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

B

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*
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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.

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

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 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

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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*

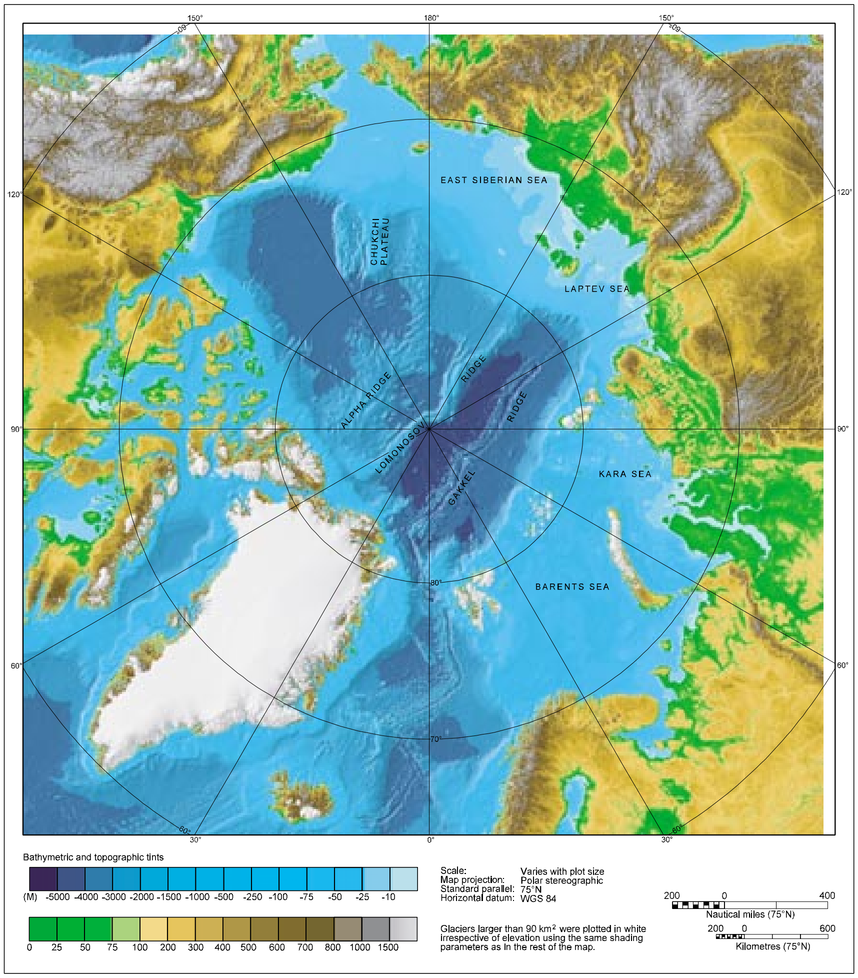
Svalbard sits in the Atlantic portals leading into the high-latitude Arctic and is uniquely situated to illuminate the Atlantic connections between the Arctic and the rest of the global ocean, including connections of climatic consequence. For example, the advection by the West Spitsbergen Current of 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.

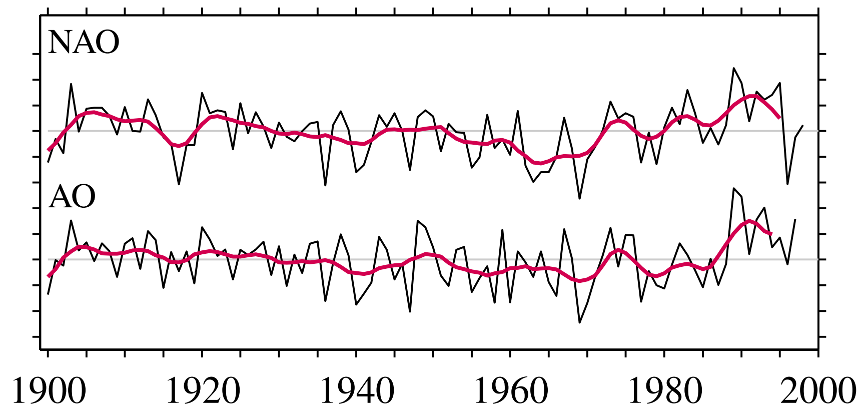
Norwegian-American cooperation on Svalbard can contribute to this problem set by:

- 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

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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

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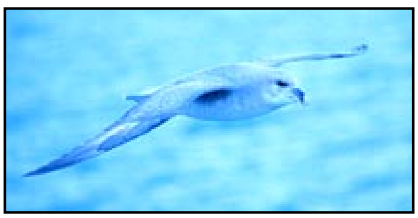
Brendan Kelly, *University of Alaska Fairbanks*
Participants: Brian M. Barnes, *University of Alaska Fairbanks*
P. Dee Boersma, *University of Washington*
Bjørn Munro Jensen, *Norwegian University of Science and Technology*
George Kling, *University of Michigan*
Pål Prestrud, *Norwegian Polar Institute*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

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

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.

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

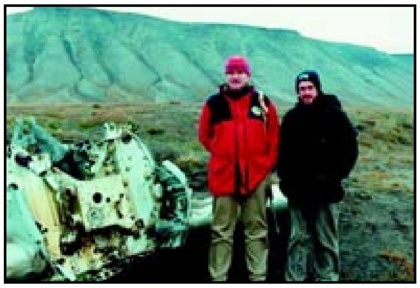
What are the consequences of bio-accumulation and bio-concentration of pollutants on arctic organisms? How do petroleum hydrocarbon spills persist in the Arctic?

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

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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

Appendix E: Participants, Contributors, and Reviewers

(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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