facility that can house up to 40 investigators.*

Finland. Kevo *Subarctic Research Institute and* ***Kilpisjärvi*** *Biological Station are year-round facilities.*

Russia*. Much of the vast Russian Arctic is inhabited, and large parts of the region potentially can be reached by commercial air and rail systems. Several research stations and sites exist in the Russian tundra regions: for example, the year-round Northeast Science Station at* ***Cherskii*** *in Sakha affords access to an experimental wildlife preserve. Due to the recent transitions in Russia, accurate information on the status of and access to other research facilities can be difficult to obtain. In response to these and other practical obstacles, NSF has recently announced establishment of a science liaison office in Moscow to assist U.S. arctic researchers interested in conducting fieldwork in the Russian Arctic.*

U.S. *The U.S. Arctic (northern Alaska) has two research facilities that include laboratory space and tracts of land reserved for research use and that act as logistics hubs for adjacent areas:* ***Barrow*** *on the Arctic Coast and* ***Toolik Field Station*** *in the northern foothills of the Brooks Range. Details on facilities available at and planned for Barrow can be found in* The Future of an Arctic Resource: Recommendations from the Barrow Area Research Support Workshop *(ARCUS, 1999). Details on Toolik Field Station can be found in* Toolik Field Station: The Second Twenty Years *(ARCUS, 1996). In other areas of the U.S. Arctic, individual investigators are responsible for making their own logistical arrangements using commercial transportation and facilities, which are sparse and expensive.*

More detailed information on international arctic research facilities can be found in Logistics Recommendations for an Improved Arctic Research Capability *(Schlosser et al., 1997).*

2 Research Support Infrastructure

Circumpolar Research Infrastructure

The infrastructure supporting research in the circumpolar Arctic, summarized in the map and caption on the previous page, is variable in quality, quantity, capability, and availability to arctic researchers. Facilities differ in many factors that determine their appropriateness for a particular research use, including:

- location and types of environments available to researchers;
- condition of the environment, for example the extent of disturbance;
- history of the area;
- costs and accessibility;
- capacity and equipment;
- utility as a logistics hub for the surrounding area;
- suitability for year-round use; and
- proximity to human communities.

Svalbard's Value and Potential

In this circumpolar context, Svalbard's value as a resource for arctic research and its potential for further development include several distinctive advantages that make it suitable for a wide variety of research uses:

- its location adjacent to the Arctic Ocean and in the North Atlantic, which optimizes access to diverse marine and terrestrial environments;
- the opportunity to build on existing scientific infrastructure and expertise, particularly the resources of the Norwegian Polar Institute, the Svalbard Science Forum, and UNIS;
- the year-round infrastructure and accessibility of many research locations, plus the sustained support of an active human community dedicated to the support of science;

One of the valuable opportunities in Svalbard is collaboration between researchers from many different countries. Photo © Kit Kovacs and Christian Lydersen, NPI.

- the history of diverse research in the area; and
- the opportunities for international collaboration in arctic science made possible by the presence of researchers from many different countries.

The workshop participants developed recommendations for improvements to the infrastructure and research programs on Svalbard designed to increase and stimulate collaborative research. These recommendations begin on page viii. Summaries of existing research facilities are listed below to provide context for these recommendations.

Longyearbyen

The Longyearbyen village, near Adventfjorden, is a permanent and modern society with year-round access by plane and ship. The town is the administrative center on the archipelago. The governor of Svalbard's (Sysselmannen) offices are located here, and the town has all the service conveniences one expects to find in larger towns on the mainland: schools, church, hospital, post office, bank, dining establishments, businesses, theatre, museum, campgrounds, etc.

Longyearbyen harbor. Photo by Per Kyrre Reymert.

Main street, Longyearbyen. Photo by Per Kyrre Reymert.

American John Munro Longyear founded the town in 1906. In 1916, the Store Norske Spitsbergen Kulkompani AS (SNSK) bought the place from the American mining company and continued the mining operations. The town was razed during WWII and rebuilt after the war. In 1976, the Norwegian government took over SNSK and the company's community tasks (schools, hospital, etc.). In the late 1980s, SNSK split up and three subsidiary companies were formed: Svalbard Samfunnsdrift (SSD), Svalbard Næringsutvikling (SNU) and the travel agency Spitsbergen Travel (SpiTra). SSD now handles the community tasks that are normally the responsibility of the municipality on the mainland, while SNU's task is to make conditions favorable for the establishment of new enterprises in

Longyearbyen. SpiTra has been privatised. Gruve (Mine) 7 is the last coal mine near Longyearbyen that is in operation, and SNSK expects to phase out operations by 2010. The mining activity is now moved over to Svea Mine (Sveagruva), about 40 km southeast of Longyearbyen, which holds large coal deposits.

Longyearbyen's economy now is based primarily on tourism and research/education. The Svalbard Science Forum (SSF) was established by the Research Council of Norway as an information and coordination project for scientific research on Svalbard and is based in Longyearbyen. Members include representatives from Kings Bay A/S, Norwegian Polar Institute (NPI), UNIS, SSD, the community of Longyearbyen, and the Research Council of Norway. The Norwegian Polar Institute can provide arctic equipment over a wide range from guns and clothing to boats and snow scooters (snowmobiles). Helicopter and light airplanes are accessible in Longyearbyen. Longyearbyen's most important research activities are carried out by the following institutions:

Svalbard Satellite Station, SvalSat in Longyearbyen. Data reception and backup control for low-earth polar orbiting satellites. Photo by Per Kyrre Reymert.

- The Norwegian Polar Institute (NPI) has a branch with approximately 15 employees in Longyearbyen;
- The University of Tromsø, Department of Arctic Biology, has a field station in Adventdalen valley;
- The Universities of Tromsø, Oslo, and Alaska Fairbanks operate an auroral station;
- The European Incoherent Scatter (EISCAT) Facility is a station for studies of electromagnetic processes in the upper polar atmosphere and the earth's magnetic field;
- Svalsat is a station for downloading of data from satellites in polar orbits, owned by Norwegian Space Centre and operated by Tromsø Satellite Station;
- The Sounding System Svalbard Radar (SOUSY-Svalbard Radar) studies polar mesosephere summer echoes into the lower thermosphere and is owned and operated by the Max-Plank-Institut für Areonomie in Germany; and
- The University Courses on Svalbard (UNIS; details below).

In June 2000, the Norwegian Parliament decided to fund a new building co-located with UNIS, which will become the Longyearbyen research and visitor center and will include offices of UNIS, NPI, EISCAT, Svalsat, and the Svalbard museum.

UNIS

The University Courses on Svalbard (UNIS) is a unique foundation established by the four universities in Oslo, Bergen, Trondheim, and Tromsø, Norway. The objective of the foundation

The UNIS building in Longyearbyen. Photo by Sue Mitchell.

is to offer university level courses and to perform research relevant to Svalbard's location in the high Arctic. UNIS is located in Longyearbyen and has some 100 students pursuing about 35 different courses. Instruction is in English and students are recruited internationally.

UNIS is a unique facility for intensive training in arctic sciences. It offers one- or two-semester courses at the advanced undergraduate and graduate level in arctic geology, arctic geophysics, arctic biology, and arctic technology. Students are exposed to a comprehensive view of recent advances via the international guest lecturer program. Support (instruction, library, field, and Internet connections) is also available for advanced, independent graduate, or postdoctoral study. UNIS has office and various laboratory facilities, apartment accommodations for visiting scientists, and storage space for heavy equipment. UNIS has CTD (conductivity-temperature-depth) meters, current meters, meteorological stations, and equipment for drilling through sea ice.

Ny-Ålesund

The Ny-Ålesund research facilities are unique at these latitudes (79° N) and offer complementary and alternative research opportunities to those in the U.S. Arctic. Plane access is possible year-

Ny-Ålesund as seen from across the Kongsfjorden, or King's Fjord. Photo © Kit Kovacs and Christian Lydersen, NPI.

round and access by boat is possible for most of the year. A large number of Norwegian as well as international programs and projects use Ny-Ålesund as a base, making it a truly scientific village with minimal influence from industry, tourism, and traffic, yet with housing and lab facilities for most purposes.

Researchers can stay at the North Pole Hotel in Ny-Ålesund. Photo © Kit Kovacs and Christian Lydersen, NPI.

Kings Bay A/S (KB), formerly a coal company and now a state-owned corporation under the Ministry of Commerce and Energy, owns Ny-Ålesund and is responsible for maintaining and developing the town's infrastructure, generating power, supplying water, running the Nordpolhotellet (North Pole Hotel) with full room and board, maintaining buildings, and constructing laboratories and field stations for Norwegian and foreign institutions. KB also is responsible for local air traffic services as well as harbor services. KB employs between 25 and 35 people in Ny-Ålesund.

Research activities in Ny-Ålesund are coordinated through the Ny-Ålesund Science Managers Committee (NySMAC). It includes representatives from institutions that have permanent research activities and larger facilities in Ny-Ålesund. NySMAC provides advice to NPI and KB regarding the coordination and administration of research activities, as well as building and maintaining infrastructure in the Ny-Ålesund area. The institutions represented in NySMAC have access to information on all aspects of research activities in Ny-Ålesund and function as focal points for this information in their respective home countries.

NPI has offices and a substantial storage capacity at both Longyearbyen and Ny-Ålesund and a variety of equipment for working in polar areas available for loan, such as polar clothing, snowmobiles, inflatable rubber boats with motors, tents, equipment for working on ice, and scientific equipment. There is presently a small marine lab, but a new marine laboratory is being planned for construction in 2001. The new lab will have seawater supply and will provide for experiments on aquatic organisms, with the ability to control temperature, salinity, and light regime.

Sverdrupstasjonen

The new Norwegian research station in Ny-Ålesund was inaugurated in 1999 and is operated by NPI. The new station is 800 m^2 and includes offices, laboratories, and instrument rooms in addition to meeting and storage space. The station has a permanent staff of engineers and technicians, which is enlarged during the summer. Projects include

Sverdrupstasjonen, the new Norwegian Polar Institute station in Ny-Ålesund. Photo © Kit Kovacs and Christian Lydersen, NPI.

research programs in terrestrial and marine biology, terrestrial and marine geology, glaciology, solid earth, atmospheric and ionospheric geophysics, meteorology, and oceanography.

The NPI station also hosts several year-round environmental monitoring programs, most in cooperation with international research institutions. For example, the Norwegian Institute for Air Research (NILU), in collaboration with the Meteorological Institute at the University of Stockholm, runs the atmospheric chemistry programs at the NPI-owned and operated station at the top of Zeppelinfjellet, a 554-m peak overlooking Ny-Ålesund. This research effort monitors atmospheric composition, components of Arctic Haze, trace gases, persistent organic pollutants, and stratospheric ozone.

Other Major Norwegian Research Activities

The Geodetic Institute of the Norwegian Mapping Authority (NMA) has built a high precision space geodesy observatory in Ny-Ålesund. This facility contributes to studies on continental drift, post-glacial rebound of the earth surface, and sea-level fluctations, as well as to practical applications in navigation and geodesy. The observatory includes a radiotelescope (VLBI antenna) which is used for geodetic research.

The Department of Physics at University of Oslo has since 1985 been responsible for the optical auroral studies based on CCD TV cameras and meridian scanning photometers at different wavelengths. In addition, a standard Dobson instrument included in the worldwide ozone monitoring network is operated here.

The University of Bergen runs year-round studies of earth movements from an earthquake monitoring station.

The University of Tromsø conducts botanical studies, including greenhouse experiments as well as auroral studies in connection with rocket campaigns. They are also responsible for running among other projects a magnetometer, which has been operating continuously since 1967.

The Norwegian Space Centre/Andøya Rocket Range operates the SvalRak facility. SvalRak is a sounding rocket launch facility for launching sounding rockets into the ionosphere and the magnetosphere for auroral and middle atmospheric research.

Outstanding glacier mass balance records from Broeggerbreen and Lovenbreen near Ny-Ålesund have been published annually since the early 1960s. These records are among the longest mass balance records available anywhere and therefore are of priceless value.

International Research Stations

The German Alfred Wegener Institute for Polar and Marine Research (AWI) established year-round activity in Ny-Ålesund in 1991. In 1994, a specially designed and newly constructed observatory was inaugurated as part of the Koldewey Station. Today AWI employs a staff of two persons and hosts about 100 guest scientists yearly with an average of eight scientists during a given month.

The Koldewey Station is run as a comprehensive base for a large spectrum of polar research with special emphasis on atmospheric sciences. The bulk of observations are dedicated to the global Network for Detection of Stratospheric Change (NDSC) and concentrates on the arctic stratosphere, in particular the ozone layer. Long-term measurements and campaigns on atmospheric research are part of cooperation with many institutes and international scientific bodies. The station is a member in several international networks, among them the World Meteorological Organization (WMO). Other research activities are ongoing in terrestrial and marine biology, geology, and chemistry.

The Japanese station, situated at Rabben, was established in 1990 by the Japanese National Institute of Polar Research (NIPR). About 50 scientists participating in several expeditions conduct work from this station each year. The station's main research activities include atmospheric, glaciological, oceanographic, and terrestrial and marine biological studies. Automatic monitoring and measurements are carried out all year round at Rabben, but the Japanese currently do not have permanent staff throughout the year in Ny-Ålesund.

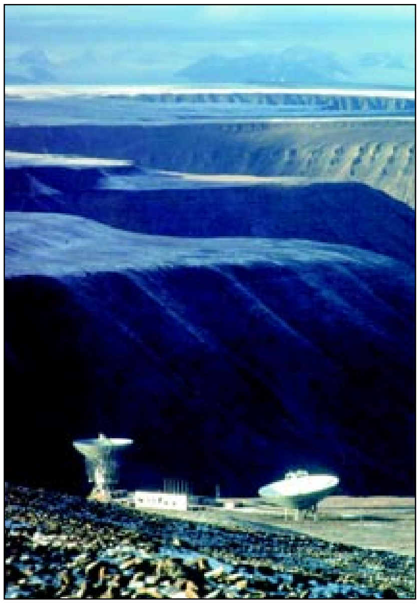
The U.K. Natural Environment Research Council (NERC) established a research station in Ny-Ålesund in 1991. A new building, the Harland House, was constructed in 1992 to support field and laboratory research. Groups from U.K. universities and institutes use the station from May through September to do research in the fields of terrestrial ecology, glaciology, and hydrology, with climate change as a central theme. During the season, up to 25 scientists use the facility. NERC research vessels have also undertaken research in the area.

The Italian research programme, established in 1996, includes atmospheric physics and chemistry, particularly investigations of the processes that govern the biogeochemical cycles of sulphur, nitrogen, and carbon and on the depletion processes of stratospheric ozone. Biological investigations concern the physiology and the biochemistry of arctic benthic invertebrates and vertebrates that can be sensitive to global change. Magnetosphere-ionosphere interactions are also studied, as well as several aspects of the arctic environment such as permafrost, small lake sediments, and snow radiometry and structure, collecting data useful to global change studies.

The French Polar Institute is involved in the implementation of French scientific programmes in polar and subpolar areas. In 1999, the Institute contracted with KB to build a new French station in Ny-Ålesund. The French research program includes biology, glaciology, and geology.

The Ny-Ålesund Large-Scale Facility

In 1996, a European Large-Scale Facility (LSF) funded by the European Union was established to draw new European polar research activities to Ny-Ålesund. The new Ny-Ålesund International Arctic Environmental Research Station (Ny-Ålesund LSF), provides



The EISCAT antenna near Longyearbyen. Photo by Ingemar Wolf, EISCAT Kiruna, Sweden.

access to scientists wishing to do environmental research in the Ny-Ålesund area. This facility includes the atmospheric climate and biological research facility of NPI, the air research facility of NPI/NILU, the ozone/stratospheric and climate research facility of AWI, the space geodetic research facility of NMA, and the NERC research station. NPI has a coordinating function and is responsible to the European Union Commission.

The LSF research facilities in Ny-Ålesund receive support from the Training and Mobility program of the EU. This program is intended to make the Ny-Ålesund facilities and the infrastructure available to young scientists for training purposes. Projects are selected through a proposal process, and the program can cover travel and subsistence as well as costs for shipping of equipment for visitors from European Union countries and associated states. The U.S. has status only through a cooperative agreement, which ensures U.S. researchers the right to use the Ny-Ålesund LSF but without European Union funding.

Specific Research Facilities on Svalbard

The EISCAT Svalbard Radar

This radar, situated in Longyearbyen, was opened in 1997 and has been further enhanced recently by the addition of a fixed antenna to make observations directly up the geomagnetic field line. The use of this facility will provide an important key to increased use of Svalbard by U.S. upper atmospheric researchers. The EISCAT Association (which does not include the U.S.) is a stakeholders group that determines the policy and scientific activities of the radar. Increased U.S. use of the radar will eventually require a substantial investment.

The Optical Observatories

At present there are two well-maintained optical facilities, one at Longyearbyen in Adventdalen and one at Ny-Ålesund. A building at the Polish base at Hornsund also may be used with the collaboration of the station crew. Optical observations have been made in an organized fashion at Longyearbyen since 1978. Beginning in 1980, similar observations have been made at Ny-Ålesund. These have been done with international collaboration between many countries, but principally Norway, U.S., U.K., and Japan.

The geodetic observatory in Ny-Ålesund. Photo by Sue Mitchell.

The CUTLASS Radar

Auroral radar echoes from a wide area of the ionosphere centered on Svalbard are observed from Finland and Iceland and combined to provide maps of scatter intensity, scattered bandwidth, and drift direction. This information is integrated with a set of polar auroral radar stations known as SuperDARN. The mapped observations are made continuously with a time resolution of two minutes and are readily available through contacts at the University of Leicester or the Applied Physics Laboratory of Johns Hopkins University.

Rocket Range

The U.S. National Aeronautics and Space Administration (NASA) has installed a launching facility at Ny-Ålesund for the flight of sounding rockets into the upper atmosphere and ionosphere in directions away from inhabited sites. Four successful flights have been made to date. New flights are expected later, using meteorological rockets launched from near the airport in Longyearbyen.

Transit Satellite Receivers and Ionospheric Tomography

The transit satellite receivers detect radio beacon signals from the transit satellites, making determinations of radio scintillation and total electron content. Work initiated by the University of Aberystwyth, U.K., by Dr. Kersley is planned to be further developed by Dr. Bernhardt of the Naval Research Laboratory.

Satellite Data

Tromsø's satellite station operates two satellite receiving stations covering the arctic region. One is located in Tromsø with a focus on near real-time data delivery of SAR data from Earth Resources Satellite (ERS) and Radarsat and of U.S. National Oceanographic and Atmospheric Administration (NOAA) data. The other station on Svalbard (SVALSAT) is, for the moment, acquiring global data from Landsat 7 and Quickscat for NASA. In the near future SVALSAT also will serve TERRA (EOS-AM-1) and later, possibly, the satellites in the Earth Observing System (EOS) series.

The near real-time SAR and NOAA data from Tromsø normally would be processed and available for users within ½ to 1 hour after acquisition. Near real-time data have significant value during campaigns. Pricing could be a limiting factor, since SAR data, especially, are quite costly due to data policies and commercialization of data sales. Data from Svalbard are transmitted to U.S. facilities for processing, meaning they will not be available in near real-time to support campaign operations.

Svalbard Satellite Station, SvalSat in Longyearbyen. Photo by Per Kyrre Reymert.

Lidar

There is a lidar at the Alfred Wegener Institute's Koldeway Station in Ny-Ålesund that is currently being used by European scientists under the European Union Large Scale Facility structure. Other scientists can apply for running time.

The research vessel Lance *at the dock in Ny-Ålesund. Photo by Sue Mitchell.*

Research Vessels

Four research vessels operate in the area in various periods between May and November:

- *Lance* (NPI), a rebuilt fishing vessel that is ice-classified; for more information about it see <www.npolar.no/npi/org/lance.htm>;
- *Jan Mayen* (University of Tromsø), another ice-classified rebuilt fishing vessel;
- *Håkon Mosby* (University of Bergen); and
- *G.O. Sars* (Institute of Marine Research, Bergen).

In addition to the above, the governor of Svalbard hires a 500-ton ship named *Polarsyssel,* which may be available for shorter periods, usually between April and November. The University of Bergen and Institute of Marine Research, Bergen, are planning a new research vessel, which will be the biggest in their fleet and should be available starting in 2002.

3 Recommendations for Investments to Improve Collaborative Opportunities

Workshop participants identified specific investments in infrastructure, logistics, and cooperative programs to stimulate and increase collaborative U.S.-Norwegian research on Svalbard.

Ny-Ålesund

The participants recommended the establishment of a dedicated U.S. research station at Ny-Ålesund to improve access for American investigators to Svalbard and its extensive international research infrastructure. The proposed station should complement, rather than duplicate, existing capabilities in Ny-Ålesund. The station should include facilities to support biological and biogeochemical investigations of Svalbard's high Arctic ecosystems, including prokaryotes, plants, and animal species. The station should include permanent personnel to allow sampling, data download, and instrument maintenance during the absence of the primary researchers. The station should have field gear for scientists, including boats, survival suits, radios, GPS, rifles, generators, cooking gear, field food provisions, tents, snowmobiles, and skis. The permanent station should also house a small electronics shop to allow repair and upgrading of instruments in the field.

The ability to carry out biological, chemical, and physical sampling is important. Much sampling could be done by small boat, provided the boats and associated required equipment (motors, small winches, sampling equipment, radios, survival suits) are available. Shipping charges for equipment could be minimized by having a permanent basic lab setup, including commonly required instruments. The station facilities should include an environmental chemistry laboratory with ample bench space and walk-in incubators suitable for experimental work (i.e., with power sockets and room for benches and equipment). The lab should also have facilities for chemical storage, efficient hoods, clean water, sufficient sinks, and freezer and refrigerator space. Flowing seawater would make it possible to maintain organisms and conduct mesocosm experiments involving environmental manipulations and measurement of responses to different regimes of UV light, temperature, and nutrients, for example.

The facilities also should include animal surgical facilities and animal housing, including outdoor enclosures and environmental chambers. Facilities for research on animals will need to comply with applicable U.S. and Norwegian regulations.

Splicing and extending the power line that feeds the airfield approach lights north of Ny-Ålesund could enable instrumentation requiring substantially more power than dry-cell batteries can provide, such as flux towers, heaters, and soil air suction pumps). Extending the power line could allow access to real-time data without adversely impacting the pristine environment outside Ny-Ålesund.

A station such as this would also support specialized meteorological and climatological observations, and include facilities to study Svalbard's unique historical and archaeological resources.

Optical Observatories

These observatories should become coordinated in the near future with a common set of operating procedures and a set of basic common instrumentation. A collaborative post-doctoral position is proposed to stimulate interest in EISCAT. The U.S. should consider providing the post doc and his or her salary, and Norway should consider providing the opportunity to use the radar for custom-designed experiments.

Rocket Range

A new rocket launching site would be desirable near the EISCAT radar where launches can be up the geomagnetic field line. Rockets would then be in the field of view of the new EISCAT antenna.

SOUSY MST Radar

A major proposal to NSF Office of Polar Programs has addressed the need for a mesosphere, stratosphere, troposphere (MST) radar on Svalbard. If funded, this proposed radar will provide the means to investigate the winds and polar mesospheric summer echoes. The proposal includes Drs. Fritts and Riggin of Colorado Research Associates, USA, Drs. Kelley and Huaman of Cornell University, USA, and Dr. Rottger of MPAE, Germany.

Satellite Data Processing

Upgrade SVALSAT for near real-time processing of specific products, for example moderate resolution imaging spectroradiometer (MODIS) on TERRA and Seawind (Scatterometer) on Quickscat.

Lidar

Install a lidar facility near the optical station at Longyearbyen. New studies of thin layers are needed, including the polar mesospheric summer echoes (PMSEs) and polar mesospheric clouds (PMCs) that occur in the summer over Svalbard. A dual-wavelength version of the lidar, the so-called differential absorption lidar (DIAL) can make direct observations of ozone.

Paleoenvironmental Research

Through collaboration with U.S. researchers, Norwegian paleoclimatologists could have access to an ice-strengthened research vessel for marine geophysical research, including high-resolution sub-bottom sediment surveys, coring site selection, sediment coring, and deployment of sediment traps. For sediment coring, a range of options should be available, using capabilities such as hydraulic piston coring, shallow drilling technology, and Ocean Drilling Program (ODP)-style operations. U.S. submarine-based research (like SCICEX) also would open up new areas of research for Norwegian scientists in global change studies in different and commonly inaccessible parts of the Arctic. Finally, the experience, equipment, and archival facilities of the U.S. ice coring community could be beneficial to an expanded ice coring operation in the Svalbard region.

Shipping

Shipping scientific equipment to Svalbard is costly and slow, and sometimes results in damage to the equipment. Shipping samples across international boundaries also can be difficult, especially when the samples require special care. Cost-effective, prompt, and safe transport of equipment, supplies, and scientific samples are important for the effective conduct of research and should be investigated in collaboration with NPI and the Norwegian authorities.

Appendices

Appendix A: Statement of Cooperation between National Science Foundation Office of Polar Programs and Norsk Polarinstitutt, Sept. 13, 1999

For the further development of polar studies and in order to strengthen the research and logistic programs of both countries and institutes, OPP and NP will continue their close cooperation in Arctic and Antarctic research as follows:

- OPP- and NP-supported scientists will participate in joint projects as they are established and with access to OPP and NP logistics facilities as necessary (usually on a cost-reimbursable basis).
- If appropriate, quid pro quo arrangements within each polar region or between polar regions should be considered.
- OPP and NP will exchange research and logistic plans including ships' schedules as well as final cruise and other reports, data lists, and publications.

OPP and NP will continue to act as information and co-ordination centers within their respective countries. Scientists and technicians from universities and other institutions shall be included into their bilateral co-operation, as the need arises.

Present major fields of mutual interest in polar studies include the fields of:

- Climate change with particular emphasis on ice-ocean-atmospheric interactions and the thermohaline circulation in the Polar Basin and surrounding sub-arctic and in Antarctic oceans, and paleoclimate and glaciology
- Geology
- Transportation and effects of pollutants in the Arctic and Antarctic
- Biodiversity with emphasis on marine ecology in ice-covered polar waters and terrestrial ecology in the high Arctic

Proposals to OPP are subject to peer review before funding or support commitments can be made.

Resources and facilities for studies in the polar regions are available as follows:

From OPP: OPP supports access by scientists to:

- Toolik Lake LTER
- Barrow Environmental Observatory
- Summit Environmental Observatory
- Søndrestrøm (Greenland) Radar Facility
- USCGC *Healy*
- Contractor support services (camps, airplanes, helicopters, etc.)
- The three U.S. Antarctic research stations and associated field camps

From NP: Svalbard office in Longyearbyen

- Research station in Ny-Ålesund
- RV *Lance*
- Helicopter services

NP has a broad range of equipment for loan, e.g., small craft/ Zodiacs, snowmobiles, field equipment, firearms, etc.

If OPP should establish a facility in Svalbard (Ny-Ålesund), OPP and NP will collaborate on the development of Ny-Ålesund into a leading Arctic Environmental Observatory. OPP and NP will take active part in the efforts to co-ordinate research in Ny-Ålesund through the Ny-Ålesund Science Managers Committee (NYSMAC).

For future work that intends to establish long-term research programs, OPP and NP shall aim to form projects where both organizations have interests and want to play an active part.

Co-operative Antarctic studies

Shall be discussed whenever a need arises.

Modalities of co-operation

For co-operative marine projects, OPP and NP will offer free accommodations on board their respective research vessels.

Each partner will normally bring along the scientific instruments needed for its own scientists' work, if these are not already available locally or on board a research vessel.

Each partner will normally pay for the travel and per diem of its scientists to and from the port-of-call of their respective research vessels.

For support to OPP from NP's bases at Svalbard, NP will provide support at cost, unless negotiated otherwise.

Both partners agree to hold regular consultations on science and logistic policy matters, taking advantage where possible of existing Arctic and Antarctic venues.

OPP and NP will, as appropriate, plan joint research programs.

Both partners will keep themselves informed on co-operative projects with additional institutions in the other partner's country.

Appendix B: Working Group Reports

The scientific opportunities discussed below have been selected to emphasize the advantages to arctic research of conducting investigations based on Svalbard. The geographic context of most arctic research is the entire circumpolar arctic region, including the Arctic Ocean, northern Canada, Alaska, northern Scandinavia, Greenland, and Siberia, as well as Svalbard. Nevertheless, the combination of geophysical location and available facilities on Svalbard justify an effort to raise the level of U.S. research activity on the archipelago; conversely, U.S. arctic research facilities should be made more accessible to Norwegian researchers. In addition, encouragement of joint U.S.-Norwegian research initiatives will likely benefit the arctic research efforts of both countries.

Upper Atmosphere

Chairs: Asgeir Brekke, *University of Tromsø*
Roger Smith, *University of Alaska Fairbanks*
Participants: Jøran Moen, *University Courses on Svalbard*
Gerald J. Romick, *Johns Hopkins University*
Per Even Sandholt, *University of Oslo*
Per Erik Skrøvset, *Norwegian Space Centre*

Upper atmospheric research includes investigations spanning the region of space from the upper stratosphere to the interplanetary medium. Observations made in the Svalbard ionosphere are traceable to processes several Earth radii away in the magnetosphere or even tens of earth radii away at the magnetopause. Below the ionosphere, studies of the high-latitude properties of the mesosphere, such as the polar mesospheric clouds and ozone photochemistry, are possible. Many of the investigations possible in Svalbard have their counterparts in Antarctica, encouraging new studies of geomagnetic conjugacy and hemispheric asymmetries.

In the past 22 years, many productive research activities in upper atmospheric physics have been based in Svalbard, and many of these have been bilaterally supported through collaborations between individual scientists and institutions. Through these activities some infrastructure has been established that enables frontline research at the present, and further enhancements of the U.S. effort in upper atmospheric studies on Svalbard can take an incremental approach. The following descriptions of potential upper atmospheric research are placed in the context of the current status and future prospects of these studies on Svalbard.

Auroral Research

The auroral oval normally lies within sight of the Longyearbyen optical observatory during daytime in magnetic local time, as well as frequently during substorm expansions during the night. During the polar night, this daytime aurora can be studied optically under dark conditions. Spectral and morphological studies of the daytime aurora have been pioneered at Svalbard (Burke et al., 1993; Deehr et al., 1980; Denig et al., 1993; Egeland et al., 1994; Farrugia et al., 1994; Fasel et al., 1992, 1993; Fasel, 1995; Minow et al., 1995; Moen et al., 1993; Sandholt et al., 1980, 1983, 1989a, 1989b, 1989c, 1994, 1996; Sivjee et al., 1980, 1982, 1983c, 1991; Yagodkina et al., 1992). The extensive infrastructure at Svalbard, including the EISCAT Svalbard radar, CUTLASS radar, rocket flights from Andøya, and rocket range at Ny-Ålesund enable more complete investigations of the aurora than is possible in most other arctic regions (Kintner, Lorentzen et al., 1996; Sigernes et al., 1996). Recent auroral studies now include in-situ measurements of fluxes of precipitating electrons and ions, ionospheric electric fields and drifts (Lockwood et al., 1989, 1990a, 1990b, 1995; Moen et al., 1994), and ionospheric outflow in the context of optical observations from the ground (Romick et al., 1999).

Observations of the aurora have been interpreted in terms of the plasma entry processes, which admit the solar wind to the magnetosphere at its sunward boundary (Burke et al., 1993, Egeland et al., 1994; Fasel et al., 1992; Jacobsen, 1990, 1995; Oioerset et al., 1996; Pudovkin et al., 1992; Sandholt et al., 1989a, 1989b, 1989c, 1994, 1996). Further investigations, made possible by the radar and rocket support, have provided more clues to the understudied regions between the upper ionosphere and the solar wind (Kintner, Lorentzen et al., 1996; Sigernes et al., 1996).

With the addition of a meridional array of total electron content observatories based on polar-orbiting radio beacons, sharp gradients of ionospheric density are continuously monitored. The anomalies in ionospheric density are associated with the aurora and the plasma instabilities which occur in the ionospheric medium (Walker et al., 1998).

The Cutlass SuperDARN radars in Finland and Iceland and the Worldwide SuperDARN system map auroral radio echoes, deriving from the radar

Image of the dayside aurora in midwinter from Adventdalen, Svalbard. Svalbard is uniquely situated and has extensive infrastructure for the study of the aurora. Photo by James Conner.

returns the Doppler shift, spectral width, and intensity of the radio signal. Also features of ionospheric disturbance are reflected in the spectral width and indicate special regions such as those that are geomagnetically connected to the low field regions called the cusps. By studying and interpreting the ionospheric properties mapped by SuperDARN, it should be possible to study geomagnetic conjugacy through comparison of SuperDARN observations from each hemisphere.

Upper Atmospheric Dynamics and Thermodynamics

Upper atmospheric research in the polar regions has concentrated on two atmospheric layers, the mesosphere and thermosphere. The thermosphere extends upwards from about 110 km altitude. Most of the thermospheric research in Svalbard has been done using the 63 nanometer (nm) and 732 nm emissions in the airglow and aurora as a tracer (Hedin et al., 1991; Killeen et al., 1984, 1986; McCormac et al., 1984; Minow et al., 1993; Rees et al., 1984; Smith et al., 1982, 1985, 1989). Winds and temperatures reported in these papers have been compared successfully with global thermosphere-ionosphere circulation models (e.g., Rees et al., 1980; Smith et al., 1989). More recently, the EISCAT system enables radar measurements of thermospheric temperatures and winds at times (during daylight or cloudy conditions) when optical measurements are not possible.

The mesosphere extends from stratopause (about 55 km) to the base of the thermosphere. Mesospheric research has been based on observations of changes in the Meinel emissions of hydroxyl (Myrabo et al., 1983a, 1983b; Sivjee et al., 1983c, 1987; Schubert et al., 1990; Viereck and Deehr, 1989). These papers reveal a complex situation involving waves of a wide range of periods and indicate a need for further investigation.

The polar regions of the mesosphere are quite different from mid-latitude and equatorial zones. The causes are part chemical, part thermodynamic, and part due to the effect of acoustic-gravity waves, tides, and planetary waves generated in the lower atmosphere. In addition to wave coupling between atmospheric layers, stratospheric warmings are associated with a counterpart cooling in the mesosphere. Indications of global change are found in the mesosphere because the changing properties of the stratosphere and troposphere cause a cooling near the mesopause, which is observable in the occurrence of polar mesospheric clouds.

The mesosphere is not in thermal equilibrium with incoming solar radiation. A substantial part of the heat budget is provided by the damping of acoustic-gravity waves and exothermic chemical reactions. Both effects serve to raise the temperature some 50°K above local radiative equilibrium. If the low-altitude wave source is interrupted by absorption in the stratosphere, cooling occurs. Vertical upward/downward wind associated with a global scale circulation cools/heats adiabatically. While it is not known if either of these mechanisms has changed during the current warming, the mean temperature of the upper mesosphere has decreased. The cooler mesosphere permits condensation processes in which ice forms on dust nuclei, resulting in clouds, which have at least three observable forms: polar mesospheric clouds, polar mesospheric summer echoes (Huaman and Balsley, 1999) and noctilucent clouds (von Zahn and Bremer, 1999). Svalbard is an excellent place to study these arctic summer mesosphere phenomena by radar and optical methods. Instrumentation useful for this research are the MST SOUSY radar, EISCAT radar, and Rayleigh lidar.

Mesospheric wave modes become heavily restricted at very high latitudes in Antarctica (Hernandez and Smith, 1995). Corresponding behavior in the Arctic has not been observed. Suitable high-latitude mesospheric wind, temperature, and airglow intensity observations are required at very high latitudes (78° and above) in order to distinguish the different wave patterns and determine the harmonic retinues present in the Arctic. This work requires optical and radar measurements of the dynamic, thermodynamic, and airglow intensity (pressure-related) aspects of the waves. Present installations that can support this work exist with the Meteor radar at Longyearbyen, the EISCAT radar, and the Rees imaging Fabry-Perot interferometer, as well as the spectrometers used to measure the rotational temperatures of molecules emitting airglow and all-sky airglow cameras which show waves of short wavelength at Longyearbyen.

The nature of the wave-breaking process that converts stream energy in the wind to thermal energy in the atmosphere is still poorly understood. It is likely that the turbulent processes involved also affect ice condensation occurring at the same heights. Further rocket observations of the microphysical processes are urgently needed at a time of polar mesospheric clouds. A very suitable place for this is Bjørndalen near the airport at Longyearbyen.

The TIMED Project

This satellite program will investigate the energy and dynamics of the altitude range between 75 and 180 km with a launch planned for February 2001. Svalbard is one of the key ground locations for collaborative optical and radar measurements for research and ground-truthing.

Ozone Measurement

Stellar observations made using spectroscopic instruments during the arctic winter will allow the determination of the ozone concentration and its spatial variability through the long polar night. In particular, it will be important to be able to study the developing structures during the appearance of any arctic ozone hole, stratospheric warming and the transition into spring. One advantage of the stellar technique is that it permits off-zenith measurements which can be combined with more standard balloon-sonde methods.

Lower Atmosphere

Chairs: Frode Stordal, *Norwegian Institute for Air Research*
John Walsh, *University of Illinois-Urbana*
Participants: Trond Iversen, *University of Oslo*
Walter C. Oechel, *San Diego State University*
David Hofmann, *National Oceanic and Atmospheric Administration (NOAA)*

The group addressing lower atmospheric research opportunities identified several possible research emphases on the basis of (1) the logistical infrastructure now in place on Svalbard, (2) the region's proximity to one of the most active ocean-ice-atmosphere interfaces in the Northern Hemisphere, and (3) the fact that research in the Atlantic sector of the Arctic can complement recent and ongoing research programs in the Alaskan Arctic (e.g., the U.S. Department of Energy's Atmospheric Radiation Monitoring [ARM] Program and the National Science Foundation's Surface Heat Budget of the Arctic Ocean [SHEBA] Program).

The Atlantic sector of the Arctic is affected by airmasses with widely different characteristics, depending on the atmospheric circulation regime. Incursions of air with predominantly continental aerosols mixed with pollutants from Eurasian source regions alternate with episodes of moist marine Atlantic air laden with sea-salt and natural aerosols. Less frequently, the region is affected by cold dry air masses of polar origin with low aerosol concentrations. In contrast to Barrow and locations in the central Arctic Ocean, for example, cloud microphysics and associated radiative interactions in the Norwegian Arctic are much less dominated by ice crystal processes, and most likely are more sensitive to variations of aerosol concentrations and characteristics.

The Norwegian Arctic is also at a crossroads of major ocean currents separated by relatively sharp ocean fronts as different water masses enter and leave the Arctic. The net effect is a highly variable climate with frequent changes in contaminant levels, cloud and radiative characteristics, and surface conditions. The fact that the region is far more accessible than other portions of the Arctic makes it ideal for monitoring changes and for testing hypotheses about the changes.

Three research areas can be outlined where a collaborative effort between the U.S. and Norway may significantly contribute to our understanding of the arctic atmosphere as well as global change. These areas are trace gases, including gases affecting ozone and UV; clouds, aerosols and radiation; and mesoscale air-sea interaction.

Trace Gases

Carbon dioxide (CO_2) and methane (CH_4) are climatically important trace gases that are changing due to anthropogenic activity. Their spatial and seasonal patterns (e.g., the poleward increase of seasonal amplitude) are not well understood. There are sizable interannual variations in the rate of increase of these gases, which may be related to temperature variations but are not well understood. Possible climate change feedbacks involving these gases must be understood well enough so that they can be characterized in climate prediction models. In particular, more information is needed on the large spatial and temporal variations in growth rates in the Arctic, perhaps related to emissions of CO_2 and CH_4 from natural biological systems or CH_4 from gas hydrates.

Surface-based Continuous Measurements

The U.S. National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (CMDL), in cooperation with the Meteorological Institute at the University of Stockholm, Sweden, has been collecting weekly air samples at Zeppelin Station above Ny-Ålesund since 1994. The samples are returned to the CMDL in Boulder, Colorado where they are analyzed. These measurements provide an important Arctic contribution to the global greenhouse gas network and will continue into the foreseeable future.

Although the science of stratospheric chemical ozone depletion is mature, continued measurements of ozone and ozone-depleting gases is a critical need and will remain so into the next century in order to track the expected recovery of the ozone layer during the next 50 years. Fortunately, since 1992 Ny-Ålesund has been a primary arctic site of the Network for the Detection of Stratospheric Change (NDSC), a global network of state-of-the-art remote sensors (lidars, visible, infrared and microwave spectrometers) to monitor ozone and ozone-depleting trace gases. The Alfred Wegener Institute for Polar Research (Bremerhaven and Potsdam, Germany) is responsible for the instrumention of the site at Ny-Ålesund.

The Norwegian Polar Research Institute at Tromsø has recently constructed a new laboratory at Zeppelin Station in Ny-Ålesund. It was dedicated in May 2000 by Crown Prince Haakon Magnus of Norway. It is owned and operated by NPI, but the science programs are organized and directed by the Norwegian Institute for Air Research (NILU). These include a full suite of radiation and UV measurements. Thus it appears at this time that the issue of ozone and UV measurements is well in hand and will not require new programs.

Aircraft Sampling

In order to improve the ability of inverse models to determine global sources and sinks of CO_2 and CH_4, additional regional information is required. Vertical profiles through and above the atmospheric boundary layer (several kilometers) are generally required to characterize a region which may have active and variable sources and sinks. Characterization of circumpolar arctic greenhouse gases through vertical profiling has begun, using aircraft in the Alaskan Arctic, and an extension to the eastern Arctic could most easily be accomplished with aircraft sampling from Svalbard. An existing (NOAA/CMDL) automated 20-sample flask system could be used, which would have the added advantage of allowing isotopic analysis of carbon and oxygen, revealing additional information on sources and sinks, for example, terrestrial versus marine. Collaboration would be sought between NILU in obtaining the samples from Svalbard and the NOAA/CMDL laboratory in Boulder, Colorado in providing the samplers and analysis.

Flux Measurements

The only long-term, continuous temporal and large-scale spatial measurements of CO_2 flux are from the U.S. Arctic. While representative of large regions of the Arctic, and important in terms of carbon stores and fluxes, the Alaskan Arctic is not representative of some high Arctic regions, including areas of low soil organic matter content, regions with little recent warming, and areas of warm ocean currents. To determine a circumpolar arctic carbon balance, adequate representation of carbon flux patterns and dynamics across a range of representative sites is necessary. Svalbard offers an area with high latitude and relatively warm conditions as well as the opportunity to study long-term effects of temperature by comparing the carbon stocks and carbon flux dynamics in warmer (western Svalbard) to cooler (eastern Svalbard) locations. The relatively mild high-latitude location of Svalbard may indicate future equilibrium effects of high-latitude warming on carbon balance, *if* all other factors are the same.

Eddy correlation towers can provide a means to determine the long-term controls in intra- and inter-annual CO_2 fluxes and correlations with environmental variability. The measurement program that we recommend includes fully automated eddy correlation towers for the measurement of CO_2, H_2O, and energy fluxes which should be established in typical vegetation in western (e.g., near Longyearbyen) and eastern (e.g., on Hopen Island) Svalbard. These towers should have line electricity and phone or, if not possible, should have satellite phone connections and remote power generation (e.g., fuel cells). Standard microenvironmental measurements should be made including soil moisture, soil and air temperatures, and albedo. The towers should have video cameras in the visual and infrared ranges to monitor the conditions of the sensors and the sites themselves and to provide video feed for education and outreach. Instrumentation should be warmed and coated to minimize problems with rime ice and frost. Sites should be selected to encourage related measurements, including soil and plant respiration, photosynthesis, plant and microbial growth, soil decomposition, and plant nutrition, thereby enabling more meaningful interpretation of flux patterns.

Aircraft flux measurements should be made across the strong climatic and vegetation gradients that exist on Svalbard. These measurements can be compared to long-term tower data to allow improved understanding of spatial components and controls. Comparisons of regional fluxes to regional Normalized Difference Vegetation Index (NDVI) obtained from Advanced Very High Resolution Radiometer (AVHRR) data, vegetation types, soil conditions, surface temperatures, snow cover, and climate can be used to estimate CO_2 fluxes for all of Svalbard.

This data should be used as input to arctic (e.g., Terrestrial Ecosystem Model [TEM]) and global models (e.g., Biome Biogeochemical Cycles [Biome BGC-2]). Together with climate data and remotely sensed information, these data will contribute to estimates of the circumpolar carbon flux balance. This information will also contribute to the validation of atmospheric inversion model results concerning the sizes and patterns of terrestrial arctic carbon sources and sinks.

Circumpolar Synthesis

There are a number of strong national, bilateral, and regional research programs addressing patterns and controls on trace gases in the arctic currently underway. In general, there is little formal circumpolar synthesis. Periodic international symposia should help synthesize information from Svalbard and the U.S. Arctic with that from the rest of the Arctic. This could be a U.S.-European Union and U.S.-Japan funded event, supported by the International Arctic Science Committee (IASC) and the International Arctic Research Center (IARC). Symposia on trace gas behavior and flux synthesis should occur as soon as can be arranged and be repeated about every two to four years, depending on need.

Using Inverse Modeling to Assess Global Budgets

Inverse calculations involve the use of global or regional transport models to simulate the evolution of a trace species forward in time. The calculations are then compared with observations at network sampling sites. The aggregate of differences between the forward calculations and observations at all sites is then used to infer the spatial distribution and source strengths of the trace gas. This approach provides seasonally and interannually varying estimates of sources and may also be used to determine where and when the assimilation of atmospheric species occurs.

Currently, the accuracy of flux estimates over continental-scale regions is limited by the sparseness of regularly sampled sites. The distribution of observations does not allow discrimination between changes in oceanic or terrestrial uptake. It is currently difficult to obtain information about the longitudinal distribution of fluxes, and therefore it is not clear how accurate estimates of a recent large North American CO_2 sink actually are (Fan et al., 1998). Additional sites in the North Atlantic and Arctic would improve the accuracy of regional mapping by inverse calculations. Vertical profile measurements would be particularly useful, since they may be used to obtain column budgets that could minimize effects of transport model biases (inaccurate boundary layer representation, for example).

These proposed flux measurements should be integrated with other long-term soil and micrometeorological research stations. This would provide synergistic and interdisciplinary benefits for all parties.

Clouds, Aerosols, Radiation, and Circulation

The proximity of open water in the Norwegian Arctic has potentially large effects on the cloud-radiative interactions that determine surface climate and, potentially, climate change over a substantial portion of the Northern Hemisphere. Radiative controls of the ice-albedo-temperature feedback must be accurately simulated by models of climate and climate change if simulations by these models are to be realistic. In addition, the use of remote sensing techniques in this region is complicated by surface melt during warm-air intrusions, by thick clouds that accompany winter storms, and by the complex interactions involving aerosols and clouds, especially when the clouds can be dominated by either the liquid or the ice phase. Consequently, remote sensing algorithms developed for other portions of the Arctic may need important modifications when applied to this "warm Arctic" region.

Motivated by needs in climate modeling and remote sensing, an attractive possibility offered by Svalbard is a coordinated set of field measurements addressing cloud-aerosol-radiation interactions. Such measurements would complement SHEBA and ARM by extending the sampling to a marine environment that is in closer proximity to (a) aerosol sources and (b) large fluxes of sensible and latent heat. A scientific driver of a cloud-aerosol-radiation field program is the need to answer the following basic question: "Do climatically important cloud properties in the Arctic depend on aerosol?"

The following suite of desirable measurements could be achieved by a coordination and augmentation of the instrumentation now in place at Svalbard:

- rawinsonde soundings at several locations, permitting computations of (horizontal) fluxes of sensible and latent heat;
- moisture profiles from surface-based microwave sounders;
- cloud radar and cloud lidar (polarized for cloud phase detection);
- surface broad-band radiation (longwave and shortwave);
- spectral irradiances;

Coincident heavy clouds and sunshine (solar radiation) at Ny-Ålesund. The post office is the small building on the left. Photo by Dag Hessen.

- precipitation (liquid and solid, separately); and
- surface temperature.

Related in-situ measurements include the sampling of clouds, which are likely to differ from their central Arctic counterparts in several respects: frequency of liquid phase and mixed-phase occurrence, droplet size, droplet and ice crystal concentration, and ice crystal habit. Svalbard also provides excellent opportunities for studies of cloud chemistry, particularly with regard to the roles of aerosol species that are advected from lower latitudes. Anthropogenic aerosol can increase droplet concentration, thereby changing cloud albedo with major climatic implications. Cloud sampling from some of the mountains on Svalbard can be an efficient means to acquire information for such studies. In addition to providing opportunities in precipitation chemistry, Svalbard is an ideal location for measurements (either in-situ or by aircraft) addressing other issues in tropospheric chemistry, including Arctic Haze. Systematic sampling of atmospheric contaminant levels at Zepplinfjellet above Ny-Ålesund can be useful in identifying sources of contaminants to the Svalbard region. With similar data from sampling sites elsewhere in the Arctic, sources and fates of atmospheric contaminants to the Arctic can be much better understood.

Model Parameterization of Aerosol Effects

Three possible climate effects of aerosols are frequently referred to. The *direct effect* is the influence of airborne particles on radiation in clear air. The *first indirect effect* (Twomey, 1977) is the influence on optical properties of cloud particles (droplets and ice) through changed size and number concentration; and the *second indirect effect* (Albrecht, 1989) is the influence on precipitation efficiency and overall cloudiness. Modeling these effects according to first principles requires calculations of aerosol size-distributed compositions and loadings, calculations of optical properties by generalized Mie-theory for each particle size, calculations of water activity (e.g., hygroscopicity, or affinity for water molecules) and realized super-saturation during condensation, efficiency of various precipitation mechanisms, and finally a line-by-line radiative transfer calculation. Size-resolved concentrations of particulate matter, such as primary sea-salt, crustal particles, natural and anthropogenic sulphate, nitrate and carbonaceous particles, have to be calculated with the same resolution as other variables in the model. This level of detail requires models designed for detailed process studies of selected episodes. In models designed for longer term calculations, including climate models, parameterizations must be used.

At present, major climate models include calculations of mass concentrations of sulphate from natural and anthropogenic origins based on present and future emission scenarios. There is presently no standard method to parameterize optical properties and potential cloud condensation nuclei from estimated size-distributed aerosols.

Testing parameterizations of aerosol-cloud-radiation interactions could be done efficiently if careful measurement campaigns are designed at Svalbard. Since widely different air masses tend to reach Svalbard in episodes, the site is particularly well suited to test parameterisations. Such tests may be strengthened by also running sophisticated episode models with more use of explicit first-principle relations, since these are suitable tools for developing sound parameterizations.

Mesoscale Air-Sea Interactions

In addition to interactions involving cyclonic systems, there is the largely unexplored possibility that local mesoscale circulations in the atmosphere may develop at the ice edge due to thermal contrast between the sea-ice and the bordering open ocean. A flight campaign in February 1984 (NOAA P-3 Orion) used on-board instrumentation, dropwindsondes and regular ground surface observations to reveal a very sharp arctic front with a corresponding low-level (below 500 m) jet along the ice-edge (Shapiro et al., 1989). Also, strong (> 6 m/s) off-ice winds, not in balance with the large-scale pressure gradient, were measured close to the ice edge. The cross-frontal extension of these arctic boundary-layer wind features was 100–200 km. Thus the system was too small and shallow to be modeled by regular climate models. It is hypothesized (S. Grønås, pers. comm.) that the low-level, off-ice winds driven by the thermal contrasts along the ice edge may cause a retarded retreat of the ice cover, potentially initiating feedbacks to the ice edge. At the present time, the nature and even the existence of such feedbacks are issues requiring investigation. Both the frictional influence on the ice edge whenever such systems are present, and the climatology of their occurrence under shifting synoptic conditions and with season, need to be examined through measurement campaigns and careful model experiments.

The issues summarized above point to a need for surface flux data sets from the vicinity of the ice edge in the eastern North Atlantic. The importance of surface flux measurements is mentioned in the oceanography working group report as well (see page 58), highlighting its importance as an interdisciplinary theme.

Because of its proximity to the ice edge, Svalbard offers distinct advantages as a base for

Zeppelin Station for atmospheric monitoring and research in Ny-Ålesund. Photo by Dag Rydmark, NPI.

aircraft flights to the marginal ice zone. Ideally, such flights would sample the lower atmospheric fields (especially near-surface winds) most relevant to air-sea coupling as well as the oceanic stratification (measurable by air-dropped expendible bathythermographs, for example). Coordinated aircraft-ship operations are also attractive, although the constraints imposed by the need to pre-plan ship deployments are more severe. A key objective of these field measurements would be an assessment of the oceanic response to surface exchanges that occur over periods in which atmospheric cyclones or mesoscale circulations affect the marginal ice zone. Model experiments can then be focused on such periods to determine the adequacy of the models' surface flux parameterizations and of the air-sea coupling simulated by the models during particular episodes of air-sea exchange.

Model Experimentation

A clear aim of the mesoscale studies along the ice edge and over open arctic waters is to develop sound parameterizations that may improve climate scenario calculations in the Arctic. Three stages of modeling can be distinguished:

1. Models resolving mesoscale features (grid resolution 25 km and finer in the atmosphere, possibly even finer in the ocean), should be used for case studies and experiments in conjunction with measurement campaigns.
2. The same fine-scaled models should be nested with re-analysed global data (NCEP or ECMWF) in a quasi-climatological mode to study the climatology of the mesoscale arctic systems and their climatological significance.
3. If found climatologically significant, results of (1) and (2) should be used for developing sound parameterizations in global climate models, which then should be run for global climate scenarios.

Under (1) and (2) regional atmospheric models, perhaps coupled to sea ice and the ocean mixing layer, should be used, while for (3) global models coupled with deep ocean circulation models are to be used.

Measuring the biological effects of UV radiation using an enclosure near Ny-Ålesund. Photo by Dag Hessen.

Oceanography and Geophysics

Chairs: Knut Aagaard, *University of Washington*
Ola M. Johannessen, *Nansen Environmental and Remote Sensing Center*
Participants: John M. Brozena, *Naval Research Laboratory*
Frank D. Carsey, *Jet Propulsion Laboratory of California Institute of Technology*
Tor Gammelsrød, *University Courses on Svalbard*
Miles McPhee, *McPhee Research Company*
Jan-Gunnar Winther, *Norwegian Polar Institute*

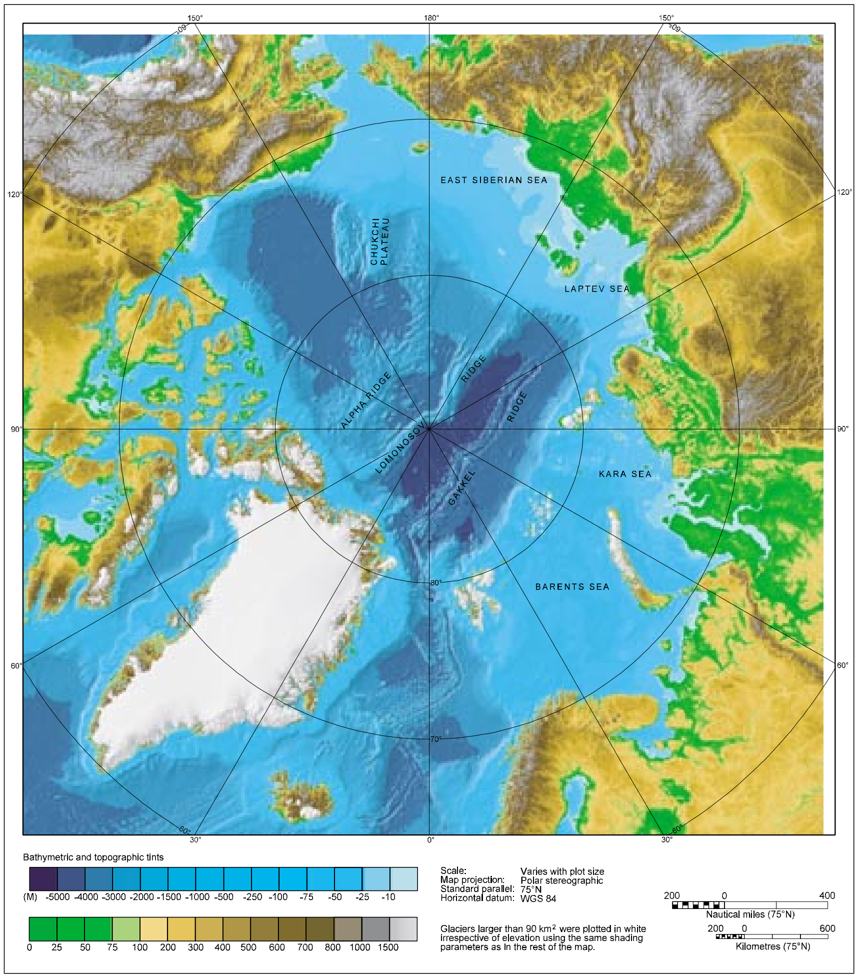
Svalbard sits in the Atlantic portals leading into the high-latitude Arctic and is uniquely situated to illuminate the Atlantic connections between the Arctic and the rest of the global ocean, including connections of climatic consequence. For example, the advection by the West Spitsbergen Current of abnormally warm source waters from the Norwegian Sea northward along the west coast of Svalbard during the past decade appears to have led to the recent large warming of the Atlantic layer in the Arctic Ocean (Swift et al., 1997). In this connection, we note that the warm inflow to the Arctic Ocean is in fact the northernmost extension of the global meridional overturning cell. Likewise, Svalbard is ideally situated to monitor the outflow of sea ice on a long-term basis. Sampling the sediment from these floes over many years will be important in determining the origin of sea ice entrainment and thus sea ice factories on the vast Arctic shelves.

We see three primary opportunities for ocean science based on Svalbard. In each case a long-term commitment is important if the opportunities are to be realized:

1. The variability of fluxes and conditions in Fram Strait, especially the eastern side.
2. Investigations in the portion of the Arctic Ocean reachable from Longyearbyen/Ny-Ålesund, either by ship or aircraft.
3. Studies of high-latitude fjords and shelves.

First, ice-free ports at such latitudes are truly remarkable, since they afford rapid and efficient access by ship into operating areas otherwise difficult and costly to reach. In particular, the immediate proximity of Ny-Ålesund and Longyearbyen to the West Spitsbergen Current argues strongly that northwestern Svalbard is the ideal base for sampling the Atlantic inflow to the Arctic Ocean through Fram Strait. The efforts over the past several years through UNIS, with ship operations based in Ny-Ålesund, provide an excellent pointer toward the scientific potential of frequent oceanographic sections in this region. Such work should be done on a regular basis, at least seasonally, including registering the upstream boundary conditions and defining perturbations to be tracked as they penetrate the Arctic Ocean system. The expanded sampling should cover a variety of measurements, e.g., radionuclides, dissolved gases, primary productivity, carbon flux, persistent organic pollutants or other organic contaminants, trace elements, and Doppler profiling, in addition to the traditional hydrographic parameters. Both shipborne and moored measurements are required and should incorporate recent advances in sampling and instrumentation. As ice conditions allow, work should also be done north of Svalbard, including over the shelf, as well as in the West Spitsbergen Current, so that the effects of recirculation, mixing, and surface fluxes can be ascertained. Eventually, and to some extent depending on the evolution of the European Variability in Exchanges in the Northern Seas (VEINS) program, all these measurements should be extended westward across Fram Strait to track the Arctic Ocean outflows and their burdens, including the exported freshwater. Evidence from a variety of observations and models suggests that these outflows of freshwater and ice may cause abrupt changes in the thermohaline circulation in the North Atlantic, and therefore also in the global ocean circulation. Direct measurements of oceanic heat and freshwater fluxes at the major arctic gateways are needed to construct and test models capable of realistic predictions.

Second, accessible modern aircraft support facilities at very high latitudes, such as in Longyearbyen, are equally rare and valuable and provide an unsurpassed base for running airborne oceanographic sections and for making a variety of other measurements in the Arctic Ocean, especially in the western Nansen Basin. An early example of such work is the Eurasian Basin Experiment (EUBEX) program based in Longyearbyen in 1981 (Perkin and Lewis, 1984). With modern techniques, an exceptionally worthwhile program can be conducted, not only in physical oceanography and climate-oriented research, but also in marine biogeochemistry and biology. Furthermore, in addition to supporting work that is actually done from the ice surface, but that is dependent on aircraft-based mobility, aircraft can deploy expendable probes (e.g., air-dropped expendable bathythermographs and conductivity-temperature-depth probes). Such work would extend the spatial coverage and increase the temporal resolution of ships both in the Arctic Ocean and in Fram Strait. It



Source: Jakobsson et al., 2000.

Extracting an ice core from a hydrohole for turbulence studies under fast ice in Temple Fjord, Svalbard, March 1999. Photo by S. McPhee.

View across newly frozen ice on Advent Fjord, toward Longyearbyen, Svalbard, March 1999. Photo by S. McPhee.

would also permit upper ocean measurements of the liquid freshwater content, which are presently impossible to obtain from moored sensors, or even from ships, since the latter disturb the near-surface layer.

Third, the proximity of the Svalbard ship and air support facilities to the seasonally ice-covered shelf regions east and south of Svalbard provides excellent opportunities for process-oriented work that has wide applicability to arctic shelves. For example, the brine-driven convective regime in the Storfjord (Quadfasel et al., 1988) typifies a process representative of ice-covered shelves generally that is of great importance to the exchange of materials between the shelves and the deep ocean. The shelf around Svalbard also provides distinct comparisons and contrasts with the shelves of the western Arctic that are the initial focus of the new NSF Shelf-Basin Interactions (SBI) initiative, for example with respect to carbon and nitrogen cycling.

Implementing these several initiatives would likely be considerably facilitated and enhanced by a dedicated small marine technical support unit for both the air and ship operations, including some analytical laboratory facilities. Perhaps this could be done in conjunction with the new marine lab to be constructed in Ny-Ålesund. The ice-free and accessible western coast of Svalbard also offers especially favorable conditions for the use of autonomous vehicles, acoustic techniques, and innovative real-time data transmission systems, whether deployed singly or as nodes in a larger Pan-Arctic array. Indeed, it is hard to visualize an arctic-wide observational system in the marine environment that does not incorporate and take advantage of the location and unique facilities offered by Svalbard.

Melting and Freezing of Sea Ice

An emerging characteristic of global climate models used in simulating climate change is the difficulty these models have in retaining sea ice in the North Atlantic, particularly during winter. The available data indicate that wintertime sea ice cover in the North Atlantic is more stable in reality than in model simulations forced by observed rates of change of greenhouse gas concentrations. One hypothesized explanation is that surface exchanges between the atmosphere and the underlying ocean are not adequately simulated by the models. Since the waters near Svalbard show some of the world's largest surface fluxes of heat and moisture, successful modeling of this region requires a systematic suite of surface flux measurements against which model-derived fluxes can be evaluated.

The large surface fluxes of sensible and latent heat over open Arctic Ocean areas are also major determinants of upper-ocean stratification. Cyclones, including the mesocyclones known as polar lows, are likely to mix the upper ocean sufficiently to be important contributors to variations in the upper-ocean stratification. The possible connections between this mixing and preconditioning of the ocean for deep convection are unknown.

Atlantic Inflow Studies and Interior Variability Mapping

The past decade has seen remarkable changes in the marine Arctic, including changes in the ice thickness, ice extent, the distribution of Pacific and Atlantic source waters, and the subsurface temperature. We do not know whether these represent temporary perturbations, long-term trends, or new equilibria. The exchange through the Fram Strait is of special importance in this context. In particular, variability in the West Spitsbergen Current has been shown to cause large changes in the Atlantic layer of the Arctic Ocean. This West Spitsbergen Current temperature variability has in turn been related to major changes in the atmospheric circulation via the Arctic Oscillation and/or the North Atlantic Oscillation.

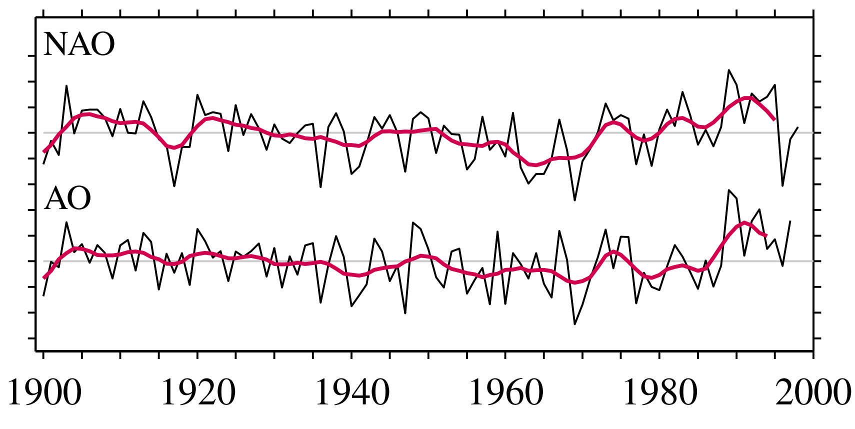
Norwegian-American cooperation on Svalbard can contribute to this problem set by:

- ascertaining the variability of North Atlantic (especially the West Spitsbergen Current) input to Arctic Ocean, including heat, salt, nutrients, contaminants, and other materials. The relationship of the variability to atmospheric forcing is of special concern;
- ascertaining the variability of outflow (including freshwater) through Fram Strait and its various burdens of dissolved and particulate material; and
- contributing to mapping basin-wide variability.

Process Studies

Norwegian-American cooperation on Svalbard provides special opportunities for studying numerous processes important to understanding the polar ocean, including haline convection, ice-edge dynamics and ecology, fjord circulation, shelf-basin exchange, biogeochemical cycling, and the influence on fjord oceanography of glaciers, icebergs, and meltwater. Improved understanding of these fundamental processes is urgently needed. Such studies are, in fact, a prerequisite for improved parameterization of these processes for effective modeling.

Of particular interest are the processes taking place along the ice edge, where during spring vigorous upwelling and phytoplankton blooms may occur. Pollutants may enter efficiently into the food web at this stage.



Major changes in atmospheric circulation via the Arctic Oscillation and/or the North Atlantic Oscillation have been related to the West Spitsbergen Current temperature variability. Figure courtesy of Todd Mitchell.

Science Interests and Questions

The Arctic Ocean presents the largest gap in the world marine record, limiting our ability to construct both global tectonic and paleoclimatic models. This gap also limits our ability to exploit the resources of the arctic shelves.

Geophysical Investigations

The Gakkel Ridge is in many respects unique among mid-ocean ridges. For example, it has extremely slow spreading rates and terminates at a continental margin (on the Laptev Shelf). Direct sampling and observations of this ridge would provide many keys to unlocking the mysteries of arctic tectonic development.

Geological Investigations

The deep sea record older than Pleistocene is virtually unknown for the Arctic Ocean and Svalbard is proximal to many prime coring sites that will be proposed for the Ocean Drilling Program (ODP) as it moves into the Arctic. While the vast Arctic shelves have been sparsely cored, the stratigraphy and sedimentology of these unique shelves needs to be better described to understand shelf-basin interactions critical to the stability of the Arctic ice cover and for other geological processes that may be unique to the Arctic. Gas hydrates may be abundant in these shelf and slope sediments and investigating these will be essential to accessing their impact on the arctic environment and perhaps global climate. The breadth of the shallow arctic shelves makes them prime prospects for economic development in the near future. As ice management technology rapidly develops, pressure to exploit the potential resources of Arctic shelves will increase. Geologic investigations (geological and geophysical) are essential to insure intelligent control of this exploitation. Again Svalbard is critically located to serve as a base of these operations in the Eurasian sector of the Arctic.

Paleoenvironmental Studies

The most critical need for arctic paleoclimate research is high-resolution sediment records in critical areas, such as the Fram Strait where most of the glacial and sea ice exit the Arctic Ocean. Svalbard is a logical base of operations for coring expeditions into the Eurasian Arctic and the Greenland Sea/Fram Strait areas. Geophysical surveys will be an essential component of the search for areas of rapid sediment accumulation. This should also be a high priority for the ODP as well.

Regional Climate Simulation—Impact Studies

Atmosphere—Sea Ice—Ocean

Global coupled climate models predict enhanced global warming in the Arctic, including significantly decreased sea ice extent and decreased deep water formation in the Greenland/Labrador Sea with potential large impact on the global thermohaline circulation. However, present global models are coarse for the arctic region, and several processes such as convection and eddy circulation are at subgrid scale and not yet properly parameterized (see recommendation for process studies). Higher resolution coupled atmosphere-ice-ocean models for the northern part of the Greenland-Iceland-Norwegian Sea, Fram Strait, and the Arctic Ocean are needed to improve predictive capabilities for decadal variability (North Atlantic Oscillation/Arctic Oscillation) and for global warming prediction. Improved predictive capability will allow us to perform impact studies in relation to fisheries, transportation, and offshore activities.

Regional Climate Modeling and Impact Studies

There is considerable interest in Norwegian-American collaboration in climate change research and environmental monitoring on Svalbard, and in developing and testing interactive climate models that can serve as tools for management of inhabited and uninhabited high Arctic regions. In addition, such regional climate models can be used to provide new insights into the geophysical and biological consequences of climate variability and change in an Arctic region that is expected to be sensitive to, and interact with, changes in regional atmospheric, oceanic, and land-based forcing conditions.

A regional climate model for the Svalbard area should account for the coupled and interactive nature of processes associated with the atmosphere (e.g., clouds, radiation, temperature, and precipitation), hydrosphere (e.g., soil moisture, snow-cover evolution, permafrost, evaporation, and runoff), biosphere (e.g., transpiration and vegetation processes), and ocean (e.g., ocean surface circulation, sea ice distribution and advection, and habitats for marine mammals and sea birds). This work should aim at improving both our understanding and our ability to describe and model the complex interactions among the atmosphere, sea ice, ocean, snow, land, and biota throughout the year. During each season the interactions between the land, ice, ocean, and atmosphere play a unique role in governing the overall arctic weather and climate.

Finally, the integration of data from a wide variety of monitoring and process studies into regional climate models calls for strong interdisciplinary collaboration.

Paleoenvironmental Research

Chairs: Ray Bradley, *University of Massachusetts*
Anders Elverhøi, *University of Oslo*
Participants: Julie Brigham-Grette, *University of Massachusetts*
Peter J. Capelotti, *Penn State Abington College*
Dennis A. Darby, *Old Dominion University*
Mark H. Hermanson, *University of Pennsylvania*
Ross D. Powell, *Northern Illinois University*

Earth history is as vital to society for planning and forecasting environmental change as human history is for understanding national and international politics. We need to know the natural variability of the Earth system in order to fully grasp what future global change scenarios might entail. We cannot, nor should we, make future predictions of the Earth system without a thorough understanding of both present and past modes of environmental variability.

Different computer models all indicate that the Arctic is highly sensitive to changes in climate forced by the atmosphere's rising concentration of greenhouse gases. Though such projections are uncertain in terms of the magnitude of expected changes, one thing is abundantly clear: whatever anthropogenic effects influence climate in the future, they will be superimposed on the underlying background of "natural" climate variability. Paleoclimatic research provides an essential perspective on climate system variability, its relationship to forcing mechanisms, and to feedbacks that may amplify or reduce the direct consequences of particular forcings. Such a perspective cannot be provided by the very limited set of instrumental data at our disposal. We know from the paleoclimate record that abrupt changes have occurred in the global climate system at certain times in the past. Nonlinear responses occurred as critical thresholds were passed. Our knowledge of what these thresholds are is completely inadequate; we cannot be certain that anthropogenic changes in the climate system will not lead us, inexorably, across such thresholds, beyond which may lie a dramatically different future climate state. Only by careful attention to such episodes in the past can we hope to fully comprehend the potential consequences of future global changes due to human-induced or, for that matter, any other effects on the climate system.

Paleoclimate data also provide a critical test of general circulation models used to simulate future climates; if they can accurately simulate climatic conditions that are known to have existed in the past, confidence in their ability to predict future climatic conditions will be enhanced. Finally, paleoclimate records provide evidence of how biological and environmental systems have responded in the past to changes in climate. Such relationships are important in understanding how natural systems may be affected by anticipated future changes in climate. The record of past climate variability is thus an essential prerequisite for understanding the evolution of the climate system in the future and the potential consequences of future global changes, whatever their cause.

The paleoclimatic research communities in both the U.S. and Norway are very active. Circumarctic research to date has revealed many interesting and significant questions that would benefit from further collaborative studies. In this context, Svalbard and its adjacent seas are in a key location for paleoclimatic research. Situated at the locus of major water and atmospheric exchanges between the Arctic Ocean and the Nordic Seas, the region has great significance for tracing changes in the entire Arctic Basin. Considering the latitude, environmental conditions are extremely mild—a direct result of the North Atlantic Drift and associated warm air masses that penetrate to high latitudes in the North Atlantic. Any change in the strength and direction of these water and air masses will have (and would have had in the past) very direct consequences for the climate and natural environment of the region. Thus, the Svalbard region and adjacent seas are highly sensitive to climate variations and should provide excellent records of past changes in climate that are relevant to a much wider region. U.S. and Norwegian collaborative research on such records should thus be carried out in the context of a circumarctic perspective.

Paleoclimatic research in the Svalbard region and adjacent seas can mutually benefit from pooling of U.S. and Norwegian logistic resources. Paleoclimatic research can benefit from the unique facilities available in Svalbard and from the educational center in Longyearbyen.

Here we identify a set of high-priority issues that would benefit from enhanced collaboration between U.S. and Norwegian arctic scientists (cf. Aagaard et al., 1999; PARCS, 1999) Many of these questions require high-resolution, well-dated natural archives of past environmental change.

Natural Variability

Understanding the range of natural environmental variability in the Svalbard region at temporal and spatial scales is relevant to anticipating future change. How much is the climate signal amplified in the Arctic and does the signal lead or lag the global climate signal? There is now data that strongly suggests that both a lead and a lag occurs. More importantly, there appears to be a sub-Milankovitch scale (1 to 3 kyr) cycle of climate change in the Arctic similar to Dansgard-Oeschger temperature cycles that can be modeled into the near future. These changes are seen both in the western Arctic Ocean and in the Fram Strait (Darby, Bischof, Spielhagen, et al., 1999; Darby, Bischof, Poore, et al. 1999; Darby et al., in rev.). Thus the opportunity for collaborative research is growing for Norwegian scientists because of the important location of Svalbard next to Fram Strait and for additional studies of glacial deposits on and around Svalbard in order to refine these changes in the sediment record.

We can ask ourselves the following questions, for example. Was the 20th-century warming unprecedented in the last 1000 to 10,000 years? Can we extend the record of changes in the North Atlantic Oscillation/Arctic Oscillation (NAO/AO) beyond the period of instrumental records? This requires high-resolution studies with excellent dating control and rigorous calibration.

Sensitivity of the Arctic

Determine and understand the sensitivity of the Arctic to altered forcings—both natural and anthropogenic.

How fast, and in what ways, does the physical and biological environment respond to climate change? Are there parts of the system—sea-ice, glaciers and ice caps, soils, permafrost, and vegetation—that are especially sensitive to climatic change?

Realistic Modeling

Evaluate the realism of numerical models being used to predict future climate and environmental change on regional to global scales.

How do model-derived paleoclimate reconstructions compare with proxy terrestrial and marine records from the Svalbard region?

Glacier Mass Balance

Evaluate changes in glacier mass balance and dynamics to provide an understanding of past ice sheet behavior of relevance to understanding future glaciological changes.

The mass balance of glaciers in Svalbard is sensitive to atmospheric and marine circulation changes. The interaction of calving glacier fronts with the marine environment is of particular interest. Surging glaciers are common in Svalbard, making this region unique in the high Arctic, and providing opportunities to understand the dynamics of glaciers and ice sheets in the region and to assess critical thresholds that may play an important role in ice movement.

Interactions Between the Arctic Ocean and the Nordic Seas

Evaluate interactions between the Arctic Ocean and the Nordic Seas to assess the natural variability of these systems, in particular, to determine the role of the Arctic Ocean and the export of ice on global climate. Do changes in the Arctic trigger global climate changes, or does the Arctic respond somewhat passively to changes initiated elsewhere? The causes and mechanisms involved in climatic "surprises" (i.e., unexpected, extreme, and/or abrupt events) in North Atlantic and arctic climate system behavior are of critical importance.

To what extent are salinity anomalies and associated changes in thermohaline circulation evident in marine and terrestrial paleoclimatic archives? What changes occurred in sea-ice extent and biological productivity within the Svalbard region during the major warmings observed in Greenland over the last 110,000 years? This requires high-resolution marine sedimentary records.

Ice Cores

Ice cores from the highest ice caps in the region can provide high resolution records of both past climate and of those factors that may have caused climate to change. These include stable isotopes (indicating past temperature and/or water vapor history); physical stratigraphy (summer temperatures); borehole temperatures (mean annual temperature); glaciochemistry (dissolved and particulate content indicating air mass type and frequency, sea-ice extent, aerosol loading from terrestrial sources and explosive volcanoes); trace gases (e.g., CH_4); cosmogenic isotopes (e.g. ^{10}Be, indicative of solar forcing).

The paleoenvironmental record from ice and firn (multi-year snow) cores can also be used to identify the atmospheric flux chronology of hydrophobic, semivolatile organic contaminants. These compounds preferentially accumulate in the polar regions by the process of cold condensation in which they evaporate from warm climates, are transported to the polar regions by the atmosphere, and condense, never to evaporate again. Some of these compounds (PCB, DDT, methyl parathion), which may be carcinogenic, estrogenic, or highly toxic, have been banned from further production or use in various countries, yet are found in increasing concentrations in polar organisms. The ice and firn record will identify the history of inputs, the influences of changing emissions, and effects of transport and accumulation processes in the Arctic.

Lake Sediments

Lake sediments provide a comprehensive terrestrial archive of past environmental changes through studies of biogenic material (diatoms, pollen, chironomids, etc.) and clastic material (sediment characteristics and geochemistry). Laminated sediments present the opportunity for annually resolved studies of past climate. Contaminant histories are also recorded in lake sediments.

Marine Sediments

Sediments document changes in ocean circulation, the extent of sea ice and ice sheets, and changes in the biogeochemistry of the marine environment. Both near-shore and deep-sea sediments are needed, especially from sites with high sediment accumulation rates. Locally, laminated sediment can allow annual-scale resolution for past climate changes.

Peat

Accumulations of peat incorporate pollen and insect remains, which provide insight into air mass changes and past temperatures.

Peat deposits are also important in assessing biogeochemical changes over time.

Geomorphology

Glacial deposits indicate the former extent of ice masses and enable changes in precipitation and/or temperature to be reconstructed. Raised marine deposits along the coast provide information on the isostatic history of the region, including past ice extent and ice thickness. Geomorphological evidence is essential for determining the former extent and thickness of ice cover, which has implications for sea-level changes in the past and for modeling of past climatic conditions.

Permafrost

Boreholes in permafrost terrain can provide a paleotemperature history of the site, with decreasing resolution back in time.

Historical Records

Human exploration and occupancy in Svalbard spans at least the last 400 years; historical records, including ships' logs, can provide insight into climatic parameters such as changing snow cover and ice extent on land, the former positions of tidewater glaciers, and of sea-ice extent in and around the archipelago.

BIOLOGY

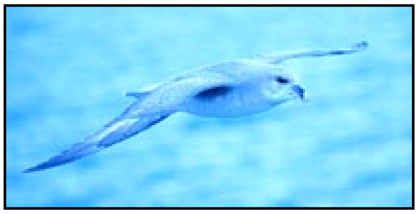
Chairs: Dag O. Hessen, *University of Oslo*
Brendan Kelly, *University of Alaska Fairbanks*
Participants: Brian M. Barnes, *University of Alaska Fairbanks*
P. Dee Boersma, *University of Washington*
Bjørn Munro Jensen, *Norwegian University of Science and Technology*
George Kling, *University of Michigan*
Pål Prestrud, *Norwegian Polar Institute*
Mike P. Sfraga, *University of Alaska System*

Polar biological systems are simple and relatively undisturbed. They are strongly influenced and controlled by extreme seasonal changes in day length and harsh climates with extensive stochastic annual variations. These characteristics offer unique opportunities for the study of basic ecological and evolutionary processes and adaptive mechanisms. Scientific knowledge of these systems may be applied to more complex systems that have been more strongly altered.

Today it is more important than ever that tools for sustainable management of the polar environments are based on a sound scientific basis. By combining experience and scientific knowledge, the U.S. and Norway will be able to contribute significantly to the knowledge of basic biological processes specific for polar environments, as well as knowledge of how polar environments are affected by human activities. Such knowledge is vital for sustainable management in polar regions.

Biological systems are integrators and reflectors of changes in the physical environment. The adaptive evolution of organisms is often driven by changes in the environment, including changes in climate. Tracking these past adaptations of organisms, as reflected in their movements, extinctions, and biogeography, is an important element of investigations into the environmental and climatic history of the Earth. A primary assumption of these studies is that learning about the rates and limits of past changes will help to constrain our predictions of how biological systems, including humans, will respond to future shifts in local and global environments. Because our understanding of the Earth's past is linked directly to past changes in biology, these changes can only be interpreted within the context of knowing how species, communities, and ecosystems function in today's world. In addition, biological systems do not only respond to environmental variations: they actively drive certain changes, such as atmospheric concentrations of greenhouse gases, through photosynthesis, respiration, and decomposition.

Arctic ecosystems appear especially sensitive to climatic variations and prone to concentrating pollutants. Recent discoveries of serious threats to arctic biota, such as accumulation of toxic compounds transported northwards from densely populated areas, ozone anomalies and increased UV radiation, and global warming, raise the prospect of severe consequences for arctic ecosys-



A northern fulmar near Ny-Ålesund, Svalbard. Photo by Dee Boersma.

tems. Understanding ecological, physiological, and behavioral adaptations to the current arctic physical environment and the structure and regulation of arctic food webs is essential to making predictions about future effects of global change.

American/Norwegian scientific cooperation offers important opportunities for collaborative, long-term investigations in biological sciences on and around Svalbard and throughout the Arctic. Svalbard offers a unique high-latitude environment with extreme photoperiods and seasonality that, due to a branch of the Gulf Stream, is not subject to extreme year-round snow and cold. Comparative studies between biological systems on Svalbard vs. Alaska (for example) may allow us to separate effects of seasonality and climate on biodiversity and community structure of plants and animals. Svalbard's indigenous populations of nonmigratory animals that over-winter in the high Arctic also allow investigations of unique adaptations to extreme environments and thus limitations to physiological, behavioral, and functional design.

Arctic tern and chick, Ny-Ålesund, Svalbard. Photo by Dee Boersma.

The Svalbard reindeer is a distinct subspecies with shorter legs and more body fat. It has little fear of people. Here Hanne Line Daae studies a reindeer near Ny-Ålesund. Photo by Dag Hessen.

Norwegian and American biologists agree that understanding the ecological, physiological, and behavioral adaptations of arctic organisms and ecosystems, and determining their responses to natural and anthropogenic changes requires comparative, long-term research. Many areas of the Arctic have pristine ecosystems, relatively untouched by direct human alteration, which present great opportunities for scientific comparison with other arctic environments that have been severely altered or polluted. Arctic systems also tend to have relatively simple biological communities, which facilitate our ability to construct realistic mathematical models for predicting future responses to global change. The ready access to and substantial infrastructure of Svalbard make it an ideal location for the long-term investigations that are required to understand how biological systems function on the relevant time scales of 10 to 50 years, in step with current predictions of the time scales of substantial change in the Arctic's physical environment. Scientists from the U.S. and Norway share interests in several areas of biological research, and the most scientifically critical areas are outlined below.

Marine Biogeochemical Cycles and Climate Change

How will climate change be mediated, and what will be the effect on cycles of carbon and other major elements?

Large-scale oceanographic processes around Svalbard have profound impacts on both the regional and global climate. Paleoclimatic records strongly indicate that changes between glacial and interglacial climates in this area may occur rapidly in response to shifts in ocean currents. Such changes could have devastating impacts on North American and European communities. Biological and biogeochemical interactions profoundly affect these large-scale processes. Drawdown of CO_2 from the atmosphere on geologically and climatologically significant time scales can only occur through sequestration (burial) of organic carbon in sediments. Burial is dependent on a variety of biologic, geochemical, and physical factors, including the rates and nature of primary productivity in the surface ocean, transformation and sedimentation of particulate organic carbon, and the nature and extent of sedimentary carbon remineralization processes. An interdisciplinary international program should be initiated including studies of marine carbon cycles and impacts of rapid climate changes on biological systems. Of particular interest and importance is the linkage of these problems to food webs and carbon, nutrient, and energy flux studies related to climate change in freshwater and marine environments. These processes will not only be major influences on arctic marine CO_2 flux, but have effects on the region's commercial fisheries.

In the arctic marine environment, sea ice is a major abiotic control factor on vertebrate communities. Several species of whales, seals, and sea birds are near the top of short food chains which are ultimately based on the seasonal production of epontic algae. Zooplankton and arctic cod are important intermediate links.

At the top of the food chain, polar bears are susceptible to organic pollutants. Photo © Kit Kovacs and Christian Lydersen, NPI.

The seasonal sea ice acts as a substrate important to cod for the growth of algae (food for their zooplankton prey) and as a complex three-dimensional habitat offering refugia from predation. Understanding the impacts of changing ice cover on vertebrate populations will require long-term studies of the dynamics of systems based on epontic algal production.

Effects of Extreme Environments on Arctic Organisms

What are unique physiological and behavioral adaptations of organisms to arctic environments?

Predicting effects of global change on arctic ecosystems will depend in part on understanding the nature and degree of physiological and behavioral adaptations to the extreme physical environment of the Arctic. Norwegian-American cooperation should include investigations of those adaptations, including:

- biological rhythms of indigenous Svalbard animals in extreme day lengths, not available elsewhere;
- reproductive and stress physiology of high Arctic nesting birds;
- controls over seasonal fattening in arctic animals from crustaceans to polar bears (since persistent organic pollutants are stored in fat, this also is important for ecotoxicology studies);
- winter energetics and regulation of arctic resignation;
- diving physiology;
- behavioral and physiological mechanisms of thermoregulation; and
- neonatal survival and adaptation.

Population Biology and Genetics

How does living on arctic islands and marine environments affect population structure and species interactions?

The Svalbard fauna and flora are geographically isolated from other arctic populations, as well as from mainland populations of the same species. This isolation, combined with strong selective pressures from seasonal and climatic conditions, may have produced population structures and genetics that differ markedly from founder populations (Weider et al., 1998). Moreover, the predominant asexual mode of reproduction in arctic species of plants and invertebrates results in a high number of genetically different clones. This is an important aspect of biodiversity, since it is not only the species per se, but also its genetic variability that should be protected.

Ecotoxicology

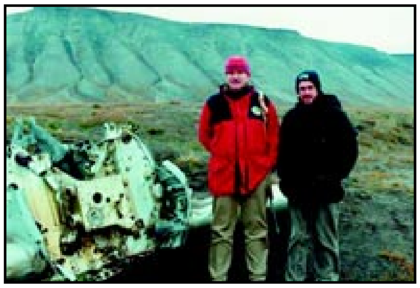
What are the consequences of bio-accumulation and bio-concentration of pollutants on arctic organisms? How do petroleum hydrocarbon spills persist in the Arctic?

Understanding the effects of pollutants in arctic ecosystems requires proper knowledge of basic animal ecology and food web patterns as well as specific studies of ecotoxicology. Organic toxins, heavy metals, and radioactive waste are transported to the Arctic through the atmosphere and ocean and accumulate in the lipid-based arctic food webs. For a number of bird species, seals, arctic char, and polar bears, alarming levels of many toxic compounds have been reported, some of which may interfere with reproduction. On the remote Bjørnøya south of Svalbard, extremely high levels of organic toxins have been reported in fish. Determining the causes and effects of such bioconcentration of pollutants will require interdisciplinary studies in meteorology, oceanography, ecology, and toxicology.

Persistent organic pollutants (POPs) are lipophilic and thus associated with the fat tissue that is important for arctic animals. To understand bio-accumulation of POPs, as well as how the pollutants are released into the circulation during periods of low prey availability, it is necessary to have detailed knowledge about lipid dynamics in arctic organisms and between trophic levels. Information on interactions between different POPs and different lipid fractions (types) is also important for understanding how organisms and cellular target mechanisms are exposed to POPs.

Due to structural similarities with hormones, many POPs may seriously affect the endocrine regulation of physiological and behavioral processes, which have evolved in arctic animals as adaptations to the extreme environment. Studies of effects of POPs on physiological and behavioral adaptations (for instance: reproduction, immune responses, predator and anti-predator behavior) will provide knowledge about how POPs may affect population dynamics. Such information is important in the development of management regimes for arctic wildlife. Key issues include:

- role of lipid metabolism and dynamics in bioaccumulation of persistent organic pollutants (POPs) and other toxic organic contaminants,
- transport of POPs, other toxic organic contaminants, and radioactive pollutants in arctic food webs,
- effects of pollutants on the physiology and behavior of organisms, and
- effects of pollutants on trophic interactions.



Svalbard historian Per Kyrre Reymert (left) and polar archaeologist P. J. Capelotti survey the wreck of a German Junkers Ju. 88, a twin-engine bomber from World War II, near Longyearbyen. This is one of several of the world's northernmost air wreck sites dating from the Second World War and located in Svalbard. Photo courtesy of P. J. Capelotti.

Social Sciences

Social Sciences workshop participants: Peter J. Capelotti, *Penn State Abington College*
Michael Sfraga, *University of Alaska*
Social Sciences contributors: Susan Barr, *Riksantikvaren*
Robert Marc Friedman, *University of Oslo*
Anne Millbrooke, *University of Alaska Fairbanks*
Gustav Rossnes, *Riksantikvaren*
Urban Wråkberg, *Royal Swedish Academy of Sciences*
Valene Smith, *California State University-Chico*

U.S.-Norwegian cooperation is already underway in archaeological research. Greater coordination and conceptualization of research plans must, however, be at the forefront of new models of research. Svalbard offers several avenues of social science research, such as history of science, industrial and maritime archaeology, political science, and studies of human exploration. Social sciences include studies of both contemporary and past societies. Communities on Svalbard offer interesting opportunities to compare to other arctic communities as remote human habitations and as examples of changing economies based on declining resource extraction, scientific research, or increasing visitor industries.

In contrast to the ancient indigenous peoples of the North American or Asian Arctic, human habitation in the Svalbard archipelago appears to be confined to historical time. This limits the depth and breadth of research on past human societies; however, Svalbard can provide insights into the history and sociology of polar explorations and early trapping, trading, and whaling societies.

Social Construction of Scientific Research in the Arctic

Studies of scientific expeditions and field installations can describe the changing nature of polar research as a social and cultural activity. Arctic scientists and support staff commonly live and work in close proximity over long periods; how they create mini-societies can be critical for the viability of scientific programs. Installations throughout the Arctic can provide comparative data for the material analysis of such issues. The foundational work by members of Norwegian Polar Institute, Norsk Riksantikvar, and Svalbard Sysselmannen can be extended through international collaboration by various cultural and social scientists concerned with restoration, preservation, and analysis of human activity in the Arctic.

Cultural Resource Management and Tourism

In Svalbard, the first yacht visitors from Europe date to the 1870s, and a record 10,000 ship passengers are said to have gathered to cheer the departure of the Andree balloon in 1897. According to Info-Svalbard, in 1993 some 21,000 cruise passengers visited the islands, most going ashore at Magdalenafjord for its scenic and historic attractions. In 1993, about 16,000 tourists arrived by air, many to trek in the vicinity of Longyearbyen.

Svalbard has strict regulations related to tourist access to historic sites. Theoretical and practical cultural resource management discussions indicate a need for social science work on site access and explanation, recording, recovery, and in-situ management.

Historical and Archaeological Research

Historical remains include those from 400 years of human exploitation and exploration of Svalbard archipelago, including remains of European, Russian, and Scandinavian hunting operations; scientific exploration of the nineteenth and early twentieth centuries and installations constructed for science research; high Arctic mining activities; construction of a maritime transportation infrastructure in the high Arctic; and military competition between the Allies and Nazi Germany during World War II.

Historical archaeology research in Svalbard has begun the systematic documentation and study of base camps of early polar explorers and early whaling and other hunting operations (see, for example: Hacquebord and de Bok 1981, Hacquebord 1984; Rossnes 1993; Capelotti 1994, 1997, 1999), as well as a considerable number of archaeological studies of Pomor (Russian) hunting stations by Soviet, Polish, and Norwegian archaeologists. Also, a substantial body of work has been published examining Svalbard's place in international politics.

Variations in access to the high Arctic have been found in the history of arctic exploration. Historical records of international whaling and sealing voyages attest to this variability during the past four centuries. Possible research questions include: How was historic human access to Svalbard regulated by local variation in annual sea ice, and were such variations due to measurable global conditions or the result of local variations in temperatures? Can historical records be collated with existing digitized Norwegian data as well as weather station and Euro-American industrial development data to form direct evidence of changing sea ice margins due to carbon and other emissions? Do local observations correlate with global data collected in the same years? How do global changes correlate with both historical and archaeological data?

Ruins of arctic exploratory, mercantile, or military base camps in Svalbard could be used in comparative examinations of sites in the Pacific related to mining, whaling, and prehistoric voyaging. Svalbard offers unparalleled preserved remains of cross-cultural industrial areas, including entire settlements (the Soviet mining community at Pyramiden), as well as localized national industrial expeditions (Camp Mansfield at Kongsfjorden). Jan Mayen is an equally important high Arctic Norwegian protected area offering preserved cultural areas.

In terms of comparative analysis of national visions of the Arctic, the crash of the polar airship *Italia* northeast of Svalbard in

1928, for example, triggered one of the most intense international sea-air-land rescue efforts in human history, which left on the north coast of the archipelago an archaeological landscape of human aeronautical and exploratory ambitions in the form of temporary landing fields, food caches, rock cairns, an airship wreck, and debris drift. The cultural landscape of Svalbard can be examined in relation to the *Italia* expedition and rescue in order to explore questions such as how did humans adapt aeronautical technology to the extreme environment of the Arctic, and what happened when they did?

The wrecks of whaling vessels from the 1600s and 1700s have likely survived in a high state of preservation and could provide comparative data to whaling sites in the Pacific such as the collection of whaling wrecks at Pohnpei. Gathering such data may be difficult without access to submarines or autonomous undersea vehicles (AUVs). Methodological breakthroughs may be possible if advanced sonar systems from long-range submarines could be used in the fjords of Svalbard. Sub-bottom-profiling sonar could be decisive in fjord areas where previous underwater surveys seem to indicate that wrecks have been covered by layers of silt from glaciers and other melting ice. This silting, securely dated to the moment of shipwreck, is another source of formation process data.

Some climatic data from whaling sources has been collated by NPI, and additional data, including historic charts and photographic data from tens of thousands of whaling voyages, remains among the archives of the New Bedford and Kendall Whaling Museums.

Recommendations

A research plan for the study of several aspects of social sciences in Svalbard should be developed, including:

- historical investigations of scientific expeditions and field installations;
- comparative studies of human behavior and adaptation in extreme environments; and
- study of the scientific, industrial, military, social, aeronautical, and whaling/hunting sites on Svalbard and use of these sites in comparative research.

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Appendix D: Agenda of the Svalbard Workshop, 16–19 August 1999

Monday, 16 August

13.20	Arrival, Bus-transport to Svalbard Polar Hotel
14.00 – 15.00	Lunch at Svalbard Polar Hotel
15.00 – 18.30	*Session 1, General orientations and mutual information* *The Auditorium, UNIS, Longyearbyen* **Chair:** Science Director, Pål Prestrud, Norwegian Polar Institute
15.00	Opening speech, Jon Lilletun, Minister of Education, Research and Church Affairs Short address, Congressman F. James Sensenbrenner Jr., Science Committee, House of Representatives
15.30	Professor Anders Elverhøi, Department of Geology, University of Oslo: Norwegian Polar Research and Science Policy, University perspectives. Norwegian interests in the Arctic and possibilities for Norwegian-American scientific co-operation
16.00	Director Olav Orheim, Norwegian Polar Institute: Norwegian Polar Research Institutes in and outside Tromsø: in particular the Norwegian Polar Institute, The Polar Environmental Centre
16.30	Director Lasse Lønnum, the University Courses on Svalbard (UNIS) The University Courses on Svalbard, and in particular the possibilities for American students, guest lecturers, and professors at UNIS
17.00	**Coffee break**
17.30	Science secretary Per Kyrre Reymert, Svalbard Science Forum Important research infrastructure and installations on Svalbard
18.00	Contributions from the American delegation: Dr. Tom Pyle, Arctic Sciences Section Head, Office of Polar Programs-National Science Foundation (OPP-NSF): U.S. National and shared interests in arctic research and the NSF programme on Environmental Observatories Dr. Julie Brigham-Grette, U.S. chair, Department of Geosciences, University of Massachusetts: American interests in the Arctic and possibilities for Norwegian-American scientific co-operation on and around Svalbard
19.30	**Dinner at Svalbard Polar Hotel**

Tuesday, 17 August

09.00 – 12.00 *Session 2, Scientific co-operation within specific themes, Introduction*
The Auditorium, meeting rooms, UNIS
Parallel sessions: Introductions and discussions about potential co-operation

1. Upper atmosphere research (research that demands heavy infrastructure):
Co-Leaders: Asgeir Brekke (University of Tromsø)
Roger Smith (University of Alaska Fairbanks)

2. Global change research
2.1 Air (ozone depletion and UV)
Co-Leaders: Frode Stordal (Norwegian Institute for Air Research)
John Walsh (University of Illinois-Urbana)

2.2 Oceanography, geophysics
Co-Leaders: Ola M. Johannessen (Nansen Environmental and Remote Sensing Center)
Knut Aagaard (University of Washington)

2.3 Paleoclimatology
Co-Leaders: Anders Elverhøi (University of Oslo)
Ray Bradley (University of Massachusetts)

2.4 Biology
Co-Leaders: Dag O. Hessen (University of Oslo)
Brendan Kelly (University of Alaska Fairbanks)

12.00 – 13.00 **Lunch at UNIS**

13.00 – 16.00 Excursions to the EISCAT Svalbard Radar, the Auroral Station in Adventdalen and the Svalsat ground station on the Longyear plateau, for those interested.

16.00 – 17.00 *Session 3, Scientific co-operation within specific themes, continued discussions*
The Auditorium, meeting rooms, UNIS
Parallel sessions: Introductions and discussions about potential co-operation

1. Upper atmosphere research (research that demands heavy infrastructure):

2. Global change research
2.1 Air (ozone depletion and UV)
2.2 Oceanography, geophysics
2.3 Paleoclimatology
2.4 Biology

17.00 – 19.00 *The Auditorium, UNIS*
Plenum session: Summing up working groups, and discussions about potential co-operation—problems and opportunities
Chair: Julie Brigham-Grette
Leaders of working groups will present summaries

19.30 – 21.30 Dinner at Huset

22.00	Ship to Ny-Ålesund (*Lance*, approx. 25 persons, 11 hours journey) Parallel departure by plane to Ny-Ålesund for those who do not travel by ship (approx. 15 persons).

Wednesday, 18 August

09.00 – 12.30	*Session 4, General orientation about Ny-Ålesund as a station for clean Environmental Research* *The New Research Station, Ny-Ålesund* Guided tour in Ny-Ålesund and to relevant research stations
12.30 – 13.30	Lunch at Messa
13.30 – 17.00	*Session 5, Scientific co-operation within specific themes, continued discussions* *The New Research Station, Ny-Ålesund* Parallel sessions (Continued discussions on potential scientific co-operation): 1. Upper atmosphere research (research that demands heavy infrastructure): 2. Global change research 2.1 Air (ozone depletion and UV) 2.2 Oceanography, geophysics 2.3 Paleoclimatology 2.4 Biology
17.00 – 19.00	Dinner, coffee at Messa, shopping
19.00 – 20.30	*The New Research Station, Ny-Ålesund* (Continued and concluding discussions on potential scientific co-operation) Either Plenum or Parallel working group sessions (TBD)
21.00	Ship to Longyearbyen (*Lance*, approx. 25 persons, 11 hours journey) Parallel departure by plane to Longyearbyen for those who do not travel by ship (approx. 15 persons).

Thursday, 19 August

08.30 – 10.50	*Session 6, Conclusions and follow-ups* *The Auditorium, UNIS* **Chair:** Professor Dag Hessen, University of Oslo, new head of the Norwegian National Committee for Polar Research Summing up of the potential for a strengthened Norwegian-American scientific co-operation on and around Svalbard. Head lines for future co-operation, thematically. Following up: Who does what, when. Discussion on a process for the handling of applications in both countries related to the workshop.

10.50 – 11.00	Concluding remarks, Tore Olsen, Ministry of Education, Research and Church Affairs
11.00 – 13.00	Lunch at the hotel, shopping
13.00	Bus departure for the airport
14.05	Departure, flight BU 464 for Tromsø and Oslo

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(Names of people who attended the workshop are in **bold**.)

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Appendix F: Acronym List

ARCUS	Arctic Research Consortium of the United States
ARM	Atmospheric Radiation Measurement program (U.S. Department of Energy)
AVHRR	Advanced very high resolution radiometer
AWI	Alfred Wegener Institute for Polar and Marine Research
CAVM	Circumpolar Arctic vegetation map
CMDL	Climate Modeling and Diagnostics Laboratory (U.S. NOAA)
DIAL	Differential absorption lidar
EISCAT	European incoherent scatter radar
ERS	Earth Resources Satellite
IARC	International Arctic Research Center
IASC	International Arctic Science Committee
MODIS	Moderate resolution imaging spectroradiometer
MST	mesosphere, stratosphere, troposphere
NASA	National Aeronautics and Space Administration (U.S.)
NDSC	Network for the Detection of Stratospheric Change
NDVI	Normalized difference vegetation index
NERC	Natural Environment Research Council (U.K.)
NILU	Norwegian Institute for Air Research
NIPR	National Institute of Polar Research (Japan)
NMA	Norwegian Mapping Authority
NOAA	National Oceanographic and Atmospheric Administration (U.S.)
NPI	Norwegian Polar Institute
NSF	National Science Foundation (U.S.)
NySMAC	Ny-Ålesund Science Managers Committee
ODP	Ocean Drilling Program (U.S.)
PCSP	Polar Continental Shelf Project (Canada)
PMC	Polar mesospheric clouds
PMSE	Polar mesospheric summer echoes
POP	Persistent Organic Pollutant
SAR	Synthetic Aperture Radar
SCICEX	Scientific Ice Expeditions
SHEBA	Surface Heat Budget of the Arctic
SNSK	Store Norske Spitsbergen Kulkomani AS
SNU	Svalbard Naeringsutvikling
SOUSY	Sounding System Svalbard Radar (Svalbard Radar)
SpiTra	Spitsbergen Travel
SSD	Svalbard Sumfunnsdrift
SSF	Svalbard Science Forum
TEM	Terrestrial Ecosystem Model
UNIS	University Courses on Svalbard
WMO	World Meteorological Organization

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