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.

Arctic fox were trapped for furs on Svalbard, beginning in the 16th century. 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.

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.

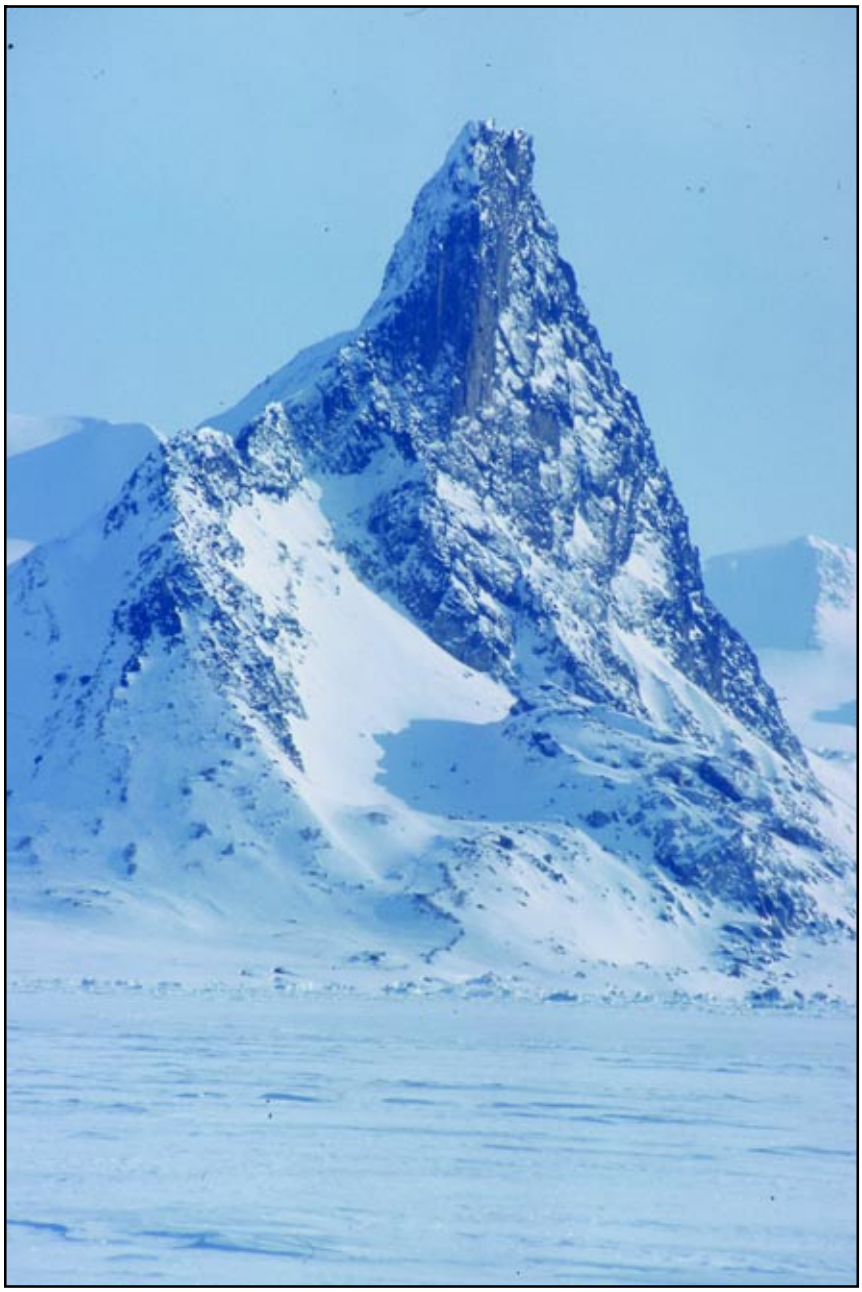
An aerial view of Ny-Ålesund, an active international science community, covered by early winter snow. Note the new pier that is able to accommodate large supply vessels. The road network is limited to the immediate vicinity of the settlement. Photo by Jaakko Putkonen.

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

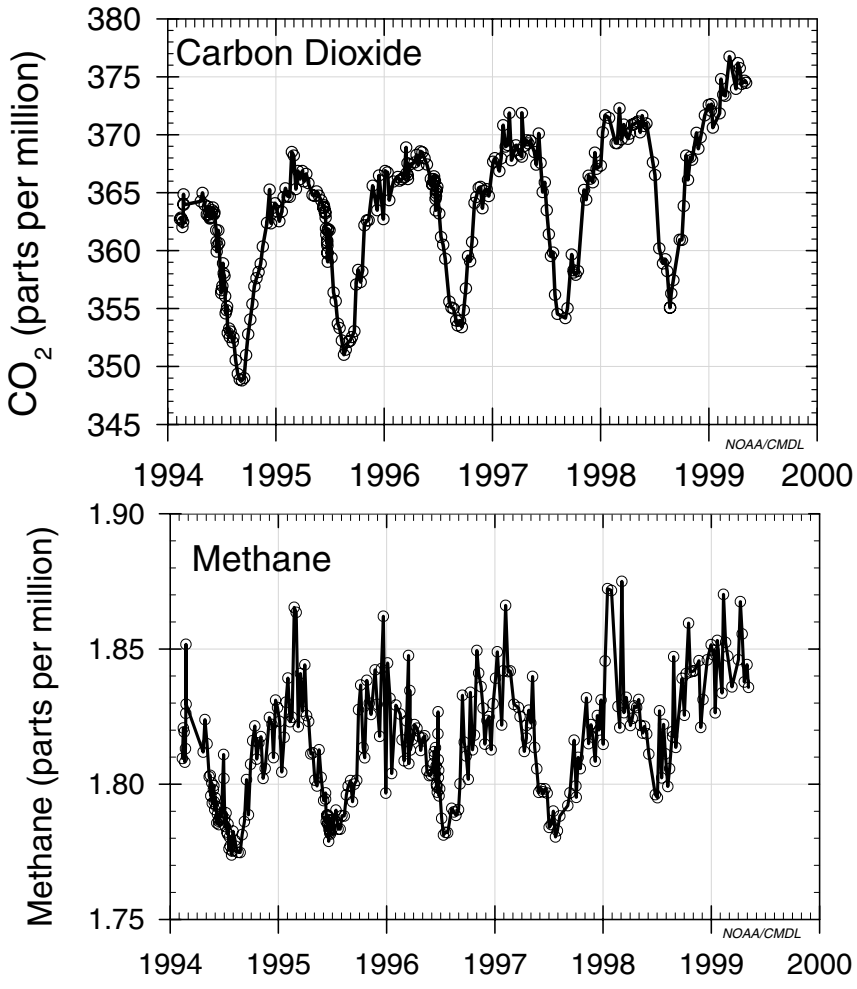
Participants at the August 1999 workshop discussed research needs and priorities and developed recommendations for potential collaboration and strengthened scientific cooperation on and around Svalbard. The multidisciplinary and disciplinary science priorities agreed upon are summarized here. Working 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 peri-

ods 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.

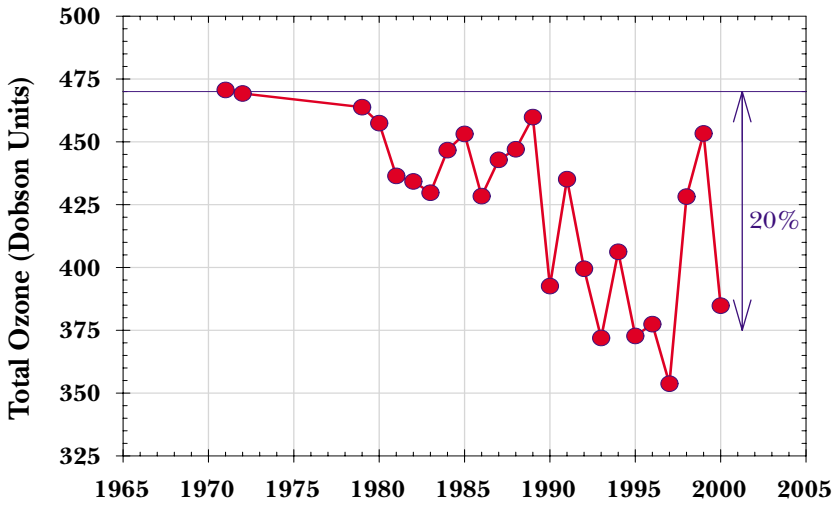
How will climatic changes interact with stratospheric ozone dynamics and UV radiation?

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.

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

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.

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.

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.

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.

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).

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

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.

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.

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.*

Illustration © Mountain High Maps, modified by Sue Mitchell.

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.

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.

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

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.