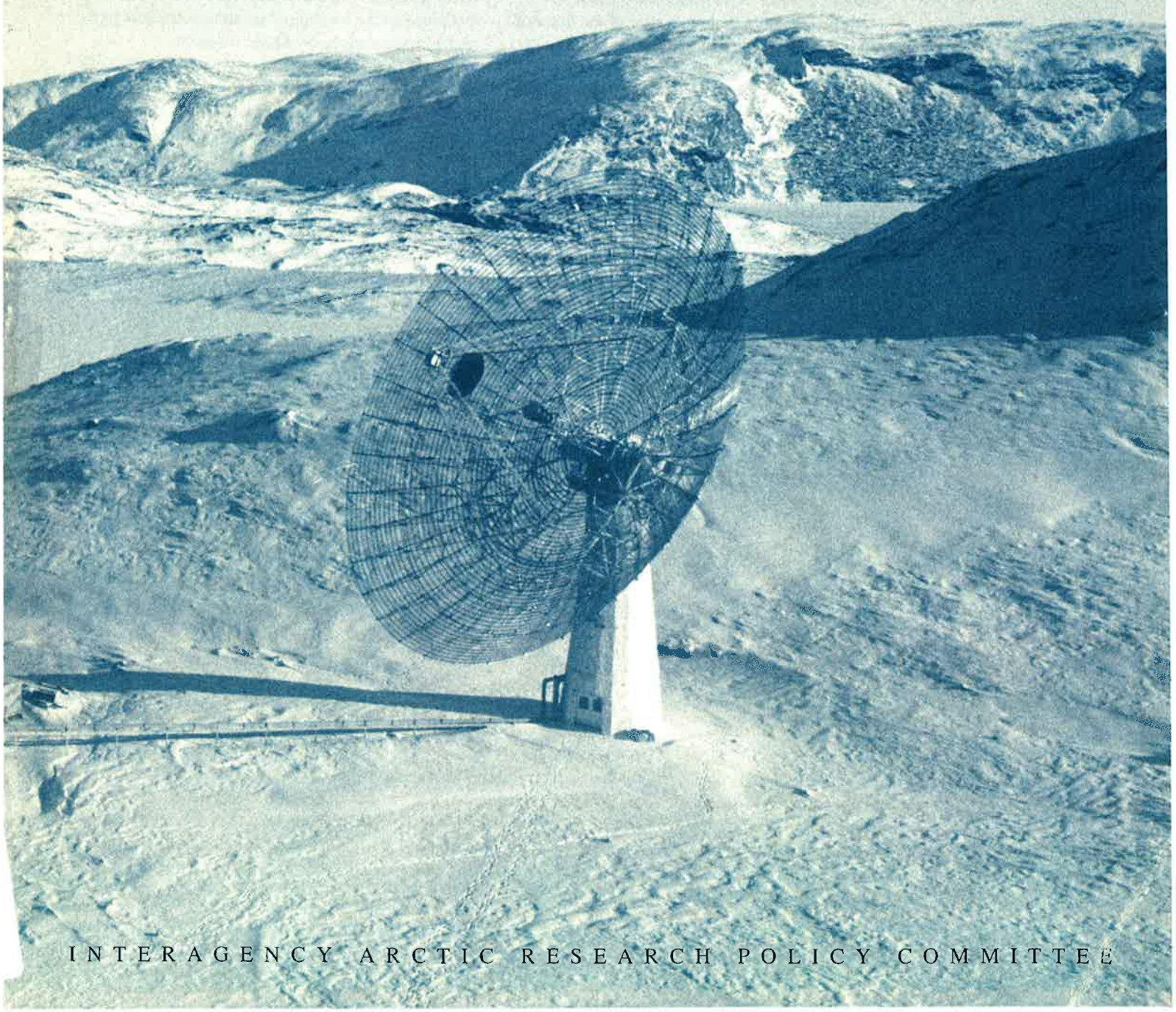
VOLUME 6 SPRING 1992

ARCTIC RESEARCH

OF THE UNITED STATES



INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

About the Journal

The journal *Arctic Research of the United States* is for people and organizations interested in learning about U.S. Government-financed Arctic research activities. It is published semi-annually (spring and fall) by the National Science Foundation on behalf of the Interagency Arctic Research Policy Committee and the Arctic Research Commission. Both the Interagency Committee and the Commission were authorized under the Arctic Research and Policy Act of 1984 (PL 98-373) and established by Executive Order 12501 (January 28, 1985). Publication of the journal has been approved by the Office of Management and Budget.

Arctic Research contains

- Reports on current and planned U.S. Government-sponsored research in the Arctic;
- Reports of ARC and IARPC meetings;
- Summaries of other current and planned Arctic research, including that of the State of Alaska, local governments, the private sector and other nations; and
- A calendar of forthcoming local, national and international meetings.

Arctic Research is aimed at national and international audiences of government officials, scientists, engineers, educators, private and public groups, and residents of the Arctic. The emphasis is on summary and survey articles covering U.S. Government-sponsored or -funded research rather than on technical reports, and the articles are intended to be comprehensible to a nontechnical audience. Although the articles go through the normal editorial process, manuscripts are not refereed for scientific content or merit since the journal is not intended as a means of reporting scientific research. Articles are generally invited and are reviewed by agency staffs and others as appropriate.

As indicated in the U.S. Arctic Research Plan, research is defined differently by different agencies. It may include basic and applied research, monitoring efforts, and other information-gathering activities. The definition of Arctic according to the ARPA is "all United States and foreign territory north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian chain." Areas outside of the boundary are discussed in the journal when considered relevant to the broader scope of Arctic research.

Issues of the journal will report on Arctic topics and activities. Included will be reports of conferences and workshops, university-based research and activities of state and local governments and public, private and resident organizations. Unsolicited nontechnical reports on research and related activities are welcome.

Address correspondence to Editor, *Arctic Research*, Division of Polar Programs, Room 620, National Science Foundation, Washington, D.C. 20550.

Covers

The Sondrestrom Radar Facility. This facility, located above the Arctic Circle in southwestern Greenland and operated for NSF by SRI International, is a major hub for upper-atmospheric and solar–terrestrial research. The principal instrument, an incoherent scatter radar with a 33-m fully steerable parabolic antenna, is complemented by a wide range of instrumentation, including spectrometers, imagers, interferometers, magnetometers, riometers and a lidar. The Sondrestrom Radar Facility is the largest NSF-supported facility north of the Arctic Circle.

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National Science Foundation

National Science Foundation research is concerned with the entire Arctic region, including Alaska, Canada, Greenland, Svalbard, the Arctic Ocean and adjacent seas, and the upper atmosphere and near space. Research falls principally within seven major scientific disciplines: atmospheric science, ocean science, biology, earth science, glaciology, engineering and education. The total expenditures for FY 91 were $27 million.

NSF supports a formal Arctic research program within the Division of Polar Programs (DPP). Other divisions and programs throughout NSF, primarily in the Directorate for Geosciences and the Division of Environmental Biology in the Directorate for Biological Sciences (formerly known as the Division of Biotic Systems and Resources in the former Directorate for Biological, Behavioral and Social Sciences), support Arctic research as part of their overall funding. Research grants are provided on the basis of unsolicited proposals and are peer-reviewed.

In FY 91, NSF awarded funds for Arctic research to 98 institutions in 38 states and the District of Columbia, representing 229 projects. NSF's support of Arctic research, including facilities support and field operations, over the past several years is shown below (in thousands of dollars).

	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
DPP	7947	8005	8095	8211	10175	12310	14696
Other NSF programs	11482	10139	13799	14907	13556	11778	12455
Total	19429	18144	21894	23118	23731	24088	27151

The following sections present highlights of several major programs and selected projects. A complete listing of NSF Arctic funded projects is given in the publication *Arctic Science, Engineering, and Education Awards: FY 91*, available from the Division of Polar Programs, National Science Foundation, Washington, DC 20550.

Arctic System Science

The National Science Foundation established the Arctic System Science (ARCSS) program in 1986. ARCSS is structured to be a regional component within the U.S. Global Change Research Program. Administration of the program utilizes review expertise and financial support from the divisions of the Geosciences Directorate and from other components of NSF as appropriate. ARCSS is coordinated by the Division of Polar Programs.

FY 91 FUNDING (thousands)

Atmospheric Sciences	5147
Ocean Sciences/Ship Support	5351
Biological Sciences	3059
Arctic System Science/Glaciology	8168
Earth Sciences	2537
Engineering	122
Social Science/Education	2026
Coordination	221
Arctic Research Commission	497

Through a series of workshops and interactions with a broad scientific community, ARCSS has refined its goals and mandates. Its goals are:

- To understand the physical, chemical, biological and social processes of the Arctic system that interact with the total earth system and thus contribute to or are influenced by global change, in order
- To advance the scientific basis for predicting environmental change on a decade to centuries time scale and for formulating policy options in response to the anticipated impacts of rapid climate change on humans and societal support systems.

ARCSS consists of two principal areas of endeavor: reconstruction of paleoenvironments and process studies of present-day environmental interactions. It consists of three principal components: Paleoenvironmental Studies, Ocean/Atmosphere/ Ice Interactions (OAII) and Land/Atmosphere/Ice Interactions (LAII). Individual Science Steering Committees (SSCs) for each component facilitate and enhance the ARCSS program and provide a focal point for communication with the scientific community. Overall coordination and integration of the ARCSS components and individual projects are accomplished by the ARCSS Coordination Panel. The panel includes representatives from each SSC, plus a few others to enhance the scientific breadth and experience of the group.

Paleoenvironmental Studies

The first component of the ARCSS program to be initiated was paleoenvironmental studies. An element of that component is the second Greenland Ice Sheet Program (GISP2), which is in the process of retrieving a deep ice core from central Greenland. The 3000-m-deep GISP2 core will yield a high-resolution, 200,000-year history of global change, including two interglacial and two glacial cycles, the longest such record available from the Northern Hemisphere. This program began with FY 89 funding. Its five-year field effort will end after the summer of 1993. Investigators will continue to analyze the ice core retrieved by GISP2 and synthesize and publish their results for years following the program. Funds released with the cessation of field work will be invested in other components of ARCSS. Further discussion of GISP is included in the description of NSF's Glaciology Program.

ARCSS is a ten-year effort, taking place concurrently with expanded operational capabilities of U.S. research platforms and improved monitoring capabilities

Paleoclimates of Arctic Lakes and Estuaries (PALE), another element of the paleoenvironmental studies component, is a program to evaluate terrestrial and near-shore climatic fluctuations and the environmental response to changing climate over the past 20,000 years by obtaining and analyzing lake and ocean sediment cores. This element was initiated through the Division of Polar Programs' Polar Earth Sciences Program in FY 90. ARCSS funding for PALE began in FY 92.

Ocean/Atmosphere/Ice Interactions

This component is designed to address the following priority areas: surface energy budget, atmospheric radiation and clouds; circulation of the Arctic Ocean; hydrologic cycle of the Arctic Basin; productivity and biogeochemical cycling in the marginal and adjacent seas; coupled modeling of the air–sea–ice system; and paleo-oceanography of the Arctic.

This program began in earnest using FY 91 funds. A solicitation, responsive to science community input, was issued in 1991. The Northeast Water Polynya (NEW) program, a multidisciplinary program composed of 14 principal and co-principal investigators, will undertake field research in July 1992 using the U.S.C.G.C. *Polar Sea.*

In addition to the NEW project, several individual proposals were funded to undertake early modeling efforts and to analyze existing data sets. Biogeochemical studies will also be undertaken in the Chukchi and Beaufort seas using the R.V. *Alpha Helix.*

An interagency (NSF, ONR, NASA) solicitation for proposals to establish a long-term mooring array in the Western Arctic was issued. Data obtained from this effort will be available to the oceanography community.

Land/Atmosphere/Ice Interactions

The Land/Atmosphere/Ice Interactions (LAII) component of ARCSS emphasizes multidisciplinary coordinated programs evaluating:

- Arctic feedback processes that may amplify global climate change;
- Changes in Arctic hydrologic and biogeochemical systems and their effects;
- Changes in biotic communities and how these will affect Arctic and global systems; and
- How these changes in the Arctic will affect, and be affected by, human activities.

Execution of all components of the program will require coordination of field experiments and laboratory studies, modeling activities, data synthesis and space- and ground-based observation systems. An efficient data and information network is necessary to facilitate research on these key areas. New modeling initiatives will be undertaken to incorporate new information and our improved understanding of Arctic processes into predictive models of the Arctic and the global climate system.

The ARCSS program is a ten-year effort, taking place concurrently with expanded operational capabilities of U.S. research platforms and improved monitoring capabilities. The early phase of ARCSS research will emphasize analysis and synthesis of existing data, time series experiments that must begin immediately, modeling and the design of experiments. Observations that aid in planning more intensive field efforts are also needed at the earliest possible stage. The measurement program will be coordinated as closely as possible with other ongoing and planned field programs to maximize the benefit derived from logistical opportunities.

Development of the ARCSS program has been facilitated through the Arctic Research Consortium of the U.S. (ARCUS) and the Joint Oceanographic Institutions (JOI, Inc.). Workshop reports,

science plans and further information on the Science Steering Committees and Coordination Panel are available from the ARCSS Project Office of ARCUS.

NSF funded 51 projects in Arctic system science and glaciology, totaling $8.17 million in FY 91, including logistical and technical support of the Polar Ice Coring Office (PICO) at the University of Alaska–Fairbanks and the scientific coordinating activities of the University of New Hampshire's GISP2 Science Management Office (SMO).

Glaciology

The research that was supported includes the study of all forms of naturally occurring ice and its history under a broad multidisciplinary glaciology research program. Some examples are studies of past climates and atmospheric paleochemistry from ice cores, ice stream dynamics, glacial geology, hydrology and the mass balance of mountain glaciers and ice sheets. The research takes place primarily in Alaska, Greenland, Arctic Canada and Washington state. However, some limited funding goes to support research in high-altitude, mid- and low-latitude regions of the Northern Hemisphere.

The program also supports research on new methods of studying glaciers and ice sheets, including the development of improved remote sensing capabilities, drilling methods and methods for analyzing ice cores. In addition a variety of theoretical, laboratory and data analysis projects were funded in this biennium. These include studies of liquid-like water in frozen porous media, a study of the motion of particles in melting snow, and analyses and syntheses of glaciological data from Greenland and Alaska.

Arctic Glacier Studies

The purpose of these projects was to increase the understanding of the mechanisms responsible for the surge behavior of glaciers. Work has focused on the role of subglacial water in the surge process. Internal deformation, basal water pressure, ice temperature, electrical conductivity and turbidity, among other characteristics, have been measured in boreholes in the ice and at the termini of various glaciers.

Scientists from the University of Alaska and University of Washington have made automated measurements since 1986 to define the seasonal motion and stream behavior of Fels and Black Rapids glaciers in Alaska. They also studied the August 1987 to July 1988 surge of the West Fork Glacier, Alaska; the maximum displacement was about 4 km.

University of Alaska and University of Maine scientists have been studying the Jakobshavn Glacier in Greenland. They measured very high velocities (up to 22 m/day) on the floating terminus. There was no seasonal variation of velocity. The grounding line was defined, and an ice rise beneath the floating terminus was discovered. They determined that the concave-up surface profile is similar to Antarctic ice streams. Large calving events occur and vary strongly with season. They studied sheet-flow-to-stream-flow transitions using orthophoto maps of surface elevation and velocity produced by photogrammetry, and they determined the relationship to the types and distribution of crevasses.

GISP2

During the summer of 1990 the GISP2 remote field camp in the summit region of central Greenland (latitude 72°34.79′N, longitude 38°27.11′W, elevation 3203 m) was reoccupied, and more camp facilities and a processing line for handling the ice core were constructed. Drilling began again at approximately 200 m (where it had left off at the end of the 1989 field season), and by the end of the season, ice core had been recovered and processed down to 335 m. The 1990 field season was the first in which the new 13.2-cm-diameter deep drill, developed by the Polar Ice Coring Office, was used with the new drilling fluid chosen for the GISP2 project, n-butyl acetate.

During the 1991 field season the camp was again reoccupied, and two shifts of drillers working around the clock successfully drilled to 1510 m. The ice core between about 700 and 1300 m was too brittle to process immediately and was put in storage over the winter of 1991-92. This ice will be processed during the 1992 field season.

Preliminary results of the GISP2 research have been published in a variety of specialized journals, and new results are being prepared for publication. Some of these results include very accurate dating (year-by-year) of the ice core obtained to date. This dating has been accomplished using a combination of techniques, including visible stratigraphy, electrical conductivity measurements (ECM), laser light scattering analyses of submicron particles, oxygen isotopes, chemical analyses and identification of volcanic time horizons. The estimated age is about 700 A.D. at 336 m and approximately 9000 years B.P. at 1500 m.

A temperature history for the last 1000 years

has been obtained, showing a record that is very different from the classical record for Europe. This record has allowed an estimate to be made of the natural variability of temperature, which is on the order of 2°C. This temperature record shows a cold period at the beginning of the 20th century, with a warming since then. Warming peaked in the 1940s and 1950s and is beginning to show evidence of a renewed increase, although at the moment there is no clear greenhouse signal. Warming of the magnitude predicted by various models should be detectable above the natural variability.

Much Arctic upper-atmosphere research focuses on understanding global change; the upper atmosphere is critically sensitive to greenhouse gas changes—an effective "thermometer" for global warming.

Analyses of carbon dioxide in air bubbles in the ice core have demonstrated a constant atmospheric level of CO_2 of 280±5 ppmv between 1530 and 1810. Thereafter the concentrations rose abruptly. The record connects smoothly to the direct atmospheric observations from Mauna Loa.

Work is in progress to extract information on a large number of variables that will provide data on atmospheric composition and climate over the last 8000 years. Drilling at GISP2, which is expected to sample the entire depth of the Greenland ice sheet, is expected to be completed in 1993. This core will provide a climate baseline record for the Northern Hemisphere extending back some 200,000 years through two complete glacial–interglacial cycles.

In addition to the coring research, several scientific projects were conducted at the GISP2 camp and in the vicinity to provide supplementary information about the site for interpretation of the deep ice core results. These include snow pit and shallow core studies and a variety of atmospheric studies at the solar-powered clean air facility (ATM) located 28 km upwind from the main camp. The research at ATM involves projects to assess air–snow fractionation and to provide information about the transfer mechanisms of material from the atmosphere to the ice sheet. Fresh and aged snow and vapor were sampled to identify precipitation sources and postdepositional processes affecting the preservation of the chemical record in snow pits and ice cores.

During this period, two new automatic weather stations were installed downslope of the GISP2 camp (100 km west and south). This brings to seven the number of automatic weather stations that have been installed in the summit region of Greenland. Four of these units are positioned in such a way so as to be able to determine the vorticity and divergence around the Greenland crest. This work is in progress.

The 1990 field season included a test to determine the feasibility of using deep ice as a neutrino detector using photomultiplier tubes lowered down a six-foot borehole to a depth of 200 m. This work has been repeated now at the South Pole and is providing some exciting new results for astrophysicists.

In addition to the NSF-sponsored projects in Greenland, NSF, through the Polar Ice Coring Office, provides support on a cost-reimbursable and non-interference basis to other agencies for work in Greenland. These include projects supported by the U.S. Geological Survey, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the Department of Energy, the Naval Command Control and Ocean Surveillance Systems Center, the U.S. Air Force and the U.S. Army Cold Regions Research and Engineering Laboratory.

Permission to work in Greenland is generously provided by the Commission for Scientific Research in Greenland and the governments of Denmark and Greenland. The 109th TAG Air National Guard from Schenectady, New York, and the U.S. Air Force Military Airlift Command from McGuire Air Force Base in New Jersey provide transport to and from Greenland. Support at Sondrestrom Air Base in Greenland is provided by the U.S. Air Force Space Command.

Atmospheric Sciences

Atmosspheric sciences programs supported 39 projects totaling $5.15 million. NSF funding supports atmospheric research in the lower atmosphere, the upper atmosphere and the geospace regions from the middle atmosphere to the sun. Research projects include meteorology, climate dynamics, tropospheric and stratospheric chemistry, aeronomy, ionospheric physics, magnetospheric physics and solar physics. Within these disciplines, research involves studies of Arctic stratus clouds, Arctic haze, long-range transport of aerosols and trace gases over the Arctic Basin, polar stratospheric (noctilucent) clouds, stratospheric chemistry related to ozone depletion, auroral physics, airglow and auroral excitation and emission processes, magnetospheric–ionosphere interactions, and wave–particle coupling processes.

Much Arctic upper-atmosphere research focuses on understanding global change. The upper atmo-

sphere has miniscule thermal inertia compared to the oceans and lower atmosphere and thus is not a significant driver of weather and climate. Nevertheless, it is precisely this property that makes the upper atmosphere critically sensitive to greenhouse gas changes—an effective "thermometer" for global warming. Model calculations performed at the National Center for Atmospheric Research indicate that surface greenhouse warming of 2–9°F would lead to cooling in the upper atmosphere by 20–90°F, depending on altitude. Such dramatic changes would cause the upper atmosphere to change appreciably. Important human economic consequences, such as increased satellite drag and altered radio communications, would result.

Models predict that increasing methane abundance will lead to increasing hydrogen densities in the highest regions of the atmosphere, where the resulting increase in drag will reduce the lifetimes of orbiting satellites

Observations of the upper atmosphere already have revealed appreciable cooling during the past decade (about 5°F). The implied change in the lower atmosphere is small and nearly impossible to measure because of uncertain assumptions in weighting the enormous range of surface measurements needed to determine a global average. Clearly another advantage of the upper atmosphere as a global change indicator is that its sensitivity to local surface variability is far smaller than for the oceans and the lower atmosphere.

The CEDAR program (Coupling, Energetics and Dynamics of Atmospheric Regions) is a Global Change initiative in the Upper Atmosphere Research Section focused on exploiting these advantageous properties of the upper atmosphere in support of national global change objectives. More than half of its projects are directly related to or are carried out within the Arctic. State-of-the-art optical and radar remote sensing equipment has been deployed in the Arctic regions, and existing Arctic facilities have been upgraded and employed in support of the CEDAR community campaign objectives.

An important focus of CEDAR studies is the enigmatic Arctic noctilucent clouds discovered in 1885, two years after the Krakatoa eruption injected massive amounts of water vapor into the stratosphere. These clouds, which form in summer near an altitude of 50 miles, are the highest clouds on earth. The dramatic increase in the brightness and occurrence of noctilucent cloud displays since their discovery is believed to be related to decreasing upper-atmosphere temperatures and to increasing levels of methane, which reacts with oxygen to form water vapor. Incompletely understood radar and lidar echoes from the region of noctilucent cloud formation are believed to hold keys to determining their relationship to global change.

Models also predict that increasing methane abundance will lead to increasing hydrogen densities in the highest regions of the atmosphere, where the resulting increase in drag will reduce the lifetimes of orbiting satellites. Sensitive measurements of hydrogen airglow by a series of CEDAR-supported optical interferometric spectrometers distributed in Arctic and lower-latitude sites indicate that the predicted effect could be confirmed in the near future if careful measurements are continued. Current measurements indicate an increase consistent with predictions but only at a low confidence level.

The Geospace Environment Modeling (GEM) program is using a combination of theory and observing campaigns in a systematic effort to develop a general circulation model for the geospace environment, comparable to and inspired by general circulation models used for the lower atmosphere. GEM includes a comprehensive set of coordinated observations of auroral emissions and associated particle precipitation, electron densities and temperatures, and electric fields and currents from the Sondrestromfjørd radar site, the Greenland magnetometer chain and other Arctic observing stations.

At the international level the Solar–Terrestrial Energy Program (STEP) is an effort of the International Council of Scientific Unions (ICSU) to study the generation, storage and transfer of energy and matter from the sun to the earth's surface. STEP comprises 30 projects and 6 working groups. It involves approximately 4500 scientists in 42 countries. Since the polar regions are the prime access region to geospace, STEP has many Arctic science linkages, including NSF's CEDAR and GEM programs and a planned NSF–STEP initiative that will focus on scientific issues generally falling outside the Global Change initiative.

The Sondrestrom Radar Facility, located on the southwest coast of Greenland and operated by SRI International, is NSF's largest permanent base north of the Arctic Circle and a major hub of upper atmospheric and solar–terrestrial research. The facility is essential to the Global Change initiatives of CEDAR and GEM. The principal instrument is an incoherent scatter radar with a 33-m-diameter parabolic antenna. This radar is capable of measuring electron densities, electron and ion temperatures, and Doppler velocities over a large field of view at all ionospheric heights. To further the scientific capabilities and usefulness of the radar, the Sondrestrom facility also supports a wide range of instru-

ments (mostly university-owned), including spectrometers, images, interferometers, magnetometers, ionosondes and riometers. With this broad panoply of instruments and capabilities, the Sondrestrom facility attracts a continuous stream of scientists. Over the last three years, 150 scientists from over 50 institutions in 10 countries have done research using the Sondrestrom facility.

Currently a Rayleigh–aerosol lidar is being developed for Sondrestrom that will permit observations of stratospheric aerosols (including polar stratospheric clouds), middle atmospheric densities and temperatures, and polar mesospheric clouds. The lidar will become operational in early 1993.

A joint project between scientists from the University of Wyoming and the Russian Central Aerological Institute, entitled "Study of North Polar Vortex Phenomena," flew balloon-borne instrumentation from four Arctic sites, two in Canada and two in Russia. The instruments measure ozone, aerosols and polar stratospheric cloud (PSC) particles. There is some evidence for the direct (non-photolytic) destruction of ozone by PSCs, as well as the expected correlation between PSC development and the photochemical destruction of ozone by chlorine. There is also evidence of the destruction of ozone by aerosols from the Mt. Pinatubo volcano. This was perhaps the first NSF grant for research with a Russian co-principal investigator.

The high-latitude oceanic environment has two unique features: the low-salinity, low-density surface layer of the Arctic Ocean and the cold surface layers of the largely ice-free surrounding seas

The University of Maryland has built an imaging riometer (Radio Ionospheric Opacity Meter) called IRIS (Imaging Riometer for Ionospheric Studies) for Sondrestromfjord, Greenland, and South Pole Station, Antarctica. In addition, they operate nonimaging riometers at Iqaluit, N.W.T., Canada, and McMurdo Station, Antarctica. The IRIS pair provides, for the first time, the capability of studying auroral morphology at opposite ends of the same geomagnetic field lines, or "conjugate" auroral studies.

New York City Technical College, in collaboration with AT&T Bell Laboratories, operates a digital fluxgate magnetometer at Iqaluit, N.W.T., Canada, as well as at South Pole and McMurdo stations, Antarctica. This array, especially when coordinated with magnetometers of other investigators, allows the monitoring of ionospheric currents associated with auroral phenomena in both hemispheres.

The University of New Hampshire, in collaboration with the University of Minnesota and Augsburg College, operates an array of search coil magnetometers at Sondrestromfjord, Greenland, as well as at South Pole and McMurdo stations, Antarctica. This instrumentation detects ultra-low-frequency plasma waves,which propagate within the earth's magnetosphere. This work is closely coordinated with similar measurements taken from several NASA satellites operating within the magnetosphere. NASA has provided funds for that part of the research.

Stanford University continues to analyze data from very-low-frequency (VLF) radio waves detected by receivers at Lake Mistasini, Quebec, which were placed there specifically to receive signals from a VLF transmitter at Siple Station, Antarctica. These VLF waves are a sensitive probe of the inner magnetosphere. This project also uses satellite data.

Ocean Sciences

Ocean Sciences Programs supported 40 projects totaling $5.35 million in FY 91. Approximately two-thirds of the totals supported traditional oceanographic and sea-ice research, while one-third supported research in atmospheric chemistry, primarily at the GISP2 site.

The high-latitude oceanic environment has two unique features: the low-salinity, low-density surface layer of the Arctic Ocean, which inhibits deep vertical convection and allows the quasipermanent ice cover to exist, and the cold surface layers of the largely ice-free surrounding seas, which promote deep convection, ventilation of the deep ocean and production of the intermediate and bottom water masses of the global ocean. The Arctic Ocean, and the surrounding Chukchi, Bering, Barents, Norwegian and Greenland seas, form an integral part of the global climate system.

FY 91 marked the conclusion of the Greenland Sea Acoustic Tomography Program. The observations obtained by the six acoustic transceiver moorings that had been deployed in the Greenland Sea from 1988 to 1989 have been analyzed. The repeated advance and retreat of the sea ice over the array had a significant effect on the structure of the upper layers, and in midwinter there was at least one major deep mixing event on a horizontal scale of about 100 km.

A three-year study of the thermal, mechanical and electrical characteristics of sea ice as func-

tions of growth conditions was begun. These properties of sea ice are complex, depending on external factors such as air and ocean temperature, salinity, dissolved gas content, winds and currents at the ice–ocean interface, as well as the immediate growth history itself. Theoretically defined models of sea-ice growth and development could not be adequately tested because of the lack of independently derived data. One early result of this project has been the development of an instrument for measuring seismic velocities in small ice samples for nondestructive observations of the elastic modulus of sea ice.

The thermal, mechanical and electrical characteristics of sea ice are complex, depending on external factors such as air and ocean temperature, salinity, dissolved gas content, winds and currents at the ice–ocean interface, as well as the immediate growth history itself

The study of Arctic atmospheric chemistry processes continued in connection with the GISP2 program. Proper interpretation of the proxy climatic data recovered from the analysis of the ice core requires a detailed understanding of the exchange of gases and aerosols between the atmosphere and the snow surface, as well as their postdepositional chemical changes. Current studies focus on wet and dry deposition processes, scavenging in the atmosphere, sublimation and the loss of deposited material back into the atmosphere. Subtle variations, such as the concentration of soluble gases in snow and the temperature dependence of chemical equilibria at the snow–air interface, need to be studied and defined.

Biological Sciences

Biological Sciences Programs supported 18 projects totaling $3.06 million in FY 91. While the program supports research in all aspects of Arctic biology, most of the work focuses on questions in ecosystem studies, population biology and physiological ecology.

The major field program supported during FY 91 was the multi-investigator ecosystem project at Toolik Lake, in the foothills of Brooks Range, Alaska. The goal of the project is to understand and predict how the tundra lakes and streams function and how they respond to change. Long-term experimental manipulations of the system, including nutrient additions and lake trout manipulations, have shown that Arctic systems often do not respond for many years. In addition, it was found that long-term responses are not often predictable from short-term responses.

Studies of lake primary productivity and its control have shown that the lakes are strongly limited by phosphorus availability. The overall level of algal biomass can be predicted from the phosphorus inflow. By dividing the lake with a curtain and treating half the lake with nutrients, whole-system experiments on the mechanisms of nutrient cycling were possible. The results showed that phytoplankton biomass and primary production responded immediately to added nutrients. Zooplankton, fish and most benthic organisms respond after one or two years or not at all. One reason for the lag was that much of the phosphorus added to the lake was tightly bound to the iron-rich sediments and was not recycled to the overlying water. Other studies of the aquatic system have suggested that Arctic lakes and streams may act as gas conduits to the atmosphere, with the carbon dioxide flux from the water to the atmosphere. This is in contrast to the terrestrial system, which is thought to be a sink for atmospheric carbon in the Arctic.

A range of topics were supported as single-investigator projects, including studies of Arctic marine macroalgae, terrestrial plant communities and marine mammals. Research on metabolic adaptation for fasting in polar bears required mon itoring changes in body composition and physiological processes during times of feeding and fasting. It was shown that polar bears probably recycle their nitrogenous wastes in ways similar to winter-dormant black bears. Studies of the behavioral ecology of sea otters are focusing on the foraging ecology and demography of sea otters at Amchitka Island, Alaska. Research on plant succession in coastal terrestrial ecosystems in the high Arctic focuses on the role of cyanobacteria in carbon accumulation and nitrogen fixation. The results showed that these nitrogen-poor lowlands have a rich and dominant cyanobacterial flora, which, through nitrogen fixation, provide the major source of nitrogen in high-Arctic ecosystems. Other studies of nitrogen cycling focused on nutrient additions to moss–willow hummock and sedge–moss communities.

The Long-Term Ecological Research (LTER) network established by NSF beginning in 1980 offers a number of advantages to the ecological research community in general and to Arctic-oriented ecologists specifically. These include:

- The emplacement of two LTER projects in the U.S. Arctic region: the Toolik Lake project described in the Spring 1990 issue of this publication and the Bonanza Creek project located near Fairbanks, Alaska;

- The accumulation of long time-series data sets; and
- The orientation of LTER projects toward collaboration and cooperation with other scientists who share interest in ecosystems of the Arctic region.

The principal focus of the Bonanza Creek LTER project is a long-term study of taiga ecosystem structure and function, emphasizing the pattern and rate of successional change and the controls over these processes during floodplain succession along the Tanana River and following fire in the uplands. To document the changing nature of ecosystem controls, a series of long-term experiments have been implemented to examine:

- Vegetation change and demographic controls over successional processes;
- Vegetation-induced modifications in resources and standing crops of biomass and nutrients;
- Controls over the nutrient supply; and
- The influence of herbivores on ecosystem structure and function.

Although one cannot expect quick results from long-term experiments or observational data sets, the value of such efforts has already been apparent during the first five years of the Bonanza Creek LTER project. During this initial period a record seed year was recorded for white spruce, which produced more than 57 million seeds per hectare during 1987. During extremely cold periods the Bonanza Creek floodplain weather station consistently records temperature that are 8–10°C colder than the Fairbanks airport weather station. The stations are located in nearly identical topographic positions, but the LTER station will be a much better indicator of climate trends than the airport station, which is subject to "heat island" effects from the city. Ongoing data-gathering efforts revealed a major disturbance phenomenon in the 1990–91 winter, when a record snowpack was recorded, 144% more than the previous record. A significant result of this record set of snow conditions was the breakage of 10–30% of the white spruce stems in both upland and floodplain tree stands. Damage appraisals of tagged and mapped trees enabled project scientists to relate breakage to tree position within a stand and stand position within the successional sequence. A much more refined view of the productive capacity of interior Alaska forests will result from the continuation of LTER project efforts like these. It is not difficult to see that these ongoing studies will become more valuable as data time lines are extended; there is no substitute for being "up and running" when irregular, episodic events occur.

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The Toolik Lake LTER project has produced equally intriguing results. Tundra plant fertilization experiments show that there is a two- to three-year delay in plant growth and flowering responses to nutrient amendments. In rivers, competitive interactions between caddis flies and black flies intensify under nutrient enrichment, causing caddis flies to outcompete and dominate black flies. Carbon dioxide occurs in a supersaturated state in tundra soil water, streams and lakes. The excess CO_2 appears to derive from organic decomposition in soils and probably accounts for 20–50% of the net primary productivity for the tundra ecosystem. A model-based comparison of the tundra system with a temperate forest has shown that the very different looking ecosystems share similar qualitative behaviors. Both respond very little to increased CO_2 alone (simulated over 50 years to a doubling of current levels) because of severe nitrogen limitations. Both systems respond significantly to simultaneous increases in CO_2 and temperature by increasing plant-bound carbon by one and a half times. This combined effect is most likely a result of more available soil nitrogen caused by increased microbial decomposition. The general similarities of the two systems are probably associated with the large stocks of soil organic matter in both and the inherently slow turnover of these soil carbon stocks.

Resurrection Bay, near Seward, Alaska, is the sampling site for a study by scientists from the University of Alaska on the genetic characterization of marine ultramicrobacteria, which are some of the smallest bacteria on earth. These mysterious organisms appear to be near the lower limit of size for cellular life, and they may also be of considerable ecological importance in Arctic waters. Studies of these bacteria involve measuring their genome size, the size of the DNA molecule coding for their life functions. Other techniques of molecular biology are being used to assess genetic diversity, define species and determine evolutionary relationships among these organisms.

Another study will be looking at phenotypic diversification in the three-spined stickleback (*Gasterosteus aculeatus*). With the retreat of Pleistocene glaciers from the coasts of Alaska, many new freshwater habitats formed. These streams and lakes were colonized by this diminutive marine

fish. These freshwater populations rapidly evolved differences in behavior and body form, a process referred to as adaptive radiation. The divergence of reproductive behavior among these freshwater populations may have already led to the origin of new species or is in the process of doing so, and it may have been the principal factor setting the stage for the genetic isolation of populations and diversification of other characteristics among the freshwater sticklebacks as they departed from their marine ancestors. This study comparing marine and freshwater populations seeks to understand the role played by changes in reproductive behavior during this episode of explosive evolution. Field data for this project will be collected for stickleback populations in many lakes surrounding Cook Inlet, Alaska. Laboratory parts of the project will be done at the University of Arkansas.

There are very few sources of paleoclimatic data from the Arctic; currently only ice cores can provide continuous records with annual resolution

Building on the recommendations of two earlier NSF workshops on the Arctic, a planning workshop for the International Tundra Experiment (ITEX) was held at Michigan State University in December 1990 to design a simple, inexpensive, long-term experiment to assess the effects of climate change on Arctic vegetation. An international group of experienced Arctic botanists and soil ecologists developed an experiment focused on organisms' responses within a system, which they felt would complement the larger, system-function experiments being conducted by multidisciplinary groups and funded by several agencies. The planning workshop and the resulting experimental protocol contribute to the terrestrial component of NSF's Arctic System Science Program and can serve as a model for further international experiments involving other critical biological taxa, such as invertebrates and microorganisms.

Earth Sciences

Earth Sciences Programs supported 44 projects totaling $2.54 million in FY 91 in geological, geophysical and quaternary research. These projects seek to understand the tectonic evolution and geologic history of the Arctic Basin and its margins and to answer local and regional geologic questions.

There are very few sources of paleoclimatic data from the Arctic. Currently only ice cores can provide continuous records with annual resolution, but the interpretation of ice core isotopic data on time scales of decades to centuries is very difficult. Different cores provide inconsistent records.

A possible additional source of paleoclimatic information is laminated lake sediments. Hydrological conditions in the Arctic favor the formation of annually laminated sediments since runoff and associated sediment flux is confined to a two- to three-month period each year, followed by a period when the lacustrine environment is quiescent and ice covered. Not all Arctic lakes contain laminated sediments; in most lakes benthic organisms disturb and mix the accumulating sediments, destroying the laminar structure. However, in some locations, seawater has been "trapped" in lake basins by isostatic emergence of the coast, resulting in density-stratified (meromictic) conditions in which the lake bottom waters contain no oxygen. Under such conditions, no benthic organisms are present to mix the sediment, and laminated sediments can be preserved.

Several meromictic lakes containing "old" seawater are present along the northern coast of Ellesmere Island. At Taconite Inlet the University of Massachusetts, in collaboration with Bates College, has established a research camp to investigate the processes involved in the formation of laminated sediments in coastal meromictic lakes. The objective is to understand contemporary processes in order to interpret longer-term environmental changes represented in sediment cores from the lakes.

To this end, meteorological and hydrological processes have been monitored during the 1990 and 1991 melt seasons, and the sediment flux in the rivers draining to the lakes was studied at the same time as the biological and physical limnology of the lakes was being monitored. The results so far point to the importance of solar radiation in controlling runoff in the early season; more than 70% of the annual sediment flux was associated with snowmelt runoff, although rain events later in the season may also be very significant.

Biological productivity is primarily confined to the shallow water moat around the lake ice. Trapping of solar radiation in one ice-covered lake has led to year-round water temperatures above 10°C at a depth of about 12 m, creating a unique habitat analogous to conditions found in some Antarctic Dry Valley lakes. Further research is underway to date the sediments and to clarify their sedimentary and biological characteristics.

Paleontologists from Harvard University continue their investigations into the origin of mammals. This work is being conducted in the Late Triassic Fleming Fjord Formation of Jameson

Land in East Greenland. Specifically scientists hope to obtain more complete material of Late Triassic mammals to resolve a number of long-standing problems; for example, the oldest record of mammals is a haramiyid tooth, but is a haramiyid really a mammal?

The Fleming Fjord Formation is well exposed and offers the opportunity to examine a range of facies over a greater geographic extent than at European localities that have yielded isolated teeth of mammals. Because of this some scientists believe that the Fleming Fjord and underlying formations may provide a more complete sample of Norian Age vertebrates than previously known. It has been demonstrated that the Fleming Fjord Formation is fossiliferous and represents the appropriate Late Triassic Age (Norian) in which to search for a more complete record of the early evolution of mammals.

Previous research identified several sites where small bones occur in abundance and has already determined that the fauna of the Fleming Fjord Formation will be one of the best-documented Late Triassic faunas known in the world. Current and future research may make it possible to actually quarry and retrieve some of these bones for further study and to examine other areas for vertebrate fossils. Establishing the age of the Fleming Fjord fauna will contribute substantially to our understanding of those major faunal transitions that took place between Late Triassic and Early Jurassic time and will provide an essential base for evaluating hypotheses regarding extinction events, as well as rates of origination.

A cooperative effort among scientists from Norway, Denmark and the University of Wyoming is focusing on processing and interpreting crustal reflection data obtained from the Archean rocks of West Greenland in 1989. The Archean rocks represent some of the best-exposed, best-studied and oldest rocks known and therefore are a prime target for crustal reflection studies.

A gravity study in the area has been completed, and scientists are working on a combined gravity magnetic interpretation. To date the research has shown that the Isua supracrustal rocks are 3.75 billion years old and that the Godthab area is marked by two Archean crustal sutures. Coincident CDP and reversed wide-angle seismic reflection profiles were recorded along the coast and along two fjords up to 150 km inland. The CDP data showed good dipping reflections to depths of 30 km that may be from mylonites marking a suture, and the wide-angle data with close-station spacing out to 150–200 km showed numerous intracrustal phases. The problems currently being addressed by their continued research are:

- The continuation of the deformation zone to depth;
- Crustal shortening and the mode of deformation;
- The role of volatiles in the deep crust;
- Changes in the Moho depth;
- Archean crustal development;
- The nature of the deep crust under granulites;
- The continuation of supracrustal rocks to depth;
- The nature of the Moho; and
- The structural transition to a passive margin.

Engineering and Technology

NSF funded five projects in Arctic engineering and technology, totaling $122,000 in FY 91. Support in engineering, material sciences and permafrost are provided by the Engineering, Geosciences, and Mathematical and Physical Sciences directorates. Research includes studies of the mechanical properties of ice, the hydraulic conductivity of frozen soils, metamorphism of dry snowpacks, three-dimensional analyses of ice, and permafrost.

NSF also sponsors a program for science-based and high-technology small business firms, the Small Business Innovative Research (SBIR) program in the Engineering Directorate. SBIR is interested in research on advanced concepts in scientific or engineering areas, particularly where the research may serve as a base for technological innovations. In FY 91 the SBIR program funded projects on water treatment by application of high potential gradients and ozone, and on fuel cells for energy production in the polar regions.

Social Science and Education

Following recommendations from the National Science Board and the Polar Research Board, a broad multidisciplinary research program in the Arctic Social Sciences was established in the Division of Polar Programs in FY 89. The NSF Arctic Social Sciences Program is the only national Arctic social sciences research funding program in the circumpolar world.

The Arctic Social Sciences Program recently initiated its fourth funding cycle. In its first year, 36 proposals from 27 institutions in 18 states were received. Some $3.2 million was requested, and awards amounting to $1.2 million were made.

Seventeen awards were made in FY 91, of which four were for dissertations, three were for workshops and one was for a three-year Research Experience for Undergraduates Program. Awards were made to 13 institutions in 11 states. Including the co-investigators' institutions, researchers from 24 universities received support. Proposals were reviewed by both U.S. and international experts, including Canadian, Nordic, British and Soviet scholars, as well as Native, Lappish, Greenlandic and Inuit experts.

The NSF Arctic Social Sciences Program is the only national Arctic social sciences research funding program in the circumpolar world

The awards encompass the disciplines of physical, social, cultural and visual anthropology, archaeology, sociology, political science, law, economics, science education and psychology, in conjunction with physiology, ecology, paleobotany, archaeozoology and paleoclimatology. The projects address timely scientific themes throughout Alaska, as well as in Canada, Greenland, Iceland and the former U.S.S.R.

One project involves research on human performance in polar environments. A joint NSF–NASA program in Human Factors Research in the polar regions has been planned. Of special interest are studies of small group interactions, stress and adaptation, and cognition and performance.

Several projects address contemporary issues of rapid social change. One project from the University of Alaska examines the complex cultural and linguistic problems faced by Native peoples in the courtroom. A sociological study from the University of Mississippi looks into the social consequences of the Red Dog Mine in northwest Alaska. A number of Native teachers are participating in this project with the support of the NSF Teacher Preparation and Enhancement Program.

Archaeology projects are investigating the earliest settlement period in America at the Broken Mammoth and Mead sites in central Alaska, as well as human subsistence practices in response to environmental fluctuations in northwest Alaska during the last millennium.

In the area of political science and policy, a workshop titled "Rational Development in the Arctic" brought together U.S. and Russian scholars at Dartmouth College. A dissertation project from the University of Alaska focuses on the political economy of whaling, a subject of great interest to Alaskans, Greenlanders and other citizens of northern whaling countries.

The Arctic Social Sciences Program provides a major impetus for science education in the Arctic through the Research Experience for Undergraduates and Young Scholars programs and particularly through the development of culturally relevant science curricula. Two dissertation grants went to Alaskan Natives. One project examines the articulation between Yupiaq and Western knowledge and assesses how traditional knowledge and practices can be used to develop science curricula in Northern schools.

Coordination

NSF expenditures for information, planning and advisory services and for the Arctic Research Commission were $718,000 in FY 91, which funded nine projects. NSF supported a program of polar information and advisory services, provided support for the Interagency Arctic Research Policy Committee, provided funds for the Arctic Research Commission ($497,000), partially supported the Polar Research Board and supported conferences, workshops and studies to further devel-op and implement Arctic research planning and policy.

Department of the Interior

The Department conducts research, mapping and monitoring programs throughout Alaska and its offshore regions and manages lands established under the Alaska National Interest Lands Conservation Act. These activities are performed by seven services or bureaus, each with administrative and technical offices located in Alaska. In FY 91, a total of $26 million was identified in support of these activities.

Minerals Management Service

The Minerals Management Service (MMS) is responsible for regulating the leasing, exploration and development of oil and gas in the Federal waters known as the U.S. Outer Continental Shelf/ Exclusive Economic Zone (OCS/EEZ). The MMS is required by law to provide assurances that operations on the OCS/EEZ are safe and pollution free and that the "best available and safest technologies" are used in the development of oil and gas. In addition, MMS must determine the environmental cost and possible multiple-use conflicts in leasing and subsequent development and production activities on the OCS/EEZ.

Arctic research is conducted under the Technology Assessment and Research (TA&R) program, and environmental studies are conducted under the Alaska Environmental Studies Program. Studies of both programs are conducted with universities, private companies, the states and other Federal agencies.

Technology Assessment and Research Program

The TA&R program is designed to assess and evaluate technology, equipment, industry procedures and internal procedures relevant to the post-lease exploration, development and production of minerals on the OCS/EEZ. It also applies engineering and research approaches to mitigate hazardous conditions, and it transfers the resulting information to MMS regulatory personnel. The MMS regulators use this information to make regulatory decisions and to issue permits and review applications for installing structures, pipelines or other equipment used to drill for and produce oil, gas or other minerals.

The TA&R's biennial report of its research program is available without charge from the TA&R Program, Minerals Management Service, 381 Elden Street, Herndon, Virginia 22070-4817. Please request Technology Assessment and Research Program for Offshore Minerals Operations—1991 Report.

FY 91 FUNDING (thousands)	
Technology Assessment/Research	1230
Environmental Studies	5975

The TA&R program has projects in the following areas: engine exhaust emission control; oil-spill containment and cleanup; well control; risk, reliability and inspection; and structures, pipelines and ice mechanics. The TA&R program projects that pertain to Arctic and subarctic OCS/EEZ waters include ice loads on structures and ice–structure interaction, design criteria, structural materials, and oil-spill containment and cleanup.

Because research in the Arctic and subarctic is very expensive, most projects are performed jointly with other interested Federal agencies, Environment Canada (EC), the offshore industry and universities. Projects are accomplished by contract, and a small administrative staff is maintained to manage the program.

During the past two years, MMS has expanded its oil-spill-response research to include, in addition to EC, the American Petroleum Institute. In addition, with financial assistance from EC and the U.S. Coast Guard, MMS has refurbished the Ohmsett oil-spill-response test facility, formerly known as the Oil and Hazardous Material Simulated Environmental Test Tank (OHMSETT). This facility is scheduled to be available in the spring of 1992 for testing by U.S. and foreign government agencies and private entities. A user fee will be charged.

The spill-response program includes mechanical, chemical (including dispersants) and in-situ burn response strategies, as well as developing capabilities for remote slick detection and identification. In addition, the program is evaluating the effectiveness of crude-oil cleanup strategies for shorelines and is investigating the behavior and fate of heavy oils spilled in the ocean to optimize response strategies as oil weathers. The emphasis has been on three major areas. The first is the in-

situ burning of slicks, a technique that under many conditions, especially in ice-covered waters, has been proven to be very efficient and environmentally safe as a primary open-ocean response technique. The National Institute of Standards and Technology has conducted research experiments at meso-scale in which burn efficiencies and combustion products have been quantified. Open-ocean, large-scale testing is scheduled for 1992. The second area has been the effectiveness of dispersants. In the laboratories of Environment Canada, new experimental dispersants have been developed that are significantly more effective on medium and heavy crude products than are existing formulations. Third, remote sensing techniques have been developed using laser technology to determine if targets are, in fact, oil slicks and to measure the thickness of slicks. These sensors should for the first time provide the capability of detecting oil in or on broken ice. Configurations suitable for aircraft use are being field tested.

Arctic offshore exploration for oil and gas continues to be slow because of the lack of commercially important discoveries, not the limitations of technology. However, the MMS program continues its investigations into the engineering properties of sea ice, where at Dartmouth College such phenomena as the effects of temperature and strain rate on brittle compressive fracture are being investigated. At the Cold Regions Research and Engineering Laboratory the stresses generated in an ice sheet impacting a structure are being studied. MMS has participated in an experiment with Esso Resources, Canada, which has demonstrated that grounded spray ice islands are feasible for use as platforms for exploratory drilling. MMS also has participated in a study by INTEC Engineering to provide updated technical and economic requirements for transporting oil and gas by pipelines and tankers from Chukchi Sea discoveries.

Arctic offshore exploration for oil and gas continues to be slow because of the lack of commercially important discoveries, not the limitations of technology

Research sponsored by the TA&R program is presented in reports, seminars and workshops. Recent international workshops sponsored by MMS include "Reliability of Offshore Operations," March 20–22, 1991, and "Offshore Pipeline Safety," December 4–6, 1991. The TA&R program planned a program seminar for the public in the spring of 1992.

Alaska Environmental Studies Program

As the managing agency for the MMS OCS leasing program in Alaska, the Alaska OCS Region has conducted environmental, social and economic studies to obtain information needed to make sound leasing decisions as well as to monitor human, marine and coastal environments. In anticipation of shifts in information needs, the program has increased studies to meet post-lease and monitoring information requirements. The detailed rationale for the Alaska OCS Region's program can be found in the Alaska Regional Study Plan (RSP), which is prepared annually. All environmental, social and economic studies are administered and contracted directly from the MMS regional office in Anchorage. The National Oceanic and Atmospheric Administration's Outer Continental Shelf Environmental Assessment Program (OCSEAP), which used to conduct a portion of these studies, has been closed out.

Endangered Species

The bowhead whale, an endangered marine mammal of importance to Native culture, makes extensive annual migrations through six OCS planning areas. Efforts to define the habitat and migrations of endangered whales and the potential effects of offshore operations on these species continue. These studies include on-going aerial monitoring of bowhead whales in the Arctic, a comparison of the behavior of the Davis Strait and Bering Sea stocks of bowhead whales, and an analysis of the stable isotopes of bowhead whale and zooplankton tissues. Also, preparation of an authoritative book on bowhead whales and a study of the effects of production activities on Arctic whales are ongoing. A study of the prediction of site-specific interactions of acoustic stimuli and endangered whales was completed. MMS has made several attempts to implant satellite tags on whales. Two right whales were tagged off Nova Scotia in the fall of 1990 and monitored via satellite for five to six weeks in field tests conducted in preparation for Arctic tagging efforts. Bowhead whale tagging will be attempted in 1992 in the Arctic. MMS is also sponsoring a study to develop an improved biopsy technique for cetaceans.

Living Resources

The Marine Mammal Protection Act of 1972 established a national policy to protect marine mammal populations and to encourage their preservation to the greatest extent feasible. Seabirds, waterfowl and commercial fish species are also

protected under various international agreements. One recent study, begun in FY 91, has applied satellite tags to male northern fur seals and northern sea lions in an effort to better understand their distributions, particularly during the winter. Another FY 91 study is producing a field manual on polar bear encounters for use near gas and oil industry activities.

The Marine Mammal Protection Act of 1972 established a national policy to protect marine mammal populations and to encourage their preservation to the greatest extent feasible

MMS studies on nonendangered marine mammals (other than monitoring studies) have focused on their vulnerability to noise disturbance and their use of specific geographic areas where OCS development might occur. Noise disturbance studies included field tests of the potential responses of beluga whales to OCS production sounds (in conjunction with similar research on bowhead whales).

Habitat utilization of specific marine areas by both marine mammals and avifauna has been studied in the Unimak Pass and Kasegaluk Lagoon. The study in the Unimak Pass included extensive oceanographic sampling to describe major ecological processes affecting the seasonal occurrence of regional seabird groups. A study at Kasegaluk Lagoon, begun in FY 89, has focused primarily on the use of this area by beluga whales, spotted seals and migratory waterfowl. The potential effects of aircraft overflights on black brant and other geese is being studied on the Izembeck National Wildlife Refuge and near Teshekpuk Lake on the Arctic coast.

The potential effects of offshore oil and gas operations on fisheries continue to be a major focus of the Environmental Studies Program (ESP). A study of fisheries oceanography in areas of potential oil and gas activities that was initiated in 1989 continues to determine the fisheries resources at risk in the central Chukchi Sea. A study of Arctic fish sensitivities and habitats in the Beaufort Sea continues. A major effort to better define the coastal fisheries and related environment in the southern Bering Sea, particularly in the North Aleutian Basin, should be completed in 1992. This work includes investigations of the life stages and sensitivities of salmon, king crab and herring, as well as the nearshore physical oceanographic environment that constitutes the habitat of these commercially important species.

Environmental Monitoring

The MMS Alaska OCS Region initiated a program in 1984 to monitor the long-term effects of oil and gas discharge in the Beaufort Sea. The initial three-year sampling and analysis study was completed in 1986. Field sampling and analyses took place again in 1989 and 1990. Comprehensive reports summarizing the results are available. Monitoring is planned for every three years.

Seabirds continue to be monitored through an interagency agreement with the U.S. Fish and Wildlife Service, beginning in FY 89. Several Bering Sea and Chukchi Sea seabird colonies are being monitored each summer using standardized protocols developed by both agencies, focusing on the numbers of birds on preestablished plots, reproductive success and feeding habits.

A multiyear project to acquire, curate and analyze marine mammal tissues continues. The study is archiving tissues for future analysis and is sampling baseline levels of chemical contaminants in tissues to monitor any increases that might be associated with future oil and gas drilling and production.

Pollutant Transport

Potential oil spills are a major focus of the environmental assessments for Alaska OCS lease sales. An improved three-dimensional numerical computer model for simulating circulation and oil-spill trajectories is being tested for predicting the movement and dispersal of spilled oil. The necessary data from the coastal environment of Alaska have been assembled for use in a model for predicting the transport of oil into and along a beach.

Efforts to improve knowledge of actual circulation for model-confirmation purposes continued. The final report for the Bering Sea Continental Shelf Edge Cross-shelf Transport Study will be completed in 1992. The report will reflect the 12 months of continuous data from the Bering Sea shelf edge. The results of this work will allow MMS to increase the accuracy of the Oil Spill Risk Analysis, which is a part of all offshore lease sales.

Ecosystems

The purpose of ecosystem studies is to learn about habitats and biological and physical processes that support important species. Ecological studies were completed recently in the Chukchi Sea and the Unimak Pass areas. An MMS-funded study, in coordination with the NSF Inter-Shelf Transport and Recycling (ISHTAR) program, was completed to assist in determining the processes responsible for the interannual variability in primary productivity, nutrient recycling and habitat

utilization for Kotzebue Sound and near Hope Basin. The Yukon Delta Ecosystem Processes Study focused on the movement of saltwater into the delta, juvenile fish use of the delta habitats, and seabird uses of the delta front. The Unimak Pass study focused on higher trophic use of the pass area and the processes that sustain this use. The Kasegaluk Lagoon on the Chukchi Sea coast is being modeled for ecosystem processes, primarily marine bird and mammal use.

Oil Spill Fates and Effects

Laboratory and field studies sponsored by MMS have shown that there may be long residence times and extended recovery periods for Arctic and Subarctic biological and physical components and processes affected by hydrocarbons. A predictive oil-weathering model is being used to describe the physical and chemical changes of oil spilled in open seas or in the presence of sea ice.

Hazards

Hazards are physical processes that may adversely affect exploration and development structures. Active surface and near-surface faulting are examples that have been studied extensively in the past. In recent years, studies that focused on sea ice mechanics, dynamics and superstructure icing were funded through the MMS TA&R program. Recent studies have focused on possible constraints to oil and gas development activities imposed by meteorological or oceanographic conditions such as sea ice movement, storm surges, and extreme winds and waves.

Social and Economic Studies

The Alaska OCS Region's social and economic studies are unique within MMS. Because subsistence activities are important in the culture of the Natives of coastal Alaska, studies of the effects of offshore petroleum development go beyond conventional economic considerations. Case studies and sociocultural and socioeconomic update studies define the social environment and describe the variables that may change with new OCS activities. Recently completed studies have documented the importance of subsistence activities in the Bristol Bay region. This research has revealed the extensive sharing networks existing within and between communities in the area. A recently released report described the economic importance of mining in northern Alaska and showed the structure of the negotiated agreements on issues such as local hire and subsistence activities between a regional Native corporation and a multinational mining corporation. A great deal of research has been conducted on the consequences of the *Exxon Valdez* oil spill for communities in the Gulf of Alaska region. Reports on these consequences are being published. In addition MMS is engaged in a cooperative agreement with the Alaska Department of Fish and Game's Subsistence Division to study the long-term subsistence, social and cultural consequences of the spill for a sample of 19 communities in Alaska.

Environmental Information Management

During FY 90 and 91 the Environmental Studies Program included approximately 30 studies in seven subject areas covering the three Alaska leasing regions. The size and scope of this program call for mechanisms to integrate study results. Information Transfer Meetings (ITMs) are sponsored by MMS to provide a forum for exchanging information among Federal and state agencies, industry, academia and the general public. The Third Alaska OCS Region ITM, which took place in January 1990, focused on marine mammals, birds and socioeconomic studies. The Fourth Alaska OCS Region ITM took place in January 1992 and covered studies in the Gulf of Alaska, Cook Inlet and the Bering Sea. This meeting also served as part of the MMS Information Base Review (IBR) process.

Fish and Wildlife Service

FY 91 FUNDING (thousands)

Migratory Birds	1900
Marine Mammals	1600
Terrestrial Ecology	1100
Fisheries Research	470
Cooperative Research	350

The U.S. Fish and Wildlife Service (FWS) conducts research in the Arctic to generate information that will help it to meet its resource management responsibilities. These responsibilities include conservation of migratory birds, certain marine mammals, endangered species, anadromous fishes and all biota inhabiting National Wildlife Refuges and other FWS lands. Research questions addressed include the effects of development, disturbance, hunter harvest and natural environmental cycles on populations. Other research seeks to develop improved methods of census and survey that will better detect trends in populations. All research has the ultimate goal of providing information that will lead to better management

decisions and actions to promote the conservation of living resources. Fish and wildlife populations in the U.S. Arctic are extensively shared with Canada and Russia, and a portion of the research effort is directed toward treaty and other international requirements for jointly managing shared resources.

Biological research is difficult to conduct in the Arctic; this has meant that some of the most advanced technologies have been developed for, or first applied to, Arctic research

Most of the Arctic research of the FWS is conducted from the Alaska Fish and Wildlife Research Center, Anchorage, and the Cooperative Fishery and Wildlife Research Units at the University of Alaska–Fairbanks. Some Arctic research is also performed by others of the 13 national research centers and the more than 30 cooperative research units, each of which has special capabilities that may be applicable to problems in Arctic research.

Biological research is difficult to conduct in the Arctic, given the harsh conditions, frequently inaccessible habitats and often wide-ranging movements of Arctic biota. Therefore, it has often been necessary to develop new methods of obtaining information. This has meant that some of the most advanced technologies have been developed for, or first applied to, Arctic research. Satellite-linked biotelemetry and molecular genetics are but two of many new techniques that have first been successfully applied to the problems of fish and wildlife conservation in the Arctic.

Migratory Birds

Migratory birds of the Arctic regions of Alaska include substantial populations of nesting geese and swans, large populations of several species of ducks, several populations of shorebirds, and some of the greatest known concentrations of breeding seabirds. The focus of FWS research is to learn more about the dynamics of these populations and to assess the effects of human activities on them. A few populations of migratory birds in the U.S. Arctic have declined to levels that cause concern, while others remain abundant. Certain species that remain abundant in the Arctic have become depleted in temperate regions. Special attention may be paid to populations that are of concern, either locally or on a continental basis, but research attention is directed to all populations of migratory birds. For those for which precarious or declining populations do not cause immediate concern, effort is directed toward predicting the effects of known or anticipated changes. The primary factors affecting geese, swans and ducks are believed to be harvest, losses to predator populations that may have been abetted by human activities, and disturbance on staging areas. Shorebirds breed and stage in tundra habitats that are extremely vulnerable to disturbance of land and vegetation. The huge seabird populations depend on both nearshore and offshore marine fishes, which vary greatly in abundance in response to changes in ocean currents and other factors. Depletion of fish stocks by commercial fishing may alter the delicate balance between need and availability of food for any of the 40 species of seabirds occurring in Alaska.

Pacific black brant are a species of small Arctic nesting geese that has shown long-term population declines. To investigate whether these declines are due to events during migration or wintering, preliminary investigations were undertaken to determine whether brant from Alaska could be found on wintering grounds in Mexico. Of a large number of birds color-banded in Alaska, a total of 1064, or 18% of the marked population, were observed in San Quentin Bay, Baja California, Mexico. An additional 41 birds were represented by bands recovered from birds harvested there by hunters. Birds from all subpopulations marked in Alaska were present in this area, suggesting that birds from different breeding areas do not winter separately. These initial results indicate that investigators should be able to assess the effects of mortality and disturbance on populations through both major segments of the annual cycle.

Newly developed satellite radio transmitters that are small enough to be carried by medium-sized geese and have relatively long life spans were donated to the FWS by the Nippon Telephone and Telegraph Company. Using this new technology in a joint project, investigators from the Northern Prairie Wildlife Research Center, Jamestown, North Dakota, and the Alaska Fish and Wildlife Research Center, and cooperators from Russia were able to track geese through their long annual fall migration. Lesser snow geese were fitted with radios at their breeding grounds on Wrangel Island, Siberia. They were tracked moving through mainland Siberia, across the Bering Sea, staging at St. Lawrence Island, proceeding down the Pacific coasts of Alaska and Canada, and moving to wintering areas in California via an inland route that took them through Alberta, Canada. Research on this population will continue, with emphasis on threats at migration stopover sites and on the wintering grounds.

The northern pintail is known as one of the most abundant species of dabbling ducks and one of the most sought-after by hunters. The breeding range includes most of the northwestern quarter of the North American continent, with the prairie potholes of Canada being the most productive breeding areas. Populations have declined seriously: continental breeding populations have declined by more than 60% over the past 35 years.

Depletion of fish stocks by commercial fishing may alter the delicate balance between need and availability of food for any of the 40 species of seabirds occurring in Alaska

Part of the decline is believed to result from permanent changes in the central prairie regions of the U.S. and Canada, including wetland drainage and intensified agriculture. Also contributing to recent declines has been a prolonged drought affecting much of the same area through the late 1980s. By 1990 it was believed that there was no significant reproduction of prairie-breeding pintails; northward-migrating ducks proceeded all the way to the Arctic, having failed to find suitable breeding areas along the way. Arriving later than the normal time to initiate nesting and failing to find suitable habitats, they appear to remain, without breeding, in the Arctic until it is time to begin the southward migration. It is believed that the only significant breeding of pintails during the late 1980s and early 1990s occurred in Alaska. Research on pintails breeding in Alaska was considered essential to explain factors that might be affecting populations in other areas.

That research has indicated that ducks arrive in the Alaska breeding areas with good fat reserves, suggesting that food reserves along migration routes may be important for the initiation of nesting. It also indicated that a large percentage of arriving ducks initiated breeding attempts. Studies of genetic variation addressed questions of whether Alaska pintails are a separate subpopulation or whether they represent a core breeding population that will repopulate other regions when conditions become favorable. Mitochondrial DNA and restriction enzymes show a large amount of genetic variation and suggest considerable interaction among regional populations. Reproductive success of breeding populations studied varied from low to high over two years, and adult survival appeared to be good. Related research conducted by the Northern Prairie Wildlife Research Center in Jamestown, North Dakota, and Dixon, California, the National Wetlands Research Center in LaFayette, Louisiana, and the Patuxent Wildlife Research Center in Laurel, Maryland, examined the breeding biology in the prairies, the wintering ecology and the movements of pintails in a coordinated attempt to better understand factors contributing to the remarkable decline of this species.

Research on shorebird populations has focused on the ecology of the bristle-thighed curlew, a large species of sandpiper in a group that includes several rare and elusive species. The world population of bristle-thighed curlews appears to be less than 7000 individuals, and the habitats they occupy are vulnerable to disturbance. Historical population levels are unknown, but reports from wintering islands in the tropical Pacific suggest either significant declines or major shifts in winter distribution. The population studied breeds on the Seward Peninsula, stages on the Yukon Flats, and may winter on any of a number of Pacific islands. Birds were banded on the breeding grounds, and studies of habitat use, food availability, timing of migration and proportion of young in the population were examined on breeding and staging areas. Detailed studies of nesting examined territoriality, the roles of parents, the behavior of the young and major causes of nest loss. The abundance of various fruits used by curlews on staging areas were tracked seasonally to determine the role of food availability in the timing of migration. Wintering-ground studies were conducted on Laysan Island in the Hawaiian Archipelago, where a marked population of about 250 birds was monitored.

Breeding studies indicated that the nesting area is restricted to the west-central portion of the Seward Peninsula. Breeding success varied from 50 to 72% in three years of study. There were high rates of returning birds banded the previous year, indicating good overwinter survival, at least in the portion of the population studied on the breeding grounds. Birds wintering on Laysan Island were marked and followed through the wintering period. They were discovered to have a flightless molting period, an unusual phenomenon in shorebirds. More than 90% of the birds wintering on Laysan Island returned the following year, indicating strong fidelity to wintering islands and confirming other indications that adults are long-lived. Birds marked on breeding areas in the northern Seward Peninsula were not found on Laysan Island; those marked as wintering birds on Laysan were discovered to breed in the southern part of the breeding range. It is believed that the breeding birds under study winter on islands farther south. Population estimates have been refined, and there were estimated to be 3400 breeding pairs in 1991. There is concern that birds undergoing the flight-

less molting period in winter may be vulnerable to predation on those islands where there are populations of introduced predators.

Marine Mammals

The FWS is responsible for managing three species of marine mammals: the polar bear, the Pacific walrus and the northern sea otter. Of these three species, the polar bear and walrus are characteristic of Arctic regions. Populations of both species are shared with Russia, and polar bear populations are also shared with Canada. A major focus of research on these populations relates to international actions that will be necessary to conserve populations. The issue of harvest is important, because both species have been subject to legal or subsistence harvest or both, and research seeks to develop methods of defining and monitoring populations so that local or region-wide populations do not become depleted by excess harvest. Another issue addressed by research is the potential impact of development on areas that may be essential for the stability of populations.

Studies of polar bear movements have been undertaken for several years, using conventional and satellite-linked radiotelemetry. The objective of this research has been to determine the extent to which local populations may be isolated from one another or may mix with larger regional populations. If populations are isolated and relatively distinct, overexploitation or excessive losses from other causes might have permanent consequences in the area affected. If, on the other hand, polar bears undertake long movements and mix freely over large areas, local depletion might be less important, but any effects could have international consequences. Results indicate that polar bears followed over relatively short periods tend to stay in reasonably distinct areas, but those tracked over the longer term may travel great distances. Bears first located in the Beaufort Sea may move to the Chukchi or even the Bering seas, indicating that there is mixing of populations; 80% of the female polar bears that were in the Chukchi Sea when they had transmitters attached have been found to den in Siberia. Examination of a variety of molecular and biochemical indicators has attempted to detect the existence of distinct subpopulations, without success; these results are not taken as definitive, however, because additional development and refinement of techniques is judged to be necessary.

The issue of harvest is important, because polar bears and Pacific walruses have been subject to legal or subsistence harvest or both; research seeks to develop methods of defining and monitoring populations so that local or region-wide populations do not become depleted by excess harvest

Long-term research on polar bear reproduction seeks to understand recruitment in polar bear populations and to relate reproductive success to environmental factors. Female bears are fitted with radio collars and followed to denning sites. Observations during and after occupancy of dens, including re-sighting bears that may be accompanied by cubs, become part of a growing base of information on polar bear reproduction. Observations of well over 100 polar bear dens have documented denning sites on drifting pack ice, on shore-fast ice and on land, primarily offshore islands. Only a minority of dens are located on land, but there are increasing indications that these sites are more productive than other sites. This information may be useful in developing safeguards should coastal areas be affected by petroleum exploration or development.

Research on the Pacific walrus seeks to develop reliable census methods that can be used by U.S. and Russian biologists to monitor population status. Walruses are normally observed when hauled out on land, and aerial surveys are used to count hauled-out walruses over large areas. The portion of the population that may be hauled out at any given time is not known, however, and any accurate census must account for animals that are in the water and therefore not recorded in censuses. A major goal of cooperative U.S.–Russian research has been to standardize existing census methods and to evaluate their ability to provide population trends. A subsample of walruses in a study area was tagged with radio transmitters to help determine the percentage of the population that might be present but not detected by an aerial census. Current interpretation of results indicates that aerial surveys, as now conducted, cannot accurately indicate population numbers and trends. Research into improved census techniques is continuing.

Wildlife Ecology

Research on wildlife ecology on FWS lands centers on the Arctic National Wildlife Refuge. Basic information on the ecology of species of management concern and specialized information on the effects of development are sought to under-

stand and predict the effects of potential petroleum exploration and development. Species of greatest concern are polar bears, certain populations of Arctic-nesting geese and populations of large herbivores, including caribou and muskoxen. A focal point for investigations is the "1002 Area," a portion of the refuge open to potential petroleum exploration. Other studies focus on areas outside the refuge where petroleum has been under production for more than a decade.

Caribou occupying areas now in petroleum production belong to the Central Arctic Herd (CAH), while those that occupy the 1002 Area are from the Porcupine Caribou Herd (PCH). Caribou undertake annual migrations, driven by the need to find suitable wintering grounds, favorable areas for calving, ample forage for calves and relief from harassment by biting insects. The PCH winters in Canada and migrates northward and westward toward the coast of the Beaufort Sea at calving time. The exact location of calving depends on the snow cover, but calving grounds are ideal on the Arctic coastal plain, where predators are not abundant. Also, calves are thought to be safer there because the flat, open topography permits the caribou to sight predators at relatively great distances. Forage is also generally good, but its quality and abundance depends on the timing of annual weather events. Research on breeding success indicates that reproduction is much more likely to be successful if calving takes place on the coastal plain; losses of calves from various causes are greater when calving occurs closer to the foothills. After calving, caribou migrate toward the coast to seek relief from insects, which reach great abundance in the short summer. The use of specific areas by the PCH have been documented, with the intent of evaluating use of the 1002 Area and its importance to caribou. Parallel studies of the CAH have sought to understand their relationship to the disturbance caused by oil production activities and the possible effects of developments in disrupting normal migration routes. Reproductive success in the portion of the CAH studied is lower than that observed in the PCH, but the reasons for this are still unknown. Also, the CAH has shown a period of growth despite apparently poorer reproduction; the population was estimated to be 13,000 in 1983 and 19,000 in 1991.

Research on muskoxen examines the ecology of a small reintroduced population. Muskoxen are year-round inhabitants of the Arctic coastal plain and could conceivably be affected by oil-drilling activities in winter. The population seems to have stabilized at 300–400 adults. Continuing research focuses on movements, habitat utilization and status of the population.

Additional details (including copies of technical publications) related to the migratory bird, marine mammal, wildlife ecology and fisheries research programs are available from the Alaska Fish and Wildlife Research Center, U.S. Fish and Wildlife Service, 1011 East Tudor Road, Anchorage, Alaska 99509. For further information on the Arctic National Wildlife Refuge studies, contact the 1002 Study Coordinator, Region 7, at the same address. Additional information on cooperative research can be obtained from the Director, Cooperative Fish and Wildlife Research Units Center, Region 8, U.S. Fish and Wildlife Service, 1849 C Street, N.W., Washington, D.C. 20240.

Fisheries Research

FWS fishery research in Alaska focused on Yukon River salmon, an anadromous resource shared by the U.S. and Canada. Allocation of the harvest has been an international issue. The objective of research has been to determine what portion of harvested populations are of U.S. and Canadian origin, as a basis for allocating the harvest. Because the U.S. harvest is of spawners ascending the river, harvest limits must ensure an adequate escapement of migrating fish to Canadian portions of the river system. There is an extended period of migration, with different peaks for different species and for fish populations spawning in different parts of the system. At any given time the salmon run at a particular point will be composed of different proportions of different stocks. Using a variety of biochemical and molecular techniques (including mitochondrial and nuclear DNA techniques) to distinguish stocks, studies were undertaken to determine the composition of salmon stocks at different times and places. As a result of those studies, it is now possible to estimate the percentage of chum salmon stocks that originate from U.S. and Canadian waters. Techniques that permit discrimination of chinook salmon stocks are still under development. The information produced in these studies has been an important component of international treaty negotiations and was presented as a report for the U.S./Canada Joint Technical Meeting in December 1991.

Cooperative Research

The FWS is involved in a national program of cooperative fish and wildlife research in partnership with state fish and wildlife agencies, land grant universities and, in some instances, the Wildlife Management Institute. The cooperative units are organized within the FWS as a single research center headquartered in Washington, D.C., but units have traditionally had a great deal of latitude to respond to local issues and needs in choosing research projects. The major goal of the cooperative research program is to provide specialized graduate-level training for fish and wildlife biologists. This training is usually provided by joint participation in research projects by faculty and students. The FWS funds salaries and some administrative costs, but funding for research projects is usually obtained elsewhere on a project-by-project basis. Research funding for the Alaska units, for example, comes from the Alaska Depart-

ment of Fish and Game, the Canadian Wildlife Service, other bureaus of the Department of the Interior (including the U.S. Geological Survey, the National Park Service and the Bureau of Land Management) and other Federal agencies (including the National Science Foundation, the U.S. Forest Service and the Environmental Protection Agency).

The Alaska Cooperative Fishery Research Unit completed a study of two shallow lakes in Minto Flats, a subarctic wetland in interior Alaska. The lakes were found to be eutrophic, with high nutrient concentrations and high biomasses of aquatic plants. Invertebrate biomasses were higher than those found in some temperate lakes. Productivity seemed to be related to the abundance of detritus.

Another study examined invertebrate abundances in glacial outwash. Streams fed by active glaciers are known to have low abundances of benthic invertebrates, but stomachs of fishes in those streams are often full of invertebrates. Research indicated that deep gravels through which there is subsurface flow may have abundant invertebrates. Groundwater monitoring wells near the Tanana River, Fairbanks, were pumped for invertebrate samples at a distance of 130 m from the river edge and at depths to 7 m. Caddisfly larvae, chironomids and springtails were recovered.

A third study completed by the Alaska Cooperative Fishery Research Unit investigated the behavioral ecology of Arctic grayling in small streams. Grayling establish stations in the pools of clear streams and feed on insect drift. Previous studies have shown that larger grayling are to be found at the heads of pools and that the largest are in the headwaters of streams. This study demonstrated that the stations occupied by larger fish are those that are most energetically cost-effective; larger fish drive smaller fish from these choice feeding stations.

A study completed by the Idaho Cooperative Fish and Wildlife Research Unit examined the breeding biology of tundra swans on the Arctic National Wildlife Refuge. Data were recorded for 100 nests, and the extreme sensitivity of nesting swans to disturbance by humans was documented.

The Missouri Cooperative Fish and Wildlife Research Unit completed a study to evaluate the ability of aerial surveys to adequately census breeding waterfowl in boreal forests of interior Alaska. Thirteen species of nesting waterfowl were observed from the air, and population estimates were compared to ground-truth data. Variables that affect estimates, such as habitat type, time of day, weather conditions and stage in the breeding cycle, were evaluated.

The Massachusetts Cooperative Wildlife Research Unit completed studies on the tundra of the northcentral coastal plain that related habitat features to use by migratory birds. The results may be used in predicting potential effects from energy development; a computer program successfully predicted the occurrence of 28 species of birds in various habitats.

National Park Service

FY 91 FUNDING (thousands)	
Cultural Resources	342
Natural Ecology	1470

The National Park Service (NPS) is mandated by the Alaska National Interest Lands Conservation Act (ANILCA) to assure, in areas under its administration, continuation of geological and biological processes unimpaired by adverse human activity. The act also, however, assures the continuation of many human activities, including sport hunting in national preserves and subsistence uses in most areas, which can potentially impair these very resources and processes. The areas are also vulnerable to outside influences, such as air pollution and oil spills, and to consumptive uses, including reindeer grazing and mining. They lack complete ecosystems, resulting in island effects. They require rehabilitation of old mine sites, fuel dumps and similar areas, and they must provide special protection to threatened and endangered species such as whales and peregrine falcons. Natural resources management, enlightened by knowledge and information obtained through research and monitoring, is thus imperative for preserving the areas and assuring the continuation of high-quality visitor experiences.

Research is conducted to identify and quantify the natural resources, to examine and understand basic ecological processes and interactions, and to determine and evaluate influences from man's activities. Monitoring is carried out to detect and measure natural and anthropogenic changes.

Natural Resources

The most significant study in the national parks of Alaska during FY 90 and 91 was the predator–

prey research at Denali National Park and Preserve. This project, which began in 1985, is continuing into 1992 in cooperation with the Fish and Wildlife Service (USFWS). It primarily involves the interactions between wolves, bears and caribou but includes predation on Dall sheep and moose and the activities of smaller predators, such as eagles, coyotes and wolverines. Tracking of radio-collared wolves allows up to 15 wolf packs to be monitored. Tracking radio-collared caribou showed that a series of contrasting mild and harsh winters has directly affected caribou calf survival. In the hard winter of 1991, for example, only 10 of 40 radio-collared calves survived into early June, and only 5 remained at the end of June.

Another continuing study at Denali is looking at golden eagles. During 1991, 53 occupied breeding territories containing 51 pairs were located in the study area, a portion of the park, and 59 young were raised to at least 80% of their fledgling age. A productivity of 1.16 fledglings per breeding pair was similar to that of 1990. In August 1990 an experimental satellite radio transmitter was attached to a golden eagle in Denali, and its movements were monitored during migration to Idaho and Montana until the transmitter batteries expired in March.

Merlins are also being studied at Denali. This cooperative research project with USFWS, which began in 1983, is carried out along a 125-km section of the park road corridor. Productivity, habitat use, contaminant levels and adult turnover were evaluated at over 100 nests found in trees and on the ground. The productivity was 2.8–3.8 young per pair per year. Mirex, DDE, dieldren, mercury and other organochlorides were detected in over 50% of the eggs analyzed. Long-distance band recoveries were from Venezuela and southern California.

Careful management founded on explicit knowledge of specific populations of grizzly bears and their basic biology is needed if they are to survive

A study of the population ecology of wolves in Gates of the Arctic National Park and Preserve, in cooperation with the Alaska Department of Fish and Game (ADF&G), was completed in FY 91. Eleven packs consisting of 100 wolves were monitored by radio telemetry. Pup production varied from 3.7 to 5 per mated pair over four years. During the winter of 1990-91, 58 wolves were harvested by subsistence users within the park, more than twice the average over the previous five years. This represents a 29% removal rate, which is at the lower extreme of the harvest rates believed to stabilize wolf populations. In November 1990 four packs were monitored daily for 25 days to compare fall predation rates (which are seldom studied) with those of the late winters of 1989 and 1990. The rates at which the packs killed prey (primarily caribou, many of which migrate out of the area) and the composition of the prey killed were similar between those periods; the wolves did not make a significant switch to other prey, but more calves were taken in the fall kill, resulting in a lower meat consumption rate for the wolves.

The demography and movements of wolves in relation to the Western Arctic Caribou Herd were studied in cooperation with ADF&G. Radio telemetry, including satellite collars, was used to follow 13 packs in areas that included Noatak National Preserve and Kobuk Valley National Park. Wolf densities ranged as high as 6.3 wolves per 1000 square kilometers. A wolf census method was tested that involved the probability of intercepting wolf tracks during aerial surveys. An outbreak of rabies in wolves was documented, affecting four or five packs in the area over a two-year period. Wolf pack territories ranged from 950 to 2358 square kilometers. Some packs migrated as far as 230 km south, apparently following migrating caribou. Caribou and moose were the primary prey species, with moose becoming dominant when caribou migrated out of the area.

The NPS continued to support an ADF&G study of grizzly bears in the Brooks Range that has been in progress since the late 1970s. These bears are smaller than their counterparts in more moderate climes, and they have a lower reproductive rate. Females produced young for the first time at an average age of seven years, but some did not have cubs until they were 11 or 12. Females often did not separate from their offspring until the young were in their fourth year, which enhances their chances for survival. These grizzlies are very vulnerable to any changes affecting their environment, and they are easily hunted because of the sparcity of cover. Human access to the area continues to increase. Careful management founded on explicit knowledge of specific populations of bears and their basic biology is needed if they are to survive.

Another study of grizzly bears was conducted in Noatak National Preserve and environs, in cooperation with ADF&G, to evaluate bear demography in relation to human exploitation and mining development. This project began in 1986; 146 bears were marked with ear tags and tattoos, 67 have radio collars and 6 have satellite transmitters. The age of first reproduction ranged from 5 to 9

years, with 77% of the young weaned at 2.5 years; the interval between weanings averaged 3.9 years. The use of the Red Dog Mine garbage dump by bears was documented by radio telemetry. The age structure of harvested bears in relation to those captured indicated that males were heavily harvested, while the female age structure was similar for harvested and captured bears. However, a large portion of the subsistence harvest is not reported, which limits the usefulness of the comparisons. Modeling indicated that the population may be overexploited at current harvest rates.

Since 1987, NPS has cooperated in a study with ADF&G and USFWS on the dynamics of a hunted brown bear population at Black Lake, on the Alaska Peninsula. The density and characteristics of the population were described. An annual exploitation rate of 5.1–5.7% was estimated for 1989-90. Over 1200 relocations of 63 radio-collared bears were recorded. Preliminary survival rates were 48% for cubs of the year, 84% for yearlings, 87% for females over three years of age and 85% for males over three years of age.

A study of the demography of a harvested marten population was started at Yukon–Charley Rivers National Preserve in FY 91; the project is scheduled to continue for three more years. A field camp was established in a 30-square-kilometer live-trapping area, where 1700 trap nights yielded 30 marten, of which 28 were radio-collared. Over 500 radio locations were recorded; 8 of the collared marten were taken by trappers. A mark–recapture density estimate exercise was completed, but the data are not yet analyzed. Over the winters of 1989-90 and 1990-91, 540 carcasses of commercially trapped marten were obtained from the preserve and nearby areas. They will be examined to determine marten fecundity rates and sex and age ratios.

A two-year study of lagoon contaminant levels and the breeding ecology of shorebirds in coastal habitats of Cape Krusenstern National Monument began in FY 91, in cooperation with the National Marine Fisheries Service (NMFS). The objectives are to document the use of the lagoons by birds, obtain data on the epifaunal and infaunal components of macrobenthic communities used as a bird food base, and establish baselines for specified organic compounds and heavy metal concentrations in these areas, where contamination from oil development and heavy metal mining could become a factor. One summer's data were obtained, and plots and transects were established for future study and monitoring.

A survey designed to characterize surface water quality for comparison with previously gathered data from NPS areas in Alaska was carried out at Noatak in FY 90 and 91 and will be extended into 1992. The project will also assess the presence of marine–terrestrial atmospheric input and provide research into natural factors responsible for variations in surface water chemistry within a watershed or lake–watershed context. Sites were established for later long-term ecosystem-level studies. Water and soil sampling were carried out and related to vegetation conditions.

A study of reindeer range and productivity was initiated at Bering Land Bridge National Preserve in FY 91, in cooperation with the University of Alaska–Fairbanks. It is intended to become a collaborative project with the Russian Republic as a part of the planned Beringian Heritage International Park. The project will assist managers in maintaining balances between herbivore numbers and range carrying capacity as influenced by fire. An international objective is to define techniques for describing critical habitat requirements for reindeer. During 1991, study sites were selected, methods were defined, and preliminary data were collected.

A three-year project began in 1990 to complete initial vegetation data collection from the nine fire-sensitive Alaska Region units. Species and their distributions were determined through aerial and ground surveys. The information will assist classification of Landsat TM data and assess the accuracy of vegetation maps produced using the data. The maps will be used for ecological studies, cultural resource inventories, vegetation species inventories, long-term monitoring of vegetation change and land use planning. Fuel maps will be generated for applications such as fire behavior prediction, wildland fire suppression and prescribed fire planning. Subsequent vegetation data will be collected to resolve and refine classifications and to update maps.

In 1990 and 1991, six stack-filter fine-particulate sampling stations were operated in Alaska Region units to establish baseline air quality conditions until more sophisticated sampling technology can be funded. The data were analyzed by the University of California, Davis. Preliminary data analysis indicated that sulphur levels were as high as those recorded at the Grand Canyon. The data appear to indicate a northwest to southeast trend, with the highest values in the northwest. Pollution from Eurasia is suspected to be the cause.

An Interagency Monitoring of Protected Visual Environments (IMPROVE) site operated at Denali National Park and Preserve during both fiscal years. The purpose was to establish baseline air quality conditions, determine if they exceeded National Ambient Air Quality Standards, and monitor for changes or trends in pollution levels.

Cultural Resources

In recognition of the important role that humans play in Alaska's ecological systems, the National Park Service has built a strong program in the social sciences. This emphasis is also in keeping with their service-wide mission, which charges the National Park Service to "preserve and foster appreciation of the cultural resources in its custody through appropriate programs of research, treatment, protection, and interpretation." Traditionally archeological and historic research have been major components of the Park Service's overall research effort, but ethnographic studies are gaining increased prominence in the social science arena. This rising interest reflects the Service's new awareness that almost all park areas are part of the homelands of living Native Americans. The links between particular park areas and Native American groups are often strong; this is especially the case in Alaska, where subsistence and other traditional uses of park lands and resources are everyday activities for one of the largest Native populations in North America.

Ethnographic studies are gaining increased prominence in the Park Service's social science research

National Park Service research goals in the Arctic are:

- To acquire and maintain an accurate park information base;
- To identify and evaluate cultural resources;
- To develop strategies for treating, protecting and interpreting cultural resources;
- To involve park-associated Native groups in research and resource management;
- To foster international and interagency coordinated research of Beringian natural and cultural resources; and
- To develop ethnographically sensitive approaches to cultural and natural resource management.

Research projects helping to achieve these goals include:

- Ethnographic and archeological overviews and assessments, which compile and evaluate existing cultural resources information and expose critical research and resource management needs;
- Development of computerized data bases and GIS capabilities;
- Cultural resource identification and evaluation studies, which help build park information bases, define the significance of resources and recover information from threatened and impacted resources;
- Integrated, multidisciplinary research that helps provide understanding of past and present human–land–resource relationships and supplies information essential for sound management decisions in both cultural and natural resources;
- Research that includes active Native participation and involvement and that enables the development of inventories of ethnographic sites, Native Alaskan place names, and traditional and current resource use, and ensures that NPS plans reflect the concerns and needs of park-associated Native groups; and
- The Shared Beringian Heritage Program, which promotes interagency and international cooperation in multidisciplinary Beringian studies.

The Shared Beringian Heritage Program is a multiyear, multidisciplinary program focused on bilateral U.S.–Russian studies in ethnography, archeology, historical architecture, geology, ecology, paleoecology, paleogeography and wildlife biology in the Bering Strait area. This integrated research has both interagency and international participation and has been stimulated by planning for the proposed Beringian Heritage International Park. The research involves close collaboration between cultural and natural scientists in the U.S. and Russia, as well as Northern Native people from both nations. The first phase of the program began in 1991 in the Bering Land Bridge National Preserve and resulted in the first Historic American Buildings Survey-level documentation of historic Native architecture on the American coast of the Bering Strait. Other results include ethnohistoric and ethnoarcheological analyses of the effects of reindeer herding on traditional economies in the early 1900s, a report on the history and ecology of reindeer herding, the initiation of American support for a Russian–English archeological dictionary project piloted in Magadan, support for the development of the "Crossroads of Continents: RFD Alaska" traveling exhibit, and partial production of a documentary videotape.

An archeological overview and assessment was initiated for Gates of the Arctic National Park and Preserve (1991) and Noatak National Preserve (1991) and completed and published for Denali National Park and Preserve (1991) and Cape Krusenstern National Monument (1992). The results of these projects are the publication of a synthesis document that compiles, reviews and evaluates all existing archeological data for a park and its immediate vicinity. The results include an up-to-date park resource information base, as well as recommendations and directions for future research and management of the resource. An archeological

overview and assessment for Klondike Goldrush National Historical Park is in the final stages of production. Historical archeological research in that turn-of-the-century trading center for the Subarctic and Arctic has generated new data on how early industrial America became established in Alaska within an amazingly brief span of years.

Archeological inventories are a dominant research activity of the National Park Service in the Arctic. A comprehensive report on a two-year reconnaissance survey of Cape Krusenstern National Monument was published in 1990, and a summary report on over 600 archeological sites located in the course of a four-year survey in Gates of the Arctic National Park and Preserve was published in 1991. These reports provide a more complete picture of the character and distribution of archeological resources and enable the parks to manage, protect and interpret these resources. A follow-up survey along a portion of the Killik River in Gates of the Arctic was conducted in 1990 and resulted in the recovery of information from threatened and impacted archeological sites.

The largest single inventory effort centers on mining claims in Alaska's parks. This ongoing, multiyear survey program continues to add to an unparalleled data base on the history of mining technology and the processes by which industrial America penetrated Alaska's Arctic wilderness. The Mining Inventory Program is in its sixth year of a comprehensive survey and inventory of cultural resources within the Alaska Region's mineral lands. The inventory program objectives incorporate compliance, research, interpretation, visitor safety and management needs into an examination of over 80% of the mineral lands found with the National Park System. Using a multidisciplinary approach to data collection, the survey field teams consist of archeologists, historians and historical architects. So far 380 properties have been documented, representing a broad range of site types that include multiple-component prehistoric sites to extensive lode mining complexes. The historic mining properties represent the most important activities in the development of Alaska's interior. Historic mineral development stimulated the first exploration and formation of permanent communities. The 1990 and 1991 field seasons saw investigations within Wrangell St. Elias National Park and Preserve, Denali National Park and Preserve, Kenai Fjords National Park and Bering Land Bridge National Preserve. Historic site documentation included the Fairhaven Ditch (1906), a 38-mile-long water diversion system in Bering Land Bridge National Preserve, and the former town site of Chisina (1903-04) in Wrangell St. Elias, settled during the last great gold rush in Alaska.

An intensive archeological testing program was conducted in the Bering Land Bridge National Preserve between 1988 and 1991 to determine the significance of several sites threatened by erosion. The sampling strategy emphasized cultural affiliations and chronological placement of the sites. The results, scheduled for publication in 1992, will be used to set management priorities and strategies for future mitigative action. Important findings, based on testing and other sampling at 16 coastal and interior sites, include data indicating that interior areas were occupied as early as 5000 years ago. This moves the earliest Paleoeskimo use of the Seward Peninsula to at least 700 years earlier than previously thought. New information on the use of coastal areas in late prehistoric times indicates the existence of a basic dichotomy in patterns of the use of coastal resources, one with a focus on seal populations and another with a focus on whales. The data also indicate that a third pattern in which caribou was the primary resource focus is ancient in the area, persisting from the time of Paleoeskimos, 5000 years ago, to traditional Eskimo times of the 19th century.

Full data recovery excavations were conducted on the National Park Service headquarters tract in Kotzebue in 1990. The excavation yielded important habitational remains and the earliest structure yet documented near Kotzebue.

A three-year ethnographic research project in northwest Alaska is nearly complete. This regional ethnography encompasses Cape Krusenstern National Monument, Noatak National Preserve and Kobuk Valley National Park. One of the most significant results is the discovery of a high degree of subregional variation that prevails in the cultural forms and practices of the study region.

Native Place Names of the Kantishna Drainage, Alaska, which was published in 1991, is an annotated record of place names and traditional land use patterns for the area. The study resulted in preserving an important aspect of the local cultural history, and it provides insight into Athabaskan land use in the Kantishna drainage between the 1890s and 1940s.

Research projects in history include the development and publication of a historic preservation plan for Unalaska (1990). The results include a program of strategies to preserve cultural resources in the Unalaska community. The city contains three National Historic Landmarks, and the island at large has 150 recorded cultural sites representing over 4000 years of local and regional history.

The Alaska Region is continuing to maintain the Alaskan portion of the National Archeological Data Base and develop a regional computerized Cultural Sites Inventory. Both Autocad and GIS formats are being used for mapping and geographic analysis of site location.

Bureau of Land Management

The Bureau of Land Management (BLM) Arctic program primarily consists of inventory, monitoring and applied research activities focused on energy, minerals and renewable resources. These activities cover more than 32 million acres of Arctic surface and subsurface lands and are performed entirely in terrestrial and freshwater environments. Research is directed towards obtaining information needed to make multiple-use management decisions for BLM-managed lands.

BLM's renewable resources program in Arctic Alaska includes several ongoing wildlife and fisheries habitat management programs. During FY 90 and 91, work continued on implementing the Norton Sound Habitat Management Plan, including inventorying anadromous-fish habitats in tributaries of the Nome River, measuring levels of subsistence use and identifying habitat enhancement opportunities. BLM participated in a cooperative fish hatchery project with the Alaska Department of Fish and Game at Nome–Beltz High School. This project, which recently received a $3000 grant from a major corporation, will help educate high school students in natural resource management issues as well as supplement pink salmon runs in the Nome area. Work continued with the Alaska Department of Fish and Game on determining the population dynamics of grizzly bears on the Seward Peninsula; radio-collaring will help identify bear denning sites. Other studies in progress focus on waterfowl, caribou and Dall sheep habitat.

The BLM, with financial assistance from the Fish and Wildlife Service and the Minerals Management Service, completed the field research phase of the Teshekpuk Lake black brant study in FY 91. This area is potentially important as a transportation corridor for North Slope oil and gas development and lies in the National Petroleum Reserve–Alaska (NPRA). The five-year study, which focused on the energy requirements of black brant geese, will help in predicting how any future development activities might affect them. The results are being analyzed, and a final report will be issued during FY 92.

FY 91 FUNDING (thousands)

National Wildlife Refuge	120
Habitat–Arctic District	345
Habitat–Kobuk District	527
Pipeline Studies	300
Fire Control	350
Narional Petroleum Reserve–Alaska	65
Minerals/Mining	310
Global Change	40

BLM's "Adventures in the Past" initiative in cultural resources sparked studies that have resulted in the nomination of the Wild Goose Pipeline to the National Register of Historic Places. The pipeline is associated with the Nome gold rush at the turn of the century.

BLM's Division of Mineral Resources completed several reports related to the oil and gas potential of Alaska's North Slope including the National Petroleum Reserve–Alaska and the Arctic National Wildlife Refuge.

Two research projects are anticipated to begin in FY 92. One study will compare sequential Synthetic Aperture Radar (SAR) images from the European Space Agency to NPRA images taken by Side-Looking Airborne Radar (SLAR). The results will help refine SLAR lake depth interpretation, provide circumpolar capability and extend interpretation capability into the Subarctic. This information will help delineate access points and routes and will also help BLM manage resources such as fisheries, waterfowl and fresh water.

A second study will use obsidian hydration techniques to date at least 250 archaeological sites on BLM-managed lands in northern and interior Alaska. Obsidian, or volcanic glass, was often used by ancient peoples to make arrowheads and other tools because it forms very sharp edges. Once obsidian has been cut, it begins to absorb moisture, so an artifact can be dated based on the amount of moisture it contains. The results will help determine prehistoric culture chronologies. These studies will be part of an ongoing involvement of BLM researchers with other researchers in Siberia and may help reveal more about the intensity of cultural contact between Asia and North America.

BLM and Alaska Department of Fish and Game biologists determining bear denning areas on the Seward Peninsula in northwestern Alaska.

U.S. Geological Survey

The U.S. Geological Survey (USGS) conducts both terrestrial and marine research in the Arctic in a number of disciplines. Among these are energy and minerals, marine geology and geophysics, natural hazards, climate and paleoclimate, glaciology, hydrology, Quaternary geology, deep continental studies, the magnetosphere, mapping and data management.

FY 91 FUNDING (thousands)	
Energy and Minerals	2534
Natural Hazards	1209
Ice and Climate	350
Hydrology	310
Glaciology and Quaternary	150
Marine Geology	500
Magnetosphere	25
Mapping	915

Energy and Minerals

Energy and minerals research in the Arctic is conducted, both onshore and offshore, to systematically describe and understand the geological settings where energy and mineral resources may occur and to provide quantitative assessments of the energy and mineral resources of the Arctic for land-use planning and national need. USGS conducts its work in Alaska through several programs, the most significant being the Alaska Mineral Resources Assessment Program (AMRAP).

AMRAP provides an assessment of "the oil, gas, and other mineral potential on all public lands in the State of Alaska in order to expand the data base with respect to the mineral potential of such lands," as directed by Section 1010 of Alaska National Interest Lands Conservation Act.

AMRAP studies are conducted at four progressively more detailed levels to produce comprehensive assessments of the mineral and energy resources of Alaska. Level I studies are statewide in scope, and published maps are generally at a scale of 1:2,500,000. During FY 90 and 91, work was completed on a statewide map portraying the metamorphic history of Alaska; also completed was the first crustal section from the Gulf of Alaska to the Arctic Ocean.

Level II studies address large parts of the state, and the resulting maps are generally published at a scale of 1:1,000,000. Level II studies were completed in FY 90 and 91 for the mineral resource assessment of southeastern Alaska, with special emphasis on Federal lands within the Tongass National Forest; studies are in progress on the geology and mineral resource potential of the Alaska Peninsula.

Level III studies, the primary focus of the AMRAP program, consist of multidisciplinary evaluations of selected 1:250,000-scale quadrangles. Geologic, geochemical and geophysical data are gathered to produce an inventory of areas defined to have undiscovered mineral resource potential. Level III studies have been completed for 34 of the 153 1:250,000-scale quadrangles in Alaska; 19 quadrangles were underway in FY 90 and 91. Geologic maps and mineral resource assessments were completed for the following quadrangles: Anchorage, Bendeleben, Bethel, Bradfield Canal, Cordova, Goodnews Bay, Hagemeister Island, Middleton Island, Mount Katmai, Naknek, Solomon, Survey Pass and Valdez. Prefield assessments based on existing data were completed for the Howard Pass, Iditarod, Lime Hills, Sitka and Table Mountain quadrangles and for the National Petroleum Reserve–Alaska (NPRA). A preliminary mineral resource assessment was completed for the proposed Beringian Heritage International Park.

Level IV AMRAP studies comprise topical studies on individual research problems at the project or deposit scale. Topical research projects underway in FY 90 and 91 investigated mercury deposits of southwestern Alaska, the Juneau Gold Belt, placer gold deposits of the Eagle area, the geology of the Prince William Sound region, gold deposits of the Seward Peninsula, ultramafic rocks and the distribution of platinum-group elements and chromium.

Other active USGS energy and mineral programs include:

- The Geologic Framework Program, involving both general and specialized research on the regional geology of the state;
- The Development of Assessment Techniques Program, which seeks to improve the ability to identify and evaluate mineral resources;
- The Critical and Strategic Minerals Program, for identifying the potential of these resources to meet national military and economic needs;
- The Evolution of Sedimentary Basins Program, which conducts studies of depositional, structural, diagenetic and thermal processes to predict and evaluate water, mineral and petroleum resources;
- The Marine Geology–Exclusive Economic Zone (EEZ) Program, which evaluates the morphology and mineral potential of the continental margin, including research cruises in the Bering Sea, which systematically imaged the seafloor using Geologic Long Range Inclined Asdic (GLORIA) sonar surveys;

- The Gas-Hydrate Program, which attempts to determine the distribution, quantity and environment of methane hydrate; and
- The Geothermal Investigations Program, which focuses on studies of the nature, distribution and energy potential of geothermal resources.

North Slope Petroleum Project

Funded by the Onshore Oil and Gas Investigations Program, the North Slope Petroleum Project focuses on the thermal history of the fold-and-thrust belt of the Brooks Range. This part of the North Slope, which is virtually unexplored for oil and gas, is estimated to have significant potential for undiscovered oil and gas and is an area of major Federal landholdings. Our preliminary findings from thermal analysis show that the areas favorable for the preservation of oil (the oil window) extend farther south (closer to the Brooks Range) in some areas than in others. This observation suggests that some parts of the fold-and-thrust belt are more favorable for oil than other parts. A detailed analysis of a profile along the Dalton Highway shows that deformation continued after the maximum heating of the rocks. If this is a characteristic of the entire fold-and-thrust belt, it has major complications for exploration strategies and future assessments of oil and gas. Because oil and gas deposits were formed when the maximum thermal imprint was imposed on the rocks, later structural deformation has likely rearranged and possibly destroyed the initial trapping architecture and any oil and gas deposits. Thus, oil and gas exploration in the fold-and-thrust belt is a matter of understanding the thermal history and the sequence of structural development and then looking for remigrated and retrapped oil and gas.

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North Slope Gas Hydrate Project

The North Slope Gas Hydrate Project, funded by the Onshore Oil and Gas Investigations Program, the Department of Energy and the Climate Change Program, has documented with well logs the occurrence of natural gas hydrates in multiple sandstone reservoirs at shallow depths in the region overlying the Prudhoe Bay and Kuparuk River oil fields. The amount of natural gas in these hydrates is estimated at about 40 trillion cubic feet (equivalent to the total volume of gas in all conventional oil and gas fields on the North Slope). Current efforts are devoted to:

- Identifying favorable locations for testing gas-hydrate production schemes;
- Examining the flux of methane (a greenhouse gas) in permafrost regions and the possible contribution of methane from the decomposition of hydrates; and
- Documenting hydrate-related problems associated with oil and gas drilling and production.

Interior Basins Project

The Interior Basins Project, funded by the Onshore Oil and Gas Investigations and the Alaska Mineral Resource Assessment programs, seeks to appraise the petroleum potential of all Alaskan basins south of the Brooks Range. A multi-tiered approach has been followed. A regional-scale approach has produced maps summarizing all salient information on offshore basins, onshore basins and the thermal maturity of the surface and, locally, the subsurface rocks relative to the stages of petroleum maturation. A basin-specific approach has focused on the Cook Inlet, Nenana and Kandik basins. Studies in these basins have evaluated the geophysical signature of the basin, the petroleum source rock potential, the reservoir characteristics, the thermal history and oil–source rock correlations.

Metallogenesis and Tectonics of the Russian Far East, Alaska and the Canadian Cordillera

In 1989 the Branch of Alaskan Geology started a cooperative project on the formation of mineral deposits and bedrock geology in the Russian Far East, Alaska and the Canadian Cordillera with the Far East Branch of the Russian Academy of Sciences, the Ministry of Geology, the Alaska Division of Geological and Geophysical Surveys (ADGGS) and the Geological Survey of Canada (GSC). The goals of this project are to conduct collaborative field studies of lode mineral deposits, metallogenic belts, bedrock geology and tectonics in the Circum-North Pacific region and to publish:

- A series of mineral deposit, metallogenic and tectonic maps that show the distribution of ore deposits, rocks associated with specific types of ore deposits, and their relations to the overall geologic evolution of the area;
- A series of tables containing detailed summaries of the major lode ore deposits and placer districts of the region; and

- A series of interpretive articles describing the formation of mineral deposits in the context of the geologic and tectonic history of the two regions.

Reciprocal visits to the Russian Far East were undertaken by USGS, ADGGS and GSC geologists in 1989 and 1991, and Russian geologists visited Alaska in 1990. Field trips in both regions were conducted to examine the details of major mineral deposit types, detailed characteristics of ore deposits and the host rocks containing the deposits. Also, scientific workshops have been held in Vladivostok, Khabarovsk, Magadan, Fairbanks and Anchorage, in which the initial compilations of mineral resource data and bedrock geologic map data for the Russian Far East, Alaska and the Canadian Cordillera were started. In 1992 the project will publish two major preliminary reports:

- An Open-File Report for the Russian Northeast and mainland Alaska containing mineral deposit maps, mineral deposit tables and metallogenic belt maps and interpretive text with references; and
- An Open-File Report for the Circum-North Pacific, including the Russian Far East, Alaska and the Canadian Cordillera, containing tectonic–magmatic maps, descriptions of bedrock geology and stratigraphic columns and references.

Eventually the mineral deposit, metallogenic and tectonic maps will be formally published in color in English by the USGS and in Russian by the Russian Academy of Sciences and Ministry of Geology. In the summer of 1992 the Russian metallogenic team will be hosted in Anchorage, Alaska, and the Canadian Cordillera. Interpretative publications on the metallogenesis and tectonics of the Circum-North Pacific region will also be started.

Collaborative Study of the Ophiolitic Terranes of Alaska and Northeast Russia

In 1989 geologists from the USGS, ADDGS and the Far East Branch of the Russian Academy of Sciences began this study of ophiolitic terranes, which are critical to the study of global plate tectonics because they lie at the juncture of North America and Eurasia, offering a unique opportunity to learn about the relative motions between these two great continental plates. Ophiolitic terranes such as these also provide an important source of chromite, nickel, copper, manganese, asbestos, talc and other commodities.

Work on the project started in 1989 with joint field trips to key ophiolite localities in Alaska, followed by workshops and study sessions at the USGS offices in Anchorage. In 1990 geologists from the USGS and ADGGS traveled to the Russian Far East, where they joined their Russian colleagues for field excursions to ophiolite localities in the Chukotka region of northeast Russia and for workshops at the Institute of Tectonics and Geophysics in Khabarovsk and the Far East Geologic Institute in Vladivostok. The U.S. team returned again in 1991 to Khabarovsk for another conference with the Russian team.

As a final project of this study the U.S. and Russian teams have prepared a 1:2,500,000-scale geologic map of the ophiolite terranes, including tables summarizing the lithology, geochemistry, age, mineral deposits and geologic setting of the terranes. The maps and tables cover all of Alaska except for the southeastern panhandle and the Aleutian Islands and an equal area of northeast Russia extending from the Bering Strait westward to the Kolyma River and south to northern Kamchatka. The maps and tables will be published in Russian by the Russian Academy of Sciences and in English by the USGS.

The initial results of this joint study show that there are many similarities between the ophiolitic terranes in Alaska and those in contiguous parts of northeast Russia. This is not surprising because both areas are composed of far-traveled fragments of continental and volcanic arc rocks that were accreted to the North American and Eurasian continents in Mesozoic and Cenozoic time as a result of the northward drift of the oceanic crustal rocks of the Pacific Ocean basin. The ophiolitic terranes mark the boundaries of these accreted fragments and are successively younger toward the present-day Pacific margin.

Paleontologic and Stratigraphic Studies in Support of Mineral Resource Assessment of Alaska

This project has focused on Mesozoic deposits in both western and southern Alaska. Diverse products over the past two years include studies of:

- The geology, geochemistry and biostratigraphy of Chugach and Kachemak terrane rocks in southern Alaska;
- New methods for extracting radiolarian faunas from Alaskan and other Cordilleran siliceous rocks;
- Detailed locality data and taxonomy of molluscan fossils from Jurassic and Cretaceous deposits in western Alaska;
- Stratigraphic investigations in Ordovician–Devonian rocks over a large part of Alaska (Kuskokwim Mountains, western Brooks Range, Shubblik Mountains, Lime Hills D-4 quadrangle, Nixon Fork Terrane and Farewell Terrane); and

- Inoceramid biostratigraphy of the Kuskokwim Group and its implications for basin evolution.

Products near completion are geologic maps (1:250,000 scale) of the Port Moller and Katmai quadrangles of southern Alaska and a study on the accretionary timing of Kenai Peninsula melange terranes.

PRISM Project

The Paleontology and Stratigraphy Branch PRISM Project has conducted the following major research studies in the Arctic and adjacent regions during FY 90 and 91:

- Reconstruction of mid-Pliocene global warmth in northern Alaska;
- Determination of the age and paleoclimate of Pliocene deposits on Meighen Island, Canada (in collaboration with GSC);
- Analysis of Pliocene paleoclimate records of northern Iceland and the Kamchatka Peninsula, Russia, and implications for global meridional ocean heat flow;
- Reconstruction of the northern Greenland Pliocene paleoclimate record;
- Publication of the modern Arctic ostracode database and application of this database to Plio-Pleistocene deposits collected from Northwind Ridge; and
- Acquisition of 1300 cores and bottom samples from the ARCTIC 91 North Pole expedition for analyses of ostracodes. These data are being used to unravel the paleooceanographic history of the Arctic.

Cores from Northwind Ridge and the Beaufort Sea continental slope show that climate change has produced 10 glacial–interglacial cycles in the last million years

Data from the analysis of conodonts, used in conjunction with other thermal maturation indices, have been used to produce a thermal maturation map of Alaska. The map is used to assess the potential for hydrocarbon and some types of mineralization, as well as a wide range of other topical geologic studies. Conodont age, paleoecologic and thermal maturation analyses of Paleozoic and Triassic rocks in Alaska are also helping in deciphering the tectono-sedimentary framework of the state. Conodont studies have proven invaluable in unraveling the geologic history of the low- to medium-grade metacarbonate terranes of the Seward Peninsula and Brooks Range.

Marine Studies

Marine Geological and Geophysical Investigations of the Arctic Basin

Studies were conducted by USGS scientists from the U.S. Coast Guard icebreaker *Polar Star* in 1988 and 1989. Continuing analyses of samples and data have significantly advanced our understanding of the geologic framework and plate tectonic development of the Arctic Basin and the history of climate change in the Arctic for the last million years. Other studies have shown that sea ice is a major mechanism for removing clastic and biogenic sediments from Arctic shelves and dispersing them in the Arctic Basin and the North Atlantic Ocean. The geologic framework studies have shown that near 75°N the Northwind Ridge of the Chukchi Borderland consists of a continental margin sedimentary prism and suggest that it and the other ridges of the borderland were derived from the continental margin in the East Siberian Sea. These findings have provided the basis for a model of the Cenozoic tectonic development of the Arctic Basin that proposes that in Paleogene time mid-Atlantic seafloor spreading in the Eurasian Basin was transformed to the north-trending basins of the Chukchi Borderland and from there into northwest Alaska via the eastern North Chukchi and Hope basins. The tensional structures created by this process in the North Chukchi Basin may have petroleum potential. The model suggests that the complex and poorly understood Cenozoic structure of the western Chukchi and Laptev shelves and adjacent Arctic Basin resulted from the inability of the Arctic Mid-Ocean Ridge, the extension of mid-Atlantic spreading in the Arctic, to work its way across the Eurasian and North American continents in Siberia and western Alaska.

Cores from Northwind Ridge and the Beaufort Sea continental slope show that climate change has produced 10 glacial–interglacial cycles in the last million years. Interpretation of several older events is underway. Correlations of variations in the relative thickness of the portions of these cycles that contain erratics and represent deglaciation, and of variations in maximum erratic clast size, are being indexed against the strength of correlative late Quaternary glaciations in the Arctic. If successful, this indexing will provide a sedimentological method for estimating the relative strength of continental glaciations in earlier Quaternary time, for which no continental morainal record is preserved. It has also been found that the distribution of erratic clasts in the glacial portions of the glacial–interglacial cycles in the Arctic

cores may reflect the relative distribution of glacial ice and sea ice in the Arctic during continental glaciations. This finding suggests that during glaciations the central Arctic was covered with thick sea ice that prevented the dispersal of erratic-bearing icebergs from the termini of continental glaciers, which are known to have reached the margins of the Arctic Basin. It also suggests that hypotheses proposing that the Arctic Basin was covered by a thick floating sheet of glacial ice during continental glaciations are untenable. Attempts were made to collect and analyze ice and iceborne sediments during several icebreaker cruises to the Arctic Basin. These studies attempted to determine the source areas, mode of incorporation, mode of metamorphosis and mode of deposition of the sediment and ice. A key reason for this analysis was to quantify changing trends in modern sediment content and to examine their influence on Arctic albedo. This ongoing activity will attempt to determine the sediment load and character in the ice canopy of the Arctic Basin. As a result of completed analyses, USGS estimates the episodic transport capacity of sea ice to remove sediment from the shelf inshore of the 50-m isobath to be 4 mm/yr.

Effects of the Exxon Valdez *Oil Spill*

Studies of the effects of the *Exxon Valdez* oil spill were conducted by USGS scientists on two cruises to Prince William Sound following the March 24, 1989, spill. Bottom sediment was sampled along the spill trajectory in May 1989 and August 1990 to assess the fate of the oil and derivative products. During the first cruise, 50 days after the spill, evidence of spilled oil could not be conclusively identified in bottom sediments collected from deep basins. Samples collected 15 months later, however, showed evidence of oil contamination. Oil and tar was present in beach sediments, and traces of crude oil were geochemically measured in samples of the nearshore sediments and deep basin sediments within Prince William Sound. The oiled sediments obtained from the island beaches matched the geochemical signature of oil impounded from the tanker *Exxon Valdez*, but tar samples from two beaches have chemical parameters that indicate a source other than the March 24, 1989, spill at Bligh Reef.

GLORIA

In November 1991, USGS released a new "I" Map (I-2053), *Atlas of the U.S. Exclusive Economic Zone, Bering Sea,* a 145-page compilation of explanatory information, maps, ship tracklines, seismic profiles, gravity profiles, magnetic profiles and 27 1:500,000-scale, long-range, sidescan sonar mosaics of 250,000 square miles of the Bering Sea Exclusive Economic Zone (EEZ) sea floor. The sonar data were collected with the GLORIA (Geological Long Range Inclined Asdic) system. Each computer-enhanced mosaic covers a $2° \times 3°$ area of the EEZ. The resulting maps show the distribution of many physiographic and geologic features of the Bering Sea EEZ seafloor. These include volcanic features, canyons, channels, deep-sea fans, submarine slides, large sediment bedforms and textural and tonal differences in sonar signal, corresponding to differences in sediment type.

Elsewhere, ongoing analyses of GLORIA images collected from 1986 to 1989 in the Gulf of Alaska between Unimak Pass and Dixon Entrance show the morphology of the seafloor 400 km seaward of the shelf break. These data are being processed for presentation in an image atlas. Major features include the following continental-margin deformational structures and submarine-channel systems.

The Aleutian convergent margin is characterized by canyons and numerous slumps along the upper and middle slope. Sediment is dominantly trapped in midslope basins, and canyons seldom reach the trench, except for some prominent canyons near Middleton Island. Unimak Ridge is a prominent midslope feature from Sanak Island to Unimak Pass. Along the lower trench slope, the structure ranges from highly discontinuous folds to long continuous folds.

The margin between Middleton Island and Cross Sound is commonly either extensively cut by dendritic drainages or covered by glacially derived sediment. Large, actively growing structures are present beneath the slope between Middleton Island and Pamplona Spur, but they are notably absent from Pamplona Spur to Cross Sound.

From Cross Sound to Dixon Entrance the active trace of the Queen Charlotte–Fairweather fault is strikingly imaged as a narrow linear feature composed of ridges and troughs that have a vertical offset. The fault lies on the middle to outer shelf from Cross Sound to Chatham Strait, then trends across the middle slope to Dixon Entrance. A horizontal offset is visible on a canyon wall and on offset channels. Off Dixon Entrance, numerous large anticlines are present seaward of, and trend parallel to, the fault.

Southeast of the Aleutian Trench, ocean plate structural and bathymetric features are either parallel to magnetic anomalies or parallel to the trench and caused by normal faults as the plate bends into the Aleutian Trench subduction zone. These features formed during the development of the seafloor at a spreading center and project

through the thick sedimentary layer that covers the oceanic basement.

On the abyssal plain, four active turbidite channel systems were imaged. The Surveyor channel system consists of tributary channels that arise along the margin between Pamplona Spur and Alsek Canyon and coalesce on the abyssal plain into a single channel, Surveyor channel, ending at the Aleutian Trench southeast of Kodiak Island. Sediment delivered by the Surveyor channel system or by slope canyon systems into the Aleutian Trench is transported southwest along the Aleutian Trench, as shown by the development of a channel that bypasses an obstruction in the trench between Chirikof Island and the Shumagin Islands. The Chirikof channel system arises from feeder drainages between Fairweather Ground and Sitka, with the greatest sediment input coming from Cross Sound. The feeder channels eventually coalesce into a single channel that terminates in turbidite fans south of the Kodiak–Bowie seamount chain. The Horizon channel system begins off Chatham Strait and shows at least two abandoned channel systems offset northward along the Queen Charlotte–Fairweather fault system. The Mukluk channel system begins off Dixon Entrance and also shows northward offset. Both the Horizon and Mukluk systems cross the Kodiak–Bowie seamount chain, then extend 1000 km southward to the Tufts abyssal plain.

As much as 1600 million metric tons of sediment are resuspended in the Chukchi Sea by the feeding processes of walruses

Studies of Coastal Erosional Processes

Elsewhere, studies of coastal erosional processes focused on the role of ice in coastal processes and the potential for existing and future influences of changing climate on coastal processes in the Arctic National Wildlife Refuge (ANWR). Observations revealed a major change in the rates of erosion and accretion in the last 200 years. Cooperative studies with the University of Alaska and GSC on nearshore ice gouging were completed. This work linked ice motion to seafloor gouges and assessed the role of ice in modifying the nearshore profile and beach replenishment. These studies confirmed the recency of gouging inshore of the 20-m isobath and documented the role of gouging in eroding the shelf. The results also suggested that ice pile-up on beaches was important in forming elevated barrier islands.

Whale and Walrus Benthic Feeding

USGS studies of whale and walrus benthic feeding in the Chukchi Sea are mapping and quantifying the extent of seafloor disturbance and feeding by gray whales and Pacific walruses. Over 5000 km of USGS side-scan sonar images have been reviewed for evidence of whale feeding pits and walrus feeding furrows. As much as 60% of the ice-free portion of the Chukchi Sea with muddy substrate is covered by walrus furrows, while an average of about 3% of the northeastern sandy seafloor is disturbed by whale pits. Mammal population estimates, sediment biomass weights and sediment bulk density data can be used to show that a significant proportion of the 234,000 walruses feed on the Chukchi Sea benthos, a minimum of 2% of the 21,000 gray whales feed on the sandy substrate, and as much as 1600 million metric tons of sediment are resuspended in the Chukchi Sea by the feeding processes of these mammals. For comparison, the northeastern Bering Sea provides 5–15% of the benthic food supply for the whales, a relatively low amount of the walrus food source, and resuspension of 172 million tons of sediment of whale feeding processes. Considering that the Yukon River, the third largest river in North America, annually discharges 60 million tons of suspended sediment into the northeastern Bering Sea, the mammal feeding on the Arctic epicontinental shelf is a major geologic process.

Natural Hazards

The primary objective of USGS research on Arctic natural hazards (earthquakes, volcanoes and landslides) is to mitigate loss of life and property by providing data and evaluations essential for land-use planning. Research is focused on hazards related to offshore lease areas, engineering design and emergency preparedness decisions. Three programs are actively investigating natural hazards:

- The Earthquake Hazards Reduction Program, which seeks to mitigate earthquake losses by providing data and evaluations for land-use planning, engineering and emergency preparations;
- The Volcano Hazards Program, which includes studies on the assessment, reduction and prediction of volcanic hazards; and
- The Landslide Hazards Reduction Program, which includes studies on the assessment, reduction and prediction of landslides.

Comprehensive studies are conducted under each of these programs.

The Alaska Volcano Observatory (AVO), a cooperative effort of the USGS, University of Alaska

and ADGGS, was created in 1988 to provide eruption warnings and information about long-term volcanic hazards in Alaska. As a result of the Redoubt eruptions of 1989-90, the AVO received significant budgetary increases. The AVO successfully warned of the initial eruption and subsequent eruptions, provided early warnings and ash-trajectory predictions to the aviation industry and deployed a new flood-monitoring system on the Drift River upstream from an oil-tank farm to monitor floods resulting from eruption-generated melting of glacier ice and snow. The AVO monitors Cook Inlet volcanoes by a seismic network, operates an ash-detection system in the Cook Inlet region and responds to reports of eruptive activity elsewhere in the Aleutian arc (such as eruptions of Westdahl volcano late in 1991) as capability allows.

The Earthquake Hazards Reduction Program has long supported projects in Alaska that focus primarily on two broad topics: the seismicity of one of the world's most active subduction zones and geologic studies bearing on the Holocene seismicity of Alaska. Support for non-USGS researchers totaled about $375,000 per year in FY 90 and 91. Activities include analyses of data from regional seismic networks, geodetic studies, geologic framework studies and studies of major historic earthquakes. About $400,000 per year supports the regional USGS network, which monitors coastal Alaska from Anchorage to the southeast and includes the transition from subduction to transform faulting. Another $175,000 per year supports USGS studies of prehistoric earthquakes, surface deformation during great earthquakes, and the relation of seismicity to changes in the crust in southern Alaska and the Aleutian Islands. One of the most significant accomplishments of the EHRP in Alaska during 1990-91 was its contribution to the successful seismic monitoring and prediction of the Redoubt eruptions.

A seismic station, part of the world seismology network, is operated by the National Mapping Division (NMD) at the Amundsen–Scott South Pole Station, a site located at 90° south latitude. The location of this station instantly provides the latitude of all epicenters, including the very active seismic areas in the Arctic–Alaska Region. Station operations include daily interpretations of analog data captured during the previous 24 hours. During the austral summer, data are sent to USGS's National Earthquake Information Center (NEIC) in Golden, Colorado, via McMurdo Station by HF radio data communications. This method of communication was interrupted during the Gulf War, and a method of sending data via electronic mail (through the ATS-3 or LES-8 satellite) was implemented. Depending on satellite window availability, the data arrive at NEIC 12–18 hours after an event is recorded, unless priority tsunami warning data are required. The NMD program also provides support for a joint USGS–university study of earth tides. These data are collected and stored for geophysicists who use the seismic data captured at the South Pole to study the structural layer of the earth's interior and its core, including studies of areas beneath Alaska and the Arctic.

Climate and Paleoclimate

The record of late-Cenozoic warm intervals in Alaska is being studied under the Climate Change and Global History Program. Glacial–eustatic high sea level stands as old as the late Pliocene are evident along the Arctic Coast. During the Colvillian marine transgression, which occurred sometime between 2.48 and 3.0 million years ago, forest vegetation not unlike that of modern south-central Alaska extended north to the Arctic Coast. A younger Pliocene transgression also was characterized by warm climates and by the absence of permafrost and sea ice, but permafrost has been present nearly continuously since that time. Marine mollusk shells from the deposits of the youngest two marine transgressions have isotopic values that suggest that summer sea ice was less extensive than it is now.

Farther inland on the Alaskan Arctic coastal plain, a continuing study of the warm period that peaked about 9,000 or 10,000 years ago has produced abundant data on former water temperatures and chemistry, wind direction, surface moisture conditions, snow cover and other parameters. This warm period is a possible high-latitude analog for future warming that will likely result from the buildup of anthropogenic greenhouse gases in the atmosphere.

Precision Borehole Temperature Studies

The USGS has been acquiring precision temperature logs within deep boreholes in the Alaskan Arctic since the 1950s. In 1986, based on an analysis of these temperature logs, USGS scientists concluded that the upper surface of the permafrost layer in northern Alaska has warmed as much as 2–4°C during the last 50–100 years. Additionally, their analysis revealed a recent cooling event in the immediate vicinity of the boreholes, coinciding with the construction of the drilling pads during the late 1970s and early 1980s.

During FY 90 a new set of precision temperature logs was obtained from 19 of the National Petroleum Reserve–Alaska (NPRA) boreholes. An

inversion method (called singular value decomposition), which was much more powerful than the one used in the 1986 study, was developed to extract the climatic signal from these logs. Application of this inversion technique to the FY 90 data confirmed the earlier conclusion that the earth's surface has warmed 2–4°C in the Alaskan Arctic during the last 50–100 years. In addition, the analysis indicated that the apparent cooling that coincided with the construction of the drilling pads has in many cases reversed; surface temperatures near at least four of the boreholes are now higher than they have ever been during this century.

The FY 90 data confirmed the earlier conclusion that the earth's surface has warmed 2–4°C in the Alaskan Arctic during the last 50–100 years

Six automated climate-monitoring stations were deployed in the NPRA during 1991. Each station monitors ground temperature at seven depths, air temperature at the standard "screen" height, solar radiation, wind speed and direction, relative humidity, and snow depth every 30 seconds. These stations will serve several purposes:

- They will establish which components of the climate system are potentially responsible for the observed 2–4°C warming of the permafrost surface in northern Alaska.
- They will provide baseline data necessary for determining the sensitivity of near-surface permafrost to future climatic changes.
- They will be used in conjunction with the existing boreholes to monitor future climatic changes in this critical region.

Late Cenozoic Climate History of Alaska and the Yukon

In FY 90 the USGS and the Geological Survey of Canada began a joint research project aimed at reconstructing the history of climates and environments of Alaska and the Yukon Territory during the late Cenozoic. An interdisciplinary research team from the USGS, the GSC and Agriculture Canada carried out the first field investigations for the project in August 1990 in northeastern Alaska. The field season was spent collecting samples and data from middle Miocene and latest Miocene fossil-bearing deposits exposed in the walls of the Porcupine River canyon. Studies included palynology, sedimentology, pedology, paleobotany, paleoentomology, paleomagnetism, geomorphology, stratigraphy and isotope geology. Preliminary analyses of samples collected from the Porcupine River exposures suggest that middle Miocene warming was of sufficient magnitude to permit many broadleaf temperate tree types to spread far north into interior Alaska. Conifers such as sequoia, dawn redwood, spruce, pine, hemlock and fir dominated the vegetation of interior Alaska during the middle Miocene, but broadleaf taxa such as elm, oak, hickory, walnut, holly, beech and basswood were growing nearby, perhaps in floodplain environments. Late Miocene floras from the Porcupine River contain few broadleaf taxa, except birch, willow, alder and a few others, and the conifer assemblage is less diverse, with pines dominating. Pines no longer grow in interior Alaska.

In 1991 the project's second field season was conducted in interior Alaska and the Yukon Territory during June and July. The field party collected a wide variety of samples from about 20 localities in Alaska and the Yukon, and the ages of the deposits sampled range from early Miocene to middle Pleistocene. In April 1992 the project members and collaborators presented scientific results from the 1990 field season and preliminary reports from the 1991 field season at a USGS–GSC workshop held in Whitehorse, Yukon Territory.

In the summer of 1992 a small USGS–GSC field party will carry out some additional field investigations in the Alaska Range to collect samples that may improve understanding of the chronology of the tectonic events associated with the rise of that high mountain barrier. The formation of east–west-trending mountain chains in southern Alaska during the late Neogene and Quaternary had significant effects on the climate of interior Alaska and northwestern Canada. Therefore, an improved understanding of the chronology of the mountain-building events will improve the research team's ability to separate regional from global climate changes recorded in the geologic record of northwestern North America.

In 1993 the USGS and GSC plan to carry out core-drilling operations in interior Alaska to recover a long, relatively continuous record of climate and environmental changes during the late Cenozoic. The current drilling target is Yukon Flats, where a long Cenozoic sediment record is likely to be preserved. Data collected during this project will not only provide a basis for reconstructing paleoclimates and paleoecological conditions from the Miocene through the Pleistocene for the region, but they will provide an improved biostratigraphic and geochronologic framework for Alaska and the Yukon that will have broad applications for mapping, resource investigations and tectonic reconstructions.

Glaciology

Glaciers cover nearly 30,000 square miles of Alaska, about 5% of the total area of the state. Snow forms a veneer on most of Alaska for half to three-quarters of the year, and the freezing and thawing of water affect virtually all of Alaska to some extent. USGS research in glaciology (the study of ice in all its forms) focuses on:

- Understanding the interaction between climate and sea ice (particularly the marginal ice zone), snow and glaciers;
- Developing remote sensing techniques from aerial and satellite platforms to investigate changes in glacier extent, sea ice extent and morphology, and snow cover characteristics;
- Evaluating the water resource and hazard potential of alpine glaciers;
- Obtaining ice cores for paleoclimatic reconstructions;
- Assessing the importance of Alaskan glaciers for interpreting climate; and
- Determining and evaluating the extent of permafrost.

The goals of USGS glaciological research closely parallel those of USGS Quaternary geological research.

Glaciers cover nearly 30,000 square miles of Alaska, about 5% of the total area of the state

Most of the sea ice studies are conducted in the international Arctic, primarily by the Water Resources Division (WRD), through long-standing joint programs with NASA and the French Space Agency (CNES). Studies consist of a three-level observational system that uses satellite, aircraft and surface sensors to acquire simultaneous observations of sea ice. The USGS role has been in both the design of microwave sensors for satellite missions and the subsequent analysis and use of the satellite data. WRD researchers continue to participate in planning and carrying out aircraft remote sensing missions in conjunction with the satellite missions and in surface-truth experiments on drifting ice stations and ships.

A joint WRD–NASA study of the upper Colorado River basin snowpack using Nimbus-7 SMMR observations to measure snow water equivalence is now entering its ninth snow season. The results from these observations are useful for understanding snowfall–runoff relationships in the Arctic. WRD researchers have developed numerical models for sea ice dynamics and thermodynamics in cooperation with other agencies, notably the Goddard Space Flight Center of NASA.

Bering Glacier Project

This project, involving researchers from the Geologic Division, the Water Resources Division and the National Mapping Division, is in its fourth year of evaluating the longest glacier in North America. The Bering Glacier, the largest temperate and largest surging glacier in the world, has been retreating for much of this century, resulting in the opening of a large, freshwater, ice-marginal lake, Vitus Lake, and in most of the glacier's southern terminus becoming an iceberg calving margin. Since 1968 this ongoing recession appears to have accelerated into an irreversible calving retreat.

Coupled with the expansion of the lake has been a downcutting of the lake's outlet channel, the Seal River; since 1938 the lake level has dropped more than 3 m to about 2 m above sea level. Gulf of Alaska storm surges entering into Vitus Lake have deposited log flotsam as much as 5 m above the present lake level. Observations of the flow in the Seal River made in 1990 and 1991 show that when Gulf of Alaska tidal stages are more than 2 m above mean high water, saline ocean waters enter Vitus Lake; this probably affects both the circulation in the lake and the ice melt rate.

Vitus Lake is more than 180 m deep. The lake basin approaches 275 m below sea level. Ice-penetrating-radar thickness measurements of the glacier show that much of the glacier's bed is below sea level for a distance of up to 60 km from the terminus.

A continuation of present conditions—drastic retreat of the glacier, erosion of the beach separating Vitus Lake from the Gulf of Alaska and saline ocean waters entering Vitus Lake—will result in the lake evolving into a large saltwater bay extending far into the Chugach Mountains.

The USGS has extended its remote sensing capability of ice sheets by developing an airborne impulse radar system. This instrumentation has been successfully used in Greenland to determine the depth and internal layering of the ice at the Greenland Ice Sheet Program (GISP2) site. These data were fundamental to the selection of the GISP2 site now being cored. Currently this radar system is being used in Antarctica.

Benchmark Glacier Program

WRD's Benchmark Glacier Program studies the effects of glacier changes on streamflow and the effects of climate changes on glacier extent. This long-term monitoring program examines

three glaciers, two of which are in Alaska (Wolverine and Gulkana). Measurements on these glaciers consist of mass exchange, ice movement and stream flow. The research objectives include understanding the mechanics of water flow through glaciers and understanding the effect of weather and climate patterns on the mass exchange at the glacier's surface.

In addition to these three glaciers, annual aerial photographic missions are flown over large geographic regions to document glacier variations. Tidewater Hubbard Glacier, which closed Russell Fjord in 1986, and rapidly retreating Columbia Glacier are being systematically monitored by photogrametric-quality, vertical aerial photographic missions, supplemented by occasional oblique aerial surveys.

High-Resolution Paleoclimate Reconstruction from Alaskan Ice Cores

Unlike Greenland and Antarctica, where deep ice cores from large continental ice sheets provide long-term climate records, little is available from Alaska, where the ice contains a record of a climate influenced by northern Pacific Ocean weather patterns. A USGS and Canadian team will recover an ice core from an elevation of 4200 m in a col between Mount Churchill and Mount Bona in the St. Elias Range of southeastern Alaska. The ice core is likely to contain a high-resolution paleoclimate record dating back as far as 1200 years. The site is a broad, relatively flat expanse of snow and ice, about 1.0 × 1.3 km, sloping gently to the east. In the late spring of 1991, initial field reconnaissance was conducted. It emphasized observation, sampling of snow strata from snow pits and sampling of gases in the snow and firn using shallow and deep probes. The site is located in the dry facies zone and is part of the ultimate source of the Klutlan Glacier, well above the equilibrium line.

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No significant melting horizons were observed in snowpits. The net annual accumulation of snow is 1.9–2.0 m/yr (about 70 cm of water equivalent), judging by the minimally compacted stratum of the most recent year. Snow densities of the topmost year range from a minimum of about 0.18 g/cm^3 near the spring surface to a maximum of about 0.43 g/cm^3 at a depth of 2 m.

The preliminary analytical results show the following. The light stable isotopic composition of snow within one year's accumulation exhibits a very large seasonal range, indicating at least two sources of moisture and a correspondingly large range in temperature. The concentration of biologically produced oceanic methanesulfonic acid (MSA) in snow strata closely parallels the isotopic extremes, with a small time lag. MSA maxima appear with the most negative isotopic values (cold times). This may suggest that there are different latitudinal sources of moisture in different seasons and that the more Arctic regions produce more biogenic sulfur. Alternatively these variations in stable isotopic composition and biogenic sulfur may be related to the tropospheric stratification proposed to dominate in these altitudes and latitudes. Shallow and deep firn gases were collected using a USGS-designed sampling probe capable of approximately 30 m of penetration. Gases adsorbed from the atmosphere onto snow crystals are present in different proportions than in the atmosphere. Upon recrystallization of snow grains with aging and burial of the strata, excess adsorbed gases are released, and residual adsorbed gases approach atmospheric proportions, exchanging in an open system with the atmospheric gases that circulate through the permeable snowpack. At least a decade may be required in this locality for desorption and redistribution of gases from the snow and equilibration of firn gases with the atmosphere. Strata isolated by impermeable layers may retain the fractionated and anomalous proportions of adsorbed atmospheric gases. From ongoing studies by isotope dilution mass spectrometry, we anticipate that concentrations of rock-forming, sea-salt and volcanic-exhalation metals in seasonal snow strata will give additional information about changing air mass sources.

In preparation for innovative procedures to be applied to ice core studies of paleoclimate records, the new National Ice Core Curatorial Facility (NICCF) in Denver is developing and installing ice core handling and processing facilities, new stable isotope mass spectrometer instrumentation, laser microbeam gas bubble sampling and quadruple mass spectrometer equipment, cold rooms and ultra-clean chemistry laboratory facilities. The NICCF is jointly funded by the National Science Foundation and the USGS. The facility is jointly operated by the University of Colorado and the USGS. Eventually ice cores collected from the Alaskan drill site targeted in 1991 will be archived at this facility. All of the ice cores returned from

the GISP2 site and all of the cores previously archived at the former NSF site in Buffalo, NY, will reside at the new facility.

Permafrost Map of Alaska

A new permafrost map of Alaska is being compiled to incorporate data that have become available since the last compilation (in 1962) of an Alaskan permafrost map. New data are available from boring records along the Trans-Alaska Pipeline route, oil exploration and development work on the Alaskan North Slope, water wells, highway improvements and other engineering projects. The map will provide baseline data for evaluating changes in the distribution, thickness and general character of permafrost that would be caused by future changes in climate. It should also shed light on whether recent climatic warming has caused perceptible changes in permafrost distribution, temperatures or other parameters.

Quaternary Geology

The goals of Quaternary geological research are:

- To understand complete cycles of glacier behavior;
- To provide advice on glacial and engineering geological hazards; and
- To interpret Quaternary geological environments and Quaternary climate by reading the record of events recorded in loess, permafrost, glacier ice and glacial deposits, and marine and lacustrine sediments.

The last interglacial period in Alaska is being studied under the Climate Change and Global History Program. This project includes an initial field survey of potential interglacial sites, a review paper discussing known and potential Alaskan sites, and follow-up studies of sites that are considered particularly significant. One important offshoot of this study was the recognition that the Old Crow tephra, a widespread stratigraphic marker in Alaska and the Yukon, is present in about half of the interglacial sites in this region. The volcanic ash, evidently deposited near the beginning of the last interglaciation, is an important marker bed for the glacial–interglacial transition.

Eolian-dominated alluvial sediments at Epiguruk, an extensive river-bluff exposure in northwest Alaska, demonstrate that river aggradation was caused by intensified eolian activity during at least two phases of the Wisconsinin glaciation. Two paleosols record interstadial conditions in which eolian sand did not reach the site and richly organic soils accumulated. Rooted willows and grasses, and the abundant remains of large grazing animals, show that the Epiguruk area was a favorable refugium for plants, animals and possibly humans during the maximum of the last glaciation.

Farther south, Quaternary geologic mapping of the Copper River Basin is continuing with the completion of the Gulkana 1:250,000 quadrangle. This map helps define the complex interrelationship between multiple glacial advances from the Alaska Range and the succession of glacial lakes that filled the basin.

Hydrology

Most USGS hydrology activities in activities in Alaska and the Arctic are conducted by WRD. These activities can be divided into three broad categories:

- The collection of hydrologic data required for planning and conducting hydrologic appraisals and research. In FY 90 and 91 this type of work constituted the major part of the USGS hydrology effort in Alaska.
- Conducting hydrologic appraisals, including studies of water resources in areas likely to be or being affected by mineral energy, fisheries, coastal zone or urban development; investigations of potential hydrologic hazards; and studies of ground- and surface-water contamination on Federal lands.
- Conducting basic and applied research in hydrologic topics unique to cold climates. Examples include studies of the quantity and quality of surface and ground water, hydrologic instrumentation, glacier and snow and ice dynamics, and limnology.

The surface waters of Alaska include many large rivers. Six Alaskan rivers—the Yukon, Copper, Stikine, Kuskokwim, Susitna and Tanana—are among the 30 largest U.S. rivers. Glacial sources for most Alaskan rivers cause important hydrologic consequences in addition to the heavy loads of glacier-derived silt carried by the glacial streams. Even a small glaciated area in a drainage basin can have a significant effect on the amount and timing of runoff. A USGS data collection and processing effort continues. In 1990 USGS operated 90 gauging stations and 70 crest-stage gauges in Alaska.

Alaska lakes are so numerous they are essentially uncounted. Lake Iliamna, Alaska's largest, covers 1000 square miles. Springs occur throughout the state as innumerable small seeps and as warm or mineral waters that support recreational centers. On the North Slope, flows from large springs produce widespread icings in winter.

Groundwater is an untested resource in most of Alaska, and in many areas the potential develop-

ment of the resource far exceeds the current use. Groundwater conditions are diverse: major aquifers are present in the alluvium of large river valleys (Yukon, Kuskokwim, Susitna), in glacial outwash deposits under coastal basins (Cook Inlet) and valleys (Seward and Juneau), and in the carbonate bedrock of the Brooks Range. In many areas, however, the fine-grained material of glacial and glacial-lake deposits and poorly permeable

Groundwater is an untested resource in most of Alaska, and in many areas the potential development of the resource far exceeds the current use

consolidated rocks offer a much less promising groundwater potential. In addition, the recharge, discharge, movement and thus the availability of groundwater over much of the interior, western and northern parts of the state and on the flanks of the Alaska Range are restricted by permafrost. In 1990 USGS monitored about 75 wells for water levels. Of these, 27 are equipped with devices that record water levels on a continuous basis. Water levels in the other wells were measured from 2 to 12 times per year.

The quality of Alaskan waters is generally acceptable for most uses. However, there are naturally occurring problems, such as suspended sediment in glacier-fed streams, saltwater intrusion and undesirable concentrations of iron or arsenic in groundwater at various locations. Pollution from septic tank leakage has occurred in several locations, and an increasing number of cases of groundwater contamination by gasoline or other petroleum products have been reported.

Water quality data collection is conducted at about 25 surface-water stations and several surface or groundwater sites. Water quality data may consist of chemical or biological constituents, sediment concentrations or temperatures. Included are five National Stream Quality Accounting Network stations. One hydrologic benchmark station provides data for a basin in which the hydrologic regimen will likely be governed solely by natural conditions. Collection of miscellaneous sediment data is continuing at the five National Stream Quality Accounting Network stations, one benchmark station and several other stations.

Deep Continental Studies

Deep continental research involves multidisciplinary studies of the continental lithosphere, with an emphasis on deep crustal environments and processes that control or influence the near-surface geology. The goal of deep continental studies is to obtain information about the composition, structure and dynamics of the earth's crust and upper mantle in order to understand the occurrence of energy and mineral resources and processes associated with major geologic hazards such as earthquakes and volcanic eruptions. In the Arctic, deep continental studies are conducted as part of the Trans-Alaska Crustal Transect (TACT) program. The TACT program applies a multidisciplinary approach to study the earth's crust along a corridor from the Pacific Ocean to the Arctic Ocean. The objectives of the program are to determine the structure and composition of the Alaska crust and to investigate the geologic processes that have shaped the crust, particularly the processes of accretion, mountain building, rifting and extension. The transect parallels the Trans-Alaska Pipeline System (TAPS) and extends from offshore south of Valdez and Cordova in the Gulf of Alaska, northward across Alaska and offshore onto the Beaufort Sea. The transect, about 1400 km long, crosses the place in North America with the greatest variety of geologic features, including active subduction zones, offscraped oceanic and island arc terranes, various fault-bounded fragments of the North American Cordillera, major active strike–slip faults and large-scale overthrust belts.

The goals of the TACT program are to:

- Obtain state-of-the-art data (including seismic refraction, deep seismic reflection, gravity, and magnetic and magnetotelluric data) and detailed geologic studies (including bedrock mapping and detailed structural, isotopic, paleontologic and geochemical studies); and
- Conduct and publish integrated, concurrent, multidisciplinary analyses of the data.

The TACT program is a collaborative study including academic institutions, petroleum and mining companies and government research groups. Within the USGS the TACT program includes scientists from the branches of Alaskan Geology, Geophysics, Geochemistry, Seismology, Paleontology and Stratigraphy, and Isotope Geology.

A complex series of maps and reports are being published by the program, including a series of bedrock geologic and geophysical maps along the entire transect and a comprehensive series of interpretive geologic and geophysical articles in the *Journal of Geophysical Research*, *Geology* and *Tectonics*. The first field studies began in the summer of 1984 in the Chugach Mountains of southern Alaska with seismic refraction surveys, bedrock geologic mapping, companion specialized studies and aeromagnetic and gravity surveys. Subsequent investigations, some scheduled

through the summer of 1992, have extended and expanded these studies. Conducted were seismic reflection in selected regions across major faults, continuous magnetotelluric studies along the entire length of the survey, and offshore marine seismic surveys in Prince William Sound.

Some of the main findings from TACT concern the processes of tectonic underplating of large rock units and the relative thinness of many Alaskan tectonostratigraphic terranes. Data from the southern part of Alaska reveal underplated oceanic-crustal rocks that were emplaced in extensive, thin (2–3 km), parallel layers, whereas below the Alaska Range in the middle part of the state, underplated Mesozoic flysch forms a thick (15–18 km) mass. The reason for this fundamental difference in geologic processes remains unknown. Geophysical data indicate that most of the terranes evident at the surface are thin, varying from as little as 4 km to about 10 km thick. Given the many thrust-fault and strike–slip-fault contacts between major rock masses, simple extrapolation of outcrop geology into the deep subsurface commonly does not aid in establishing the likely composition of deep crustal rocks.

TACT is coordinated with the Trans-Alaska Lithosphere Investigations (TALI), which utilizes earth scientists from the ADGGS, the University of Alaska, other universities and private industry.

Magnetosphere

Geomagnetic measurements are made to:

- Infer the physical properties of the earth's interior and atmosphere;
- Aid in the navigation of air-, sea- and space-vehicles and satellites, and
- Identify short- and long-term variations of the earth's magnetic field for thousands of maps and charts.

The USGS magnetic observatory at Barrow, Alaska, is the only source of geomagnetic data close to the geomagnetic pole

Accurate, up-to-date magnetic information is necessary to orient instrument approach systems at some 4000 airports, to establish and verify land surveys, to operate sophisticated weapons systems, to determine the effects of solar and terrestrial magnetic substorms on communications and other electronic systems and to estimate the amounts of energy transferred within the coupled system of the magnetosphere and the ionosphere.

The USGS operates three magnetic observatories in Alaska, one of which is located at Barrow on the Arctic coast. This station is of particular importance as it is the only source of geomagnetic data close to the geomagnetic pole. It is at the geomagnetic pole where charged particles following magnetic field lines enter and leave the earth. Geomagnetic data are critical for understanding the effect of sunspots on communications and the relationships between the earth's internal magnetic field and the atmospheric magnetic field.

Mapping

NMD mapping goals with respect to the U.S. Arctic and Alaska include preparing and maintaining a variety of high-quality multipurpose base maps and digital cartographic databases to meet specific national priorities, including the requirements of Federal and state agencies, the Congress and others. The primary map product and series are 1:63,360-scale (1 inch = 1 mile) topographic maps. Additionally, complete 1:250,000-scale topographic map coverage is available for all of Alaska. Multi-color orthophotomaps at 1:24,000 scale are available for about a dozen quadrangles in the Prudhoe Bay area. A number of cities are covered by 1:24,000-scale and 1:250,000-scale topographic maps.

Other cartographic data and products available include:

- Black-and-white orthophotoquads at 1:63,360 scale for selected areas;
- A series of more than two dozen black-and-white Landsat RBV image maps at 1:250,000 scale for Alaska north of 68°N latitude;
- Multicolored Landsat MSS image maps at 1:250,000 scale for ANWR;
- Side-looking airborne radar (SLAR) digital and photographic data;
- SLAR image maps at 1:250,000 scale for selected quadrangles;
- Land cover maps and digital data;
- Digital elevation data at 1:250,000 scale and selected areas at 1:63,360 scale;
- Digital planimetric data at 1:2,000,000 scale;
- Alaska Boundary Series of 1:250,000-scale maps for the ANILCA units;
- Alaska High-Altitude Photography (AHAP) program products, including 1:120,000-scale black-and-white and 1:60,000-scale color infrared coverage for most of Arctic Alaska; and
- Small-scale state base maps and 1:1,000,000-scale topographic maps.

The first phases of data collection for the Fed-

Additional information on Arctic and Alaska mapping activities may be obtained from the USGS Earth Science Information Center, USGS, 4230 University Drive, Anchorage, Alaska 99508-4664.

eral Land Information System were completed in 1985. Information essential to the development of policies governing mineral exploration and resource development on Federal lands and data on surface and subsurface ownership, restrictions and withdrawals related to mineral development were obtained from BLM's Alaska Automated Land Records System and combined with data from the USGS's various mineral resource data and assessment programs, the Bureau of Mines' Mineral Industry Locational System and the USGS's base cartographic and water resources data programs.

An "Arctic Sheet" has been added to the Circum–Pacific Council for Energy and Mineral Resources' Circum-Pacific Map Series. Produced by USGS are an Arctic Geographic Base Map and an Arctic Geodynamic Map. In preparation is an Arctic Tectonic Map. The new permafrost map of Alaska will serve as the cornerstone of an Arctic permafrost map now in preparation.

Data Management

In response to requirements stated by the Arctic Research and Policy Act, USGS has taken the lead in developing a two-part Arctic data management effort: the Arctic Environmental Data Directory (AEDD), an inventory of about 500 existing Arctic data sets; and the Arctic Data Interactive (ADI), an innovative CD-ROM (compact disk–read only memory) for distributing Arctic information and data. USGS has begun both projects on behalf of the Federal Interagency Arctic Research Policy Committee (IARPC). IARPC member agencies have contributed both data and financial support to develop ADI and expand AEDD.

AEDD is maintained by the USGS as an online system, accessible from anywhere in the world. AEDD consists of a compilation of information about specific earth science, environmental and natural resources data sets. AEDD databases are held by a number of entities, including academia, government and industry.

The ADI prototype is an electronic Arctic research journal using multimedia and CD-ROM technologies. A CD-ROM can hold more than 600 megabytes of digital information, a volume substantially in excess of 25,000 printed pages. The ADI prototype can put large quantities of Arctic data in the hands of a researcher in a mode where it can be used on a standardized and inexpensive workstation, either an Apple Macintosh II or IBM PC-compatible computers. ADI uses a graphical and intuitive hypermedia interface, a software system that permits full-text retrieval of bibliographic data and data set descriptions, image display, and text and graphic integration. In addition to AEDD the ADI prototype contains full-text articles with illustrations and selected data sets, including tabular data, text with figures and imagery. The joint AEDD–ADI concept is an effective way for the permafrost community to inventory the results of past programs, keep track of present research and provide selected results and data for peer groups.

The results of USGS Arctic and Alaska research are reported annually in several publications. See, for example, *Geologic Studies in Alaska by the U.S. Geological Survey During 1990* (USGS Bulletin 1999) and *United States Geological Survey Yearbook, Fiscal Year 1990*. Both are available from the Books and Open-File Reports Section, USGS, Federal Center, Box 25425, Denver, Colorado 80225.

Bureau of Mines

FY 91 FUNDING (thousands)	
Minerals	1028

The Bureau of Mines (BOM) is a primary source of information on mineral production in the United States and throughout the world. BOM assesses the worldwide availability of minerals, giving highest priority to deposits in the U.S. It analyzes the impact of government policies, economic conditions and political events on the mineral sector of the economy and the Nation's mineral supplies.

Minerals Availability

Under the auspices of the Minerals Availability Program, BOM investigated mineral development potential near proposed port sites, studied cyanide use in precious-metal extraction under Arctic conditions, and assessed the impacts of permitting and environmental costs on mining.

Port Site Evaluation

The BOM examined the potential for minerals development in the areas adjacent to Balboa/Herendeen Bay, Beluga, Bethel, Iliamna Bay, Kivalina, Kotzebue, Lost River, Nome, Omalik Lagoon and Point MacKenzie, as well as coal development impacting Beluga, Kotzebue, Omalik La-

goon and Point MacKenzie. The evaluations were done as part of a study by the Army Corps of Engineers on the future needs of port site facilities in Alaska. The BOM inventoried the mineral deposits around the port sites, listed the commodities found in each mineral deposit, and determined the likelihood of mineral development around each site.

The number and types of mineral deposits were determined within a radius of 100 miles around each site; for Point MacKenzie, deposits were identified within 30 miles of a major road or railroad. The BOM identified 859 deposits that meet the criteria for development within the proposed access area of the ports. The deposits contain aluminum, antimony, asbestos, barium, bismuth, calcium, chromium, clay, coal, cobalt, copper, diatomite, fluorine, gemstones, gold, graphite, iron, kyanite-group minerals, lead, mercury, mica, molybdenum, niobium, pumice, silver, sulfur, tin, uranium and zinc. Major commodities using each port would include coal for Omalik Lagoon, Kotzebue and Beluga; copper and molybdenum at Balboa/Herendeen Bay; lead and zinc at Kivalina; tin at Lost River; gold at Nome; and coal, copper and gold shipped to Point MacKenzie.

Coal basins underlie nearly 51 million acres of Alaska, of which about half are under Federal jurisdiction

Cyanide Leach Technology

Data on cyanide use in Alaska collected by the BOM include information on the chemistry of cyanide leaching, the types of leach operations available (heap vs vat), the environmental effects on leaching, and economic information to conduct a feasibility study of a gold-leach operation in Alaska. The costs of a hypothetical heap-leach mining operation in Alaska were compared to those in Nevada.

Although there are a few problems unique to northern heap leaching, this study showed that heap leaching is economically feasible in Alaska. However, an Alaskan precious-metal deposit that would be amenable to cyanide heap leaching requires a recoverable metal value twice that of similar deposits in Nevada to realize a 15% return on investment. The increased costs of Alaskan heap leaching stem from circumstances such as a shorter leach season, larger holding ponds to accommodate heavy snowmelt, permafrost insulation, heavier vegetative cover and higher costs of labor, transportation and shipping.

Permitting and Environmental Constraints

The BOM published a report detailing the costs of mine-permitting requirements and procedures for placer and lode mines in Alaska. For placer mines the study found that increased operating costs and lost production time during a short operating season account for a markedly decreasing rate of return as effluent treatment is increased. Lode mines face greater permitting and compliance costs than placer mines of similar size due to the physical impact of their operation. Direct permitting costs for lode mines average 4% of the total project cost, and total permitting and compliance costs are approximately 8%. Indirect costs associated with compliance include mitigation, monitoring and reclamation.

Policy Analysis

The BOM inventoried all lands in Alaska to determine the availability of land for oil, gas and coal leasing. The BOM found that coal basins underlie nearly 51 million acres of Alaska. Of this land, 26.4 million acres are under Federal jurisdiction, 17.3 million acres of land are managed by the State of Alaska, and nearly 7.3 million acres are managed by Native corporations.

Mineral Land Assessments

Mining District Studies

The Mining District Studies in Alaska are designed to assist land management agencies in land-use decisions and to reduce the dependency of the United States on foreign sources for strategic and critical minerals. The Anti-Apartheid Act of 1986 (P.L. 99-440) mandates that the United States decrease its import reliance on South African supplies of platinum-group metals, chromium, manganese, cobalt and other minerals. The Mining District Studies are conducted in cooperation with the State of Alaska and provide detailed information on identified mineral resources on Federal and State lands and the potential for their economic development. Emphasis is also placed on developing more extensive quantitative information on potentially economic mineral resources, especially of strategic and critical minerals.

Valdez Creek

Work in the Valdez Creek mining district (VCMD) during 1990 was the culmination of a four-year project begun in 1987. Field work performed by the BOM encompassed district-wide reconnaissance, geochemical rock and stream sedi-

ment sampling, and detailed examinations of 176 of the 218 previously known mineral occurrences in the district. Of the 42 occurrences not visited, 13 were located inside Denali National Park, 11 were located but could not be investigated safely due to rugged terrain, and 18 could not be located on the ground. The BOM collected and analyzed 1632 rock samples and 781 placer samples and had 7 bulk samples tested for beneficiation characteristics.

During the mining district study the BOM located 19 new mineral occurrences within the VCMD. Reconnaissance placer sampling resulted in the identification of 10 previously unreported gold placer occurrences, some of which contain subsidiary placer platinum-group metals (PGM) or tin or both. Conglomerate units in the district were identified as sources of the placer gold and PGM. Reconnaissance lode sampling resulted in the identification of two gold–silver occurrences, three PGM occurrences that contain subsidiary chromium, nickel or cobalt, three copper occurrences that contain subsidiary molybdenum or zinc, and one zinc occurrence. The BOM found that the VCMD also has a potential for economic quantities of the industrial minerals argillite, limestone, intrusive rock, basalt, perlite, zeolite and sand and gravel.

The BOM and the Alaska Division of Geological and Geophysical Surveys jointly conducted a probabilistic mineral resource and economic assessment of the mining district. The results indicate that the bulk of the present-day gross metal value of the mineral endowment (except placer gold) lies in plutonic-related deposits, including skarns, vein-replacement gold, plutonic tin–silver–zinc, various porphyry-type deposits and ultramafic-hosted deposits. This partly reflects the abundance and variety of plutonic rocks in the district and the variety of plutonic-related deposits known to exist, and it partly reflects the fact that many plutonic-related deposit types contain large quantities of metal. Much of this plutonic-related endowment is speculative, however, because so little is known about the plutonic rocks in the district.

Order-of-magnitude mining feasibility investigations were conducted for eight mineral deposit models. The models were based on real and hypothetical deposits that occur in the VCMD. Sixty-six mine models were developed for application to the mineral deposit models, and capital and operating costs were calculated for each mine model. From the cost data for each mine model, a capital investment schedule (CIS) was developed to show the timing of capital investment into the mining model. A cash flow analysis was performed for the CIS data for each mine model, and the discounted cash flow rate of return on investment versus the recoverable metal value distribution was evaluated. The results of the mining feasibility analysis of these mine models can be used as a preliminary evaluation of the mining potential of real mineral deposits in Alaska that are similar to the deposit models.

Colville

The Colville mining district is located in northern Alaska and includes the southern portion of the National Petroleum Reserve–Alaska (NPRA). A mineral resource inventory of the NPRA was conducted in 1977 and 1978 by the BOM and the United States Geological Survey (USGS). The USGS conducted regional geologic mapping and regional geochemical sampling, while the BOM conducted site-specific examinations and detailed sampling of mineralized localities. Samples showing high zinc and lead values, along with anomalous values of silver, gallium, indium and germanium, were collected. Rocks with high fluorine, phosphate, rare earths, barium, vanadium and chromium values were also identified in the area, as was coal.

In 1991 the BOM started a four-year investigation of the district. The mineral information gathered will be used by the Bureau of Land Management for their land management plan of the NPRA. The BOM examined in more detail the portion of the study area between Drenchwater Creek in NPRA and the Chandler River in Gates of the Arctic National Park and Preserve. Approximately 97% of the earlier-identified USGS geochemical anomalies in the area were investigated, and approximately 750 samples were collected. Thirteen mineral occurrences and 12 mineralized areas were identified, examined and sampled at a reconnaissance level. Detailed site-specific examinations of the Drenchwater, Story Creek, Kivliktort West, Koiyaktot East, Koiyaktot West and Kady occurrences were completed. Examinations included detailed mapping, soil sampling, geophysical surveys (at Drenchwater Creek) and bulk sampling.

Site-Specific Mineral Investigations

The BOM site-specific program, which began in 1981 in Alaska, provides detailed data on small areas of Federal lands that have potential for important metals like chromium, tin and cobalt. Investigative procedures include estimation through field studies of the identified resources, characterization of deposit types and mineralogy, and beneficiation and metallurgical testing. Nearly 300 Alaskan sites containing strategic and critical minerals have been, or continue to be, under study.

Reconnaissance field work was carried out at several localities in 1990 to identify future projects. On the Seward Peninsula, beach sands at Golovin and nearby radioactive dikes in the Kachauik Mountains were evaluated for rare-earth elements (REE) and zirconium contents. In the Cape Prince of Wales area, marine placer deposits were investigated for titanium-bearing ilmenite and accessory REE-, tin-, tungsten- and zirconium-bearing minerals. Forty-five core samples were collected from the sea floor. In central Alaska the Egries sedimentary occurrence near Medfra was examined, as well as manganese-bearing sedimentary rocks in the nearby East Fork Hills. Reported grades of 22% manganese at the Egries occurrence were confirmed.

During FY 90 and 91 the BOM conducted detailed investigations of the tin deposits, which may also contain niobium, REE and tungsten by-products. Most of the tin deposits in Alaska occur on land available for exploration and development and are located near water or road access. The Win prospect in southwest Alaska yielded samples averaging as high as 7% tin and 19 oz/ton of silver. High-grade zones contained as much as 57% tin and 334 oz/ton of silver. Reports of high indium values in the tactite deposits around Tin City were investigated, and samples containing up to 750 ppm of indium were collected.

A cooperative BOM and USGS investigation of the ultramafic complex at Sinaktanneyak Mountain identified about 2.5 million tons of chromic oxide. Anomalous concentrations of PGM and gold detected in the bedrock suggests a potential for platinum and gold placer deposits in the area.

Field investigations in northeastern Alaska, near the Yukon River, consisted of sampling outcrops of the Calico Bluff Formation, Ford Lake Shale and Lower Glenn Shale. These units may contain anomalous vanadium and silver values.

Technology Research

The BOM is conducting the following technology research projects in Alaska: mine closure in Arctic environments, subaqueous disposal of mining wastes, analysis of underground mining, underground mining methods for Alaskan deep placers, borehole mining of precious metals, and frozen tailings as backfill material.

Mine Closure in Arctic Environments

The goal of this project is to identify possible environmental impacts from various types of mining activities and to develop methods for closing mines that will mitigate any undesirable impacts. Factors evaluated include revegetation, wetland preservation, surface drainage and visual aesthetics. The work is conducted in cooperation with the USDA Soil Conservation Service on mined lands near Nome.

Subaqueous Disposal of Mining Wastes

This project will determine if it is environmentally and economically feasible to dispose of mining wastes in marine or lacustrine environments. In 1991 a bibliography that contains 2000 references was prepared. A reconnaissance of Alaskan and Canadian mines that use or would like to use marine disposal of tailings was also conducted. Samples of tailings were collected from the Island Copper Mine (British Columbia), the AJ Mine (Alaska), the Kensington Mine (Alaska) and the Greens Creek Mine (Alaska).

Analysis of Underground Mining

This cooperative project between the Greens Creek mine and the BOM entails an analysis of the behavior of soil, rock and the mining infrastructure in extreme environments. A rock mechanics study of the Greens Creek mine confirmed that the present mine layout would not create any surface disturbance. Sensors have been installed in the mine to monitor stress and SO_2 levels. A BOM evaluation of the backfill method used in the mine led to a change from backfilling using "slinger" trucks to backfilling with slurries pumped into the underground openings.

Underground Mining Methods for Alaskan Deep Placers

The purpose of this project is to develop economic, safe and environmentally sound techniques for recovering metals from deep placer deposits in Alaska. In 1991, underground placer mining operations were examined in the Fairbanks area, and samples of material were collected to characterize the physical properties of materials under different conditions. Initial computer modeling has indicated that a creep material code is needed to predict the behavior of permafrost accurately. Pertinent data have been compiled from the Cold Regions Research and Engineering Laboratory tunnel research to quantify the behavior of the materials in the Fairbanks region.

Borehole Slurry Mining

Borehole slurry mining is a method in which large cavities can be eroded in an ore body using a high-pressure water jet and slurry pump operating in a vertical borehole. The BOM is trying to adapt the method, which has been successful in mining uraniferous sandstones, coals, phosphate and

foundry sand, to deep Alaskan placer deposits. BOM researchers have developed a borehole mining jet that cuts frozen as well as unfrozen gravel. Research is concentrating on pumping between boreholes and on mechanical means of breaking cobbles in the borehole to improve pumping capabilities.

Frozen Tailings as Backfill Material

This project evaluates the disposal of frozen tailings as backfill material in Arctic environments. A literature search was conducted on current and proposed underground mining techniques and placer deposits. The chemical stability of the frozen material will be evaluated.

Department of Defense

Arctic research is conducted by all three services and includes virtually all environmental sciences, engineering and health disciplines. A total of $25 million was devoted to basic research and related testing in FY 91.

The Department of Defense (DOD) conducts Arctic research to ensure the development of the knowledge, understanding and capability to meet national defense needs in the Arctic. The range of military requirements extends from Army ground operations to Arctic engineering, logistics, health, oceanography and atmospheric research. Within the broad scope of current research are such topics as human adaptability to cold, auroral and ionospheric phenomena, deep ocean water formation and construction in permafrost regions.

The military services conduct Arctic research to address specific needs stemming from their requirements. The Army is strongly driven by the need to understand the Arctic terrain and its impact on ground operations and equipment performance, to understand the performance of troops in the field under adverse conditions, and to understand the constraints imposed by the Arctic environment on construction, roads, buildings and support systems, such as wastewater. The Navy focuses largely on Arctic oceanography but also conducts research on high-latitude communications, Arctic storms and the response of sea ice to atmospheric and oceanographic forcing. The Air Force's primary interest is the impact of ionospheric processes and phenomena on communications, navigation and surveillance systems.

The Army must be sure of its capability to conduct combat operations in northern regions. The stationing of the 6th Light Infantry Division in Alaska has focused Army attention on the special environmental conditions of the Arctic. Three major bases are located in Alaska. Fort Wainwright and Fort Richardson are the locations of the 6th Light Infantry Division, and Fort Greely is the home of the Cold Regions Test Center (CRTC) and the Northern Warfare Training Center. In addition, the 10th Mountain Division at Fort Drum, New York, must be capable of operation in winter terrain.

The Army Corps of Engineers has responsibilities for military construction, water resources and environmental impact permits. Both nationally and internationally the Corps is called on to provide construction and engineering services at cold weather sites. These include Army bases in Korea, Europe and the northern tier of the United States, as well as Air Force sites in Canada, Greenland, Iceland and Norway. The Alaska District of the Corps of Engineers is located on Elmendorf Air Force Base and at Fort Richardson.

FY 91 FUNDING (thousands)

Arctic Engineering	2507
Permafrost/Frozen Ground	1417
Snow and Ice Hydrology	2681
Oceanography	13513
Lower Atmosphere	794
Upper Atmosphere	3525
Medical and Human Engineering	560

Five U.S. Army organizations are involved in Arctic research and development: the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire; the CRTC at Fort Greely, Alaska; the Natick Research, Development and Engineering Center in Natick, Massachusetts; the Army Research Office (ARO) in Research Triangle Park, North Carolina; and the Medical Research and Development Command at Fort Detrick, Maryland. CRREL is a national center of excellence in cold regions research and technology. The mission of CRREL is to study and understand the characteristics of cold regions and to use this knowledge to solve cold regions problems of the Army and other Federal and state agencies. CRREL conducts the largest share of the Army's Arctic-related research, concentrating on snow, ice, frozen ground and cold weather engineering. It sponsors the Cold Regions Bibliography at the Library of Congress, which includes over 140,000 citations and is available both on-line and on CD-ROM. Natick conducts research on cold regions clothing, equipment and rations, while the Medical Research and Development Command investigates basic cold physiology and cold stress adaptation. ARO sponsors Arctic-related research in snow and ice, atmospheric propagation of near-millimeter waves (NMMWs) in adverse weather including snow, and NMMW backscatter from snow surfaces. The ARO program provides support to CRREL and other Army cold regions research and development activities and is executed largely through grants and contracts to the university research community.

The Army CRTC at Fort Greely is a test and

evaluation activity focusing on cold weather operations. CRTC does not conduct research but performs technical testing for the Army Materiel Command, other DOD agencies and services, government agencies such as the National Aeronautics and Space Administration (NASA), and industry. Its support facilities, instrumentation and firing ranges allow it to test a variety of military equipment and weapons.

Air Force efforts over the past several years have concentrated on the high-latitude ionosphere, thermosphere and magnetosphere and the coupling processes that take place there. The objectives of the Air Force Arctic research program are to develop the fundamental understanding necessary for comprehensive models and real-time support for DOD systems affected by ionospheric processes and to develop predictive models that depend on ground-based and satellite measurements. The program uses multitechnique observations from a number of high-latitude locations.

The Navy's Arctic-related activities range from basic environmental investigations to applied research associated with operational systems. These activities are pursued within a number of organizations. The Office of Naval Research (ONR) in Arlington, Virginia, supports basic multidisciplinary efforts through grants and contracts, primarily with academic institutions. The Naval Research Laboratory (NRL) performs basic and applied research with an emphasis on acoustics, numerical modeling and remote sensing. The Office of Naval Technology (ONT) in Arlington, Virginia, supports applied research and development through specific Navy laboratories such as the Naval Underwater Weapons Center (NUWC; formerly NUSC, the Naval Underwater Systems Center) in New London, Connecticut; the Naval Command Control and Ocean Surveillance Center (NCCOSC; formerly NOSC, the Naval Ocean Systems Center) in San Diego, California; the Naval Surface Warfare Center (NSWC) in Silver Spring, Maryland; and the Naval Civil Engineering Laboratory (NCEL) in Port Hueneme, California. ONR and ONT form the core of the Naval Research Command, which addresses broad, basic research issues and the initial transition of useful results to fleet applications. More focused applications occur under the Chief of Naval Operations through the Space and Naval Warfare Systems (SPAWAR) Command.

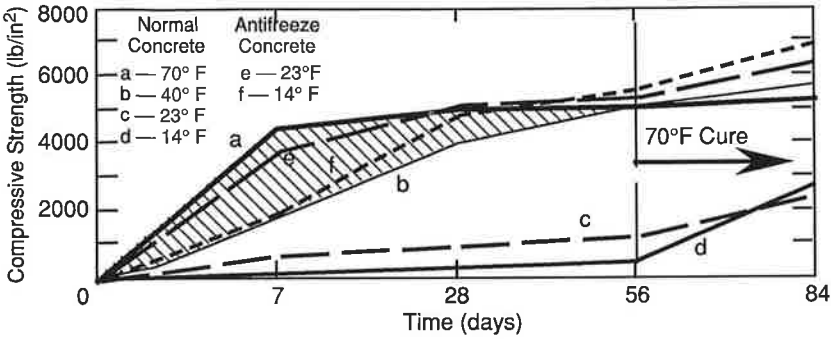
The overall goal of the Navy's research in the Arctic sciences is to provide accurate knowledge of the environment for naval operations. In pursuit of this goal the Navy funds comprehensive theoretical and experimental research on a range of high-latitude processes and phenomena. A multidisciplinary perspective is necessary for a full understanding of the inherent interactions. Contributing disciplines, in order of relative emphasis, are physical oceanography, ice dynamics, acoustics, meteorology, biological oceanography, geological oceanography, chemical oceanography and geophysics. Within each discipline, insight is pursued through both observation and modeling. Observation includes remote and in-situ sensing with the strategy of determining optimal sampling distributions in time and space. Modeling includes analytical, numerical and physical analogs with the strategy of formulating essential governing dynamics and estimating the limits of predictability. Across disciplines, some infrastructure (for example, platforms and data management systems) is common and supported to ensure adequate expertise and capability when necessary. For example, logistics for the Arctic basic research program (ONR) is contracted to the Polar Science Center at the University of Washington. Ice camps, aircraft, ice-strengthened vessels and remote staging facilities are deployed regularly and effectively with a permanent staff of three. No ships or planes are owned but rather are chartered as necessary to support specific science experiments.

Investigations for which enhanced funding has been formally identified within ONR are termed Accelerated Research Initiatives (ARIs). ARIs are typically five years in duration and are established on the basis of scientific merit, technical feasibility, timeliness and relevance. Current ARIs within the ONR Arctic Sciences Program are Ice Mechanics, Ice Electromagnetics and Arctic Lead Dynamics.

Arctic Engineering

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, and Fairbanks, Alaska, is the center of expertise in engineering for cold regions and winter conditions for the Corps of Engineers, the Army and DOD. The current CRREL program reflects recent world events and the resulting changing national policy. The engineering emphasis has shifted to the technologies needed to rehabilitate and maintain the aging military infrastructure that must support forces returning from foreign posts. Alaska, because of its strategic, resource-rich location, is experiencing the opposite trend, with continued growth in military installations and mission. This has increased the need to make Army and Air Force installations there more energy-efficient and maintenance-free.

One CRREL program is studying the use of



Increase in the strength of concrete cured at low temperatures when antifreeze admixtures are used.

concrete in cold regions. The strength of concrete is best developed when it is cured between 50 and 70°F. When placed during cold weather, concrete must be protected to prevent damage from freezing. Estimates indicate that the cost of using concrete can increase by 50–100% in cold weather. CRREL, in partnership with private industry, is working to develop a chemical admixture that will eliminate the need for thermal protection and thereby simplify cold weather construction. In energy savings alone, antifreeze admixtures have the potential of saving the lion's share of the estimated $800 million spent each year to protect freshly placed concrete.

Research in pavements has included laboratory criteria for using less costly materials, design criteria for seasonal performance changes, and a new standard for evaluating low-temperature cracking in asphalts. Laboratory tests and computer modeling were used to develop pavement designs for the $16-million Minnesota Test Road Facility. The performance of the test facility will provide further verification of the frost effects pavement design model developed at CRREL. Meanwhile, validation tests in CRREL's Frost Effects Research Facility (FERF) were completed on cold regions asphalt pavement designs. The 29,000-square-foot FERF is unique because it allows the opportunity for full-scale evaluation of pavement designs. The facility can rapidly freeze and thaw soils, yielding several winters' worth of data in a few months.

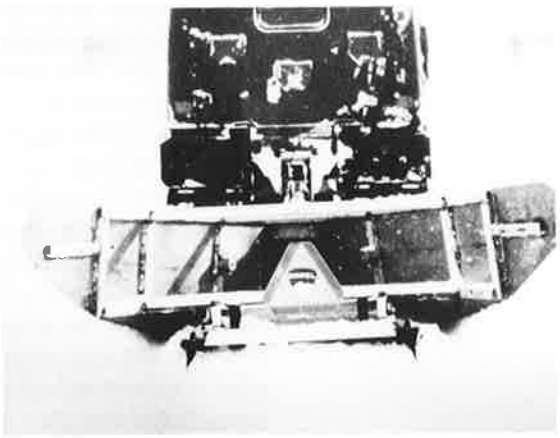
Studies were completed on the use of insulation under pavements to reduce frost effects and on the use of scrap rubber from tires in asphalt concrete to reduce the retention of ice on roadways. New methods were developed for interpreting nondestructive test data obtained from falling-weight deflectometer tests on frozen and thawing pavements. A refrigerated test chamber was fabricated to measure the drainage of water through pavement structures during freezing and thawing.

An investigation of the use of geotextiles to mitigate frost heave was completed. In laboratory tests geotextiles reduced frost heave by up to 60%. It is speculated that the material's pore size and structure and the surface properties of the fibers attribute to the geotextile's capillary break action. The reduction in frost heave may mean a cost savings in military runways of up to several million dollars per year.

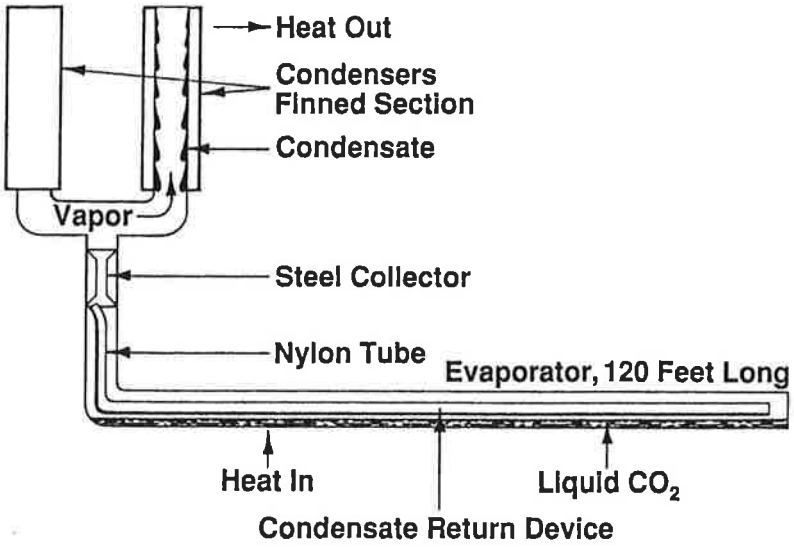
Other engineering research at CRREL focuses on the performance of equipment in cold regions. CRREL and the Army's Tank–Automotive Command evaluated the performance of the Swedish Flextrac vehicle. CRREL engineers participated in the winter evaluation and also tested the vehicle's performance in a wetland and in summer terrain typical of cold regions. The Flextrac is an all-terrain vehicle designed primarily as a snowmobile, but because of its unusual design it is in reality an all-terrain vehicle having potential as an individual soldier transporter.

A model study of the stability of a towed snowplow for the Small Unit Support Vehicle (SUSV) was completed. The SUSV is the over-snow, all-terrain vehicle used extensively by the Army's 6th Infantry Division (Light) in Alaska. The purpose of the plow is to clear winter trails for wheeled vehicles during field training exercises. A hitch arrangement was devised that controlled the location of the plow bottom relative to the ground and snow surfaces. A half-scale version of the plow was constructed, attached to the SUSV and evaluated at the Keweenaw Field Station in northern Michigan.

In conjunction with Belvoir Research and Development Center (BRDEC), the Army's Quartermaster School, the 6th Infantry Division (Light) and the 10th Mountain Division (Light Infantry), CRREL conducted a preliminary field evaluation of the concepts involved in a winterization kit for the 600-gallons-per-hour Reverse Osmosis Water Purification Unit (ROWPU). A tent and heaters were used to shelter the ROWPU and the water storage tanks. CRREL also evaluated heating sys-



Half-scale model of snow plow successfully demonstrated with the Small Unit Support Vehicle (SUSV).



Thermosyphon with a horizontal evaporator equipped with a condensate return device.

tems to provide warm water to keep the raw water subsystem from freezing.

CRREL completed work for the Navy on a laboratory test for measuring the adhesion strength of spray ice on coated flat plates. Icing by sea spray and atmospheric precipitation is a problem for all shipping and creates similar problems for all materials from railroad switches to radar antennas in the world's cold regions. This effort was undertaken to compare the force required to shear freshwater ice from flat test plates coated with the candidate materials. The results showed a significant difference in surface performance, but none of the candidate coatings shed ice better than the deck paints that are already being used.

CRREL researchers have developed and tested two new devices that improve thermosyphon operation. Thermosyphons are passive heat transfer devices that are widely used in Alaska and other permafrost areas to maintain the stability of foundations. They remove heat from the ground when the air temperature is below the soil temperature, and they keep the permafrost frozen under structures such as buildings, roads, oil tanks and pipelines. The first patented device is a decondensate return collector and pipe that delivers about 70% of the condensate to the far end of the evaporator section by gravity. This device enables the evaporator to be installed horizontally under a building or other structure and prevents thermosyphon failure caused by differential soil heaving. The second device is an integrated heat exchanger that is connected to a mechanical refrigeration system. This active component enables the thermosyphon to operate any time of year. A passive–active (hybrid) thermosyphon reduces the risk of summer thaw and capitalizes on the advantages of both a passive and an active thermosyphon.

Permafrost, Frozen Ground and Geology

DOD research on permafrost and frozen ground is primarily conducted by two agencies: CRREL and the Army Research Office (ARO). This research provides design data and criteria for constructing and operating facilities in cold regions. Other efforts include studies of toxic and hazardous waste movement and control in frozen soils.

ARO efforts include laboratory and field programs that study the physical mechanisms controlling processes in frozen ground. An experimental program being conducted by the Geophysical Institute of Alaska is examining the physical mechanism controlling the strength and deformation behavior of frozen sand. Another program, being performed by the Massachusetts Institute of Technology, is measuring water and salt movement in permafrost and the active layer.

The behavior of water at the freezing front of frozen soil and in thawing soil is critical to understanding frost heave, ice lens formation in permafrost, and the transport and movement of contaminants and impurities. Emphasis on this topic continued, with measurements of the hydraulic conductivity of frozen soil, measurements of unfrozen water content using freezing-point depressants, and formulation of a theory relating water movement to the gradients of moisture content and temperature. The consolidation and permeability effects caused by freeze–thaw cycling of soils were measured and reported. These are important for evaluating and predicting the performance of clay landfill liner caps during winter.

Methods for exploring geophysical conditions beneath the surface continued to be developed, with efforts centered on the behavior of radar wavelengths, antenna–receiver configurations and improved signal processing. The source of an anomalous thaw zone in a permafrost setting on Caribou Peak in central Alaska was mapped by radar and shown to be a probable fracture zone. This technology is critical to the construction of new strategic facilities in the Arctic and the location of buried objects, such as might be encountered at a hazardous waste site.

Field observations were made to investigate the concept that variations in the surface concentration of radon gas should provide an indication of frozen ground distribution at depth. At Alaskan study sites there was a noticeable contrast between radon levels in areas of shallow permafrost and areas free of frozen ground when the subsurface geological conditions were similar. The results also seem to reflect variations in the depth to the

top of the permafrost because of a radon contribution from thawed overburden at the sites. It is not clear if data on surface concentrations of radon can be used to provide quantitative information on permafrost distribution; however, these results suggest that radon measurements might be a useful reconnaissance tool, particularly in geological settings where major subsurface variations are related to permafrost distribution, in contrast to changes in soil and rock type.

Snow and Ice Hydrology

DOD research in snow and ice hydrology is primarily carried out by CRREL and ARO. CRREL carried out hydrologic investigations at several sites in Alaska using high-resolution ground-penetrating radar to determine its ability to locate and define highly localized sources of water at depths up to 20 m. Particular attention was devoted to detecting water in frozen Arctic alluvium, to mapping frozen river beds and to delineating water beneath icing mounds that form in otherwise solidly frozen Arctic rivers. At the margin of the Matanuska Glacier in southeastern Alaska, water conduits up to 5 m in depth were identified by polarization reversals between signals reflected from the top and bottom of the conduit. On the North Slope near Prudhoe Bay, surveys were carried out on the Sagavanirktok River floodplain to evaluate large ice blisters in the river for use as water sources. It was concluded that radar can map the thaw–freeze state of riverbeds in winter and thus identify winter water sources, a critical requirement for the deployment of military forces in northern latitudes.

Radar can map the thaw–freeze state of riverbeds in winter and thus identify winter water sources, a critical requirement for military forces in northern latitudes

An electromagnetic system for lake and river sub-bottom profiling was developed and tested. This was done in an attempt to develop methods to obtain data in cases where acoustic systems are ineffective. Recent experience with marine resistivity sounding and with calibration of low-frequency radar antennas in aquatic environments suggests that techniques that discriminate subsurface changes based on electrical properties may be able to perform well where sediments contain gas and where acoustic velocity contrasts are poor.

CRREL continued work on characterizing and measuring the properties and processes associated with snow and ice as they occur and evolve on the ground. The snowpack's liquid water content greatly influences its strength, its interaction with energy across the spectrum of wavelengths, and its thermal response to the ever-changing flows of energy into and out of it. The interaction between these energy flows and the snowpack also results in layering, vapor transport, changes in crystal size and temperature profiles. A one-dimensional model of the flow of air and vapor transport in dry snow was completed and validated. A three-dimensional finite-element model of the thermal behavior of dry snow was constructed, and initial field experiments were completed, including measurements of the multidimensional dry snow temperature profiles. These models enable characterization and explanation of the nonuniform and temporally changing appearance of snow fields to various sensors.

Floating ice studies at CRREL include lake ice, river ice and Arctic sea ice. At the near-molecular scale a cyclic loading experiment was conducted to determine the mechanical properties of ice and relate these to the molecular structure and dislocation movement in ice. At the intermediate scale a relationship was established between porosity and tensile strength. This is important when estimating loads associated with ice at both geophysical and structure-size scales. The growth of the ice cover through the process of wave-induced collisions of small floes was identified and measured. Coincident stress and strain measurements during deformation of Arctic pack ice were related to the external thermal, wind and current forces acting on the pack.

The evolution of the optical properties of the sea ice cover during freeze-up was documented and modeled using a multi-stream approximation of the spectral adsorption, transmission and scattering properties. An estimate of the carbon incorporated into sea ice covers or associated with ice edge processes in the ocean showed that significant productivity in polar regions is associated with the ice and may be a substantial contributor to the carbon dioxide cycle of the earth.

The atmospheric boundary layer in cold regions is distinctly affected by the presence of and interaction with the snow and ice surface beneath it. Continued theoretical studies and field observations resulted in a technique using electromagnetic wave scintillation to infer the turbulence parameters and heat flux rates occurring over a path length. This is advantageous since most applications involve the effects of transmission or assessment over distances. It also makes it easier to assess the effects of turbulence over such distanc-

es from the more usual point measurements of turbulence parameters that often are not representative or are too sparse to enable such evaluation. This method is being extended to use these path-averaging techniques to measure the flux of gases such as carbon dioxide and methane. CRREL participated in a first-ever experiment in New Mexico with other agencies to evaluate this technique. The path-averaged results are far more useful than the current technique of assessing aerial behavior from a single measurement or very few point measurements.

ARO is sponsoring several snow- and ice-related projects. The University of Iowa is studying fatigue crack propagation in freshwater ice. Montana State University is investigating changes in microstructural parameters in snow during deformation. The University of Washington is conducting research into the physical processes in snowpack during rain or melt. Dartmouth College is working in three areas for ARO: ductile-to-brittle transitions in polycrystalline ice under compression, the production of a book and a series of monographs on ice physics, and MMW surface scattering from freshwater lake and river ice. The last project resulted in the construction of an FM-CW radar with an extremely wide bandwidth to give high-resolution measurements of river ice thickness. A fully assembled, easily portable radar is now available for river ice and river bottom studies.

Oceanography

A large part of DOD's oceanography research is under the direction of the Office of Naval Research (ONR). The overall goal of ONR's oceanography research in the Arctic is to provide accurate knowledge of the environment for naval operations. In pursuit of this goal, ONR funds comprehensive theoretical and experimental research on a range of high-latitude processes and phenomena. A full understanding of the inherent disciplines requires a multidisciplinary and multiagency approach. Current research thrusts are the Arctic Buoy Network, the Ice Tomography Experiment, the Barents Sea Acoustic Program, the Lead Dynamics Experiment, and Ice Mechanics. These programs involve researchers from the Navy, as well as from academia, the private sector, NOAA, NASA, the Army and other countries (for example, Norway). Furthermore, in many cases the funding is from multiple agencies and international sources.

A singular feature of the Arctic Ocean is a permanent, dynamic ice cover, which significantly impacts the environment on all scales from climatic to molecular

A singular feature of the Arctic Ocean is a permanent, dynamic ice cover. This ice cover significantly impacts the environment on all scales from climatic to molecular. Critical processes governing this impact occur in the atmospheric and oceanic boundary layers above and below the ice. These processes regulate the evolution of larger-scale features within the atmosphere and the ocean through dissipation downscale or feedback upscale or both. Understanding the dynamics controlling the vertical fluxes of mass, momentum and energy within the coupled air–ice–ocean system is critical to prediction on all scales.

ONR's research has produced a number of accomplishments. Research on stochastic tracking, data compression and lead dynamics led to the development of a fast, accurate method for automatically identifying ice floes in satellite images. The new approach is based on probability distributions rather than cross correlation, which has been the primary tool in the past. Evidence was obtained that sea ice keel draught distributions could be inferred from observed elevation distributions. Also, the probability density function of sea ice draught can be derived from airborne laser profiling.

To investigate the role of sea ice ridging on the large-scale dynamics of sea ice, a variable-thickness sea ice model with explicit treatment of ridging was developed. A prognostic ice–ocean circulation model, which was developed to examine the effect of an ice cover on ocean circulation, is being used to examine the circulation of the Arctic Ocean.

A computer simulation of large-scale sea ice decay was performed using the results from laboratory and field experiments on how ice floes melt. Models of the reflection and transmission of light were developed for spatially and temporally varying ice covers and have been coupled with thermodynamic models to investigate the role of leads in ice decay.

Procedures for retrieving lead statistics have been developed and applied to Landsat imagery successively degraded to more coarse resolutions. Lead signatures from different sensors have also been compared. The relationship between "apparent" lead widths measured along a transect (for example, from submarine sonar or as a sampling method for satellite imagery) and the "true" lead width distribution has been formalized in a statistical sense, so that one distribution can be obtained

from the other. A full 10-year sea ice lead database for the eastern Arctic has been completed.

Ice profile data collected in 1987 revealed a significant thinning of the ice cover relative to data collected over identical tracks in 1976. The thinning amounts to more than 15% over a 800,000-square-kilometer region between Greenland and the North Pole and has been ascribed to anomalous ice motion during the 1986-87 winter, as indicated by ARGOS buoys.

Understanding the dynamics controlling the vertical fluxes of mass, momentum and energy within the coupled air–ice–ocean system is critical to prediction

For the first time, unambiguous evidence was obtained for the fundamental mechanism of the brittle compressive fracture of sea ice.

It was discovered that the most energetic mixing in the eastern Arctic is found in relatively shallow water (200 m or less) over the Yermak Plateau and that the mixing there is diurnally modulated. Analyses of turbulent stress measurements in the boundary layer, and turbulent kinetic energy measured near the mixed-layer/pycnocline interface near the CEAREX O Camp, suggest that breaking internal waves contributed to the overall turbulence levels in the mixed layer and helped maintain the deep mixed layer in the absence of unstable surface buoyancy flux.

A quasi-analytic model that incorporates submodels for internal wave drag and heat and mass exchange at the ice/ocean interface was developed and used to simulate mixed-layer evolution with a relatively coarse vertical grid.

Another focus of ONR research is shelf–basin dynamics and structure. Three principal components of Arctic upper-ocean hydrography are a cold, low-salinity surface mixed layer in the upper 50 m, cold halocline water between 50 and 200 m, and a layer of warm Atlantic water with a core between 300 and 500 m. Because of the strong dependence of density on salinity at low temperatures, the halocline is also a well-defined pycnocline. The pycnocline water effectively decouples the warm Atlantic water from mechanical mixing with the surface layer, thus insulating the surface ice cover from a large subsurface heat source. In a steady budget the advection of heat by Atlantic water is balanced by vertical diffusion into the pycnocline layer rather than into the overlying ice. The persistence and extent of the Arctic ice pack depends critically on the nature of this balance.

An analysis of the first comprehensive hydrographic data set from the western and southern Greenland Sea was completed. It was found that saline outflows from the Arctic Ocean result in several distinct intermediate and deep salinity maxima within the Greenland Sea. Measurements in the Chukchi Sea allowed for a major breakthrough in obtaining data from key portions of the Russian EEZ, which previously have been closed to western investigators but in which well-designed measurements are essential to acquiring an overall understanding of the Arctic.

A series of prototype frazilometers, which measure suspended ice concentration by the amount of heat required to melt the ice, were built and tested. This instrumentation was used to measure suspended ice in seawater in the LEADS experiment, allowing for the analysis of the interaction of suspended ice and turbulence in freezing waters.

Using rotating tank experiments, it was shown that the density-driven exchange through broad Arctic straits is accomplished on short time scales by narrow boundary currents controlled by the deformation radius and on longer time scales by eddies generated in the cross-strait front by baroclinic and barotropic instabilities.

A one-dimensional version of an ice–ocean model was used to simulate the seasonal cycle of the Arctic ice–ocean system and to study contributions from different fluxes on the salt balance in the upper Arctic Ocean. Long-term calculations of the Arctic ice mass and mixed-layer properties were done using air temperature data for 1880–1986. The results reflect considerable fluctuations of the Arctic ice mass as well of the mixed-layer salinity, but overall the oceanic influence on the ice mass is minimal for the range of atmospheric variability that occurred during that period.

A three-dimensional model was used to simulate deep convection. The model is forced by specified winds and surface cooling; simulations showed that the influence of a barotropic mean flow over topography can precondition and select the location of deep convection in the regions affected by ice edge upwelling. It was also shown that the intrinsic eddy decay dynamics combined with surface cooling is the essential mechanism leading to deep convection.

Based on tritium/^{3}He analyses, data from the central Greenland Sea clearly indicated that the formation rate of Greenland Sea deep water decreased significantly during the 1980s. The reduction rate was about 80%, implying that almost no deep water formation is occurring in the Greenland Sea. Studies of the vertical distribution of ^{85}Kr in the Nansen Basin, coupled with the results of a multibox model of deep water renewal of the

Greenland, Norwegian and Eurasian basins, suggest that there may be a source of ^{85}Kr, in addition to the atmospheric input, to the deep water masses of the Arctic Ocean. Comparisons of 1988–1989 data on water masses and their variability in the Greenland Sea with that of 1958 and 1982 show that deep Greenland Sea waters have continued to warm since 1982. Acoustic studies of the sediment dynamics of the deep eastern Arctic Basin and its approaches indicated that deep bottom current activity was much stronger in the past than at present.

GIS technology provides Arctic oceanography with an efficient tool for interpreting and analyzing complex three-and four-dimensional data sets obtained by experiments or computer modeling programs

ONR has used SAR images in combination with drifting buoys, current measurements and CTD/Seasoar data to quantify ice edge variability in the western Barents Sea during SIZEX 89. The detailed ice edge morphology is to a large extent determined by the polar ocean front and correlation with bottom topography.

A coupled ocean–ice interaction numerical model was developed to include the wave effects and wind stress for predictions in the marginal ice zone. The Fram Strait MIZ was also modeled for the spring period when biological productivity is just beginning. Also modeled were the time-varying effects of melting ice, winds, eddys and stratification on the spring phytoplankton bloom, the results of which compare very favorably with the relatively few observations available from the Fram Strait.

For the first time, a new region of salt flux into the Arctic Ocean from Fram Strait, as well as the circulation patterns that it drives, has been observed using Geographic Information System (GIS) technology. The introduction and continual use of GIS technology in Arctic oceanography was shown to be an important and extremely efficient tool for interpreting and analyzing complex three-and four-dimensional data sets that are obtained more routinely by experiments or computer modeling programs.

ONR also has a series of projects in the field of ice–acoustic interaction. The cold surface waters in high-latitude oceans result in permanent or seasonal ice cover and a mean upper-ocean sound speed profile with a minimum at the surface. Thus the axis of the main acoustic wave guide is at the surface, in contrast to lower latitudes, where the equivalent SOFAR channel occurs nearer the depth of the permanent thermocline. The combination of a refracting medium makes ice–acoustic interaction a central issue for the propagation of acoustic energy in this environment. The ice itself is also an active source of acoustic energy.

Ultrasonic modeling studies revealed that the amplitude of the pulsed leaky Rayleigh wave in a water layer over a rock bottom drops with range; however, the amplitude of the second leaky Rayleigh wave component increases with range over defined regions, affecting partitioning of energy and the apparent attenuation coefficient of the solid.

A much better understanding of how the fine-scale oceanography of the Arctic Ocean affects the positioning accuracy of acoustic sensors was obtained. Very small deviations in the sound speed profile led to significant changes in the local multipath structure.

Finite-difference solutions for an acoustic wave scattering off an ice keel indicated that the keels can efficiently couple energy to flexural waves in the ice. Analyses of both PRUDEX-87 and CEAREX-89 geophone data indicate significant scattering into flexural waves and SH-waves in ice, both of which have been ignored traditionally in Arctic acoustics.

Simulations using a new perturbation approach for three-dimensional scattering has provided theoretical evidence for significant scattering into both flexural and SH-waves by overall ice roughness. A new hybrid Boundary Element–SAFARI model was developed for simulating seismo-acoustic propagation in a stepwise stratified media, including ice-edge and ice-lead environments.

At low frequencies (5–100 Hz) in the central Arctic, ice stress moment and ice normal stress, as induced primarily by winds and currents, were discovered to be most important in noise creation. At low frequencies in the marginal ice zone, however, surface waves from the open ocean incident upon the ice were found to be most important in noise creation. Ice concentration was an additional factor.

Studies of motion-induced stresses in sea ice indicate that internal stresses are only compressive stresses. Moreover, this type of stress only provides a background stress field; it is quite small and likely never results in fracturing under compression. This leaves bending stresses and the horizontal strumming of an ice floe as the primary candidates for motion-induced ambient noise in the Arctic.

Two experiments amply demonstrated that cross-hole tomography can provide information on the elastic properties of sea ice with good spatial

resolution. Further, engineering of such a system for unattended operation over extended periods is feasible.

A new method was developed to estimate surface and bottom backscattering strengths from single and double bottom-bounced data. This method was used to obtain ice backscattering strength measurements at steeper angles than measured previously. It was also used to obtain low-frequency bottom backscattering strength, which has never been measured before.

Another area of ONR research is electromagnetic–ice interaction. Ice properties particularly important for electromagnetic (EM) interaction are the dielectric constant and the porosity, as well as the surface morphology. A number of physical processes critically affect the interaction of EM energy with ice. Upward expulsion of brine during new ice formation produces a surface ice layer of very high salinity, as well as patches of liquid brine. The dielectric properties of such highly saline ice are poorly known. In addition, salt or frost flowers often form on new ice, under conditions that are not well understood. The resulting salty, low-density layer of ice crystals can produce strong backscatter, particularly at high (microwave) frequencies. Also, the evolution of the briny snow/ice interface and the development of layering in the snow (due to melt–thaw cycles) produce strong frequency and polarization effects. Temporal data on snow cover metamorphosis and its effect on electromagnetic emission and attenuation under Arctic conditions have only recently been acquired.

Shortwave (UV, visible, near-IR) radiation is a major factor in the heat and mass balance of the ice pack, the thermohaline structure of the upper ocean, and the biological activity beneath the ice. At present the full radiation field in the ice and water is difficult to predict. Large vertical variations in the optical properties of the air–snow–ice–ocean system combine with temporal changes in transmission and absorption caused by thermally induced changes in the structure and chemistry of the ice, brine drainage, algal growth and other factors. Complicating the analysis of transmission spectra is the coupling of some variables. Ice growth, for example, not only increases the optical thickness but also changes the temperature and salinity distribution, which can alter the optical properties. A change in air temperature can also affect light levels beneath the ice without a change in thickness or optical radiation. A detailed understanding of scattering and absorption mechanisms related to the structure and composition of the evolving ice cover is needed. The inverse problem can then be addressed using a high-resolution radiative transfer model with the appropriate attenuation physics.

In FY 90 and 91 a model was developed for scattering from an inhomogeneous, densely populated plane-boundary layer above a homogeneous half space. The results showed that when the scatterer size and the near-field effect between scatterers are accounted for, the inhomogeneous medium such as a snow layer will scatter more as the medium gets denser, that is, as the volume fraction of scatterers increases.

Laboratory measurements of temperature-dependent changes in the optical properties of sea ice between 400 and 1000 nm have been completed. Large changes in reflection and transmission associated with the precipitation of sodium chloride in brine pockets were found to occur between –26 and –30°C. Scattering increased continuously across this temperature range, becoming constant again below –30°C.

C-VV-25 radar look-up tables were assembled for multiyear ice, first-year ice, young ice and open water for winter, early spring, late spring, early summer, midsummer, late summer and fall.

The description of the evolution of the microwave signature of first-year ice beginning with the freezing of open water has been improved with the contributions of observations made during CRRELEX and CEAREX, as well as the other investigations for the case when conditions are winter-like. This work includes a description of the changes in the physical properties of the ice sheet, the snow and frost flower layer, the dielectric properties and surface-roughness statistics. In addition, polarimetric measurements have been made throughout the evolution process, providing a complete electromagnetic description of the backscattered field for a wide range of frequencies and angles. Further, understanding of the backscatter response of new and young sea ice has been improved by the integration of a theoretical dielectric property and scattering models and the study of the empirical and theoretical responses over a frequency range (1–35 GHz).

The relationship between the properties of the upper portion of the ice sheet was shown to be highly correlated with the intensity of microwave backscatter. The variation of the conditions found during CEAREX were ideal in that a reasonable range of combinations was observed, which allows the relationship between physical properties and backscatter cross section to be well defined.

Computer programs were developed to examine various properties of an image of leads: the temperature, the albedo, the channel-3 reflectance, the potential open water, the lead width distribution, the characteristic lead orientation, the "con-

nectedness" of lead systems and the heat flux from leads. Ridge and lead extraction and characterization algorithms were completed and applied to SAR sea ice images collected with L-band SEASAT SAR.

Another area of ONR research is the geodynamics of the Arctic Basin and its margins. Yearlong field experiments that deployed heavily instrumented arrays at two stations in the southern Barents Sea were completed. Significant advection of sediment was found, including carbon and carbonate constituents. A mooring array has now been deployed at the approximate geographic center of the Sea of Okhotsk. A wealth of biogeochemical and physical oceanographic data should result.

Investigations focused on the processes controlling sediment input and distribution and its relation to the sea floor echo character in the deep eastern Arctic Basin. Long and short sediment cores were dated by thorium, radiocarbon AMS, magnetic susceptibility and, in part, oxygen isotopes. Sedimentological and isotopic data were used to reconstruct paleoenviroments. Qualitative analyses of lithologic tracers in the ice-rafted debris allowed "back-tracing" of ice drift paths and reconstructions of ice-transporting surface systems. Sedimentation rates in the eastern Arctic Ocean are highly variable. High rates were calculated for the glacial periods, whereas low rates prevailed during interglacials. Two major sea ice sources were clearly distinguished by sea ice sediment loads in the eastern Arctic Ocean, the east Siberian Sea and the Laptev Sea. Sedimentary tracers indicated an ice drift from the Arctic Ocean through Fram Strait to the Norwegian Sea during early and late glacial times; however, chalk fragments in Fram Strait sediments are evidence for a northward ice drift during times of maximum glaciation.

Lower Atmosphere

Lower atmosphere research in the Arctic is primarily done through the combined efforts of ONR and the Naval Research Laboratory. The following are some of the major results of this work.

The response of a floating ice sheet to atmospheric turbulence was characterized and modeled, showing that this can be the dominant source of vibrational energy within a certain frequency band. Also, the effect of long gravity waves on the vertical displacement of Arctic ice was quantified.

Model calculations and analyses of CEAREX soundings show that heat flux through the ice is insufficient to maintain Arctic temperatures; northward temperature advection by transient storms is required, even at 81°N. Leads and thin ice (less than 0.8 m) contribute 12% to the winter tropospheric heat budget in the central Arctic.

Aircraft observations indicated that the vertical structure of the boundary layer was related to local shear and wave processes rather than being driven by sensible air–ice heat flux at the surface. A conceptual model for data analysis of the turning angle between the surface stress and geostrophic wind direction and the geostrophic drag coefficient, which relates surface stress to the geostrophic wind, was developed. Wind forcing experiments demonstrated the climatically important role of wind in the transfer of a freshwater layer between "polar" and "subpolar" basins.

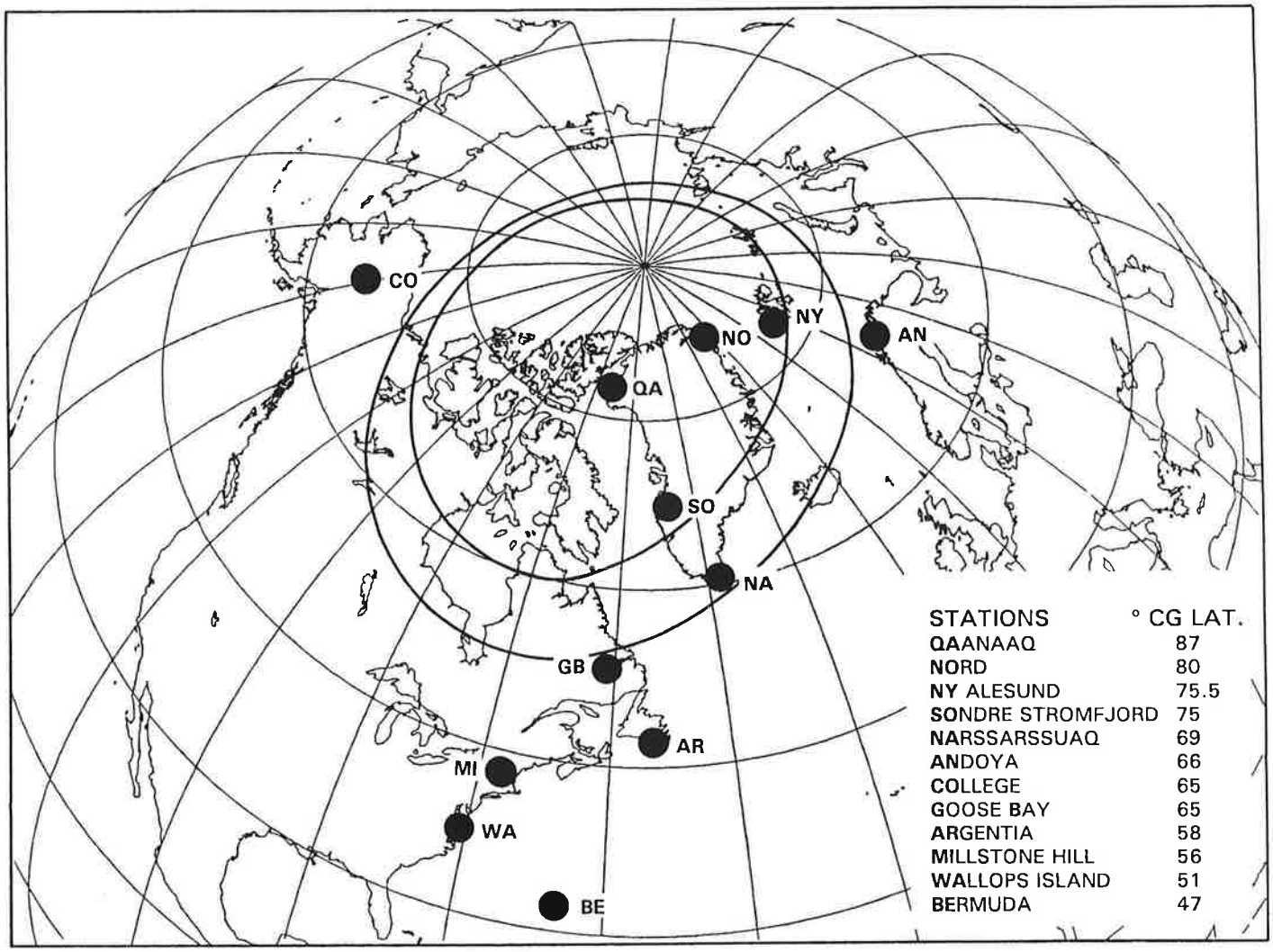
Analyses of temperature, salinity, current, meteorological and sea ice data obtained from the Chukchi Sea shelf in autumn 1977 and 1978 have shown that summer and autumn ice distributions are highly sensitive to vertical salinity stratification, which is in turn a function of the recent past wind field and its effect on ice cover and melting. Atmospheric temperature and humidity profiles for the Arctic were constructed from Soviet ice island data and are being used in the LOWTRAN-7 radiative transfer model.

Upper Atmosphere

A major DOD program in upper atmosphere and ionospheric research is conducted by the Air Force Phillips Laboratory (PL) and the Air Force Office of Scientific Research (AFOSR) in a coordinated effort. The goals of this comprehensive research program are to understand the basic physical and chemical processes that control the large-, medium- and small-scale structure and dynamics of the polar ionosphere. The main objectives of this effort are to specify, predict and mitigate disruptions to DOD communications, navigation and surveillance systems that are affected by poorly understood variations in the plasma density within the polar ionosphere. These processes include plasma physics, ion chemistry, ion-neutral coupling and electrical coupling to the distant magnetosphere. All of these processes act simultaneously to influence the structure of the polar ionosphere. In addition, all of these processes exhibit variations over time periods ranging from minutes to diurnal, seasonal and ultimately solar cycles. The research effort is primarily experimental, although theory and numerical modeling are actively pursued to maintain a well-rounded program. A wide range of ground-based radio, radar and optical diagnostics are employed to perform the needed

measurements. Many of these state-of-the-art instruments are developed and tested for field deployment under this effort. Measurements are obtained through the routine operation of ground stations for long-term variations and during dedicated campaigns to obtain coordinated measurements from a variety of sensors. The ground-based measurements are often complemented by measurements from instruments on polar-orbiting satellites. From this understanding, numerical models to specify and ultimately predict the behavior of this complex region are being developed. The models are updated using real-time data from a variety of ground and satellite sensors. Development, calibration and validation of these sensors is an important aspect of this effort. This research and model development is needed for real-time support to DOD communications, navigation and surveillance systems, since radio wave propagation is severely affected by variations in the ionospheric plasma density. Disruption is caused by ionospheric irregularities or density fluctuations, which cause unacceptable fading of satellite communications and navigation signals, as well as clutter on ground-based, long-range, high-frequency communications links to surveillance radars. This research effort also includes studies to quantify the effect of ionospheric disturbances on actual system performance in order to establish specific impacts caused by the various types of disturbances encountered in the polar region.

A series of experiments were conducted at Sondrestrom, Greenland, to investigate the electrodynamic circuitry and plasma flow in the vicinity of auroral arcs. The experiments involved real-time measurements of auroral arcs using the PL all-sky imaging photometer to determine the location and orientation of one or more arcs. This information was then used to position the scan pattern of the Sondrestrom incoherent scatter radar to optimize measurements of the plasma density and line-of-sight ion velocities in the vicinity of the arc. The combined measurements led to a complete description of plasma flow, electric fields and currents near auroral arcs. Specifically the measurements show two components of flow



Multistation polar and subauroral network of stations equipped with modern instrumentation, which provides the database for the specification, modeling and prediction of the high-latitude ionosphere.

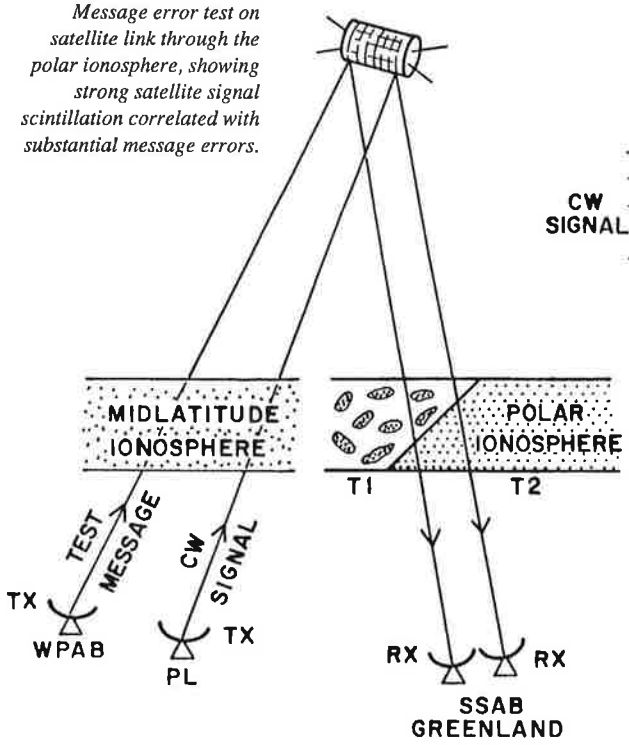
near the arc: a shear component associated with field-aligned currents and a component directly across the arc associated with reconnection of magnetic field lines in the distant magnetosphere. These detailed results are only possible because of the high spatial and temporal resolution of the measurements obtained by using this specialized observing mode.

Analyses of the results of a rocket flight through a polar cap arc near Sondrestrom, Greenland, have recently been completed. Optical imaging measurements using the airborne ionospheric observatory were used to locate a polar cap arc within the trajectories of two rockets with payloads designed to probe the plasma, particle and electric circuit parameters of polar cap arcs. The rockets were successfully launched into the arc. Analyses of the measurements show electric field components parallel as well as perpendicular to the arc. These field components were measured by injecting a barium chemical tracer into the arc. A second payload was instrumented to measure plasma, particles and fields within the arc. The results show a consistent relation among electric fields, magnetic fields and associated field-aligned currents, and electrical conductivities. The experimental measurements verify current theoretical models of polar cap arc formation and provide a means for improving these models.

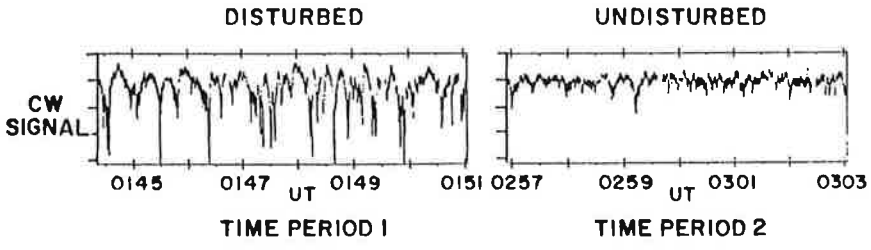
Over the last decade, the PL high-latitude ionospheric program has focused on the study of the polar cap ionosphere. The structure and dynamics of this disturbed and irregular region had resisted description and modeling for decades. With the development of new measurement techniques, two major features of the polar cap ionosphere have been identified: polar cap F-layer arcs and large-scale plasma patches. While the former typically occur during quiet magnetic conditions, the latter, which are cloud-like patches of solar-produced ionization, occur during magnetically active conditions. Major progress has been made during the last year in characterizing the F-layer patches and the overall convective flow and its influence on the polar plasma redistribution.

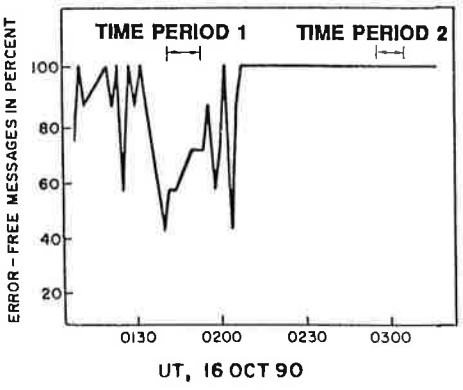
While the initial observations were made with an instrumented research aircraft and limited ground measurements, it soon became clear that a more comprehensive approach was required to measure and understand the complex situation. Now measurements using digital ionospheric sounding systems and all-sky imaging photometers, complemented by scintillation and total electron content measurements, are underway at several observatories in the Arctic operated by the Danish Meteorological Institute, the Norwegian Polar

Message error test on satellite link through the polar ionosphere, showing strong satellite signal scintillation correlated with substantial message errors.



EXPERIMENTAL SET-UP





MESSAGE ERROR RATE

MESSAGE ERROR AND SCINTILLATION

Institute and the U.S. Air Force. The stations form two chains along significant magnetic meridians; one goes over the geographic pole and the second is at right angles to the first. The very different relation of geomagnetic and geographic latitudes along the two chains permits the separation of geographic (solar illumination) and geomagnetic effects.

With the 1990-91 measurements of patch characteristics in the central polar cap, a database spanning a solar cycle from its minimum to its maximum has been completed. The maximum patch densities clearly show the effect of the solar cycle on their source region, the sub-cusp solar-produced ionosphere. The reason for this effect is not clear and is the subject of intense investigations.

PL is using a global array of ground-based ionospheric sounders to observe the daytime F-layer trough, a major result of ionospheric–magnetospheric convection. The trough is a continuous band thousands of kilometers in extent in which the daytime F-layer electron density is depleted, often by an order of magnitude. It is formed where sunward convection transports low-density nighttime plasma into the day sector so as to displace high-density daytime plasma.

A network of UHF and L-band observing stations is maintained at high latitudes to continuously record radio signals from Air Force communications and navigation satellites. In the presence of ionospheric irregularities, the recorded satellite signals exhibit fluctuations of amplitude and phase, called scintillations. Scintillations introduce fading and phase jitter in satellite signals that degrade the quality of satellite communications and impair the operation of surveillance radars. Phillips Laboratory and Wright Laboratory recently performed joint measurements at Sondrestrom, Greenland, and established that the error in messages received via the satellite can be predicted from the simultaneously recorded magnitude of the amplitude scintillation. The simultaneous incoherent scatter radar and all-sky imaging photometer identified the ionospheric structures that caused errors in messages.

The high-latitude ionospheric total electron content (TEC) and scintillation along the same line of sight is monitored using navigation satellite signals. A station at Thule, Greenland, using passive reception of L-band signals from the global positioning system (GPS) satellites, has monitored TEC and L-band scintillation since the onset of the recent solar maximum. These observations will continue during the decreasing phase of the solar cycle, when the effect of large magnetic storms may be observed. This data set will define the diurnal, seasonal and, to some extent, directional variation of these parameters at solar maximum, and it will serve as a basis for the development and validation of polar cap models. The L-band scintillation data define worst-case fading conditions for polar cap radars, since UHF scintillation monitors frequently saturate during solar maxima. Both parameters provide insight into the effects of the large-scale patch and arc structures. TEC variations associated with the passage of solar maximum polar cap patches can exceed in a few minutes the spread of values over a month of equatorial TEC observations. Combined with sounder data, these TEC measurements yield an integrated value for the topside ionosphere.

TEC and L-band scintillation from GPS signals has also been monitored throughout the recent solar maximum from Lerwick, U.K. In addition the Lerwick station obtains latitude profiles of TEC and both VHF and UHF scintillation from the Navy Transit satellite signals. By monitoring these satellites nearly to the horizon, the station can make observations that cover the midlatitude, trough and polar ionosphere. Dramatic directional variation in effects is evident, since north-looking observations can see into polar effects while simultaneous south-looking observations see midlatitude conditions. From these Transit data, coupled with four-direction GPS data, three-dimensional maps of TEC vs latitude vs time have been developed, which together with the scintillation data show the association of scintillations with geophysical features such as the trough wall. This data set is being expanded and analyzed for application to model validation and development for the U.K. region, with an emphasis on the northern sector.

The scintillation recording systems are deployed at crucial locations, such as at Ny Alesund in Svalbard, and Thule and Sondrestrom in Greenland. During magnetic noon, Ny Alesund and Sondrestrom are located in the cusp region, where the solar wind particles obtain direct access into the ionosphere along the earth's magnetic field. When the interplanetary magnetic field is southward, ionization patches from midlatitudes with sizes in the order of 1000 km are convected through this cusp region into the polar cap. Scintillation measurements at these cusp stations are used to study the development of small-scale irregularities in patches during their entry into the polar cap. After entry the ionization patches convect through the polar cap from the dayside to the nightside. Scintillation measurements at Thule have detected the presence of small-scale irregularities in the convecting patches. Using satellite in-situ measurements performed by NASA's Dynamics Explorer

2 satellite, PL established that the density gradient in the ionization patches and their convection velocity generate small-scale irregularities through the gradient drift instability process. The polar cap patches exit into the nightside auroral oval, and the small-scale irregularities associated with these exiting patches have been detected by scintillation measurements performed at the Sondrestrom station. When the interplanetary magnetic field is northward, sun-aligned polar cap arcs are observed within the polar cap instead of patches. Using satellite in-situ measurements, PL established that scintillation-causing small-scale irregularities develop in conjunction with velocity shear at the edges of the arcs through the nonlinear evolution of a collisional Kelvin Helmholtz instability mechanism.

The plasma density in the high-latitude ionosphere is known to be both temporally and spatially highly structured. While there is a variety of potential sources for this structure, a clear quantitative understanding of their relative roles is lacking. Research in this project is focused on the development and validation of physical models, simulation codes and forecasting techniques, which will complement the experimental observations of the structured high latitudes. These models will describe the formation and evolution of high-latitude structure and provide a theoretical framework for understanding the observations. Specifically studies will be made to assess the roles of auroral precipitation, cusp and cleft precipitation, steady-state convection patterns and time-varying convection patterns in creating a spatially structured polar ionosphere. When combined with real-time ground- and space-based sensor data, these models will provide the means to accurately specify the high-latitude electron density.

As part of an Air Force–Navy research effort, titled High-Frequency Active Auroral Research Program (HAARP), a unique, high-power, HF ionospheric heating facility will be constructed in Alaska. The heater will be capable of providing sufficient energy densities in the ionosphere to enable investigations to be conducted on the modulation of auroral currents to generate ELF/VLF waves, the acceleration of electrons to produce optical emissions, the production of field-aligned ionization to scatter radio waves, and other phenomena triggered by the interactions of very-high-power radio waves in the ionosphere. A ground-based heating instrument having effective radiated powers in excess of 1 gW, with HF tuning over the 2.8–12 MHz band and beam steering agility is planned. In addition a wide variety of diagnostic instrumentation will also be acquired, including ELF/VLF/HF receivers, HF ionospheric sounders, HF/VHF radars, UHF scintillation receivers, optical and IR cameras and an incoherent scatter radar. Construction of the facility is expected to begin in early 1994.

AFOSR recently initiated a basic task to exploit the research opportunities that the new HAARP facility will provide for helping to identify, understand and control the ionosphere's response to high-power-density radio frequency (RF) waves. A key research goal is to determine with what efficiency various ionospheric processes, such as wave generation, electron acceleration and electron-density structuring, can be triggered by direct stimulation. Another goal is to develop sufficient understanding of the basic chemical, physical and plasma processes associated with high-power RF effects in the ionosphere to be able to select the process into which maximum RF energy is to be deposited, that is, to control and potentially exploit ionospheric processes, rather than be limited by them. The research will involve two parts. One will develop an understanding of competing plasma structuring processes, including plasma turbulence and nonlinear structures. The other will determine the partitioning of energy deposition between plasma heating, radio emissions, particle acceleration, production of ionization and optical emissions in the IR, visible and UV.

A reevaluation of meteor scatter propagation in the Arctic has been underway since 1983. At that time, knowledge of the properties of meteor scatter, auroral scatter and sporadic E-layer propagation mechanisms in the Arctic were not sufficient to cover needs for design of new and vastly improved scatter communication systems. Such design efforts are parametric, as antenna deployment, transmitter power, modulation and coding, and communication protocols must be traded off to provide the wanted performance with the least-complicated system configuration. PL has undertaken a range of theoretical and experimental investigations in Greenland to determine propagation properties in the frequency range of 35–147 MHz. Two diagnostic scatter links have been operated. One, between Sondrestrom and Thule, is entirely within the polar cap; the other, between Sondrestrom and Narsarsuaq, crosses the auroral oval. Extensive databases of propagation statistics have been constructed. From these, propagation and communication system performance statistics can be derived. Studies of naturally occurring polar cap and auroral absorption have been performed and compared to periods without absorption. Also, multipath structure, Doppler shift, fast and slow fading, and frequency diversity effects on meteor scatter propagation have been investigated. The results of the work have added to the understanding of the high-latitude propagation en-

vironment in the lower VHF region. Specifically it was established that operations at higher frequencies (for example, 104 MHz) provided availability similar to a 65-MHz link during quiet conditions but without the degradation found at this frequency during naturally occurring absorption events. Fading was not a problem on the Greenland links, and very little improvement can be expected from simple frequency diversity schemes.

Medical and Human Engineering

Arctic-related medical studies in the areas of human physiology, performance and bioengineering are carried out primarily by the Army's Natick Research Development and Engineering Center and the Research Institute of Environmental Medicine, both located in Natick, Massachusetts; the Naval Medical Research Institute in Bethesda, Maryland; the Naval Health Research Center in San Diego, California; the Naval Aerospace Medical Research Laboratory in Pensacola, Florida; and civilian contracts and grants awarded by the Army and Navy medical research commands.

Humans repeatedly exposed to cold in experimental chambers modify their metabolic and physiologic responses to cold air on subsequent cold exposure

The principal objective of this research is to identify and resolve human medical, bioengineering and performance problems common to operations in cold climates. DOD research is focusing on the acute and chronic human physiologic and cognitive responses to cold, the pathophysiology and management of cold injury, the acquisition of human cold adaptation, improved cold-weather clothing and improved nutritional supplements.

Humans repeatedly exposed to cold in experimental chambers modify their metabolic and physiologic responses to cold air on subsequent cold exposure. This form of cold adaptation is characterized by blunted blood pressure rise, decreased oxygen utilization and lowered activation of the sympathetic nervous system in response to cold. This reduction in cold-induced blood pressure elevation with habituation is superior to at least one commonly used antihypertensive agent.

The production and use of the most active of thyroid hormones, triiodothyronine (T_3), is increased with as few as 20 short experimental exposures to cold air. This hormone, which primarily regulates energy balance and body temperature, increases independently of the usual control mechanisms in cold conditions. Theoretically the cold-associated requirements may predispose persons to low thyroid states unless the normal thyroidal reserve is present. After rapid transport to the Arctic winter environment and eight weeks of residence, military personnel showed a similar increase in T_3 requirement, suggesting that Arctic residents are subject to these changes. A combined year-long simultaneous study of seasonal changes in T_3 requirements contrasted residents of Bethesda, Maryland, and McMurdo, Antarctica. These studies suggested that high-lattitude living may exaggerate the normal circannual patterns of increased T_3 use found during the winter in Bethesda. One of the possible biological consequences of these patterns, known now as Polar T_3 Syndrome, was recently reported in the Antarctic group. That group was found to have heterogeneous responses to polar life, with a direct relationship between thyroid hormones and the atherogenic cholesterol, low-density lipoprotein cholesterol.

The performance error rate for short-term memory tasks increases in cold conditions. Drug treatment with tyrosine to modify this error rate is under active investigation in both chamber and field studies, with early beneficial results.

A Natick Research Development and Engineering Center (NRDEC) development is the Air Crew Cold Weather Clothing System (ACWCS). This is a new flame-retardant and layered ensemble suit/system for aviator wear in cold regions.

The Research Institute of Environmental Medicine (USARIEM) has conducted biophysical evaluations of standard and prototype U.S. Navy extreme-cold-weather foot protection systems. During prolonged vertical immersion in shallow water, winter-issue boots completely lined with a hydrophilic polyester membrane showed significantly less reduction in thermal insulation performance and had less increase in total boot weight than a wide assortment of conventional footwear.

USARIEM has conducted research on the effects of pyridostigmine bromide (a chemical warfare pretreatment drug) on soldier work performance in the cold and on soldier susceptibility to hypothermia. In another effort USARIEM scientists conducted preliminary research concerning cold-induced diuresis and the use of glycerol beverages to minimize its effects. USARIEM research has also determined that freezing and thawing produces significant releases of prostaglandin E_2, interleukin 1a and potassium from human skin cells in artificial human skin.

In addition, several agencies have conducted

studies of the Deployable Medical System (DEPMEDS). The DEPMEDS Winterization Program Manager, the Belvoir Research and Development Center (BRDEC), the 85th Evacuation Hospital and CRREL conducted a winter evaluation of the proposed cold-weather add-ons for the DEPMEDS potable water distribution system. Representative tents and expandable shelters were set up, and the potable water distribution system with its proposed cold-weather enhancements was deployed to deliver water to these shelters. Cold-related system failures were documented, and BRDEC representatives were advised on how to solve or reduce these problems.

The Naval Health Research Center has been conducting cold-related combat research to understand the decrements in military task performance and to determine effective countermeasures, including a series of field experiments with U.S. Marines and the Norwegian Army. Experiments on U.S. Marines showed that rifle performance is seriously degraded when they were inadequately clothed for the cold weather and also after 30 minutes of moderate exercise. Rifle performance in Norwegian soldiers, wearing cold-weather clothing, was not affected by the hours of sleep received (2 vs 6 hours), the level of physical activity (high vs low) or the level of dehydration. Snowshoe performance in Norwegian soldiers wearing light clothing was unaffected by cold-weather field exercises. However, snowshoeing while wearing full winter gear and carrying a weapon was affected by prior physical activity level but not by differences in the amount of sleep received (2 vs 6 hours).

Dehydration measures from the Norwegian studies suggest that there are three groups of indices: measures related to hematocrit and hemoglobin, measures related to urine concentration and body weight. One of the general findings is that snowshoe performance and anaerobic power are most strongly associated with urine concentration measures.

The stress encountered with physical exertion and cold weather has been shown to influence many hormonal systems. In the Norwegian studies, thyroid hormone levels fall in direct proportion to caloric intake, similar to reports in U.S. Navy Seal team members conducting Arctic maneuvers. Circulating cortisol levels were elevated in Norwegian soldiers sleeping in tents during a 10-day cold training exercise. A separate group, bivouacked in barracks overnight, exhibited significantly lower cortisol levels.

Current plans for FY 92 and 93 include the assessment of water turnover and dehydration status in U.S. Marines conducting cold-weather training, the influence of shivering on rifle performance, the effects of dehydration on temperature regulation and exercise in the cold, and the corresponding psychological performance. The ultimate objective of this research is the development of a nomogram or table of human performance in the cold at various metabolic rates and clothing ensembles. This table could then be used by commanders in the field to ensure optimum performance and safety during military operations.

National Aeronautics and Space Administration

NASA supports a variety of research programs in the Arctic that emphasize the application of airborne and spaceborne remote sensing to studies in the earth and space sciences. Of particular interest are Arctic processes that influence or are influenced by the behavior of the overall earth system. The Arctic program, which includes studies of the role of the Arctic in global climate, Arctic vegetation, solid earth processes, stratospheric ozone and space plasma physics, was funded for $16.5 million in FY 91.

Role of the Arctic in Global Climate

FY 91 FUNDING (thousands)

Polar Ocean/Ice Sheets	8500
Land Processes	550
Solid Earth Sciences	1100
Atmospheric Sciences	100
Arctic Ozone	2500
Sounding Rocket Program	620
Dynamics Explorer	1600
Space Plasma Research	1100
Solar Terrestrial Theory	430

This program continues to focus on using spaceborne sensors to determine the characteristics of the Arctic ice cover and to understand how polar ice influences and, in turn, is influenced by the state of the overlying atmosphere and the underlying ocean. Specific long-range scientific goals include determining the energy flux between the ocean and atmosphere at high latitudes, identifying the processes that control the formation of intermediate and deep ocean water, understanding the processes that control the growth, drift and decay of sea ice, measuring the surface characteristics and mass balance of the Greenland ice sheet, and generally advancing current capabilities for extracting meaningful geophysical information from remote sensing data collected over snow- and ice-covered regions.

The growing awareness of the importance of high-latitude processes to a global climate that may be changing has helped expose the poor performance of global climate models (GCMs) at high latitudes and their sensitivity to high-latitude processes such as deep-water production. Consequently NASA has significantly increased its support for process studies likely to contribute to model improvement and for modeling studies aimed at identifying and correcting high-latitude weaknesses in existing GCMs.

The program relies heavily on data from remote sensing techniques that operate in the microwave portion of the electromagnetic spectrum since these techniques are not constrained by either darkness or clouds, which commonly limit Arctic observations. Sensors operating in this frequency region include the SSM/I passive microwave system aboard Defense Meteorological Satellite Program (DMSP) spacecraft (beginning in 1987), radar altimeters aboard both the U.S. Navy's Geosat (1985–1989) and the European Remote Sensing Satellite (ERS-1, launched in July 1991), and the Synthetic Aperture Radar (SAR, also aboard ERS-1). SARs will also be included aboard the Japanese JERS-1 (launched in February 1992) and Canada's Radarsat (to be launched in 1995). Together, these microwave instruments permit the acquisition of the consistent time series of observations that are required by most climate problems. Particular emphasis has been placed on methods for extracting geophysical information from such data sets and for validating the resulting estimates. NASA is also investigating potential high-latitude applications of satellite infrared and atmospheric sounding data, and they expect to devote increased resources to the analysis of these data in the future.

In the past, NASA aircraft studies at high latitudes have been applied primarily to the development and validation of remote sensing techniques. Although these applications will undoubtedly continue, increasing emphasis is being placed on the use of aircraft to assist with studies of important processes. For example, NASA is assessing the feasibility of measuring thickening and thinning rates of the Greenland ice sheet using airborne laser altimeters.

Passive Microwave Data

Studies continue on validating and refining existing algorithms for estimating sea-ice concentration and snow-cover parameters, including mapping areas of melting on the Greenland ice sheet. A major priority is to archive and widely distribute useful data sets derived from the various microwave radiometers that have operated since the 1970s. To this end NASA supports the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, as a Distributed Active Archive Center (DAAC) for processing SSM/I data to gridded brightness temperatures and derived sea-ice products, and for distributing these data on CD-ROMs to interested researchers. The earlier passive microwave data, collected by the Scanning Multichannel Microwave Radiometer (SMMR) aboard NASA's Nimbus-7, are also available on CD-ROM. In addition, sea-ice parameters derived from the nine-year SMMR data set will soon be available both on CD-ROM and in atlas form.

Synthetic Aperture Radar

NASA's Arctic SAR program is strongly linked to ERS-1 (launched in 1991), JERS-1 (1992) and Radarsat (1995), all carrying SAR systems. To receive, process, archive and distribute data from these systems, NASA has established a second polar DAAC, the Alaska SAR Facility (ASF), at the University of Alaska–Fairbanks.

One continuing activity that is part of this larger effort has been to collect airborne and field observations on the nature of the radar return from sea ice, glaciers and the Greenland ice sheet and to model the observed radar backscatter in terms of frequency, angle of incidence, polarization, crystal structure, brine and gas content, ice wetness, ice type, snow characteristics and surface roughness. Measurements have also been obtained in a near-laboratory setting using artificial sea ice grown on a pond at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in New Hampshire as part of a continuing program jointly supported by the Office of Naval Research.

Another area of research important to the success of the ASF is directed towards extracting meaningful geophysical information from SAR data without extensive operator–system interaction. Attention has focused on developing algorithms for tracking the motion of ice floes in successive SAR images and on classifying sea-ice types in the images.

Following the launch of ERS-1, activity levels at the ASF have increased dramatically, with almost four times as much data being received as was originally expected. This has resulted in a backlog in data processing, and intensive efforts are underway to upgrade the processing system sufficiently to handle the data from ERS-1 and JERS-1, which will start to transmit to the ASF in May 1992.

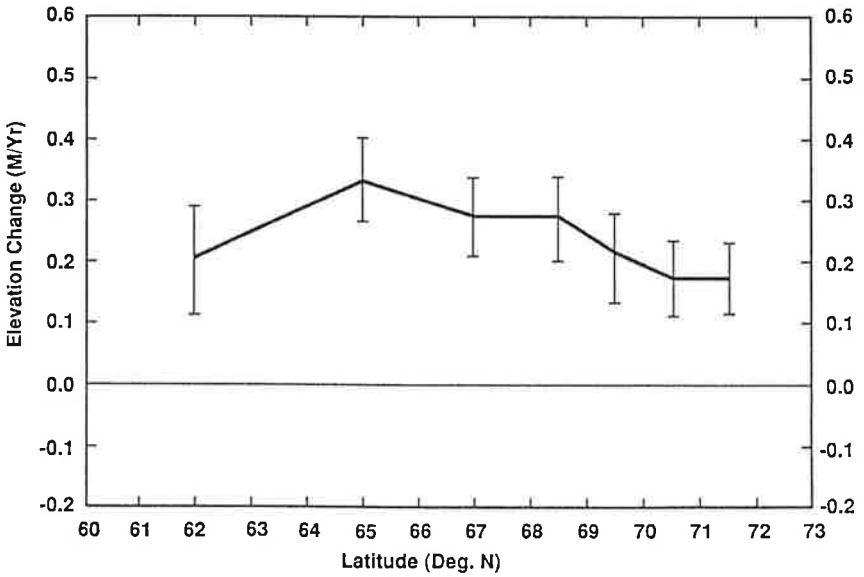
In response to a NASA Research Announcement soliciting research proposals making use of ASF data, 26 projects were approved. These are complemented by other existing efforts to total almost 50 projects. Most are concerned with sea ice and polar oceanography, but glaciology, hydrology, geology, permafrost, forestry, ecology and application demonstrations are also represented.

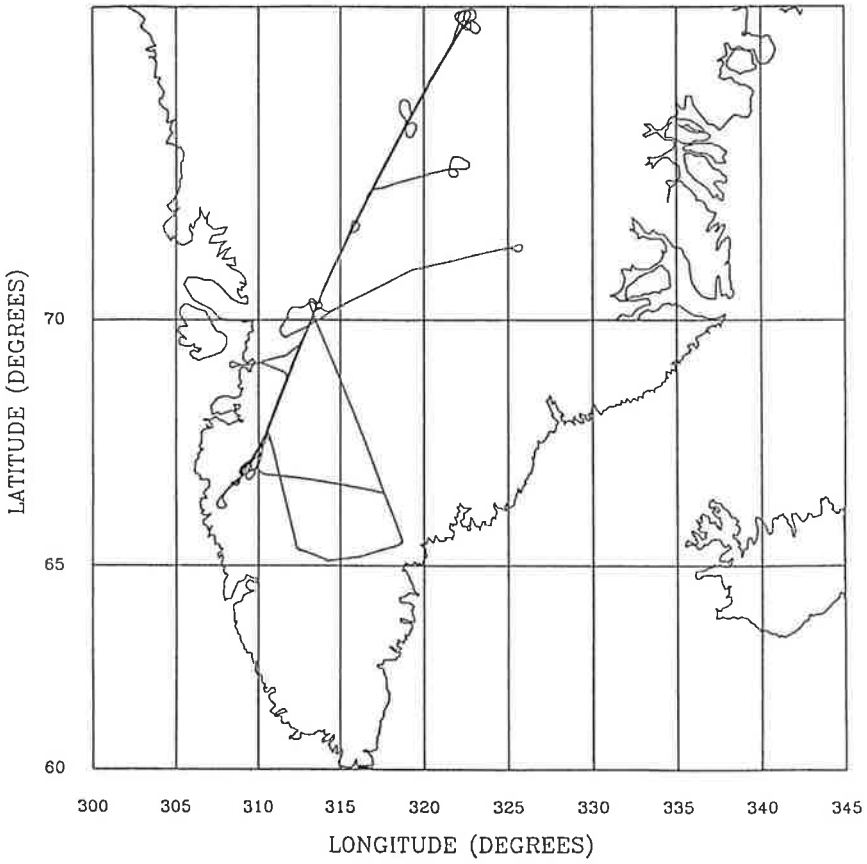
Radar altimeter data

Over the past two years, data from Geosat have been applied to the study of topographic variations of the Greenland ice sheet. Developing benchmark elevations and general analysis capabilities is essential for studies of the future contributions of ice sheets to anticipated rises in sea level. The onboard software that "tracks" the radar pulse reflected from the surface was designed to function well over the relatively flat ocean surface, and although it was sufficiently agile to keep the return pulse within the tracking window over much of the ice sheet, it generally yielded estimated surface elevations that have significant errors. Consequently much effort has been devoted to "retracking" all the altimeter pulses acquired over the ice sheets and sea ice. Present plans call for continuing this effort using data from the altimeter aboard ERS-1.

The resulting data sets provide the best estimate of ice-surface topography, accurate to within a few meters. Much of the error in individual estimates is associated with the effects of local surface slope and with the tendency for the altimeter to smooth local undulations. This part of the error is systematic and will also apply to any meas-

Greenland ice sheet surface-elevation change derived from comparison of Geosat and Seasat radar-altimetry data. The rate of thickening of the ice is plotted against latitude. The error bars are estimates of standard deviation, assuming errors in each orbit-crossover comparison are independent.





Routes on the Greenland ice sheet along which airborne laser- and radar-altimetry data were obtained.

urement made when the satellite is in the same location. Consequently comparing data obtained at orbit crossing points provides the best indication of changes in ice-surface elevation that have occurred between the two orbits. Comparison of Seasat altimeter data (collected in 1978) with those obtained by Geosat (1985–1989) suggest that the Greenland ice thickened by approximately 20 cm per year between the two missions. This conclusion has been the subject of much debate, partly because it is not confirmed by "traditional" estimates of mass balance, and partly because of the difficulty in correcting the measurements for errors in the calculated orbit. Moreover, useful data can only be acquired over portions of the ice sheet with surface slopes less than about 1:100.

Airborne laser altimetry

To provide a check on the estimates of ice-thickening rate derived from radar-altimetry data and to make measurements over the more steeply sloping ice-sheet margins, where thickening and thinning rates might be expected to be highest, NASA conducted an experiment during 1991 using airborne laser and radar altimeters to obtain estimates of surface elevations along a 42-km traverse on the ice sheet that had been optically levelled. The aircraft location was determined using GPS (global positioning system) receivers aboard the aircraft and at Sondrestrom Air Base, from which the aircraft operated. The prime objective of the experiment was to compare the airborne estimates with those from the surface traverse. The analysis is incomplete, but preliminary comparisons of aircraft laser data, obtained on different flights over the same track, show agreement to within tens of centimeters. These data have not been fully corrected, and further improvement in data consistency is expected.

POLES: Polar Exchange at the Sea Surface

POLES is one of 29 interdisciplinary investigations within NASA's global change program, Earth Observing System. It is the only investigation of polar atmospheres, oceans and sea ice and is a collaboration between nine investigators from the Universities of Washington and Colorado and from the Jet Propulsion Laboratory under the direction of Drew Rothrock. As the title suggests, POLES focuses on surface fluxes. A prime objective is to improve the ability to estimate surface fluxes from satellite observations combined with buoy observations and models, and to provide an observation-based understanding of the system comprising the lower atmosphere, the ice cover and the upper ocean.

The science issues that drive the research focus on the role of polar regions in the global climate system. We need an understanding of the heat, momentum, water and salt budgets of this high-latitude air–ice–ocean system and how these relate to the global energy and water cycles. How, for instance, does the interplay of fresh water runoff into the Arctic Ocean (the world's largest estuary) and the brine production in polynyas in the seasonal ice zone and within the perennial ice cover determine the overall stability of the Arctic Ocean? Do freezing processes on the Siberian shelves precondition the Arctic outflow into the Greenland Sea to either permit or restrict deep convection? How does climate change manifest itself in the high latitudes? Is there any evidence for the amplified response over the Arctic Ocean predicted by models of global warming?

NASA is approaching these questions in three ways. The first two concern the availability and quality of data. Several important global satellite data sets are simply not credible at high latitudes. The first component of the project is to improve this situation by investigating sensor algorithms that yield estimates of cloud parameters, sea ice surface temperatures and profiles of atmospheric temperature and moisture with the Tiros-N Operational Vertical Sounder (TOVS) and the Advanced Very High Resolution Radiometer (AVHRR), as

well as algorithms for sea ice types and thickness with the Special Sensor Microwave Imager (SSM/I), the Scanning Multichannel Microwave Radiometer (SMMR) and SAR. Next, there are crucial polar data sets that are not available or are estimated from very sparse data. Surface temperature is one example. There are data from drifting buoys and stations, thermal surface imagery from AVHRR, and surface temperature estimates from sounders, yet NMC analyses, for instance, use only station data. POLES is working towards producing routine surface temperature fields of known accuracy, using all these data sources. The need is similar for better routine estimates of ice motion, polar clouds and ice type concentrations. Third, models are being developed to assimilate these observable data and allow estimates of variables that cannot be directly observed. Many flux quantities fall into this category. Salt flux to the ocean from a growing ice cover can be estimated from an ice model that assimilates high-quality estimates of surface temperature and ice type concentrations. Data on clouds, atmospheric temperature profiles and surface temperature can be assimilated into a model that estimates the surface radiation balance. A heavy emphasis is placed on models that assimilate data, including not only "forcing" data but also spot observations of the variable that is being estimated.

Work is proceeding on a number of projects. For instance, a radiation flux climatology for the Arctic is being developed from the cloud product of the International Satellite Cloud Climatology Project (ISCCP) monthly (C2) data for 1983–1986. This data set contains information on cloud fraction, cloud-top temperature and pressure, optical thickness (visible), surface temperature and surface spectral reflectance. There are a number of difficulties with computing radiative fluxes from these quantities, such as the unknown geometrical thicknesses of the clouds, the conversion of narrow-band surface reflectances to broad-band albedos, and the potential errors in the cloud amounts. Directional surface albedos for snow are being modeled so that a small number of spectral reflectance curves can be used to represent the snow or ice surface at various times of the year. To determine the accuracy of cloud amounts, the ISCCP data are being compared to the 20-year cloud climatology from surface observations. These radiation computations will be used to determine the sensitivity of the various radiation terms to uncertainties in the data.

Satellite data have an enormous untapped potential for clarifying the role of polar regions in global climate

Algorithms for processing TOVS radiances (24 channels in the visible, infrared and microwave bands) are under investigation to assess whether they can be modified to estimate temperature and humidity profiles, surface temperature and cloud parameters. POLES has worked with products derived from two of these algorithms, but the focus has primarily been on the Improved Initialization Inversion (3I) system developed at the Laboratoire Meteorologie Dynamique (LMD) in France. A comparison of 3I- and NOAA-derived products to conventional data has revealed several major deficiencies in the retrievals over snow and ice surfaces:

- Surface temperatures are nearly always too high, sometimes by as much as 14 K. As a result, surface-based temperature inversions are usually missed. Over high-latitude open water, retrieved surface temperatures are often below the freezing point of seawater. An algorithm has been added to the 3I system to determine surface type: land, open water, multiyear ice or young ice. This is necessary to improve surface temperature calculations and to better detect clouds over snow and ice.
- Water vapor amounts are generally too high (sometimes by a factor of two) in typical polar air masses, but when a deep moist air mass is present, the retrievals generally underestimate water vapor amounts. Because water vapor and surface temperature retrievals are coupled, this problem undoubtedly contributes to incorrect surface temperatures.
- Surface emissivity at 50 GHz decreases with increasing satellite view angle. The error in brightness temperature at large view angles is 6–8%, or about 15 K in early winter. A correction for this effect has been added.
- Clear scenes are often misidentified as cloudy. The original algorithms did not account for the possible existence of clouds that are warmer than the surface. Research is ongoing to improve the detection and measurement of clouds over snow and ice. A better value of surface emissivity will help. ISCCP cloud parameters are being compared to those retrieved using 3I. Other improvements are being incorporated as they are produced by the originators of the algorithm. For instance, the library of first-guess profiles in polar regions has recently been expanded with radiosonde data from Soviet drifting ice stations. Once more credible atmospheric profiles have been derived from TOVS, a major interest will be warm air advection into the high Arctic.

Another area of research is the production of Arctic intermediate water by polynyas. Numerous Arctic Ocean circulation and geochemical studies suggest that polynyas in the winter ice pack over the Alaskan, Siberian and Canadian continental shelves produce cold, saline water that contributes to Arctic Ocean intermediate water. There are few direct observations in support of this hypothesis. Estimates of the production of dense shelf water within these polynyas have been derived through the combined use of satellite data from SMMR, meteorological data from coastal weather stations and surface salinity data from oceanographic surveys. The satellite radiance data are used to monitor the occurrence and open-water area of the polynyas for winters from 1978 to 1987. These polynyas occur along the Canadian and Alaskan coast from Banks Island to the Bering Strait on the east and from the Bering Strait to Wrangel Island on the west. In the Bering Sea, additional contributing polynyas form in Norton Sound, south of St. Lawrence Island and in the Gulf of Anadyr. The polynyas that make the largest contributions occur south of St. Lawrence Island, in the Gulf of Anadyr, along the Bering Sea Siberian coast from Cape Chukotskiy to the Bering Strait, and along the United States Chukchi Sea coast from Cape Lisburne to Point Barrow. Computed time series of oceanic surface heat fluxes and salt fluxes from each polynya allow estimates of the contribution of each polynya to the Canadian Basin water masses.

The POLES program is planned to continue into the next century, but progress already achieved strongly confirms that satellite data have an enormous untapped potential for clarifying the role of polar regions in global climate. The decade of the 1990s will be rich in satellite data for polar research, providing the polar community with an opportunity to make significant progress at a time when the importance of polar processes to global climate is becoming increasingly apparent.

Arctic Ozone

NASA's Atmospheric Chemistry Modeling and Analysis Program supports a number of tasks designed to increase our understanding of chemical processes in the Arctic stratosphere and their effect on northern midlatitudes. Studies underway include the analysis of data from various sources, including space-, aircraft-, balloon- and ground-based measurements. A number of investigators have made extensive use of data from the Airborne Arctic Stratospheric Expedition (AASE), based in Stavanger, Norway, in the winter of 1989. By interpreting these data with atmosphere chemical models, scientists were able to make progress on separating out the simultaneous effects of chemical and meteorological processes on Arctic ozone amounts during the AASE. They found evidence of a small chemically induced depletion of ozone in the lower Arctic stratosphere over the course of that winter. Model development related to the Arctic stratosphere has centered on improving the way in which chemical reactions occurring on cloud and aerosol particle surfaces are represented in multi-dimensional models. Both two- and three-dimensional models have been studied. The improved two-dimensional models have been used extensively for assessment purposes. Correct representation of polar stratospheric clouds (PSCs) and their effect on stratospheric chemical composition is an important goal of the modeling effort. Three-dimensional models have allowed the simulation of the spatial and temporal distribution of air that has been "chemically processed" by PSCs, both within the Arctic and at midlatitudes. These models have also been used to simulate ozone "mini-holes" observed from data taken by the Total Ozone Mapping Spectrometer (TOMS) instrument on NASA's Nimbus-7 satellite.

Land Processes

NASA has recently reorganized its Land Processes activities into programs under the general category of Ecosystem Dynamics and Biogeochemical Cycles. These activities focus on the function of global ecosystems and the interactions of the earth's biota with the atmosphere and hydrosphere. Particular emphasis is placed on land–atmosphere interactions, carbon cycling and the biophysics of remote sensing of ecosystems. The goal of these activities is to improve understanding of the role of the biosphere and the biologically linked components of the hydrologic cycle in processes of global significance. Specific objectives include understanding landscape and oceanic patterns and processes, the factors controlling ecosystem function, the response of ecosystems to change, and the interactions between biological and ecological processes, including surface energy balance. Airborne and spaceborne remote-sensing measurements are used extensively to achieve these objectives and to extrapolate small-scale process information to regional and global contexts.

With respect to the Arctic, the Ecosystem Dynamics and Biogeochemical Cycles activities support research on remote-sensing studies leading to new and more accurate estimates of methane flux in the North American Arctic tundra. Ongoing in-

terdisciplinary methane investigations are measuring methane flux in situ and studying microbial process leading to methane flux in the Arctic. These studies include investigations to classify and stratify ground cover types to derive estimates of methane flux, and to use this stratification to develop statistical estimates of flux for the Arctic tundra and taiga. In addition, studies are underway to develop radiative transfer models for synthetic aperture radar to measure structural properties of high-latitude forests.

Understanding the current ecological and climatological functioning of the boreal forest and its sensitivity to environmental change is crucial to understanding and predicting larger-scale global dynamics

The Boreal Ecosystem–Atmosphere Study (BOREAS) is by far the largest effort in the Arctic conducted by NASA's Ecosystem Dynamics and Biogeochemical Cycles organization. The goal of BOREAS is to improve understanding of the interactions between the boreal forest biome and the atmosphere and to clarify their roles in global change. BOREAS is a multidisciplinary field and remote-sensing study that will be implemented jointly by the United States and Canada. The agencies involved in planning and executing BOREAS are the U.S. National Aeronautics and Space Administration, the U.S. National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the U.S. National Science Foundation, the Canada Centre for Remote Sensing, Forestry Canada, Agriculture Canada, Environment Canada, the National Research Council of Canada and potentially the Natural Sciences and Engineering Research Council of Canada.

The boreal forest constitutes one of the earth's largest circumpolar biomes. There has been much conjecture and debate regarding the boreal biome's sensitivity to global change. Specifically modeling results differ regarding the nature and severity of potential ecological and biogeochemical perturbations imposed by anticipated global climate warming. Understanding the current ecological and climatological functioning of this circumpolar ecosystem and its sensitivity to environmental change is therefore crucial to understanding and predicting larger-scale global dynamics.

The specific objectives of BOREAS are:

- To improve our understanding of the processes that govern the exchanges of energy, water, heat, carbon and trace gases between boreal ecosystems and the atmosphere, with particular reference to those that may be sensitive to global change; and
- To develop and validate remote-sensing algorithms for transferring understanding of these processes from local to regional scales.

A wide array of disciplinary and interdisciplinary experiments will be needed to make this study successful. Relevant study areas include terrestrial ecology, hydrology, land surface climatology, trace gas biogeochemistry, atmospheric chemistry, boundary layer meteorology, energy and water fluxes, and integrative modeling. Two sites of 400–600 km^2 will serve as the foci of the experiment. Pending successful environmental impact review, they will be in Prince Albert National Park, Saskatchewan, Canada, and near Nelson House, Manitoba, Canada.

BOREAS is a short-term experiment. There will be initial monitoring, pilot and planning activities at the field sites during 1993. However, the concentrated observational effort for this experiment will occur throughout 1994. A series of intensive field campaigns spanning the annual cycle are planned, along with continuous monitoring. Afterwards some continued monitoring activities and limited revisits may be required. Within the experiment's time frame, BOREAS will provide the opportunity to pursue a wide range of investigations into the boreal forest's ecological, hydrological and biogeochemical dynamics and its coupling to the regional and global physical climate system.

Solid Earth Science

The NASA Crustal Dynamics Project has performed geodetic measurements in Alaska and western Canada since 1984 to better understand the deformation of the region resulting from the subduction of the Pacific Plate beneath the North American Plate along the southern coast of Alaska. Using the radio astronomy technique known as Very Long Baseline Interferometry (VLBI), which records the wide-band noise emitted continuously by quasars, distances between different VLBI antennas were measured periodically. The VLBI antennas receive the quasar signals timed to about 30 picoseconds (the time it takes light to travel one centimeter). Such data acquired over one day can be used to determine baselines between antennas to an accuracy of about one centimeter, even when the antennas are separated by thousands of kilometers.

The observations in Alaska center on the large (25-m-diameter) radiotelescope near Fairbanks,

which is permanently installed, and a smaller (3-m-diameter) mobile system, which has collected data at several sites of geophysical interest. Two of these sites (Cape Yakataga and in the Shumagin Islands) are in seismic gaps, areas that are predicted by some to be overdue for major earthquakes. A site on Kodiak Island is near the site of the damaging earthquake in 1963, which had a magnitude of 8.3. Four additional sites are located far from the subduction zone to provide control sites that define the "stable" interior of Alaska. The results from these sites show that there is significant motion within the North American Plate as a result of the ongoing subduction. This suggests that strain is accumulating south of Fairbanks and that this will be released during future earthquakes.

The VLBI site at Cape Yakataga is a current example of the building of southern Alaska by the addition of small parts of continent and islands known as terranes. Cape Yakataga is moving relative to Fairbanks at an average rate of 34 mm per year; however, after two magnitude-7.6 earthquakes in 1987 and 1988, the motion increased to 8 cm in the next two years.

In 1990 the Crustal Dynamics Project used the Department of Defense's Global Positioning System (GPS), which uses signals broadcast from satellites, to make first apoch measurements in Alaska. Techniques under development at NASA's Jet Propulsion Laboratory and elsewhere suggest that the accuracy of GPS will soon match the present VLBI accuracy. This technique will allow densification of the observations in Alaska because of the lower costs and greater mobility of GPS receivers.

Space Physics

The Space Physics Division of the Office of Space Science and Applications supports a vigorous program of experimental and theoretical studies of the upper atmosphere of the Arctic regions, including the ionosphere, thermosphere and magnetosphere. The Arctic upper atmosphere is the sink of many geophysical processes operating in the solar–terrestrial environment, with the most obvious being the Aurora Borealis.

Sounding rocket probes launched from Poker Flat in Alaska probe the fine-scale details of thermospheric, ionospheric and auroral processes at altitudes and with temporal resolution unavailable from satellites. Conversely the Dynamics Explorer Satellites offer morphological studies over the entire Arctic region of the energy inputs and outputs from solar–terrestrial processes.

These experimental efforts are complemented by the Space Plasma Research (Supporting Research and Technology) and the Solar Terrestrial Theory programs. These programs of theory, modeling and data analysis are crucial to understanding the physics operating in the Arctic upper atmosphere and enabling the construction of global-scale models.

Department of Commerce

National Oceanic and Atmospheric Administration

NOAA performs research in the high-latitude regions of the planet in connection with its environmental monitoring and prediction responsibilities. Individual research programs focus on scientific questions addressing the Arctic environment and its relation to the global environment. NOAA also conducts research in support of services it performs, such as weather forecasting and fisheries management. Funding totaled $12.9 million in FY 91.

Meteorology, Climate and Air Quality

Geophysical Monitoring at Remote Polar Sites

At the baseline observatories of NOAA's Climate Monitoring and Diagnostics Laboratory (formerly Geophysical Monitoring for Climatic Change) headquartered in Boulder, Colorado, continuous and discrete measurements of atmospheric trace constituents are taken to study their impact on global climate. Four baseline observatories are located at remote global sites, including Barrow, Alaska. Regularly monitored constituents include carbon dioxide, methane, carbon monoxide, total column ozone, surface ozone, chlorofluorocarbons, halons, nitrous oxide, aerosol scattering coefficient, condensation nuclei concentration, solar radiation, meteorological variables and precipitation chemistry. In addition, the NOAA observatories provide a facility for university and other government-agency investigators to conduct atmospheric research.

A primary objective of the laboratory is to determine regional-scale sources and sinks of the primary greenhouse gases—carbon dioxide and methane. At Barrow, continuous, in-situ monitoring of carbon monoxide was begun last year to complement similar monitoring of carbon dioxide and methane. Once per week, flask sampling of CO_2, CH_4, CO, $^{13}C/^{12}C$ and $^{18}O/^{16}O$ is conducted at Alert (82°N) and Mould Bay (76°N), Canada, and Ocean Station M (66°N), Barrow (71°N), Cold Bay (55°N) and Shemya (53°N), Alaska.

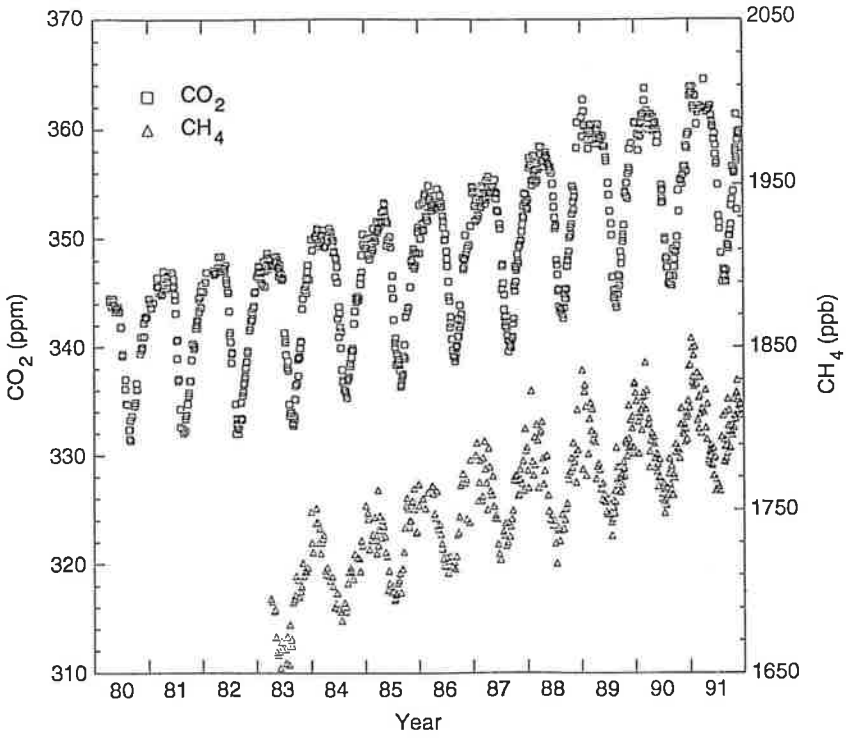
The resulting data from this array of measurements are analyzed, in conjunction with two- and three-dimensional transport–diffusion model results, for insight into the global and regional carbon cycle. For example, the seasonal cycle of the $^{13}C/^{12}C$ isotopic ratio shows that the atmospheric carbon dioxide added and removed each year has an isotopic composition characteristic of plants, implying that biospheric photosynthesis, respiration and decay, in contrast to oceanic processes, are primarily responsible for that variability. In addition, hourly averages of the newly implemented carbon monoxide measurements at Barrow show very high correlation with similar methane measurements during winter, implicating combustion-related processes as the source of both species.

FY 91 FUNDING (thousands)

Arctic Haze	100
Solar Terrestrial	250
Atmospheric Trace Constituents	180
Climate Modeling	300
Environmental Prediction	810
Fisheries Assessment	1900
Marine Mammal Assessment	1200
Sea Grant	260
Ocean Assessment	150
Stratospheric Ozone	400
Arctic Ecosystems	1890
Data Management	1161
Human Resources	619
Aircraft/Vessels	1928
Global Change	1718

Arctic Gas and Aerosol Sampling Program

The Arctic Gas and Aerosol Sampling Program (AGASP) is a multinational, cooperative research program focusing on understanding the phenome-



Results of carbon dioxide and methane flask sample measurements from Mould Bay, Canada.

non of Arctic air pollution known as Arctic haze. AGASP has conducted three major NOAA WP-3D-based field campaigns in 1983, 1986 and 1989. In 1986 the program fielded four aircraft from the U.S., Canada and Norway and conducted measurements from Alaska through the Canadian archipelago to Spitzbergen. In 1989, AGASP NOAA WP-3D activities were focused in the Greenland Sea–Spitzbergen region, partially in support of the ONR CEAREX research program at O and A ice camps located northwest of Spitzbergen. Below are presented some of the main results from the analyses of the data collected on the 1989 AGASP flights and related Arctic measurements supported by the program:

- Aircraft, ice-based and land station measurements during springtime photolytic tropospheric ozone destruction episodes have shown that bromine gas is produced by under-ice algae and that ozone destruction processes may occur on hour or shorter time scales.
- Model calculations have been able to duplicate the energetics involved in the rise of convective plumes from open leads that rise through the Arctic surface inversion into the free troposphere.
- From lead isotope ratios in Arctic springtime aerosols, it has been determined that northeastern Europe is a major contributor to Arctic haze.
- In the spring of 1989, clean, warm, marine tropospheric air penetrated into latitudes north of 82°N, regions normally inundated by Arctic haze; 1989 was a record-breaking year for high temperatures in the Norwegian Arctic.
- Analyses of Arctic radiosonde records suggest that a slight warming occurred in the Arctic basin beginning in the late 1960s.

In the spring of 1992, AGASP-IV will be conducted in the Arctic off Barrow and Prudhoe Bay, Alaska, as part of the ONR Lead Experiment (LEADEX). In addition to the core objectives, AGASP scientists will be involved in surface measurements from the Arctic baseline stations at Barrow, Alaska, and Alert, Northwest Territories, and in an associated NOAA WP-3D and University of Washington C-131 airborne program. The focus of the studies is to determine energy fluxes from leads and to study the synoptic-scale aspects of lead–atmosphere–ice interactions. The NOAA WP-3D will be based in Anchorage, Alaska, and the C-131 in Deadhorse, Alaska, for the one-month (March–April 1992) aircraft program.

To facilitate studies of the Arctic boundary layer, Arctic haze transport, ice–air interactions and climate trends in the Arctic, two data sets have been constructed containing all available in-situ Arctic meteorological soundings. A third database, containing data from Arctic ice stations, polar ships and short field programs, is nearing completion. The NOAA Climate Change Program supported this research.

Historical Arctic Rawinsonde Archive

The Historical Arctic Rawinsonde Archive (HARA) contains records from over 1.2 million rawinsonde ascents, vertical soundings of temperature, pressure, humidity and wind, from fixed-position (mostly land) stations north of 65°N. For most stations the record begins in 1957 (the International Geophysical Year) and extends to 1987. For some stations, particularly in North America, the record begins as early as 1948. The archive contains data from 95 individual stations. Records of at least five years in length are available for 80 stations; records of at least 10 years are available for 69 stations.

The database was subjected to a comprehensive error-checking procedure. Obvious and suspected errors were flagged; however, all original data values were retained. This gives users the option to make their own determination of data quality. The database is archived in ASCII files on magnetic tape, and the archive is being transferred to a CD-ROM. Each file contains one year of soundings for one station. Users requiring station-ordered data can append individual one-year files to obtain a

Researchers interested in obtaining the Historical Arctic Rawinsonde Archive may contact the National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Science, University of Colorado, Boulder, Colorado 80309. The Ptarmigan Dropsonde Archive may be obtained by contacting Dr. J. Kahl, Department of Geosciences, University of Wisconsin–Milwaukee, P.O. Box 413, Milwaukee, Wisconsin 53201.

station history of a suitable length. Users requiring synoptic-ordered data can select files for several stations corresponding to a particular year and extract from them the dates and times that are needed.

Ptarmigan Dropsonde Archive

The Ptarmigan Dropsonde Archive (PDA) consists of over 10,000 vertical profiles of temperature, pressure and occasionally moisture taken over the uninhabited Beaufort Sea and western Arctic Ocean. The measurements were made as part of the Ptarmigan weather reconnaissance program conducted by the U.S. Air Force during the period of 1949–1961. Most of the flights were conducted at 500-hPa pressure altitude, so the sounding data reflect atmospheric conditions in the lower troposphere. The dropsonde data were originally received on microfilm and subsequently digitized and decoded. The data are now on floppy disks.

The HARA and PDA databases have been used in investigations of the Arctic low-level temperature inversion and of convection above leads. The data are currently being used to analyze tropospheric and low-stratospheric temperature trends over the period of record.

Arctic Observations of Stratospheric Chemistry

Observations of the dramatic ozone depletion in the Antarctic have resulted in increasing efforts to understand and quantify the stability of the Arctic ozone layer. These have shown evidence for significant decreases in Arctic ozone abundances (on the order of 8–10%) and accompanying chemical perturbations similar to those found in the Antarctic. Scientists from NOAA's Aeronomy Laboratory are participating in airborne and ground-based measurement campaigns aimed at obtaining a better understanding of Arctic ozone decreases.

Observations of the dramatic ozone depletion in the Antarctic have resulted in increasing efforts to understand and quantify the stability of the Arctic ozone layer

The Airborne Arctic Stratospheric Expedition (AASE I) was a multi-agency airborne campaign carried out in early 1989 involving NASA, NOAA, NSF, universities and the private sector. The campaign was based in Stavanger, Norway, and used two aircraft: a high-altitude ER-2 and a modified DC-8. Scientists from the NOAA Aeronomy Laboratory designed and built some of the instruments used on both airplanes and participated in analyzing and interpreting the data. During 1989 and 1990 the results were analyzed and interpreted. Many of the studies were published in the March 1990 issue of *Geophysical Research Letters*.

Water Vapor and Total Reactive Nitrogen at Stratospheric Altitudes

These species are of particular importance because they are involved in the low-temperature formation of the cloud surfaces that perturb stratospheric chemistry and thereby lead to enhanced ozone losses in the polar winter and spring. Reactive nitrogen also reacts with chlorine compounds, and reduced levels of reactive nitrogen lead to greater ozone depletion. The measurements showed evidence for the removal of reactive nitrogen species in the Arctic, which implies a greater susceptibility for ozone losses there than previously believed. The simultaneous measurements of water vapor showed that the detailed mechanisms for cloud formation and sedimentation in the Arctic may be somewhat different from the Antarctic, with attendant effects on ozone losses.

Redistribution of Nitrogen Species

Observations of reactive nitrogen and ozone at DC-8 flight altitudes suggested that reactive nitrogen species that deposit on cloud particles from the stratosphere likely re-evaporate in the Arctic upper troposphere. These observations are important in attempts to understand and quantify ozone losses with altitude.

Theoretical Studies

A series of calculations using coupled chemical and microphysical models were used to gain insight into the processes leading to ozone loss. These studies showed the importance of parcel excursions in controlling the rate of ozone loss in the Arctic. Further, a series of measurements during the formation of a stratospheric cloud, coupled with these model simulations, provided the first observational evidence of a direct association between the formation of clouds and enhanced chlorine monoxide levels (and thus ozone depletion).

A second Airborne Arctic Stratospheric Expedition (AASE II) was conducted from October 1991 through March 1992. This campaign extended the seasonal and latitudinal domain of the earlier studies, with the goal of obtaining informa-

tion on polar ozone losses and their coupling to midlatitude ozone decreases.

Marine Observation and Prediction

Exchanges through Barrow Canyon

Analyses of recent measurements in Barrow Canyon and supporting oceanographic and meteorological time series were completed. No hypersaline plumes, such as would be expected to result from intensive sea ice formation along the Alaskan coast, were observed to exit through Barrow Canyon during the intensive measurement year of 1986–87. Instead, cold and fresh waters advected down-canyon by the mean flow alternated with up-canyon flows of warm and saline water upwelled onto the shelf. At times the latter resulted in onshore heat and salt fluxes large enough to be of possible local significance, for example, to the surface heat budget. Contrary to earlier findings, the flow was only weakly correlated with the wind and the atmospheric pressure gradient. Instead, both upwelling and flow reversals were coherent along the shelf at sites 400 km apart, with phase differences corresponding to a speed of 2.3 m/s. The majority of these events therefore appear to be manifestations of remotely forced shelf waves propagating eastward along the Arctic Ocean margin.

The Greenland Sea is one of the few regions in the world capable of ventilating the deep ocean

Greenland Sea Investigations

The Greenland Sea is one of the few regions in the world capable of ventilating the deep ocean. Of particular interest is the role of the western boundary current in supplying the deep Atlantic's interior region with buoyancy and salt, thereby controlling both the surface-driven convective regime and deep mixing. To assess the supply of buoyancy, two instrumented moorings were recovered and a new one deployed in the recirculation region of the southern Greenland Sea. Meanwhile, analyses of recent data sets concentrated on the contribution of saline sources to the deep mixing regime. Multiple sources of slightly different density, all originating in the Arctic Ocean, can be shown to compete with the cold and fresh deep water produced in the central convective gyre of the Greenland Sea to determine the deep structure of the basins that overflow into the North Atlantic. During the 1980s, a failure to drive deep convection in the Greenland Sea has resulted in a significant warming and a slight salinization of the deep water in the formative region.

Joint U.S.–U.S.S.R. Chukchi Sea Circulation Study

A joint U.S.–U.S.S.R. field investigation of the shelf circulation from the Bering Strait northward was conducted, with two cruises during the latter part of the 1990 field season, one on the *Professor Khromov* and the other on the *Surveyor*. Sixteen instrumented moorings were deployed for a year to provide a detailed time history of currents, sea surface elevation, temperature and salinity. In addition, each cruise conducted extensive mapping of water properties, including nutrients and dissolved oxygen and a number of trace substances, such as chlorinated organics and stable isotopes. Satellite-tracked surface buoys were used to determine ice drift and meteorological forcing. This joint research program will provide the first comprehensive measurements of a vital Arctic shelf area, which has one of the largest biological production rates in the world and which plays a pivotal role in the climate of the Arctic Ocean.

Ocean Assessment

Arctic Environmental Assessment Center

The Arctic Environmental Assessment Center (AEAC), formerly the Outer Continental Shelf Environmental Assessment Program, was established by means of an interagency agreement between the Minerals Management Service (MMS) of the Department of Interior and NOAA. AEAC is a multidisciplinary environmental studies program that provides MMS and other agencies with scientific data. The agencies can then formulate leasing decisions and develop management strategies to avoid potentially undesirable environmental effects of oil and gas development on Alaska's outer continental shelf. In addition, field studies provide needed new information, and existing information is synthesized so that it can be applied more effectively to assessment and management needs.

In recent years, major AEAC studies have been designed to:

- Describe ocean circulation and cross-shelf exchange of properties along the continental shelf break in the eastern Bering Sea;
- Determine the effect of the *Exxon Valdez* oil spill on the viability of eggs and larvae of Pacific herring in Prince William Sound;
- Describe the early life histories and habitat relationships for major finfish and shellfish in the southeastern Bering Sea;
- Document behavioral responses of Pacific salmon during spawning migration to very

low (parts per billion) concentrations of the water-soluble fraction of petroleum;
- Assess the fishery resources of the northeastern Chukchi Sea;
- Formulate numerical models of lagoonal ecosystems in the Arctic; and
- Delineate migratory corridors and stock composition of Arctic char and Arctic cisco along the Beaufort Sea coast.

FY 90 and 91 accomplishments include the following:

A technical report summarizing 1990 in-house fisheries research in the Beaufort Sea was completed and is in the final stages of publication (available in October 1992). The report provides important new information about arctic char, arctic cisco and other fish relative to their distribution, abundance and migratory behavior in areas scheduled for OCS oil and gas leasing.

A report (and a scientific journal manuscript) on anadromous char and arctic cisco in the nearshore waters of the eastern Beaufort Sea was completed, describing their swimming speed, movement patterns and habitat preferences. The data were derived from ultrasonic tracking of individually tagged fish and concurrent measurements of oceanographic features in the study area. The report's findings—even though based only on a few observations in 1990—have important implications relative to temperature preferences and utilization of a band of brackish water along the Arctic National Wildlife Refuge (ANWR) coast by these species during summer.

Analysis of oceanographic and meteorologic data obtained off the Arctic National Wildlife Refuge (ANWR) was completed, and a report was published describing the hydrography and currents in the region during the open water season. The report provides new information on key habitat characteristics in the eastern Beaufort Sea.

A comprehensive report (and a scientific journal manuscript) was completed describing the amounts, source and "nutritional quality" of organic matter in bottom sediments in the Soviet and American sectors of the northern Bering and Chukchi seas. The report was prepared as a collaborative effort between the AEAC and the NSF-supported ISHTAR study personnel. The study data are significant in elucidating the role of the Arctic Ocean and adjacent shelves in global carbon budgets.

The Arctic Environmental Assessment Center has developed a database that enables the user to access the desired portions or subsets of fisheries data from the Beaufort Sea. Data can be retrieved according to species, gear type, date, investigator and location of samples. The retrieval system employs a graphic user interface and formats the output data for use with most PC-based statistical packages available commercially. This database is the first such attempt and is likely to improve the accessibility and use of archived data, such as those at the National Oceanographic Data Center.

Marine Mammal Tissue Archive

NOAA, in collaboration with the National Institute for Standards and Technology (NIST), has designed and implemented a protocol to collect and preserve tissue samples from Alaskan marine mammals. These samples are stored at the National Biomonitoring Specimen Bank as reference material for use as a contaminant baseline for analysis in the future. Samples are collected from animals harvested by Alaskan natives for subsistence use. Liver, blood, fat, kidney and bile samples have been collected from northern fur seals, ringed seals, bearded seals and beluga whales. A fraction of the preserved material is occasionally analyzed for selected contaminants (metals, pesticides, PCBs and aromatic hydrocarbons) to ensure that the materials are adequately preserved and stored.

During FY 90 and 91 the Alaska Marine Mammal Tissue Archival Project (AMMTAP), involving field collections of marine mammal tissues in cooperation with Alaskan native subsistence hunters and native organizations, were continued. Ringed and spotted seals were sampled in Nome in May, and ringed seals were sampled in Barrow in July. Arrangements were also made to support and coordinate the AMMTAP work with the Alaska Frozen Tissue Collection at the University of Alaska and the Wildlife Serum Library of the Alaska Department of Fish and Game.

The AEAC, in collaboration with the National Institute of Standards and Technology (NIST), reported on chemical analyses of a portion of the stored tissues. The samples were analyzed for concentrations of PCB congeners and chlorinated pesticides, as well as metals, including cadmium, mercury and lead, among a total of 36 elements. These are the first such data, which are essential to determine the health and contaminant load in species heavily used for subsistence in the Arctic.

National Status and Trends

The National Status and Trends Program for Marine Environmental Quality was formed in 1984 to monitor spatial distributions and long-term trends of contaminant concentrations in U.S. coastal and estuarine regions and biological responses to

that contamination. A broad suite of contaminants is measured periodically in sediments, bivalve mollusks and fish tissue samples from stations around the U.S. coast. As of 1989, nine Alaskan sites had been sampled, including five in the Bering, Chukchi and Beaufort seas.

The sediments and tissue samples are analyzed for polynuclear aromatic hydrocarbons (PAHs), PCBs and other chlorinated hydrocarbons, and toxic metals. Fish tissues have also been examined for petroleum-metabolizing enzymes (aryl-hydrocarbon hydroxylase), petroleum metabolites in bile, pollutant adducts of DNA in liver tissue, and histopathological conditions. These procedures are carried out according to documented requirements for quality assurance of sampling and chemical analysis. As of 1991, 17 Alaskan sites have been sampled, including nine in the Bering, Chukchi or Beaufort seas.

During the past decades, significant changes have been observed in the numeric composition of several populations of birds, fishes and marine mammals in the eastern North Pacific and Bering Sea ecosystems

Fisheries

Arctic Marine Mammals

NOAA's National Marine Mammal Laboratory (NMML) at the Alaska Fisheries Science Center in Seattle, Washington, is conducting long-term research on the population biology and ecology of Steller sea lions, northern fur seals and bowhead whales in the western North American Arctic. Research in 1991 was conducted jointly with the Soviet Union under the U.S.–U.S.S.R. Environmental Protection Agreement (Project V–Marine Mammals) on Steller sea lions, and with Japan on northern fur seals.

During the past decades, significant changes have been observed in the numeric composition of several populations of birds, fishes and marine mammals in the eastern North Pacific and Bering Sea ecosystems. Apex predators, such as the Steller sea lion and Pacific harbor seal population on the Pribilof Islands, has declined by 60% since the 1950s. The causes for these declines are unknown, but synergistic effects of commercial fisheries and changes in oceanographic and atmospheric conditions (for example, water temperature and storms) appear to be important.

The Steller sea lion population from the western Gulf of Alaska to the western Aleutian Islands, including the Bering Sea, where more than 70% of the species resides, has declined from 67,617 animals observed on land in 1985 to 21,737 in 1991, which is 4.5% below 1990 counts. Furthermore, since 1960 the population has declined over 80%, a result of increased mortality of all sex and age classes and a reduction in pup production. Mass emigration is not a factor in the decline of the population in Alaska, because the number of sea lions in Soviet waters has also declined since about 1970, and no significant increase in the population has occurred in other areas of the species range. Further work is needed to identify the locations and causes of mortality once the animals leave the summer breeding rookeries to feed at sea. The decline of the Steller sea lion throughout most of its range is significant because of the potential effect that human activities, including competition for available food resources, may be having. Because the species has declined to a fraction of its former size, the population has recently been listed as threatened under the Endangered Species Act of 1973.

NOAA's research on the endangered bowhead whale population has provided insights into critical life-history parameters. These whales are photographed during their spring migration past Point Barrow, the northernmost tip of Alaska. By using calibrated camera systems installed in an aircraft, image lengths can be measured, and well-marked individuals can be reidentified. Since 1984 there have been over 1700 bowhead whales measured and 1300 cataloged as identifiable in these aerial photographs. The results indicate that the population is composed of 41.8% sexually mature adults, 53.0% immature and 5.2% calves. This high proportion of immatures suggests that the population is increasing. The NMML photographic collection, including images from other research groups, now represents over 2500 bowhead whales with sufficient markings to allow reidentification. Four pairs of adults were reidentified with calves more than once between years, indicating calving intervals of approximately four years.

Marine Fisheries Assessment

NOAA's National Marine Fisheries Service (NMFS) maintains a long-standing commitment to assessment studies of U.S. living marine resources (LMRs). This effort includes fishery-independent resource surveys, collection of recreational and commercial harvest statistics, and basic population biology and ecological research. The scientific information generated by these activities support Federal fishery conservation and management re-

sponsibilities in the 200-mile U.S. Exclusive Economic Zone.

The Alaska Fisheries Science Center (AFSC) in Seattle, Washington, annually assesses stock conditions for most species of marine finfish and shellfish having commercial, recreational or ecological significance in western U.S. Arctic waters. These assessments provide measures of population abundance independent of those derived from analyses of fisheries statistics, and they also address the status and health of the marine ecosystem as a whole. Information syntheses incorporate identification of stock units, short-term (1–3 year) predictions of abundance trends, biological interactions of species and species groups, and general ecosystem responses to environmental change. When combined with data from the commercial fleet (for example, fishing effort, location, catch composition and fish size and age), AFSC stock assessments provide recommendations for management of the fisheries and conservation of the supporting resource base.

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LMR populations are sampled at sea aboard NOAA ships, chartered fishing vessels and cooperating foreign research vessels. Significant area-extensive survey efforts rotate every three years between the eastern Bering Sea, the Gulf of Alaska and the Aleutian Islands. During intervening years, standardized AFSC assessment cruises are conducted within each region. Annual estimates are completed for commercially important species such as walleye pollock, Pacific cod, sablefish, yellowfin sole and king and Tanner crab. Dedicated scientific cruises are also conducted to study the biological and physical processes that affect stock assessments.

The principal survey methods include bottom trawls for crabs and demersal fish, hydroacoustic and midwater trawls for semipelagic fish, and special-purpose nets for eggs, larvae, juvenile fish and shellfish. Trawl and acoustic surveys are used to estimate biomass and define the community structure; biological collections are taken to examine variability in growth, mortality and stock recruitment. Recruitment indices and processes that generate variations in abundance are studied to improve prediction. To increase the accuracy and precision of these assessments, AFSC scientists conduct biological research to define recruitment processes, develop computer models to simulate the interactions and dynamics of population change, and conduct or collaborate in extramural studies to improve sampling methods and survey designs.

In 1991 the annual Bering Sea crab–groundfish survey was expanded as a fourth triennial survey of the eastern Bering Sea, extending from the Alaska Peninsula into Norton Sound. The eastern continental slope was also surveyed from 54°N to 60°N latitude at depths of 200–800 m. AFSC scientists joined with their Soviet counterparts in a survey of the northern and western Bering Sea shelf from north of Cape Navarin westward to Karaginski Island. This field effort was a second attempt to characterize the biological resources found in Soviet waters of the western Bering Sea, adjacent to the U.S. EEZ and bordering the international waters of the central Aleutian Basin.

Joint hydroacoustic surveys by the AFSC with the Far Seas Fisheries Research Institute (Shimizu, Japan) were conducted in 1990 and again in 1991 in the central Bering Sea (the Aleutian Basin) and over the eastern Bering Sea shelf. The results from both survey years showed a continuing year-to-year low abundance over the Aleutian Basin (of approximately 1 million metric tons) during the summer months. A 1991 winter survey for spawning pollock showed a substantial decline in abundance to about a third of a 1988-89 estimate of two million metric tons for the Aleutian Basin.

Related Programs

Fisheries–Oceanography Coordinated Investigations

The Fisheries–Oceanography Coordinated Investigations (FOCI) program is an effort by NOAA scientists at the Pacific Marine Environmental Laboratory (PMEL) and the Alaska Fisheries Science Center to understand the processes leading to recruitment variability of commercially valuable fish and shellfish stocks in the Gulf of Alaska and Bering Sea. The goal of FOCI is to understand environmental processes that lead to enhanced or failed recruitment. This information will be used to improve predictions of year class strength.

The major FOCI program for FY 86–91 has been a study of the physical and biological environment of the pollock fishery in the western Gulf of Alaska. The FOCI hypothesis is that the survival of pollock less than a year old is enhanced by remaining in the coastal region as opposed to being transported to the offshore Alaska Stream current. FOCI research has been organized on three scales.

A climate-scale approach examines the meteorological, oceanographic and biological conditions that correlated with historical year class success. Interannual variations in transport and larval concentrations are being studied via annual field surveys and environmental time series. Both field and laboratory studies of transport, mixing, food availability, growth and predation investigate the intra-annual processes that affect mortality.

FOCI studies have improved understanding of the oceanography of the northern Gulf of Alaska. Our knowledge of the circulation of the upper mixed layer is now based on results from 23 satellite-tracked drifters. Contrary to initial ideas, much of the upper layer water in the Shelikof Strait flows southwest along the Alaska Peninsula, rather than out through the sea valley. An estuarine-type circulation pattern is present in the Shelikof Strait, with deep water entering the strait from the southwest. The response of currents to interannual variation in winds has been observed and modeled. Eddies have frequently been found in the lower Shelikof Strait, and their characteristics have been studied.

The vertical distribution and drift pattern of the eggs and larvae have been characterized and related to circulation in the area. Larval patches are often found in eddies, and the condition and feeding regime of larvae in patches is better than outside the patches.

Year class size in pollock from the Shelikof Strait seems to be established by the end of the larval period, except in some years when events during the first summer may further reduce abundance. There is considerable interannual variation in larval transport, and this may be important in determining how many larvae reach the nursery grounds along the Alaska Peninsula. Periods of relaxed winds during the first feeding stage seem to be particularly important for larval survival.

A model that relates changes in numbers of larvae to the physical processes of advection and diffusion and the biological processes of feeding and predation is being developed. Relationships between year class strength and large-scale meteorological indices are being explored.

Recruitment of Shelikof Strait walleye pollock is a complex problem but one that is amenable to study through coordinated biological and physical investigations on a variety of time and space scales, such as are occurring in FOCI.

Bering Sea Fisheries–Oceanography Coordinated Investigations

In FY 91, NOAA's Coastal Ocean Program provided the initial funding that inaugurated the Bering Sea Fisheries–Oceanography Coordinated Investigations (Bering Sea FOCI) project. Bering Sea FOCI is a multidisciplinary effort by NOAA scientists at PMEL and the AFSC and collaborating scientist at five academic institutions (Stanford University, the University of Washington, the University of Alaska, Woods Hole Oceanographic Institution and the University of Colorado). Like the six-year FOCI effort in the Gulf of Alaska, Bering Sea FOCI seeks to examine the biological and physical processes that contribute to recruitment variability of walleye pollock.

The scientific issues targeted for study include stock structure, stock production and biophysical factors affecting recruitment. The project focuses on the biotic and abiotic effects of the environment on the early life stages of walleye pollock spawned in various regions of the Bering Sea, their transport and natural mortality, and the role of physical oceanographic conditions in maintaining stock structure. The principal hypothesis to be tested is that transport of larval pollock from the deep Aleutian Basin to the continental shelf contributes to the viability of the U.S. fisheries. Understanding the linkages between possibly different aggregates of Bering Sea pollock will advance fisheries oceanography of the region and improve national and international fishery management of what is now the largest single-species fishery in the world.

Bering Sea FOCI has two phased components:

- To determine the structure of Bering Sea pollock populations and the role of currents and shelf–slope exchange processes in maintaining or mixing discrete stocks; and
- To understand how the different oceanographic domains affect the productivity of larval pollock populations.

The initial research effort consists of analyses of observations from large-scale biological and physical surveys, mathematical modeling and development of new technology for biological tagging and stock identification. Analyses of population structure and migration will include the application of biotechnological procedures to differentiate spawning groups: mt-DNA, molecular probes of genomic DNA and otolith studies.

Under-Ice Ecology

An under-ice ecology program is being conducted on Great Slave Lake in the Canadian Northwest Territories involving the Environmental Sciences Division of the National Hydrology Research Institute of Environment Canada and the Great Lakes Environmental Research Laboratory

of NOAA. After a successful pilot field program in 1991, the major goal of the 1992 field program is to determine the physiological condition of zooplankton under the extreme conditions of food limitation during winter. Laboratory feeding experiments, lipid concentrations and reproductive conditions will be used to determine whether the zooplankton from the western basin, as well as the very deep (614 m) ultraoligotrophic eastern arm, are physiologically active or in metabolic arrest.

Solar–Terrestrial Services and Research

The Space Environment Laboratory (SEL) of NOAA/OAR/ERL continued to monitor solar activity and its effects on the space environment near earth and on man's activities. The real-time monitoring and forecasting service provided by SEL's Space Environment Forecast Center in collaboration with the USAF Air Weather Service serves the needs of Federal agencies, including DOD and nongovernment users. The most dramatic effects on and above earth occur in Arctic and Antarctic regions, where the geomagnetic field lines pass vertically through the upper atmosphere.

People and Health

In the area of people and their health in the Arctic, the National Sea Grant Program developed a model to examine the way fishermen make fishing area decisions in current open-access situations.

Also, National Marine Fisheries Service economic and social science activities related to the fisheries of the Arctic Ocean, the Bering Sea and Straits, and the Gulf of Alaska focused on the issues of allocating groundfish (pollock) resources between competing user groups. Economic input–output models for the Bering Sea and Gulf of Alaska trawl fisheries have been developed jointly with the North Pacific Fishery Management Council, and a data collection program was put in hand in July 1990. Community profiles of Kodiak, Sand Point, St. Paul and Unalaska were developed by contractors to the Council as part of the social impact assessment of the relative benefits of onshore and at-sea fish processing.

Additional social and economic research was carried out jointly by NMFS and the North Pacific Fishery Management Council for fishery management planning related to the Alaskan crab, salmon, Pacific and black cod, and halibut fisheries. Economic impact studies of the effects of the *Exxon Valdez* oil spill on fisheries were carried out by the NMFS Alaskan Fisheries Science Center. In addition, studies of the effects of marine mammal bycatch limits on commercial fisheries were begun.

Operational Weather, Hydrological and Ice Services

Navy–NOAA Joint Ice Center

The Navy–NOAA Joint Ice Center (JIC) is the only organization in the western world that provides global sea ice analyses and forecasts. Standard weekly analyses of Arctic and Antarctic sea ice conditions are distributed to government, military, university, research, private industry and foreign interests. The JIC has several activities that support research, although it is primarily an operational center producing sea ice analyses and forecasts on global, regional and local scales. The activities or programs that support research include the Digital Ice Forecasting and Analysis System, the Arctic Drifting Buoy Program and the Synthetic Aperture Radar Communications system.

Digital Ice Forecasting and Analysis System (DIFAS)

DIFAS is workstation technology developed by NOAA's Program for Regional Observing and Forecasting Services and was introduced at the JIC in FY 89, with ice analysis production beginning in FY 90. Sea ice analyses for the Arctic and Antarctic are produced interactively on DIFAS using digital satellite data presently from the Advanced Very High Resolution Radiometer (AVHRR) aboard NOAA's TIROS-N polar orbiting satellites. Eventually other satellite data, such as the Special Sensor Microwave Imager (SSM/I), will be available on DIFAS as the system is upgraded. DIFAS has many features that allow the ice analyst to produce a better-quality product. For example, satellite imagery can be enhanced on DIFAS to help differentiate between clouds and ice, resulting in a more accurate analysis of the ice cover. These products, which are archived at the National Snow and Ice Data Center, should prove beneficial for the cryosphere portion of the Climate and Global Change Program.

Arctic Drifting Buoy Program

In FY 90 the JIC was given the responsibility for coordinating and managing the Arctic Drifting Buoy Program, which consisted of participants

from the Navy and NOAA. During FY 91 the U.S. Interagency Arctic Buoy Program (USIABP) was formed, with continued representation and financial support from the Navy and NOAA and the addition of the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). The JIC has continued its coordination and managerial responsibilities for the

The Navy–NOAA Joint Ice Center is the only organization in the western world that provides global sea ice analyses and forecasts

buoy program and will work with the USIABP to establish and maintain a baseline network of drifting buoys of sufficient spatial resolution and longevity to define surface synoptic-scale atmospheric pressure, air temperature and sea ice drift fields in the Arctic. A budget of $300,000 has been established for FY 92 to purchase additional buoys and to analyze the buoy data to meet the requirements of the research community. To improve the accuracy of air temperature measurements for research purposes, the JIC is experimenting with an airdrop-deployable, A-sized buoy with a thermistor that is located away from the possible environmental contamination of snow cover and surface meltwater and covered with a radiation shield.

Synthetic Aperture Radar Communications System

During FY 90 and 91 the Synthetic Aperture Radar Communications (SARCOM) system has been built at the Alaskan SAR Facility (ASF) in Fairbanks, Alaska. SARCOM will allow the JIC to receive SAR imagery from ASF and demonstrate the use of SAR data for ice analysis. The European Space Agency (ERS-1) satellite, which was launched in July 1991, and the National Space Development Agency of Japan (JERS-1), which was launched in February 1992, carry SAR instruments. The purpose of the demonstration is to show the ability of SAR data to improve the sea ice analysis capabilities of the JIC, especially in the Alaskan region. The ice motion and ice classification algorithms that have been implemented by JPL during the past year will be particularly tested. As more SAR data become available at the JIC and are integrated into the ice products, the quality of the analyses should be much improved, benefiting researchers, especially those involved in the cryosphere portion of the Climate and Global Change Program.

Satellite, Data and Information Services

NOAA's National Environmental Satellite, Data and Information Service (NESDIS) manages the U.S. civil operational earth-observing satellite systems. NESDIS also has the basic responsibility for collecting, archiving, processing and disseminating environmental data; developing analytical and descriptive products to meet user needs; and providing specialized data analyses and interpretations. As part of this overall responsibility, NESDIS maintains a variety of Arctic and Antarctic environmental data sets. The data holdings of the National Geophysical Data Center in Boulder, which includes World Data Center–A for Glaciology (Snow and Ice), are of particular relevance to Arctic studies.

A valuable source of high-latitude data is the Advanced Very High Resolution Radiometer (AVHRR) on NOAA's polar-orbiting environmental satellites. Magnetic tape and hard-copy prints of the AVHRR data are archived by the NESDIS National Climatic Data Center. AVHRR data for the Arctic are routinely mapped for the Navy–NOAA Joint Ice Center (JIC) for use in generating ice analyses and forecasts by interactive analyses of digital satellite imagery. A satellite communications system for rapidly transmitting SAR data from the Alaska SAR Facility at the University of Alaska–Fairbanks to the JIC in Suitland, Maryland, was established and tested in 1991. SAR data transferred over this link will be used initially in demonstrating the utility of SAR data for operational ice analysis activities and for coastal ocean monitoring.

Arctic data from the Special Sensor Microwave/Imager (SSM/I) flown on Defense Meteorological Satellite Program (DMSP) satellites are now being tested for use in ice analyses and forecasts. The National Climatic Center archives the SSM/I sensor data, and the World Data Center–A for Glaciology archives mapped SSM/I data for the polar regions and provides software to convert these data to maps of ice concentration. In FY 91, NESDIS received funds from the Air Force for an interagency program to fly a solar X-ray imager on one of NOAA's Geostationary Operational Environmental Satellites (GOES). One of the uses of the data from this instrument will be to increase the accuracy of forecasts of geomagnetic storms and proton flares. Instrument construction will begin in FY 92.

NESDIS also participates in the Search and Rescue Satellite System, an international program using emergency position-location instruments on polar-orbiting spacecraft to detect distress signals

from Emergency Locator Transmitters on aircraft and Emergency Position-Indicating Radio Beacons on boats and ships. Emergency signals are relayed by the satellites to Local User Terminals (LUTs) in participating countries. Search and rescue coverage of part of the Arctic is provided by LUTs in Norway, Canada, the United Kingdom, Russia and Alaska.

Operational Weather Services

Plans for and acquisition of new technologies for the NWS Alaska Region were completed; they included:

- A Doppler wind profiler installed in Homer, Alaska, on November 15, 1990; this provides hourly vertical wind profile data from the surface to 16 km;
- A satellite downlink and processing system installed in Anchorage, Alaska, on April 15, 1991; this provides acquisition, processing and display of real-time polar orbiting satellite (DMSP, TIROS, METEOR and Chinese) imagery and vertical sounding data including ARGOS over the Alaska region; and
- C-band radar installed in Kenai, Alaska, on October 15, 1990; this provides continuous weather radar coverage of the Cook Inlet region of southcentral Alaska.

In addition, a new technologies database is being archived for operational research studies.

Department of Agriculture

The Department of Agriculture conducts research in the Arctic through the Forest Service, the Agricultural Research Service, the Cooperative State Research Service and the Soil Conservation Service. The total expenditures for FY 91 were $4.2 million.

Forest Service

FY 91 FUNDING (thousands)	
Forest Service	1147
Agricultural Research Service	778
Cooperative State Research Service	1242
Soil Conservation Service	994

The 250 million acres of taiga in Alaska, all within the zone of discontinuous permafrost, include 106 million acres of spruce–birch–aspen forest. About 30% of this taiga forest is within the Arctic, as defined by the Arctic Research and Policy Act. Much of the remaining taiga forest is on sites that, by virtue of interacting elevation, slope and aspect, have climatic conditions equivalent to the Arctic. Forest composition in the taiga is primarily controlled by soil temperature, drainage and fire history. Warmer, more productive sites are occupied by white spruce, aspen, paper birch and balsam poplar. Less productive forests, often overlying permafrost, are dominated by black spruce and occasionally tamarack, often intermingled with shrub and wetland communities.

The Forest Service's Pacific Northwest Research Station (PNW) conducts research in Arctic areas of Alaska. The mission of the PNW is to improve understanding, use and management of natural resources. Research teams operate from the Forestry Sciences Laboratory (FSL) at Anchorage and the Institute of Northern Forestry (INF) at Fairbanks, bringing in scientists from other Forest Service stations in Juneau, Alaska; Seattle, Olympia and Wenatchee, Washington; and Corvallis, Bend and La Grande, Oregon. Research needs are identified in cooperation with Federal, state and private managers of forest and related renewable resources.

Ecosystems Processes

Research is devoted to improving understanding of the biological, ecological and physical components, interactions and processes of terrestrial ecosystems.

Vegetation classification

Research, analysis, documentation and manuscript preparation have been completed for the Alaska Vegetation Classification System. The report is in the final publication phase, as a Forest Service Research Report. The major objective of this project is to provide a common classification system to be used by all agencies and groups involved with vegetation inventories in Alaska. The Alaska Vegetation Classification System is already widely used, though not yet formally published. The final document includes 75 color photographs, keys, descriptions of 169 vegetation types at the series level, a listing of approximately 450 plant communities within the series, and a comprehensive bibliography of related Alaskan reports, both published and unpublished. Major support for this task was provided by the Alaska Department of Natural Resource, the U.S. Fish and Wildlife Service, the Bureau of Land Management and the National Park Service.

Long-Term Ecological Research

The Long-Term Ecological Research (LTER) program is funded by the National Science Foundation's Division of Biotic Systems and Resources. The LTER program was developed to provide a coordinated network of sites on which long-term ecological experimentation and monitoring could be conducted. Research addresses five core areas:

- Pattern and control of primary production;
- Spatial and temporal distribution of populations selected to represent trophic structure;
- Pattern and control of organic matter accumulation in surface layers and sediments;
- Pattern of inorganic inputs and movement of nutrients through soils, groundwater and surface waters; and
- Pattern and frequency of disturbance to the research site.

The Bonanza Creek LTER site is located in the Bonanza Creek Experimental Forest (BCEF) near Fairbanks, Alaska. Bonanza Creek LTER is a collaborative project of the Ecosystems Processes Research Program (Pacific Northwest Research Sta-

Monitoring long-term changes in vegetation succession.

tion) and the University of Alaska–Fairbanks. Studies are guided by Forest Service and University of Alaska co-principal investigators. Research is concentrating on primary successional processes of floodplain forests following alluvial deposition, as well as secondary successional processes of upland forests following wildfire. The research examines the premise that the pattern of succession is determined primarily by the initial soil and chemical environment of the site and by the life history traits of component species, and that the rate of successional change is determined by vegetation-caused changes in environment and ecosystem function. Through a set of four corollary hypotheses, research is designed to test the central question of dominant controls of ecosystem structure and function at major turning points in the successional sequences. A suite of 24 study sites representing various successional stages are used to monitor vegetation and environmental changes and to test hypotheses through field experiments. In addition, environmental parameters are continually recorded at one site in each of successional stages (five on the floodplain, three in the uplands) and at two permanent weather stations. The LTER program is integrated with other Forest Service research on long-term ecosystem productivity, management strategies and global change.

Remote Sensing

With the installation of the Synthetic Aperture Radar (SAR) facility at UAF, there has been considerable interest in uses of SAR imagery for measuring ecosystem parameters in the boreal forest. In the spring of 1988 and again in 1991, Bonanza Creek Experimental Forest was imaged using SAR mounted in National Aeronautics and Space Administration (NASA) aircraft. Scientists at INF, in cooperation with the Jet Propulsion Lab (JPL), obtained ground-truth data concurrently with airborne and satellite imaging, focusing on ecosystem characteristics, phenology and local environmental parameters. During the 90-day calibration period of the European ERS-1 satellite in 1991, scientists from INF obtained stand structure, environmental and phenological data at a remote companion research site on the Tanana River floodplain between Manley Hot Springs and Tanana. When the ERS-1 SAR satellite becomes operational in 1992, INF scientists will obtain ecophysiological and environmental data on a regular basis in BCEF. Combined satellite-based SAR and ground-based data sets will be analyzed with the aid of GIS systems to interpret ecosystem parameters, environmental conditions and phenology over a wide area of the northern boreal forest in Alaska and adjacent Canada.

Wildlife Ecology

In 1987, research was initiated to determine major winter moose habitat and use of important winter ranges of the Copper River Delta and to determine range condition and trends. The objectives of the study were:

- To determine basic seasonal movement patterns and home ranges of both east-delta and west-delta moose;
- To determine seasonal use patterns and vegetation characteristics of different habitats;
- To determine seasonal food habits;
- To determine seasonal activity patterns and activity budgets; and
- To identify important winter habitats with potential for habitat enhancement.

Research began with the radio-collaring of 36 moose on the Copper River Delta. Moose behavior is still being monitored.

Moose habitat research is concurrently conducted at Denali National Park, which has a naturally regulated population of moose that exploits treeline habitats typical of moose in mountainous portions of south-central and interior Alaska. Summer and winter research has focused on foraging strategies and long-term trends of moose in relation to habitat condition, along with long-term changes in rutting habitats, nutrition, antler breakage and social behavior during the rut. Monitoring of mortality in radio-collared animals is continuing in Denali, into the second decade for some moose.

Fire Ecology

Recurrent wildfire is an integral component of the environmental matrix of Alaska's northern boreal forest. Research continues into fire ecology and fire effects in relation to ecosystem process, forest stability and productivity, and global environmental protection. Current research activities include pre- and post-fire management work in the Yukon Flats National Wildlife Refuge (YFNWR). Prefire vegetation and woody fuels have been studied in two of the resource units. When the YFNWR successfully burns these areas, Forest Service scientists will assess the initial impact of the fire and follow revegetation and successional processes.

Research on the 1988 Selawik fire in northwest Alaska was initiated immediately following the fire. Forest Service scientists are assessing the initial and long-term effects of this tundra and taiga fire on lichens and other vegetation consumed by migrating caribou. Little is known about the effects of fire on lichens and on caribou winter range.

Fire ecology research continues in the area burned by the 1950 and 1985 Porcupine River fires. Existing vegetation plots have been resurveyed, and new study plots were established in areas burned by both fires and in areas affected by active mudslides following the 1985 burn. This is the only site in Alaska's taiga where changes in vegetation have been documented through one complete interfire cycle. Research is also continuing on wildfires and prescribed burns of varying age near Fairbanks: the Chicken fire (1966), the Wickersham fire (1971), the Grenac Road fire (1977), the Rosie Creek fire (1983) and experimental prescribed burns at Washington Creek (1978) and Willow Island (1983).

Studies of the consequences of fireline explosives (FLE) in permafrost terrain have been completed. Fireline explosives are much less expensive than handline construction and are increasingly being used in fire control in central Alaska. Replicated FLE lines were installed on level terrain at BCEF and on sloping terrain at Caribou–Poker Creeks Research Watershed, following documentation of physical, vegetation and permafrost thaw conditions. INF scientists monitored these installations to ascertain vegetation succession, erosion, sediment production, permafrost thaw and effectiveness of FLE rehabilitation measures.

Assessing white spruce seedling regeneration.

Resource Management and Productivity

The mission of the Resource Management and Productivity Research Program is to understand factors affecting the productivity of forest and range lands and to understand the cumulative effects of management alternatives on this productivity. Alaskan research focuses on silviculture, genetics and regeneration of forest stands.

Research has been begun on the structure and dynamics of young, mixed-species forest stands on upland sites in the taiga. Vertical and horizontal stand structure, growth patterns and stand development characteristics are being determined. Reconnaissance plots have been established throughout the Tanana River basin for intensive sampling of these mixed stands. Detailed stem mapping and growth analysis provide the basis for describing and modeling stand development processes. This research provides a quantitative basis for developing management prescriptions aimed at maintaining and enhancing forest productivity.

Species provenance trials for white spruce, Sitka spruce and lodgepole pine have been continued. Sitka spruce plantations established in the Aleutians shortly after Russian colonization have been visited to determine long-term survival and growth rates. The genetic basis for tree improvement pro-

grams in central and south-central Alaska is being established through research at the Institute of Northern Forestry.

Environmental Health and Protection

Research is underway to develop different forest management prescriptions for spruce stands to protect them from attack by spruce beetles in south-central and interior Alaska and to develop strategies for managing populations of spruce beetles. Studies on host suitability and susceptibility indicate that white spruce is less resistant to attack, but infested Lutz spruce produces more beetle brood. Resistance can be increased by stand manipulation through selective cutting and fertilization. Host resistance also can be correlated with increased levels of myrcene, limonene and beta-phellandrene. Host terpene levels are regulated by site and weather factors and by minor disturbances to the physiology of the trees' water and nutrient transportation systems, such as the phloem.

An expert-systems model was developed for short- and long-term risk of beetle outbreaks in stands of spruce in south-central Alaska. This system, termed SBexpert, is an object-oriented knowledge-based system designed to provide advice on spruce beetle management and, more generally, information about the biology, ecology and management of spruce beetles. SBexpert is actually a collection of four applications developed in the KnowledgePro Windows environment. The applications include SBinfo, SBtext application, SBsearch application and SBrisk application.

A five-year project on the development of new blends of spruce beetle pheromones and operational use strategies using semiochemicals continued. A new formulation of spruce beetle pheromone, methylcyclohexenol (MCOL) + alpha pinene + frontalin, was successfully tested in Canada and Alaska and has been incorporated in all pheromone-based strategies for managing spruce beetle populations. Antiaggregation pheromones have been tested for individual tree protection and entire stand protection where the risk of beetle infestation is high.

Strategies have also been developed to reduce the impact of engraver beetles in stands of white spruce in interior Alaska. These strategies use some of the same beetle-management methods developed for the spruce beetle. The Alaska Division of Forestry has applied this information in its timber-harvest activities in the Tanana Valley State Forest.

Measuring permafrost thaw to establish a baseline for evaluating future changes.

Global Environmental Protection

Alaska's taiga forest includes settings considered particularly sensitive to the temperature changes that are postulated to result from global climatic change. The discontinuous permafrost of interior Alaska's taiga is especially susceptible to thaw caused by climatic warming. Thawing of permafrost terrain could have serious consequences for slope stability, soil movement in streams, forest growth rates, species composition, forest flora and fauna, and landscape ecology. The northern boreal forest of central Alaska has been identified as a critical ecosystem in the Forest Service's Pacific Global Change Program. Global change research was initiated in FY 91 by scientists based at the Institute of Northern Forestry, Fairbanks, and the Anchorage Forest Sciences Laboratory, in four research programs of PNW. The overall coordination is through the Alaska Global Change Research Team, established in 1990.

An initiative to model boreal ecosystem response to global change is being pursued in cooperation with University of Alaska scientists. The goals are to evaluate:

- System response in terms of redistribution of plant communities over the landscape and

associated changes in community composition;
- Impacts resulting from these changes; and
- Comparative efficacy of alternative mitigation measures.

Because of the potential size and complexity of the project, the initial focus is on developing a sound conceptual model.

Thaw measurement transects have been established across ecotones and in representative taiga settings of Bonanza Creek Experimental Forest and Caribou–Poker Creeks Research Watershed to determine the depth of seasonal thaw of permafrost and to establish a baseline condition for evaluating future changes in permafrost distribution and active-layer thickness.The forest–tundra transition in Alaska offers an ideal environment to study the effects of climate change on forest species at the temperature limits of their range. A three-part study of treeline is in the initial phase. Researchers will:

- Prepare a comprehensive annotated bibliography of treeline in Alaska;
- Establish permanent measurement transacts across representative treeline sites to document the past, present and future dynamics of treeline processes; and
- Develop and use small field greenhouses at treeline in the Caribou–Poker Creeks Research Watershed to study the effects of increased temperature on the reproductive ecology of white spruce at the limit of its range.

The results of these field studies will be integrated with the global change modeling initiative to relate treeline environmental responses to future observed climate change.

Understanding fire severity is a priority of the Global Environmental Protection Program. Attempts to predict the impact of changes in wildfire frequency and severity due to changing global climate require a better understanding of the role of fire in ecosystem structure, function and distribution. Fire is a dominant feature of upland ecosystems in interior Alaska and will likely increase in frequency and perhaps severity with changing climate. Fire will also be important in speeding the transition of species towards equilibrium under new climatic regimes. This work will relate natural regeneration of white spruce in interior Alaska to seedbed conditions following a fire.

Aquatic–Land Interactions

The mission of the Aquatic–Land Interactions Research Program is to improve understanding of how natural processes and human perturbations affect aquatic and terrestrial ecosystems and linkages, emphasizing ecological interactions at the landscape scale and cumulative effects of land use on the biophysical components of aquatic ecosystems.

Research is underway into hydrologic and water-quality regimes of subarctic stream and catchment systems. Work is concentrated in the 104-km^2 Caribou–Poker Creeks Research Watershed (CPCRW). A new RAWS (Remote Automated Weather Station) climate station was installed in 1991, providing satellite-linked direct data telemetry from a remote upland study site. The consequences of riparian vegetation clearing in a headwaters valley have been studied in collaboration with University of Alaska scientists. Treatment effects are limited to alteration of litter and leaf fall and solar radiation energy sources for in-stream primary production. Studies of the hydrologic and geomorphic regime of a pingo (a permafrost-related ice-cored upthrust terrain feature) in CPCRW are nearly complete. One pingo is thermally and physically degrading, contributing meltwater (of markedly different chemical composition from stream baseflow) to Caribou Creek. Water discharge and quality have been monitored since 1987. The hydrologic relationships and thermokarst terrain development associated with such ice-related land forms can be regionally significant in land-use planning in the taiga. Hydrogeochemical stream-system monitoring of both permafrost-free and permafrost-dominated catchments continues in CPCRW. The strong influence of permafrost on flood regime and total water yield has been conclusively documented. This stream-system monitoring anticipates major experiments in landscape perturbation (whole-catchment timber harvest and fire). Water-quality monitoring of streams subject to placer mining for gold, concurrently with measurements of unmined "control" streams in CPCRW, has been completed. While affecting relatively little land area, placer mining can have severe water quality effects and remains a volatile public issue in central Alaska. INF scientists also cooperated with Chugach National Forest personnel in monitoring placer mining sites in south-central Alaska.

Production of Goods and Services

The Production of Goods and Services Research and Development Program has concentrated on taiga wood products, including developing innovative techniques for drying lumber and firewood and investigating methods for using wood residue from land clearing and timber harvesting.

Current cooperative research projects (with the University of Alaska, the Alaska Division of Forestry and private industry) deal with methods for treating local white spruce with preservative and using it in exposed structures like timber bridges. Additional information is being developed on the strength and mechanical properties of the wood species of interior Alaska. Initially this research is concentrating on white spruce, for which there is only limited information, and the hybrid Lutz spruce, for which there is no such information. There is a need to develop research into the availability and sustainable production of other "products of the forest," such as berries, rose hips and other minor products. These minor products appear to have good potential for all forest lands, including those that are marginal for wood products.

Inventory and Economic Research

The Inventory and Economic Research, Development and Application Program has responsibility for inventorying forest resources in the United States, including Alaska, in accordance with the objectives of the Forest and Rangeland Renewable Resources Research Act of 1978, and maintaining periodic updates. The inventory staff at the Anchorage Forestry Sciences Laboratory is responsible for the inventory and analysis of Alaska's 129 million acres of forest lands, within the state's total area of 378 million acres. A state-wide multi-agency, multi-resource soils and vegetation inventory has been in process since 1981. Landsat imagery is used to sort forest, woodland, shrubland, herbaceous land, barren land and water into subpopulations. Each subpopulation is sampled separately, and at differing sample intensities, in two phases: small-scale photography (1:60,000) and ground plots. Inventories of the Kuskokwim and Bristol Bay river basins are currently underway, with data acquisition designed to address the timber, understory vegetation, biomass, soils and wildlife habitat. The sample design uses satellite data to define subpopulations of forest, woodland, herbaceous vegetation, shrubland and barren (either water or rock). A two-stage aerial photo and ground plot sample follows the satellite work to estimate the resources within the subpopulations. Forest Service scientists are analyzing data from the Kenai Peninsula especially designed to address an increasingly severe and controversial bark beetle problem. Several reports have been and are being written, summarizing findings that should be helpful for making important environmental and management decisions. For example, white and Lutz spruce stands (the species are very difficult to tell apart and are favored by spruce bark beetles) account for more than 765,000 ft^3 (48%) of the growing stock volume on Kenai Unit forest land. On timberland available for harvesting, 56% of the mortality in white and Lutz spruce trees was caused by insects. More than half the average net annual mortality of growing stock on timberland (4,157,000 ft^3) was insect-caused damage to white and Lutz spruce.

Anchorage Forestry Sciences Laboratory personnel inventorying forest resources.

Cooperative State Research Service

The Cooperative State Research Service funds research projects at the University of Alaska's Agriculture and Forestry Experiment Station (AFES). AFES research projects are designed to provide results useful for the development and conservation of land resources in Alaska. Specifically the AFES research objectives are to:

- Provide a base of research information for the management of renewable resources of high latitudes and
- Provide technology for enhancing the economic well-being and quality of life at high latitudes.

AFES research results are used by foresters, farmers and land managers.

In identifying local Alaskan research needs, experiment station scientists regularly meet with land managers, foresters and farmers from throughout the state to discuss specific needs and problems. AFES researchers also work directly with producers through farm forums, agricultural field days, greenhouse workshops, vegetable conferences,

reindeer herder workshops and forestry workshops. Through these direct public contacts they discover additional research needs. Most AFES research projects in the plant and animal sciences have been developed in response to producer requests. Research projects in the forest sciences and resources management were developed at the request of industry or state or Federal agencies.

Research completed at AFES is published in scientific journals as well as experiment station bulletins, circulars, conference proceedings, books and the station's own journal, *Agroborealis*. Experiment station scientists disseminate their findings through conferences, professional journals, workshops and other public programs. Subjects range from greenhouse operations to potato production, from reindeer herding to forest productivity, and from mine soil reclamation to the management of outdoor recreation.

Plant and Animal Sciences

In a repeat of a study conducted in 1988 and 1989, researchers at AFES examined the effect of residual and applied nitrogen on yields of head lettuce in 1990. As was the case in the two previous years, high rates of residual nitrogen in the soil had a stunting effect on lettuce transplants early in the season, and the leaves of these plants were thicker and more rigid. Growers should probably avoid planting head lettuce in fields where tests detect more than 25 ppm of nitrogen in the surface 9 inches of soil.

The University of Alaska–Fairbanks has applied for the U.S. patent for cold-tolerant *Trichoderma*, which is a fungus that lives in the soil. As a biological seed treatment, it offers the opportunity to protect food plants from pathogenic soil organisms without using chemicals.

Fodder rape and brassica hybrids are high-yielding, high-quality forage crops that are well adapted to Alaska. Studies were conducted at the Matanuska Farm and Point MacKenzie to determine appropriate seeding rates and nitrogen and phosphorus fertilizer inputs for two varieties.

Another AFES study is looking at the effects of low levels of salmon meal in dairy cow diets on milk yield and composition. The feeding of salmon meal resulted in improved milk production and lactational efficiency; however, the percentage of milk fat decreased with increasing levels of salmon meal. Milk protein percentage was not affected by treatment. The proportion of long-chain fatty acids and the degree of unsaturation in the milk fat increased as the level of salmon meal increased. Small amounts of salmon oil omega-3 fatty acids were detected in the milk fat of cows consuming salmon meal.

Forest Sciences

Research in forest hydrology and watershed management has focused on the interrelationship between vegetation and the hydrologic cycle—the link between the terrestrial and aquatic dimensions of the ecosystem. A model of the watershed hydrologic balance is used as the framework for organizing knowledge, forming hypotheses to be field tested, and gaining insights on the probable impacts of vegetation changes. The current research objective is to develop a daily weather simulator for the Fairbanks area. This model would randomly calculate a meteorologically meaningful set of weather variables for each day while maintaining the overall statistical characteristics of the historical record. It could then be used with a variety of deterministic hydrologic models to estimate probability distributions of phenomena such as snow depths, frost depths, dates of snow melt or soil thaw, dates when critical soil moisture levels or river stages are reached and so forth. This ongoing research should enable more meaningful results to be obtained from a variety of management and ecological models and present a means of converting decision-making situations of "uncertainty" into ones of "risk."

The forest floor is a key ecosystem compartment controlling the supply of elements that maintain forest growth. An AFES research project emphasizes the control exerted by the organic matter chemistry on the nitrogen supply for plant growth in successional vegetation types on the Tanana River floodplain and in the adjacent uplands near Fairbanks. This work has three areas of emphasis:

- Establishing the net rate of nitrogen supply in relation to vegetation development;
- Establishing the net rate of nitrogen supply in response to clearing of vegetation in different successional stages; and

Weather station for climate monitoring in taiga upland forests.

Investigating permafrost soils.

• Analyzing the role of organic matter chemistry as a control of the net supply of nitrogen.

Another AFES study is looking at the wetland properties of permafrost soils in Alaska. Permafrost soils in subarctic Alaska have been extensively influenced by recurring wildfire, with a natural fire cycle of 50–200 years. The warmer permafrost in the subarctic zone is more sensitive to thermal changes than in the Arctic. The permafrost may thaw after natural fire or mechanical disturbance because of the loss of the shading effect from the spruce forest and the loss of the insulating effect of the moss layer. The soil temperature regime may change from pergellic to cryic, and the drainage class may change from poorly drained to well drained. Following vegetation succession the soils will cool and permafrost will appear until another fire cycle. A thawed permafrost soil has low chroma mottles in the upper profile, so it has the morphology of an aquic suborder. Yet the soil is often well drained and may no longer support hydrophytic vegetation. The active layer is often saturated above the permafrost during summer, and it can have a temperature between 0° and 5°C, which is below biological zero. Researchers in the Arctic, however, have observed biological activity below this temperature. The validity of 0°C and growing seasons as hydric soil criteria is questionable in Arctic and subarctic regions. To gather quantitative data on the duration and depth of saturation, and the redox potential of the active layer, a cooperative study on wet soil monitoring has been initiated.

Resource Management

Outdoor recreation research at AFES in the past has focused on the supply side—management programs, resource allocation, etc. The studies have usually concentrated on major problems throughout Alaska. Currently several studies are underway under this project umbrella. A case study at Gates of the Arctic National Park involved detailed interviews of National Park Service personnel, conservation leaders and Nunamiut Eskimos, with follow-up interviews as needed. The major problem was differing world views of human relationships with the natural environment. The conclusion suggests co-management as a way to protect the homeland of the Eskimos and the wilderness attributes of the park.

A study of the Wrangell–Saint Elias subsistence permit system, including a thorough legal analysis of subsistence and an analysis of subsistence use (from the ADF&G database), has been completed. The database had to be reformatted so that the subsistence use by specific local communities could be estimated. An analysis of changing social structure from existing databases was also completed. The final step is assessing the impact of subsistence based on changing community social structures. The ultimate policy question of impacts based on rural zones (where everybody qualifies) or individual permits can then be addressed.

A study of the management of scenic overlooks involved approximately 300 interviews of visitors to Alaska to determine how well their expectations were being met. The preliminary conclusions paint a poor picture of Alaska's scenic overlooks. Analyses of stated preferences give a strong indication of the future direction of management.

A statistical study of visual preferences along the Dalton Highway was done in 1990 using approximately 200 interviews of Alaskan visitors using a photo-choice technique. Now a correlation between the physical parameters and visitor choice will be done to determine which parameters are significant and their level of contribution to the landscape. The results will be used to locate recreational developments.

The farming systems research program concentrated on analyzing three development models for the Alaskan agricultural industry based on the degree of Federal, state and private investment. In the models, minimal Federal and state investment was provided to the vegetable and potato segment. Dairy farmers received moderate support. Substantial state but little Federal and private investment was available for grain and livestock production; this was the least successful model. The varying degree of success is directly related to the transportation and infrastructure needs specific to each industry segment. Elements specific to the grain and livestock industries (slaughterhouses, grain and fertilizer facilities, port elevators) were not in place when development was promoted. Reasonable facilities were available for dairy, vegetables and potatoes. Federal capital injections were not forthcoming. Without a compelling need to produce food and without the need for agricultural income, it is doubtful that Alaska's public sector will construct the appropriate transportation systems and infrastructure. Alaska's agribusiness industry is a microsystem in the macrosystem of the circumpolar North. Five other regions have been identified where agricultural production was initiated in a manner similar to Alaska's—an initial, critical need for food by those engaged in extracting natural resources. These regions are: the Transbaikal Region and the Yakuti Republic in the Soviet Far East, the northern region of Finland, Canada's Yukon Territory and the MacKenzie District, the Canadian Shield in eastern Canada,

and the northern region of Alberta in western Canada. Information concerning successes or failures will add perspectives to agricultural development in Alaska and prospective directions for development in other agriculturally underdeveloped regions.

The quality of meat from the forequarters of field-slaughtered Alaskan reindeer is being assessed through a cooperative agreement with the University of Tennessee in three ongoing studies. The first looked at the relationship among dietary fat, flavor and acceptability. While the levels of fatty acids varied, the differences have little practical nutritional significance because the low overall fat content (approximately 3.5%) of the reindeer chuck muscles ensures a low consumption of saturated fat. A sensory panel rated grilled reindeer samples in the acceptable range. The second study looked at sensory profiles and yields for forequarter muscle groups from reindeer harvested in September 1989. The salable yield from five forequarter shoulder sections was 75.5±10%. A consumer sensory panel characterized similarly fabricated and prepared chuck blade roasts as moderately soft and chewy and slightly moist and greasy with a mild gamey flavor. Fifty-eight percent of these panelists, the majority of whom were not consumers of hunt-killed deer or field-slaughtered reindeer, rated reindeer chuck roast samples as moderately to very acceptable. The final study looked at the production feasibility of restructured steaks. These steaks were fabricated from meat flaked to two sizes and with various levels of sodium chloride and sodium tripolyphosphate. Phosphate alone did not appreciably affect sensory properties and negated the effects of salt. Larger flakes and salt improved quality and acceptability. The feasibility of producing restructured steaks from the reindeer forequarter was demonstrated. However, additional work is needed to verify these results over time.

Installing instrumentation for soils research.

Soil Conservation Service

The Soil Conservation Service (SCS) cooperates and coordinates with state, village, regional and Federal land owners. SCS field office personnel in Alaska provide technical resource planning and application assistance to these various landowners and users. Coordinated resource management plans, allotment management plans or interim plans are developed.

Soils Activities

The SCS, in conjunction with the University of Alaska–Fairbanks and Agriculture Canada, has established a transect of representative permafrost-affected soils in the Northwest Territories, Yukon Territory and Alaska. At these sites, measurements are being made of soil moisture and temperature, active layer properties and atmospheric parameters. This information is being gathered to help explain cryogenic processes in soils and their influence on soil genesis and morphology. At all of the monitoring sites, soil profiles were sampled for complete characterization. These data will aid the process studies and will also support the development of an expanded database of soils information for this region.

The information gathered from these research sites in Canada and Alaska will be used to improve the classification of permafrost-affected soils. The studies will also increase our knowledge about the amount of carbon that is sequestered at the high latitudes. The information from these studies will be used in soil process models to further our understanding of cryogenic processes. These sites have been established as long-term monitoring sites to help in understanding changes that may occur as a result of global climate change. There is interest in expanding this monitoring network in Alaska by establishing sites along the Haul Road from Fairbanks to Prudhoe Bay.

Soil surveys will also be conducted through the National Cooperative Soil Survey (NCSS). There is an ongoing soil survey in the Gestle River area, where the permafrost is discontinuous. Work is also scheduled for the Gates of the Arctic National Park, where the soil survey would be supplemented with studies of associated vegetation and landforms within this area of continuous permafrost.

The SCS, along with the University of Alaska–Fairbanks, has also established a series of sites in Alaska to study soil processes in wetlands. At these sites, soil moisture and temperature, redox properties, depth of water tables and other proper-

ties are being measured. At selected sites, gas flux (methane, carbon dioxide and nitrous oxide) will also be measured. This work will allow a better understanding of wetland processes at high latitudes. This work is a continuation of similar projects located in Texas, Louisiana, Oregon, North Dakota, Minnesota, Indiana and New Hampshire. Comparisons can be made to determine how soil processes are different or similar in these different areas.

Future activities are also being discussed between the SCS, the University of Alaska–Fairbanks and the National Park Service to establish Long-Term Ecological Research (LTER) sites in Denali National Park; initial soil survey activities will be conducted in the park in 1992. There are also discussions regarding the gathering of characterization data and soil mapping for the Bonanza Creek Experimental Forest LTER site.

The SCS, Agriculture Canada, the University of Alaska–Fairbanks and the Alaska/Yukon Society of Professional Soil Scientists are organizing a tour and meeting to discuss the genesis and classification of permafrost-affected soils. The trip will start in Inuvik, Northwest Territories, and end in Fairbanks, Alaska. The dates are July 19–30, 1993. Along with the field tour, invited speakers will discuss topics related to soil genesis, classification and related subjects. Persons interested in this meeting should contact Dr. John M. Kimble, USDA-SCS-NSSC, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, Nebraska 68508-3866. Also in 1992 the same organizing group will host a joint soil sampling and discussion of permafrost-affected soils in Siberia followed by a visit of Russian pedologists to Alaska and Canada.

Range Activities

A major part of the range management program involves areas grazed by 36,500 reindeer. The present tundra monitoring program involves conducting utilization checks in selected reindeer grazing permit areas. Exclosure monitoring has involved evaluating plant treatment response and plant succession. The exclosures are located on Adak, Hagemeister, Nunivak islands; there are also eight on the Seward Peninsula. Exclosure data organization, standardization and exclosure maintenance are needed. A cooperative study with the University of Alaska–Anchorage and the Fish and Wildlife Service has resulted in the establishment of ten long-term vegetation trend monitoring plots on Nunivak Island in 1990. Data from the Nunivak study will be completely automated and made available. A lichen growth rate study by the University of Alaska–Anchorage and SCS (1991–1994) will evaluate lichen growth rates relative to grazing, fire and other treatments and make other ecological and physiological assessments as they pertain to reindeer and caribou habitats.

Wyoming precipitation gauge at Barrow, Alaska.

River Basin Study Activities

The final reports for the Tanana and Copper River Basin studies were issued in 1991. Portions of the soils and land cover mapping have been digitized. Field work on the Kenai River Basin study was completed in 1991, including streambank inventory and designs for erosion control structures. Soils and land cover maps will be digitized, and the final report for the Kenai study should be produced by 1993. Field work for the Kuskokwim River Basin study is expected to begin in 1992.

Snow, Climatological and Water Supply Activities

The SCS continues to collect snow and related climatological data. Of significant importance in the Arctic is the amount of annual snowfall the region receives. The true amount of snowfall for the Arctic coast is approximately three times the amount historically reported by the National Weather Service (NWS). This is the average difference in total snowfall catch between the NWS non-shielded or Alter-shielded precipitation gauges and the SCS Wyoming-shielded gauges. SCS currently coordinates data collection at seven North Slope Wyoming-shielded gauges. A non-shielded or Alter-shielded precipitation gauge may be providing inadequate shielding to allow an accurate catch of snowfall in the windy and exposed tundra environment. In July 1989, SCS established a study site at Barrow at the NOAA Climate Modeling and

Nipher precipitation gauge at Barrow, Alaska.

Diagnostic Laboratory (formerly Global Monitoring for Climatic Change) in which precipitation gauges with various kinds of wind shielding are located in close proximity to each other. The windshields being evaluated are the Wyoming shield, the Canadian national standard Nipher shield, the Alter shield and the NWS standard (no shield). The results of total snowfall in 1990 show that the Nipher shield collected 64% of that of the Wyoming shield, the Alter shield collected 47% and the NWS standard collected 28%.

Snow survey data are used in the Arctic for engineering and development, forecasts of river breakup timing, calculations of snowmelt runoff volumes in Arctic rivers, determinations of fresh water availability and augmentation, studies of blowing snow control, studies of caribou movements and global warming modeling research.

Agricultural Research Service

The Subarctic Agricultural Research Unit of the USDA Agricultural Research Service located at Fairbanks, Alaska, cooperates with the University of Alaska and Agriculture Canada (Beaver Lodge, Alberta) on various aspects of agriculture at high latitudes. The research emphasizes plant science, soil fertility, microbiology, soil physics and micrometeorology. In the past the mission of the research unit was to develop conservation tillage practices for crops at high latitudes. However, the mission of the unit was recently expanded to include the effects of agricultural practices on the flux of radiatively active gases and the response of native and imported plant species to increased atmospheric CO_2 concentration. This research is supported with $725,000 for FY 92.

Plant Sciences

Research on weed biology and control has been aimed at understanding the effects of the subarctic environment on weed seed longevity in soil and on the degradation and environmental fate of herbicides.

The longevity of 17 weed and native-colonizing seeds was investigated in the Subarctic to determine those species that pose the greatest challenge in controlling. Eleven of 17 weed species had greater than 6% seed viability after being buried for seven years. The study indicated that the viability of shepherdspurse (*Capsella bursa-pastoris*) and Pennsylvania smartweed (*Polygonum pennsylvanicum*) was retained longer in Alaska than at more southerly locations.

The degradation rates of metribuzin and linuron were studied at Fairbanks and Palmer, Alaska, because carryover from the herbicides could potentially injure subsequent crops. A subsequent crop of cabbage was killed by metribuzin that remained after one year from the time of application. However, linuron that remained after one year did not injure cabbage or lettuce.

Tillage management may alleviate injury from herbicide carryover. A study conducted at Fairbanks indicated that herbicide residues were deposited below a depth of 5 cm by moldboard plowing, whereas residues were evenly distributed by rototilling and remained near the soil surface by chisel plowing. Subsequent crops were severely injured by herbicide residue when chisel plowing was used for seedbed preparation. Therefore, growers can minimize herbicide injury by using tillage methods that incorporate the residue in the soil, such as with moldboard plowing.

Soil temperature and organic matter content were studied as factors affecting the absorption of metribuzin and metolachlor. More metribuzin was absorbed at 5°C than at 28°C, while more metolachor was absorbed at 28°C. However, temperatures accounted for less than 10% of the variation in absorption, while soil organic water content accounted for greater than 80% for both herbicides.

Leaching of pesticides and fertilizers is of concern on all agricultural lands, but little is known of the leaching potential of subarctic soils. The movement of metribuzin and metolachlor was studied in interior Alaska; preliminary data show that there was little or no movement below 15 cm over two years. These data will be used to determine the adequacy of models for predicting leaching in the subarctic.

The response of plants to changes in CO_2 concentration and other climate changes (temperature and water, for example) must be known to aid in forecasting future needs in food and fiber. Information is available that characterizes the response of temperate and tropical plants to changes in CO_2 concentration. However, little is known concerning the response of subarctic ecosystems to climatic change. Therefore, studies will be undertaken to ascertain the responses of subarctic plants to CO_2, temperature and photoperiod.

Soil Fertility and Microbiology

Newly cleared soils in interior Alaska are deficient in plant nutrients, and applications of nitrogen, potassium, phosphorus and sulfur are re-

quired to sustain plant productivity. The organic material on the forest floor is generally removed during the clearing operation to facilitate the use of agricultural machinery in tillage and planting. This material contains a significant portion of the plant nutrients in the forest. Field and laboratory studies have found that this material, when incorporated into the soil, decomposes rapidly. Inorganic nitrogen and potassium, both of which are required in large quantities by plants, are released during the

Clearing large tracts of native forest in the Subarctic has the potential to influence the radiation balance and regional climates

decomposition process. Other studies have shown that barley straw placed on the soil decomposes much slower than when incorporated into the soil. Surface crop residues are therefore slower to release carbon and plant nutrients and may result in greater sequestration of carbon into dead plant material. Therefore, agronomic practices that allow placement of straw on the soil surface will help slow the increase in atmospheric CO_2.

Previous studies have shown that only a small portion of the nitrogen in green manure is taken up by subsequent crops. Research is being undertaken to determine the fate of nitrogen from green manures by comparing the rate of nitrogen released by decomposition of fall-incorporated green manure with that of barley uptake requirements. The effect of organic and mineral nitrogen on the flux of radiatively active gases (CO_2, CH_4 and NO_3) in soil will also be studied. Other locations cooperating on this study are Ft. Collins, Colorado, and Mayaguez, Puerto Rico.

Soil Physics and Micrometeorology

Soils of interior Alaska are very friable and are prone to erode during the dry, early spring. Tillage practices that affect the stability of the soil in the spring were evaluated near Delta Junction, Alaska. The stability of the soil was found to increase as the number of tillage operations decreased. Reduced tillage also provided a wetter seedbed environment, a factor important for seed germination in dryland cropping regions.

General circulation models predict that global warming in the next century will be accentuated at high latitudes. Climate warming could have a major impact on agriculture in Alaska. Analysis of temperature records for several locations in Alaska indicated that the growing season at half of the locations has lengthened over the last 70 years.

Soil surface slope and aspect and surface crop residues influence the absorption of solar radiation and thereby plant growth, but few studies have evaluated this relationship at high latitudes. Field studies at Fairbanks indicated that southerly ridges with a 40° slope absorbed 40% more radiation than east-facing or west-facing ridges and 90% more than north-facing ridges. Black barley straw was found to reflect less than 5% of the incident radiation, while natural-colored and white straw reflected 20 and 30%, respectively. Black straw resulted in an increase in soil temperature, as much as 2°C, compared to white or natural-colored straw. In addition, the soil thawed faster under black straw.

Clearing large tracts of native forest in the Subarctic has the potential to influence the radiation balance and regional climates. Studies near Fairbanks are investigating the effect of clearing native forest on the radiation and energy balance. This information is needed for predicting the effect of large-scale agricultural development at high latitudes on future climatic changes.

Department of Energy

DOE Arctic research efforts include studies of the response and resiliency of Arctic ecosystems to disturbances associated with energy development and global change, the role of Arctic ecosystems in the global flux of carbon, potential sea-level changes associated with changes in runoff from polar glaciers, plasma processes associated with magnetic field annihilation in the magnetosphere, and unconventional gas recovery methods. Funding totaled $2.1 million in FY 91.

Integrated Research on Tundra Ecosystems

FY 91 FUNDING (thousands)

Ecosystem Response	1298
Response to Carbon Dioxide	492
Magnetosphere	145
Gas Hydrates	165

The development of energy resources in tundra regions of Alaska has resulted in various types of disturbances to the fragile landscape, for example, road construction, chemical spills and dust deposition. In addition, the burning of fossil fuels may result in changes in global climate, with particularly dramatic impacts in polar regions. To better understand the consequences of these disturbances on Arctic ecosystems, the Environmental Sciences Division of the Office of Health and Environmental Research sponsors basic ecological research on the response, resistance, resilience and recovery of Arctic ecosystems to disturbance (R4D). The R4D program is being carried out along the Dalton Highway in the Imnavait Creek watershed (2.2 km^2), a tributary of the Sagavanirktok River, 150 miles south of Prudhoe Bay. The dominant vegetation type in the North Slope foothills region, including the Arctic National Wildlife Refuge (ANWR), is tussock tundra. Working out of the Toolik Lake field camp operated by the Institute for Arctic Biology, University of Alaska–Fairbanks, 12 principal investigators from seven universities are participating in the DOE R4D program.

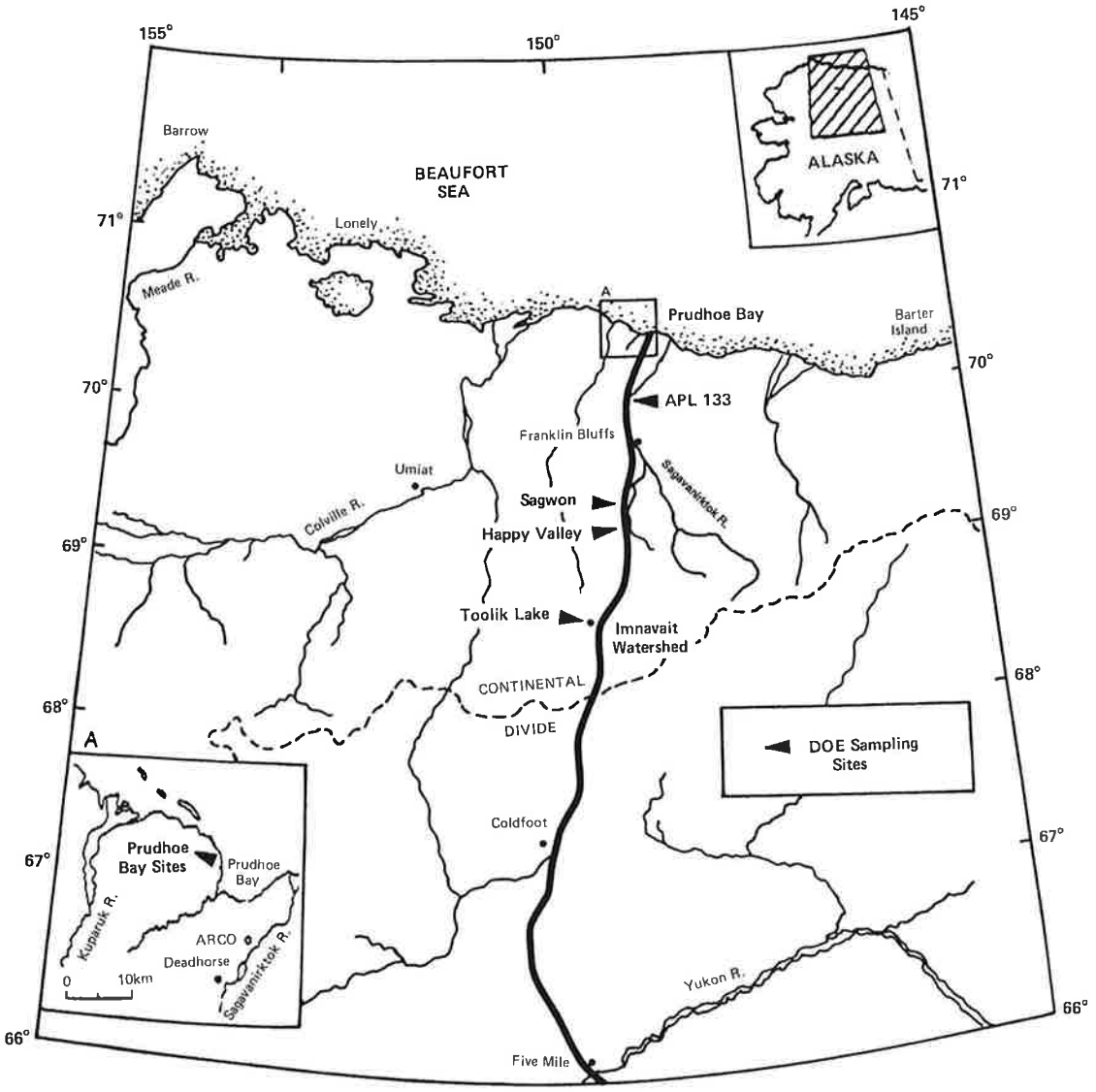
One of the long-term objectives for the R4D program is to develop a predictive understanding of how Arctic landscapes may respond to multiple perturbations so that appropriate, cost-effective measures can be used to minimize harmful disturbances. This has led to the development of the General Arctic Simulator (GAS), a family of computer models that are based on basic ecosystem phenomena that occur at small scales, such as a square meter, and then extrapolating these findings to larger scales, such as hill slopes or watersheds, and ultimately to other Arctic areas that are likely to be affected by energy development. Three major tasks are being addressed by the GAS modeling efforts:

- Describing phenomena that occur at specific locations ("patches") on the landscape (process models);
- Characterizing the transport of energy and materials between patches (transport models); and
- Interfacing process and transport models in a landscape framework (landscape models).

GAS is based on experimental studies being conducted at each of these scales, including studies of soil–plant interactions, biogeochemical cycling, hydrology and remote sensing.

Process studies of plant growth and nutrient uptake at the patch scale are presently based on studies of *Eriophorum vaginatum*, a dominant sedge responsible for the "tussocks" of the tundra. Field studies are concentrating on measuring plant growth as influenced by variations in oxygenation and the availability of soil nutrients and water. Initial results suggest that the growth of another important tundra plant, *Sphagnum* moss, is apparently inhibited when exposed to high light conditions. Thus, soil thermal properties, net ecosystem gas exchange and nutrient trapping by the moss layer in lower-slope and riparian communities is strongly influenced by the distribution of dense vascular-plant canopies that shade the moss layer.

Large quantities of carbon are stored in the organic soils of tundra ecosystems. Results from patch-scale microcosm studies suggest that increased Arctic air temperatures associated with elevated atmospheric carbon dioxide concentrations will tend to accelerate decomposition, chang-



1990 and 1991 DOE sampling sites.

ing tundra ecosystems from sinks for atmospheric carbon dioxide to sources. FLUX, one of the modules of GAS, has been designed to help understand sensitivities to controls on tundra net ecosystem gas exchange. It has been developed to integrate existing physiological information on gas fluxes from plants and soils, to relate plant physiology (especially that of sedges) to methane fluxes from tundra communities, and to understand net ecosystem gas exchange of tundra communities distributed along water availability gradients.

Compared to tussock tundra, dry tundra vegetation types have received little attention. Yet these areas may be important in the attempt to relate patch-level information to a landscape perspective, since they may play an important role in contributing nutrients to downslope communities. Studies are being carried out to quantify carbon fixation and production by the poikilohydric plants that dominate these areas (as much as 400 g/m^2 for lichens). These studies are being conducted in cooperation with students from the University of Würzburg in Germany.

Tundra sedges are being studied to determine how whole plants may respond to variations in soil conditions, a direct consequence of many types of disturbances. Sedges are a particularly important component of the tundra's response to global climate change as they appear to act as conduits for transferring methane from the soil to the atmosphere. During the summers of 1990 and 1991, patch-scale growth, allocation, and root and shoot activity were assessed for *Eriophorum vaginatum* (which grows on slopes) and *Eriophorum angustifolium* (which grows in wet boggy soil) using two water regimes and four nutrient treatments (nitrogen and phosphorus). Plants were transplanted into pots, which were then set directly into the tundra, a semi-controlled growth experiment in which natural above-ground environmental conditions are imposed. Findings from this study will be invaluable in computer modeling of plant growth in response to soil conditions (FLUX).

In terms of transport studies, the DOE R4D program has produced a detailed record of stream geochemistry and its relationship to the landscape

in the Arctic. Hydrologic and aquatic chemistry studies were begun in the upper reaches of Imnavait Creek in 1985. Investigators from Ohio State University have collected snowmelt water at calibrated weirs with stage recorders and automated water sampling systems at first-order water tracks along watershed slopes and on Imnavait Creek. They have found that winter snow contains substantial amounts of nitrate, sulfate and calcium ions. Spring snowmelt is responsible for a major loss of nutrients from the ecosystem, with the lowest pH and the maximum concentrations of ions, suspended solids and dissolved organic carbon occurring with peak flow from the watershed. Strong summer rains that result in surface runoff contribute to the transport of carbon from the watershed, with observed low pH and high amounts of dissolved and particulate organic carbon occurring in the stream. This release of organic acids is particularly pronounced when rains follow a prolonged dry period. Similar releases of inorganic ions to the stream system do not occur during summer rains. In addition, studies have begun to determine local sinks and sources of ions and to establish the degree of ion transport across geobotanical boundaries within the Imnavait Creek watershed.

Researchers from Oak Ridge National Laboratory have used isotopic and radionuclide tracers to quantify inputs of water to Imnavait Creek from different sources (for example, snowmelt, ground water and summer rains) and to trace the movement of atmospherically derived contaminants in the Imnavait Creek watershed during snowmelt. The results indicate that chemically reactive metals, SO_4, radiocesium and other energy-related materials that are scavenged from the atmosphere and deposited in the snowpack are efficiently retained within the top 10 cm of the tundra vegetation. This implies that most of the ions, suspended solids and dissolved organic carbon that escape the watershed during peak flow originate largely from decomposition rather than from atmospheric inputs.

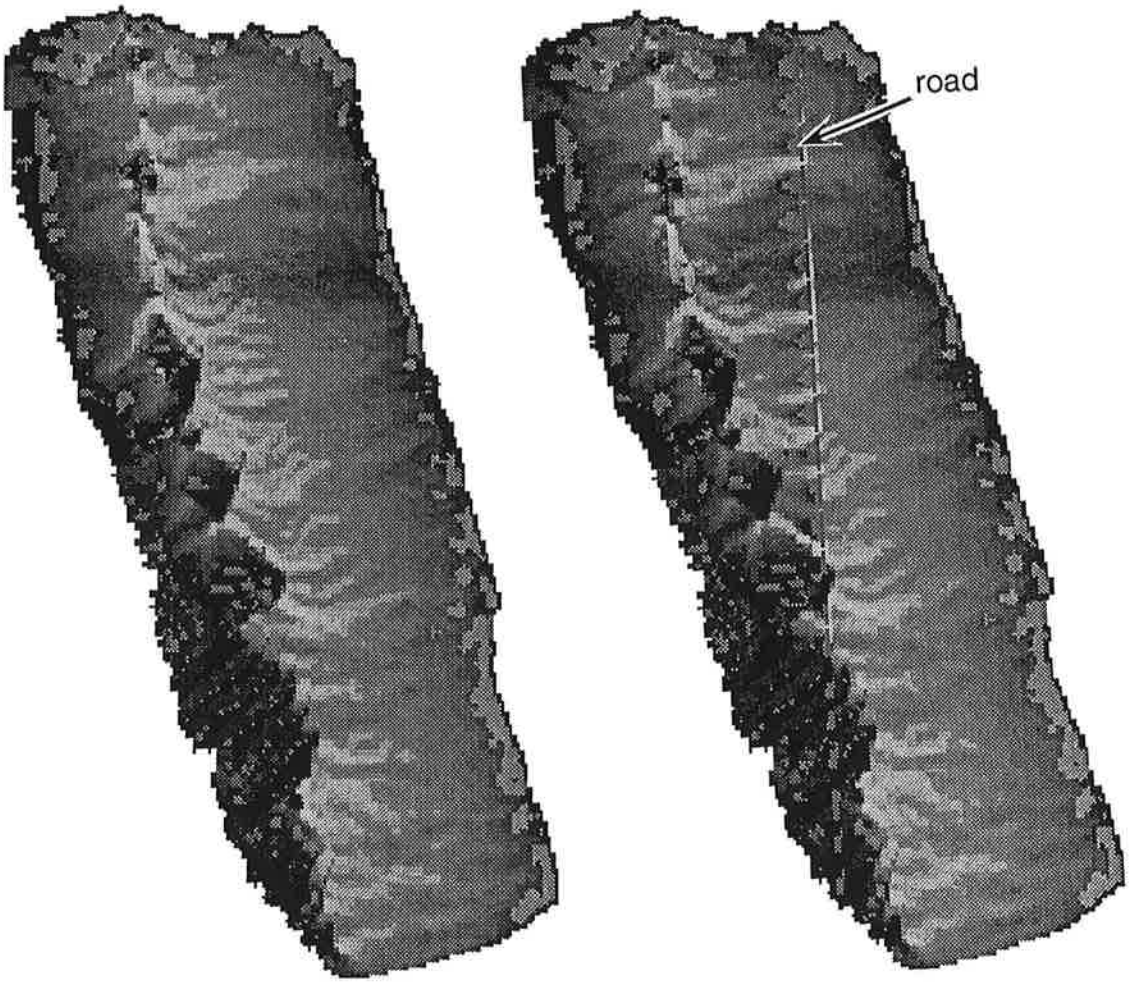
Researchers from the University of Alaska have developed a hydrological transport model for Imnavait Creek that has been validated against hydrographs for small water tracks that drain the slopes, as well as for the entire watershed. This model operates on a daily time step and provides information on the depth of thaw (the active layer) and the soil-water content. Using a two-dimensional, non-steady-state heat conduction model with phase change to predict the thermal regime of the active layer, this model predicts that the active layer will increase in thickness by 20 cm to more than 50 cm in response to a 2–8°C warming of the ground surface over a 50-year period. In addition, under some scenarios, simulations suggest that the volume of evapotranspiration will increase, runoff will decrease, and the spring melt will be earlier and less intense, given no changes in precipitation.

At the landscape scale, researchers from the University of Colorado are developing a series of maps describing terrain features, vegetative cover, soils and hydrology from the intensive study area and its surrounding region. The scales of these maps range from 1:600 to 1:24,000. The maps and all of the other spatially discrete data are digitized in the R4D Arctic Geographic Information System (R4D/AGIS). R4D/AGIS is structured to take advantage of data that will be obtained by the newest generation of NASA remote-sensing satellites. DOE investigators are developing the ground-truth signatures for landscape features observable using an array of new satellite observation capabilities. The information from these maps and from other sources can by layered via R4D/AGIS, and many layers of spatial information obtained over large land areas can be manipulated rapidly. Furthermore, through the use of correlative models, R4D/AGIS will provide the important initial conditions necessary for spatially explicit landscape versions of the GAS models.

Multispectral image data with 10-m resolution have been obtained from the French SPOT satellite and are being used with R4D/AGIS for distinguishing vegetation classes. Using SPOT images it is possible to recognize spatial patterning in dry ridgetop, moist riparian and tussock tundra slope plant communities in the Imnavait Creek research watershed. These remotely determined maps have been compared with photointerpretation and ground-truth studies.

If the effects of anthropogenic disturbances to tussock tundra landscapes are to be adequately modeled, it is important to establish the natural variability of albedo for undisturbed vegetation and to assess the possible changes due to disturbances. DOE-supported researchers from San Diego State University collected albedo data from sites on undisturbed tussock tundra and adjacent to the Dalton Highway where the tussock tundra was subjected to dust depositions. Dust was found to significantly reduce the albedo, particularly under low light conditions.

In cooperation with NASA researchers, a pilot project has been initiated to measure scattered radar signals from the vegetation. An MPS scatterometer was placed on a 10-m-high tower at Imnavait Creek to obtain dielectric constant data (the reflected microwave energy that is returned to the scatterometer) associated with vegetation structure, microtopography, soil water content, moss water content, plant water potential, water table



Computer-generated maps of nutrient availabilities in the Imnavait Creek Watershed before and after road construction. Drainage culverts are placed every 20 m. Low availability levels of nitrogen and phosphorus for plant growth are shown as dark tones; high levels are light in tone.

depth and thaw depth. These data are being analyzed in modeling efforts to determine the cause of the change in radar backscatter as influenced by these tundra biophysical properties. The initial results show trends in radar signals with changing soil moisture during the summer. These models will support later analyses of ERS-1 data at the regional scale.

This ability to manipulate spatial data and provide inputs to ecosystem models provides a powerful tool for testing terrain sensitivity and analyzing hypotheses. Using various modules of GAS (patch and transport), researchers from Duke University have developed a preliminary version of the Arctic Landscape Simulator (ALS) that predicts water movement, vegetation type, nutrient availabilities, plant productivity and plant biomass in the watershed. For example, the spatially explicit ALS assumes that nutrient availability is positively correlated with drainage and negatively correlated with anaerobic soil conditions. Drainage and nutrient availability are correlated because water movement enhances nutrient uptake by roots, increases thaw depth (and therefore rooting volume), appears to be correlated with organic matter accumulation, and may move nutrients downslope. Anaerobic soils have low nutrient availabilities due to slow decomposition rates and immobilization of nutrients; in addition, uptake by plant roots is also inhibited. The effect of road construction on nutrient availability is simulated via its direct effects on changes in water drainage. The major question being addressed by ALS is whether nutrient uptake or the loss or storage of water by a given plant community has a major influence on downstream communities, which is important in assessing the effects of disturbance propagation across the landscape.

Response to Carbon Dioxide

Northern ecosystems (Arctic, boreal forest and northern bogs) contain vast stores of carbon. About 500 Gt of carbon is stored in these ecosystems, mostly in the soil active layer and upper permafrost. This is equivalent to about two-thirds of the carbon now in the atmosphere. The Arctic

alone contains about 60 Gt of carbon, 83% of which is present in the active layer and the upper permafrost. Until recently the Arctic has been considered a sink for atmospheric carbon dioxide, accumulating approximately 0.1–0.3 Gt of carbon annually.

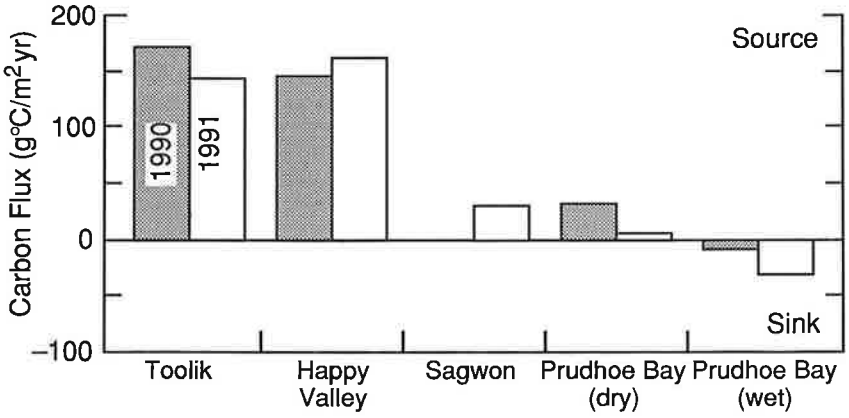
The high latitudes are anticipated to undergo the greatest increases in surface temperature. Global warming may already be occurring, as permafrost temperatures indicate a temperature rise across the North Slope of Alaska of 2–4°C within the last century. Greenhouse warming associated with elevated levels of atmospheric CO_2 and other greenhouse trace gases could increase the depth of the soil active layer, the depth to the water table, soil aeration and rates of organic decomposition. If rates of organic decomposition increase at a rate that is greater than the net primary productivity, Arctic ecosystems may become sources for atmospheric CO_2 and thus create positive feedback for global warming by greenhouse gases. On the other hand, increasing atmospheric CO_2 could stimulate net primary productivity and CO_2 uptake from the atmosphere, especially if changing climatic conditions increase mineralization rates and, therefore, nutrient availability.

DOE-sponsored research on ecosystem responses to carbon dioxide is designed to determine the effects of elevated levels of atmospheric CO_2 on ecosystem function and to quantify carbon fluxes. Recent findings have indicated that the tundra ecosystem may have shifted from a carbon sink to a carbon source with respect to the atmosphere, although the regional extent of this shift is still uncertain. If this shift is wide ranging, then the net release of CO_2 to the atmosphere could be substantial. As a result, research conducted during 1990 and 1991 was aimed at determining the regional patterns of carbon flux (sources and sinks with respect to the atmosphere). Seasonal diurnal measurements of net ecosystem CO_2 flux were made along a latitudinal gradient in Alaska from Prudhoe Bay near the Arctic Ocean to Toolik Lake in the foothills of the Brooks Range for two growing seasons. Carbon flux measurements were also made on 0.5-m^2 plots using a fast-response infrared gas analyzer to help understand the effects of moisture availability and other environmental factors on carbon assimilation and decomposition.

Results from the 1990 and 1991 field seasons showed that several areas of moist, inland tussock tundra and wet coastal tundra have shifted from being carbon sinks to being carbon sources with respect to the atmosphere. Of the sites sampled, the greatest rates of carbon loss occur near Toolik in the drier, better-drained foothills of the Brooks Range. At Happy Valley (about halfway between Toolik Lake and Prudhoe Bay), daily CO_2 loss rates varied seasonally from about 0 to 2.7 g°C/m^2d between May and September. Near the peak season the net ecosystem carbon flux was typically positive (that is, there was a net loss of CO_2 to the atmosphere) for a majority of the day. The fluxes from well-drained coastal tundra sites were also positive, indicating that carbon is being lost to the atmosphere. Only in the wettest coastal sites (for example, flooded sites near Prudhoe Bay) were diurnal carbon balances slightly negative, indicating a net sink for atmospheric CO_2.

On an annual basis the seasonal carbon loss to the atmosphere was found to decrease from the foothills to the Arctic Coast. Carbon loss was between 140 and 160 g°C/m^2yr at the inland Happy Valley site for both 1990 and 1991. At Sagwon Hills, which is located within the transition zone between the moist, inland tussock tundra and the wet coastal tundra, the carbon loss was approximately 25% of the amount lost at the more-inland (southern) sites. The carbon loss from well-drained areas near Prudhoe Bay averaged 12 g°C/m^2yr, while carbon accumulation in the flooded coastal tundra was between 3 and 25 g°C/m^2yr. These data suggest that the net carbon flux for wet-coastal tundra ecosystems near Prudhoe Bay may be in balance.

These rates corresponds to a net global loss of approximately 0.14 Gt°C/yr to the atmosphere for moist, inland tussock tundra, and between 0 and 0.03 Gt°C/yr for wet coastal tundra. Although uncertainties are large, these data indicate a change in the carbon balance of the tundra with respect to the atmosphere, especially in moist, inland tussock tundra. To broaden the geographic coverage, Russian and Norwegian scientists have recently joined the DOE research effort and will be applying the same measurement techniques to quantifying carbon fluxes in the Russian Arctic and on Svalbard. Another cooperative project is being developed for Iceland.



Annual net carbon flux along the latitudinal gradient on the North Slope of Alaska.

The AORIS database has been completed and is available to industry, universities and other Government agencies on CD-ROM disks by writing to the Energy Science and Technology Software Center (ESTSC), Oak Ridge, Tennessee, 37831, or calling (615) 576-2606.

Another research activity funded by the DOE Carbon Dioxide Program seeks to understand and predict how runoff from the Greenland ice sheet will respond in the next century to a climate changed by increased atmospheric CO_2. The approach involves:

- Observing the processes of infiltration and refreezing, which lead to the formation of impermeable firn layers;
- Reproducing these observed processes in the laboratory to better quantify our understanding;
- Developing and calibrating a regional-scale numerical model that can simulate these processes based on measured parameters and driven by boundary conditions determined by climate; and
- Applying this model to predict the development of impermeable firn (and consequent runoff and discharge to the ocean) in response to predicted future climate change.

In 1990 and 1991 a local-scale numerical model was developed and tested. This two-dimensional model treats meltwater infiltration and refreezing in a layered snowpack, including a realistic treatment of heat conduction, phase change and fluid flow in the snow, with moving boundaries (freezing and subfreezing) and heat or water inputs at the surface that vary in both space and time. It has been applied to Arctic snowpacks measured in the field.

At the other end of the spatial scale, a model was developed to estimate the retention of meltwater in the Greenland ice sheet. This describes how infiltration, refreezing and runoff can be estimated based on two simple assumptions. Using a typical scenario for greenhouse warming (+4°C and +10% precipitation), this model predicts runoff for the area above the present runoff limit to be 4.0–4.3 cm (in global sea-level equivalent) less than would be predicted without refreezing. Field work currently underway includes detailed measurements of snow stratigraphy near the runoff limit in Greenland and a joint program with NASA to correlate snow zones with images for regional analyses.

Other DOE Activities

The Geophysical Institute of the University of Alaska–Fairbanks is studying magnetic field annihilation in the magnetosphere as part of a research project involving theoretical and computational studies of basic plasma processes associated with magnetic connection at the dayside magnetopause and the nightside magnetotail. These processes are important in the solar wind–magnetosphere interaction transferring mass, energy and momentum from the solar wind into the earth's magnetosphere. The aurora seen in the sky is one manifestation of this interaction. Based on the simulation experiments, the investigators proposed an ion-heating mechanism of slow shocks associated with the chaotic motion of particles in the downstream rotational field. Current research emphasizes the extension toward three-dimensional modeling including ionospheric conductivity.

DOE is also active in research that advances the technology for recovering Arctic fossil fuels. One of the important results of DOE's research effort has been the development of the Arctic Offshore Research Information System (AORIS), which is a database that makes available the diverse scientific and technological information needed for fossil energy development in the Arctic.

DOE's research in gas hydrates is a part of the Unconventional Gas Recovery (UGR) program, a multidisciplinary effort to develop the technology for producing natural gas from resources that have unusual geology and require the development of unique methods for production. The current approach for characterizing and delineating the location of gas hydrates involves development of techniques for geologic and geophysical research, determination of diagnostic detection methods, modeling of reservoirs, optimization of production concepts, and development of strategies for stimulating wells. The primary research has been on understanding the in-situ detection of hydrate deposits and on the development of onshore extraction and production technologies.

Geological analysis of offshore gas hydrate deposits has been completed for 14 basins surrounding North America and has resulted in gas-in-place estimates of approximately 2700 trillion cubic feet (Tcf) of gas. About 44 Tcf of gas has been estimated onshore in the Kuparuk and Prudhoe Bay fields on Alaska's North Slope. Gas shows in North Slope wells have been at both the top and bottom of the suspected hydrate horizons, and two wells in Prudhoe Bay have significant gas shows at four hydrate deposit horizons preselected from well logs in the hydrate stability zone.

Preliminary identification of gas hydrates has been made in the Barrow Gas Field area, and an agreement has been completed with the North Slope Borough of Alaska to investigate the feasibility of drilling a gas hydrate production well. The research and development associated with the drilling of this well in the Barrow Gas Field will provide useful production data on gas hydrates.

Department of Health and Human Services

Six agencies of the United States Public Health Service of DHHS conduct Arctic health research. Of these the Centers for Disease Control, the Indian Health Service, the National Institutes of Health and the Alcohol, Drug Abuse and Mental Health Administration support the greatest amount of Arctic health research. Total DHHS funding for Arctic health research in FY 91 was approximately $12 million.

Centers for Disease Control

FY 91 FUNDING (thousands)	
Alcohol, Drug Abuse and Mental Health Administration	4079
Centers for Disease Control	4023
National Institutes for Health	2352
Indian Health Service	1350
Health Care Financing Adminstration	90
Health Resources and Services Administration	224

Arctic research funded by the Centers for Disease Control (CDC) is managed through the Arctic Investigations Program (AIP) with offices and a laboratory located in Anchorage near the Alaska Native Medical Center of the Indian Health Service (IHS). The mission of the AIP is to conduct infectious disease epidemiology, laboratory research, and prevention and control activities for Arctic and subarctic populations, particularly Alaskan Natives. Activities within this mission include disease surveillance, studies in the etiology of disease, analytic and descriptive epidemiologic studies, development of laboratory methods, evaluation of disease intervention strategies, dissemination of information, support for the research efforts on other agencies, and training in research, epidemiology and public health.

The research conducted in Alaska by AIP and IHS is an outstanding example of focused interagency cooperation. Recently the AIP extended its collaboration to Alaska Native agencies and organizations. The CDC has significantly increased its activity in the Arctic during 1991 with the development of new research programs in occupational injury and fetal alcohol syndrome. In FY 91 an additional CDC activity, the National Institute for Occupational Safety and Health (NIOSH), established a field site adjacent to the AIP.

Prevention and Control of Infectious Diseases

Meningitis

Haemophilus influenza type b (Hib) is the leading cause of bacterial meningitis in infants and young children. Infection can lead to death, severe neurologic damage and hearing loss. Rates of the disease in Alaskan Native children are at least four times greater than in non-Native Alaskan children, and the disease occurs earlier in life, peaking at the ages of 6–7 months. Until recently the only available vaccines, made of the outer capsule of the bacteria, were licensed for use only in children over 15 months old. Because of the early onset of Hib disease, this vaccine did not significantly affect Alaskan Native disease rates. A major vaccine trial that used a conjugated vaccine administered at the same time as routine well-baby immunizations was completed in FY 89. Although this vaccine was highly effective in a trial in Finland, vaccine efficacy was disappointingly low in the Alaska trial (36%), and only low levels of antibody were stimulated by the vaccine.

Since the initiation of the Alaska trial, three new conjugate vaccines have been developed and have undergone immunogenicity trials in Alaskan Native infants, as well as in infants elsewhere. Two of these vaccines were highly immunogenic in Alaskan Native infants. These two vaccines were highly efficacious in other populations and have been licensed for use in infants. However, the characteristics of these vaccines are quite different, and current studies are underway to identify how best to use these vaccines in this high-risk population.

Because of the high risk of Hib disease in Alaskan Native infants, a project has been underway since 1989 that involves administering four shots of bacterial polysaccharide immune globulin (BPIG) that has been especially prepared to pro-

vide high levels of antibody against Hib and two other bacteria. Because of the early onset of Hib disease in Alaskan Native infants, a demonstration project is now underway in the highest risk areas; this involves administering BPIG at birth before administering the licensed vaccine.

Hepatitis

Alaskan Natives have high rates of hepatitis B virus (HBV) infection, which can cause acute hepatitis as well as cirrhosis and cancer many years after the initial infection. Persons chronically infected with hepatitis B are nearly 200 times more likely to develop liver cancer, which is usually fatal. Overall, 3% of the Alaskan Native population is chronically infected with HBV; the rate ranges up to 7% in some regions. In 1983, IHS, the State of Alaska Division of Public Health, and AIP joined in a statewide effort to test all Alaskan Natives for HBV infection and administer hepatitis B vaccine to all uninfected persons. The first phase of this program has been completed. The vaccination series has been administered to more than 50,000 Alaskan Natives, and illness from hepatitis B has dramatically declined. The second phase of the program requires the vaccination of all newborn Alaskan Natives. In a vaccine demonstration project initiated in 1981, persons were vaccinated with the first licensed vaccine and were followed up to determine how long protection will last after an initial three-shot vaccination series. After nine years, 74% of study participants who were vaccinated have protective antibody levels, and none of these persons were positive for the antigen. The Alaskan study is the only long-term study in the United States designed to address the question of the need for or timing of a booster dose of hepatitis B vaccine.

Pneumonia is the fourth leading cause of hospitalizations in IHS hospitals in Alaska and ranks sixth among causes of death among Alaskan Natives

Approximately 1400 persons chronically infected with HBV are tested twice a year to determine their current viral status and their blood for alpha-fetoprotein (AFP), a biochemical marker for liver cancer. Six patients have had tumors detected at an early stage, and five have lived as long as seven years after surgery. Alpha-fetoprotein testing will continue. Because HBV carriers are widely dispersed throughout Alaska, laboratory efforts are directed toward developing a test for AFP that can be performed by the village health aide. This new test is now being field tested in a number of villages. In September 1989 an international meeting was held in Anchorage to review work in AFP screening that was being carried out worldwide. Participants made recommendations for screening of hepatitis B carriers and future research needs on AFP and liver cancer.

In addition to hepatitis B, epidemics of hepatitis A infection have occurred about every 12–15 years. Surveillance documented an increase in cases reported in Alaska beginning in 1985. By early 1986 it was clear that a new hepatitis A epidemic was sweeping through the state. Vaccines for hepatitis A infection are just becoming available. Studies of antibody responses of Alaskan Native children and adults to the new hepatitis A vaccines are now underway and will continue through 1992.

Pneumonia

Pneumonia is the fourth leading cause of hospitalizations in IHS hospitals in Alaska and ranks sixth among causes of death among Alaskan Natives. Upper-respiratory problems and otitis media rank third and fourth among leading causes of outpatient visits. *Streptococcus pneumoniae* (SPN) is responsible for about 20% of all pneumonia cases and is also a cause of bacterial meningitis in children. Statewide laboratory-based surveillance records for confirmed cultures of SPN obtained from normally sterile body fluids document increased rates in Alaskan Natives. Rates overall are six times greater in Alaskan Natives than in non-Natives and as high as ten times greater in certain age groups.

A vaccine is available that produces antibodies in persons over two years old; it is recommended primarily for persons over age 65 and for those with serious heart and lung conditions and diabetes. The pneumococcal vaccine has not been optimally used in the Alaskan Native population. A disease prevention project to vaccinate all persons at increased risk and to revaccinate those whose primary vaccinations were given more than six years previously in one northwest region of Alaska was completed during 1990. New conjugate pneumococcal vaccines will be available for immunogenicity testing during 1992. These new vaccines will be offered to various age groups of Alaskan Natives in an effort to assess their response to these vaccines.

Laboratory work is directed toward characterizing the serotype and antibiotic resistance patterns of SPN isolates, developing rapid diagnostic tests for detection of pneumococcal disease, and developing immunoglobulin class-specific and serotype-specific antibody assays for assessing responses to conventional and conjugate vaccines.

Cancer

Previous research by CDC and IHS, with support from the National Cancer Institute (NCI), documented that cancer patterns among Alaskan Natives differed markedly from those of the general U.S. population and even from those of American Indians outside Alaska. Studies and programs have focused on cancers that occur in excess and that are virus-related: for example, those involving the nasopharynx, cervix, esophagus or liver.

Cancer patterns among Alaskan Natives differ markedly from those of the general U.S. population and even from those of American Indians outside Alaska

Human papilloma virus (HPV) has been implicated in cervical and esophageal cancer. Studies to examine the presence and specific genotypes of HPV in cervical specimens of Alaskan Native women, among several patient groups using IHS health care, have been completed. Studies to examine pap smear histories of women who developed invasive cervical cancer and to compare screening techniques for examining the cervix (pap smear, cervicograph and HPV tests) are underway and will continue through 1992.

Alveolar Hydatid Disease

Alveolar hydatid disease (AHD) is primarily a disease of the liver and is caused by inadvertent infection of humans by a dog or fox tapeworm, *Echinococcus multilocularis* (EM). Untreated lesions on the liver result in severe, prolonged, chronic liver disease and eventual death. AHD is a problem in Arctic and subarctic populations, including residents of northwestern Alaska. Cure can be complete only by surgical resection of small lesions, although benzinadazole compounds may be helpful. In 1985, new serologic tests became available, and serosurveys were performed annually. In 1988, ultrasound examinations were performed in conjunction with the serosurveys in two villages. Recent research activity has been directed toward:

- Identifying new EM-specific antigens for use in serologic testing and standardization of laboratory tests;
- Studies of voles to assess the prevalence of infection in the intermediate host, and vole assays to assess the viability of tissues removed surgically from patients; and
- Treatment of nonresectable tumors with benzinadazole compounds.

Currently research data are being analyzed, and proposals for further studies are being evaluated.

Anemia

Iron deficiency can affect immunologic defenses; therefore, studies of iron deficiency, especially in populations at high risk for infection, are important. Iron deficiency has long been recognized as a problem among Alaskan Native children. An iron supplementation project in the 1970s improved mean hemoglobin levels. Recent efforts have focused on improving programs in health education to enhance the use of iron-rich foods available in the traditional Alaskan Native diet.

A number of small surveys to assess the prevalence of iron deficiency anemia have been conducted over the past few years in conjunction with other serosurveys among the Alaskan Native populations. Recent surveys indicate that iron deficiency may be a more general problem affecting not only children, but adults as well. In one study in southwest Alaska, 16.9% of Alaskan Natives were anemic, and 44.2% were iron deficient. Recent investigations of iron deficiency anemia among men have suggested that chronic blood loss may be a mechanism for iron deficiency. This possibility is supported by several dietary surveys that have found above-average iron intake among Alaskan Natives. Current plans are to define more clearly the causes and extent of iron deficiency among Alaskan Native men by studying the relationships among dietary intake, iron nutrition status, and stool blood loss in persons from selected villages in which iron deficiency is highly prevalent.

Sexually Transmitted Diseases due to Chlamydia trachomatis

This longitudinal project was designed to measure the effectiveness of various control interventions for sexually transmitted diseases (STD) on a community-wide basis. The geographically isolated communities in northwest Alaska, which have a regional health-care system, provided a setting for implementing and measuring specific chlamydial control measures in an Inuit population with high rates of chlamydial infection. An initial *Chlamydia trachomatis* (CDT) assessment was followed by the regional implementation of dual therapy and presumptive treatment. Through this project a regional prevalence study was carried out using randomly selected patients from a population database. Specific risk factors were determined, and complete clinical histories, physical examinations for multiple STD, and serologic studies were carried out. Several nonculture tests for CDT, as well as culture determinations, were compared. Preliminary results demonstrated continued high rates of infection despite the current regional prevention activities (greater than 15%

prevalence among women of reproductive age). Further analysis will be carried out in the coming months, and these data will be used to develop recommendations for specific interventions.

Prevention of Occupational Trauma

The Division of Safety Research (DSR), NIOSH, is establishing an Alaskan field site in Anchorage to develop program activities focusing on occupational injury research and prevention in the Nation's geographic area of highest risk. This program is being conducted in collaboration with the Alaska State Department of Health and Social Services, the Alaska Department of Labor, the Indian Health Service, other Federal agencies, industry, labor, communications media, health-care providers, universities and community colleges, and other individuals and organizations in the private sector that are interested in public health.

The program has the following objectives:

- To study occupational injury and fatality reporting systems in order to develop and pilot-test selected aspects of NIOSH's new national electronic surveillance and investigation system for fatal occupational injuries;
- To characterize and reduce occupational risks in workplaces and industries by using a combination of epidemiologic surveillance and analytic methods and engineering hazard and task analysis techniques;
- To conduct prevention-oriented research addressing high-risk operations and populations (for example, fishing, air transport, trucking, logging, mining and oil exploration) that have been identified by NIOSH's National Traumatic Occupational Fatality (NTOF) system;
- To use the on-site location as a "living laboratory" for conducting intervention trials and demonstration projects that are based on other DSR research or research conducted elsewhere in the circumpolar regions; and
- To promote the transfer of worker protection technologies that prove to be effective in Alaska to all workers in the state and to other states and nations where similar workplace risks exist, and also to promote the transfer of worker protection technologies effective in other nations and states to Alaska.

In addition to surveillance and investigative activities, an initial, in-depth study will focus on identifying and reducing risks associated with commercial fishing in Alaska. Epidemiologic and engineering disciplines will be integrated to comprehensively analyze the risks inherent in Alaskan commercial fishing operations and identify injury prevention strategies. This multidisciplinary approach will be used in studies of other high-risk areas (for example, construction, logging and air transport).

The following summarize the project's status:

- Strong working relationships have been established with many local, state, Federal and international agencies and associations that are involved with preventing occupational injuries and fatalities. Included in this group are the jurisdictional agencies covering the highest risk industries in Alaska.
- The researchers have initiated a comprehensive inventory and assessment of surveillance systems and agencies that provide the number of workers participating in high-risk industries. These data are crucial in order to have an accurate denominator when calculating industry-specific fatality rates.
- NIOSH has invited the Finnish Institute of Occupational Health to participate in a visiting scientist program with the Alaskan researchers.
- A major task of the Alaskan researchers was to investigate all occupational fatalities in calendar year 1991. The most current NTOF surveillance data for the nine-year period from 1980 to 1988 indicates that Alaska averages about 53 traumatic occupational deaths each year. Through the first three quarters of 1991, there were 54 fatal incidents reported to the researchers; 43 have been investigated and determined to be occupationally related, and 63 deaths have resulted. One-fifth of the incidents have had multiple fatalities. There have been 30 fishing-related deaths, 20 in air transport, 3 in logging and 10 others.

Prevention of Fetal Alcohol Syndrome

A joint effort is being developed between CDC, IHS and the State of Alaska to understand the magnitude of the fetal alcohol syndrome (FAS) problem through surveillance and to evaluate the effectiveness of programs designed to prevent FAS in Alaskan Native populations. Fetal alcohol syndrome is completely preventable, yet it is the most commonly known environmental cause of birth defects and developmental disabilities. The rate of FAS is very high among Alaskan Natives: 42 per 10,000 live births, compared with an estimated 6 per 10,000 in the general population in the U.S.

The purpose of this joint FAS prevention project is to determine, through research and training (collaborative epidemiologic, operational, behavioral, evaluational and health education communication), better means of FAS prevention and intervention in Alaska and the lower 48 states.

Fetal alcohol syndrome is completely preventable, yet it is the most commonly known environmental cause of birth defects and developmental disabilities

The project goals are the following:

- Provide technical and programmatic review of IHS FAS programs and data, actively analyzing and evaluating these programs;
- Assist the State of Alaska in developing and implementing FAS surveillance systems to capture data from program services currently being provided by the state and by IHS; and
- Develop model surveillance, data analysis and program evaluation methods that could be used to assist other states, communities and American Indian populations.

These goals are expected to optimize potential for long-term statewide FAS surveillance systems.

Prevention of Injury

The National Center for Environmental Health and Injury Control (NCEHIC), in collaboration with IHS, has developed an Injury Surveillance System currently being used by IHS in American Indian villages and the IHS regional office in Anchorage. The objectives of this system are to routinely collect data on injuries in order to help identify priority injury problems, determine trends and evaluate interventions. This system is used as part of the IHS injury prevention program in Alaska.

The NCEHIC recently awarded the Alaska Department of Health and Social Services (DHSS) two grants to support work in injuries that affect rural Alaskans. The first, a grant in applied methods in injury surveillance, will be used to establish a statewide system for surveillance of head and spinal-cord injuries that can serve as a model for other states. In addition, the Alaska DHSS has been awarded a grant for developing a state-based injury control program that will establish a statewide injury control focus. The department, through an established emergency medical services unit, will focus on intentional and unintentional injuries. This unit will help provide services to 70% of Alaskan Natives in 175 villages, as well as to 70 rural towns with primarily non-Native populations.

National Institutes of Health

Five institutes within the National Institutes of Health fund Arctic health research through a variety of grants, contracts and collaborative research projects.

National Institute of Arthritis and Musculoskeletal and Skin Diseases

U.S. and Russian clinicians (among others) have noted a substantial burden of poorly understood and inadequately described rheumatic diseases in circumpolar populations. These diseases, referred to as the spondyloarthropathies, are a group of related rheumatic diseases that include Reiter's syndrome, ankylosing spondylitis and arthropathy syndrome in children. All spondyloarthropathies appear to be associated with a genetic factor that is much more frequent is some Native populations than in the U.S. Caucasian population. Microbial triggers also seem to play a role in the etiology of the disease in genetically susceptible hosts. The mechanism by which these diseases are initiated in susceptible individuals remains unknown.

The National Institute of Arthritis and Musculoskeletal and Skin Diseases entered into a collaborative agreement with the IHS to carry out epidemiologic studies of the spondyloarthropathies in groups of Eskimos in Alaska. The objectives of these studies are:

- To determine the prevalence of spondyloarthropathies in selected Alaskan native populations;
- To describe the spectrum of spondyloarthropathic disorders in these populations; and
- To lay the groundwork for investigations of specific genetic and environmental factors in the pathogenesis and expression of spondyloarthropathic disease.

Separate but related studies are being carried out by the Russian Institute of Rheumatology. They are studying Eskimos from the Russian eastern rim who share common ancestors with the Alaskan study population and may share many genes, quite possibly those that are responsible for conferring susceptibility to the spondyloarthropathies. Comparative studies of Russian and United States circumpolar populations may be helpful in clarifying the role of genetics and environmental triggers in these diseases.

National Cancer Institute

Preventing Tobacco Use Among Native American Adolescents

This five-year study is testing personal environmental interventions to prevent smokeless and smoked tobacco use among Alaskan Native and Native American youth in Alaska, Idaho, Montana and Washington. Personal interventions delivered by groups of Native youths will cover ethnic pride and values, health and self-image, as well as skills in problem solving, coping and communication. Environmental interventions delivered to Native youths, families and peers will develop social and situational support to prevent tobacco use. The subjects will be 3584 Native American females and males who will be 11–13 years old at the time of initial involvement. Recruited from 28 sites, the participants will take a pre-test and will be randomly assigned to one of four study groups: personal intervention, environmental intervention, both together or no intervention. All subjects will take a post-test and will be followed at six-month intervals. Semiannual booster sessions are part of the intervention. Outcome measures will quantify subjects' smokeless and smoked tobacco use and will assess variables associated with tobacco use.

Preventing Cervical Cancer in Alaskan Native Women

Among Alaskan Natives, mortality rates from cervical cancer exceed those of the general U.S. population; furthermore, there is evidence of increasing rates of cervical cancer and severe dysplasia in this population. High rates of factors associated with increased risk of cervical cancer have been documented, for example, smoking and sexually transmitted diseases, including human papilloma virus and chlamydia infections.

Among Alaskan Natives, mortality rates from cervical cancer exceed those of the general U.S. population

The long-term objectives of this project are to reduce the morbidity and mortality from invasive cervical cancer in Alaskan Native women. The specific aims are:

- To promote knowledge and awareness of the disease, its risk factors and appropriate screening programs;
- To enhance the existing cervical screening program and follow-up care of precancerous lesions; and
- To reduce risk factors.

The project is being conducted primarily in one large urban and one smaller rural IHS service unit within the Alaska Area Native Health Service. In Phase I of the project, information will be collected about knowledge, attitudes and beliefs about cancer in general, and cervical cancer in particular, among a random sample of Alaskan Native women. The current level of pap smear screening and follow-up care will also be ascertained. The study's second phase will implement intervention strategies directed toward reducing barriers to screening and follow-up care that were identified in Phase I. Follow-up colposcopies and cervical biopsies will be provided regionally by specially trained women's health-care providers who will use HPV testing to focus screening resources on women who are infected and are at highest risk of cervical dysplasia and cancer. Appropriate treatment of diagnosed cervical infections will also be provided.

Data-Based Cancer Intervention Research in Alaska

The State of Alaska Section of Epidemiology is receiving support from NCI to develop a project that will serve as a model of data use for planning and evaluating statewide cancer prevention and control interventions. The specific goals of this project are:

- To reduce Alaska's age-adjusted cancer mortality rate by 50% by the year 2000;
- To develop and institutionalize a comprehensive cancer prevention and control program in the Alaska Division of Public Health; and
- To assure a mechanism for implementing state-of-the-art techniques for translating research findings into public and private practice.

This project extends over a seven-year period and includes four phases: data appraisal, planning, implementation of model interventions, and evaluation. The priority areas for the initial phase of this project are cessation and prevention of tobacco use, cervical cancer detection and breast cancer detection.

Discovery of Antitumor Marine Products

A study is underway to isolate and identify new natural marine products from Arctic and other locations as leads for cancer chemotherapy by using assays that assess biochemical differences between tumor cells and their normal counterparts. This project has three aims:

- To demonstrate that natural products that inhibit specific biochemical targets will also exhibit antitumor activity;
- To confirm that the use of such target-directed

assays will minimize the discovery of agents possessing already-known mechanisms; and
- To provide anticancer drug leads from marine organisms that are structurally different from those obtained from terrestrial sources.

A screening schedule will be implemented that provides a rational network of natural products' chemistry and biochemistry assays to discover activity in crude extracts, guide the isolation of active principles, and provide adequate quantities of pure active compounds for in-vivo follow-up testing. Extracts of selected marine invertebrates, collected cyanobacteria, cultured microalgae and cultured anaerobic bacteria and fungi will be prepared and tested in the biochemical prescreens. Active leads will be tested further in whole cells and then in animal models.

Community Clinical Oncology Program

The cooperative agreement with the Virginia Mason Research Center in Seattle is being expanded to include a new major component in Anchorage and an affiliate in Fairbanks, Alaska. The goal of this program is to reduce cancer mortality and morbidity by bringing patients to cancer treatment and cancer control research trials in the communities where the patients live and by facilitating the transfer of state-of-the-art knowledge and technology from research bases to the communities.

Hepatic Changes in Primary Hepatocellular Carcinoma

The goal of this study is to determine whether genetic factors are of clinical importance in primary hepatocellular carcinoma (PHC). At least one Alaskan Native family that includes members with early onset of PHC is being studied. In addition, a molecular genetic karyotype is being derived for a collection of approximately 100 PHC tumors, some of which are being provided by the Indian Health Service and may include tumors from Native Alaskan patients.

Network for Cancer Control Research among American Indians and Alaskan Native Populations

The purpose of this network, initiated in April 1990, is to reduce preventable cancer morbidity and mortality to the lowest possible levels and improve cancer survival to the greatest possible extent. The network comprises individuals from reservations, tribal organizations, urban organizations and the IHS and includes service providers, academicians, clinic directors, researchers and organization leaders. To date, the network has:

- Identified long-range goals, objectives and tasks;
- Formed subcommittees on data collection and research; education and training of researchers and providers; and advocacy and funding; and
- Suggested activities for the Special Populations Studies Branch to undertake to emphasize cancer on the Native American health agenda.

Those suggested activities include but are not limited to developing a culturally specific cancer exhibit and culturally and regionally sensitive cancer-prevention promotional and educational materials.

Five-Year Cancer Surveillance of Alaskan Natives

The NCI effected two intra-agency agreements with the IHS. The overall objective of the first intra-agency agreement is to provide accurate cancer incidence, mortality and survival data for Alaskan Natives. The data will be collected in a format that meets the criteria and standards of the Surveillance, Epidemiology and End Results (SEER) program of the NCI, which will enable comparisons of cancer patterns in the Alaskan Native population to those in other U.S. populations. Data from this project may lead to the formulation of intervention research and also allow for continued surveillance and monitoring of the effects of intervention strategies.

Reduction of Cancer in American Indian and Alaskan Native Populations

The second project proposes a three-year study of cancer incidence and the determinants of cancer mortality in American Indian and Alaskan Native communities. The first phase of the project will be characterized by descriptive epidemiological work designed to explain possible variations and possible excess cancer occurrence and mortality by geography, tribe and IHS catchment area. A later stage of this project is to determine the effectiveness of cancer intervention protocols that are implemented in Native populations to ensure participation in cancer screening, early detection of cancer, participation in clinical trials and compliance with follow-up recommendations after receiving abnormal screening results.

National Institute of Child Health and Human Development

In FY 90 the National Institute of Child Health and Human Development (NICHHD) supported research at the University of Alaska on the role of the reproductive endocrine system in hibernating

mammals and mechanisms by which Arctic ground squirrels spontaneously adopt subzero body temperatures without freezing. These experiments may elucidate novel functional relationships between the reproductive endocrine system, plasma binding proteins and central nervous system control over body temperature in mammals. In addition they address important basic questions about mechanisms of freeze resistance in mammals, the answers to which may relate to the use of cryopreservation of transplant organs and mammalian tolerance to severe hypothermia.

National Heart, Lung and Blood Institute

Sleep Apnea

Sleep apnea is a major sleep disorder affecting more than three million adults in the United States. Patients with this disorder experience fragmented sleep due to periods of apnea (absence of breathing) that result in low blood-oxygen levels. The hallmark of the syndrome is excessive daytime sleepiness. Cardiac arrhythmias, systemic and pulmonary hypertension, coronary heart disease and congestive heart failure have also been associated with sleep apnea.

Investigators are performing the first systematic study of apnea in a mammalian species that routinely experiences prolonged absence of breathing during sleep, the northern elephant seal. As pups and adults, these Alaskan seals are capable of withstanding sleep apnea of up to 30 minutes—a condition that would prove lethal to terrestrial mammals. This study will characterize the metabolic impact of sleep apnea in the seal pup and compare it with the apnea experienced while the seal is awake and diving. The findings will, in turn, allow basic biological and medical comparisons with humans and other mammals that exhibit abnormal respiratory patterns during sleep.

Smoking Cessation Strategies for Minorities

Cigarette smoking is the chief preventable cause of cardiovascular and respiratory disease and death for Alaskan Natives, as for all Americans. This makes smoking cessation efforts a high public health priority. Among some minority groups, language or cultural barriers may limit the success of available smoking cessation programs. To address this issue, the NHLBI launched an initiative in FY 89 entitled "Smoking Cessation Strategies for Minorities."

Through this program the American Indian Health Care Association (St. Paul, Minnesota) is receiving support for a project entitled "Giving American Indians/Alaska Natives No Smoking Strategies (GAINS)." GAINS is assessing a modified "Doctors-Helping-Smokers" model that incorporates culturally sensitive materials at seven sites and is comparing the results with the usual care provided to patients at seven other sites. Included among the clinical population are Alaskan Natives living in Seattle.

The intervention consists of an integrated clinic-based support system in which the primary care provider gives the cessation message and staff members supply prolonged reinforcement and support to smokers interested in smoking cessation. A major part of the support system is provided by culturally sensitive materials delivered and reinforced by Native American outreach workers, who are also available for additional counseling.

Atherosclerosis and W-3 Fatty Acids in Alaskan Natives

The purported low mortality from coronary heart disease (CHD) in Eskimos has been interpreted by many investigators as being a consequence of absent or infrequent atherosclerotic lesions (fatty streaks and raised lesions) in the coronary arteries.

Investigators are performing studies designed to:

- Characterize the prevalence and the extent of atherosclerotic lesions in the coronary arteries and aortas of Alaskan Natives and non-Natives;
- Examine the relationship of omega-3 fatty acids and clinical risk factors to atherosclerosis in the two populations; and
- Compare these findings with similar studies in other ethnic groups.

Findings from this study should elucidate the nutritional benefits of fish oil.

National Center for Research Resources

The National Center for Research Resources, through the Biomedical Research Support Program, supports research on acquired immunity to the rabies virus in native Alaskan trappers. The work is being conducted at the University of Alaska–Fairbanks.

Indian Health Service

The mission of the IHS is to raise the health status of American Indians and Alaskan Natives to the highest possible level. Thus the IHS uses its resources primarily for providing direct curative and

preventive health care. However, the IHS funds some clinical research and enters into collaborative relationships with other Federal agencies to support research that is designed to find more effective methods of disease treatment and prevention. These collaborations are especially strong in Alaska and are enhanced by the proximity of the Alaska Native Medical Center to the AIP. Thirteen of the research workers assigned to the AIP are IHS personnel, and five IHS physicians collaborate as research associates with AIP investigators. In other Arctic research activities, the IHS collaborates with NIH and ADAMHA.

Alcohol, Drug Abuse and Mental Health Administration

In FY 91 the Alcohol, Drug Abuse and Mental Health Administration (ADAMHA) supported a variety of research projects that involve or have an impact on Alaskan Natives. Many of the Arctic health research activities by ADAMHA are part of general American Indian and Alaskan Native programs.

Among the activities funded by ADAMHA are the following:

- An American Indian and Alaskan Native Mental Health Research Center for promoting excellence in mental health research and research training appropriate for American Indians and Alaskan Natives;
- A conference on suicide research to review current knowledge regarding research and theory on sociocultural factors in the perception, risk and prevention of suicide among Indian and Native adolescents;
- A grant to the State of Alaska to enhance their ability to collect data on alcohol and drug abuse treatment services through the adoption and implementation of National Data Standards;
- Conferences directed at rural providers of substance abuse prevention and intervention services to share information in a manner that is culturally relevant; and
- Demonstrations directed at family-based and community-based approaches for dealing with youth substance abuse and high-risk youth and their families.

Health Care Financing Administration and Health Resources and Services Administration

Two additional DHHS agencies, the Health Care Financing Administration (HCFA) and the Health Resources and Services Administration (HRSA), funded a variety of Arctic health research in FY 91.

HCFA is administering the Rural Health Care Transition Grants Program, which is designed to strengthen the ability of eligible small rural hospitals to provide high-quality care to Medicare beneficiaries. Under this program, non-Federal, nonprofit hospitals having fewer than 100 beds and currently being paid as a rural hospital under the Medicare hospital prospective payment system could request up to $50,000 per year for up to three years for a variety of developmental projects and service enhancements.

This program has aided two hospitals in Alaska. Wrangell General Hospital received a third and final award of $50,000 to provide adult day care for frail and impaired elderly. Seward General Hospital received an award of $40,200 for the first year of its project to provide basic acute care hospital services and emergency health services. The availability of funds under this grants program is publicized nationally. A determination on an FY 92 Rural Health Care Transition Grant solicitation will be based on the availability of funds for this program.

The Maternal and Child Health Bureau of HRSA, through the Maternal and Child Health Services Block Grant's Special Projects of Regional and National Significance grants, supports an Alaska Infant Mortality Review Project ($75,000). This Multi-Disciplinary Infant Mortality Review Committee of health and social services professionals from State, IHS and local agencies, as well as private practice, will facilitate the reduction of Alaska's infant mortality rate through an integrated review process that will provide prevention and response information to health professionals and to the public. A second project ($149,000), in Juneau, is designed to improve the emergency medical care system and its ability to treat and rehabilitate acutely ill and injured Alaskan children.

Smithsonian Institution

The National Museum of Natural History's Arctic Studies Center continued the North American tour of the "Crossroads of Continents" exhibition, conducted archeological research on the voyages of Martin Frobisher and early European–Inuit contact in the Eastern Arctic, and initiated new exhibits and educational programs in Canada, Alaska and the Russian Far East. A total of $705,000 was expended in FY 91.

Four years ago the Smithsonian's National Museum of Natural History created the Arctic Studies Center dedicated to research, education and management of the nation's national anthropological collections. Arctic research has never been a novelty to the Smithsonian, which pioneered Alaskan studies even before Russian America was purchased by the United States in 1867. But before 1988 this effort lacked focus and sustained commitment; for more than a century curators conducted Arctic research on an individual basis with little formal institutional support. With the creation of the Arctic Studies Center, Arctic research has been institutionalized as a permanent Smithsonian program. While the Center's programs include a major commitment to studies of Alaskan anthropology and natural history, they are not restricted by national borders. In keeping with history and the Smithsonian tradition, the program has an important international focus. Research aimed at understanding Arctic cultures and natural history necessitates circumpolar scope.

In this regard the Center's commitment to basic research, without restriction by national borders, parallels the Smithsonian's founding mandate for "the increase and diffusion of knowledge." Providing a foundation for intellectual enterprise and freedom of research, this mandate also places a responsibility upon the Institution not only to conduct research and maintain systematic collections but to utilize new knowledge and understandings in educational exhibitions, publications and media presentations.

These institutional goals have provided the setting for development of the Center's Arctic programs. During the past two years two new staff positions have been added to the Arctic Studies Center: a museum anthropologist and an Arctic ethnographer. These positions have expanded the Center's capabilities to conduct research, to facilitate education and training, to increase public access to Smithsonian collections, and to prepare exhibitions.

FY 91 FUNDING (thousands)

Anthropology	630
Arctic Biology	75

Research Activities

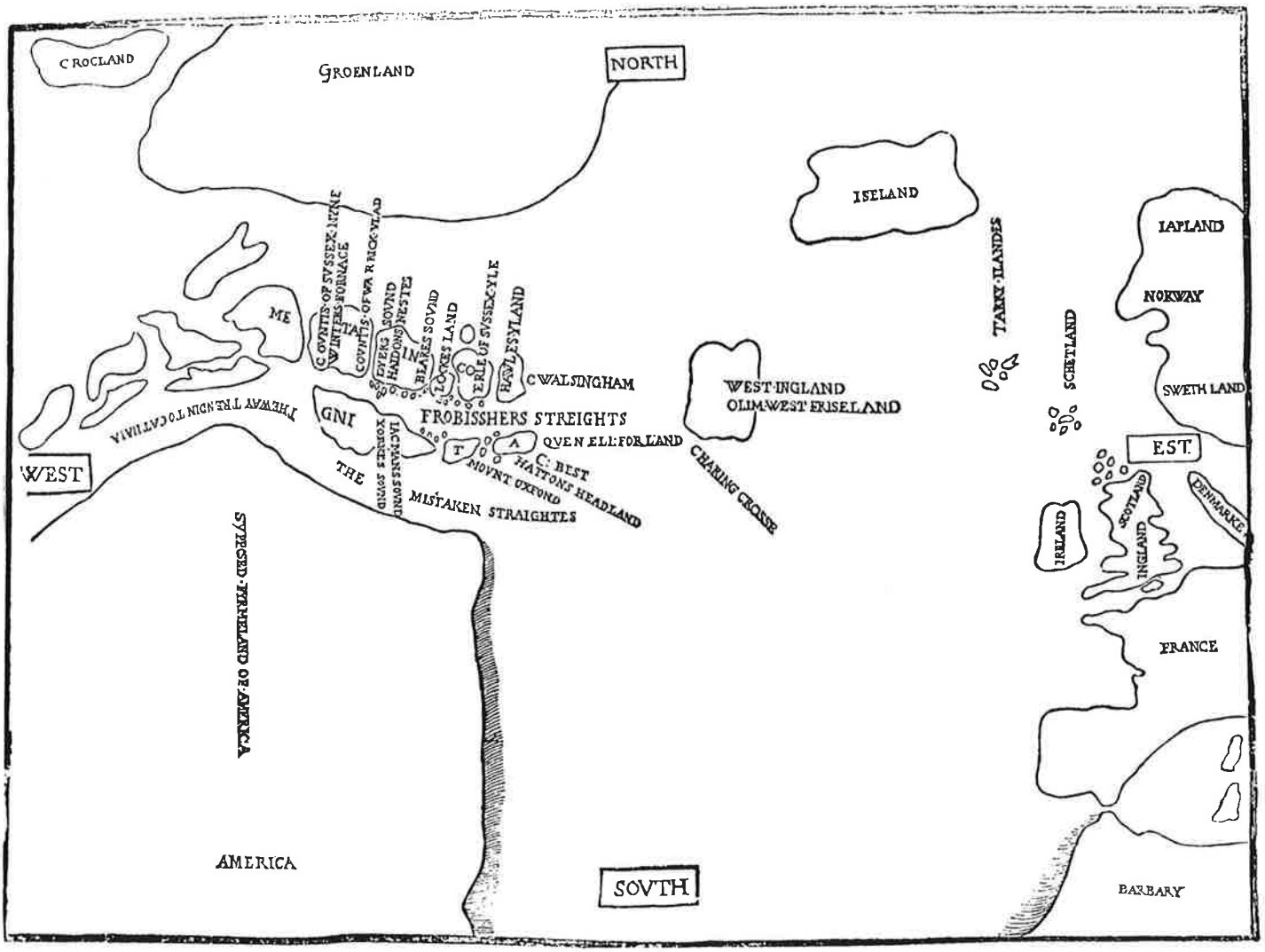
Research constitutes a major portion of the Center's program. During the past two years much of this effort has been directed at projects in the eastern Canadian Arctic.

Archeology of the Frobisher Voyages

In 1990 the Arctic Center extended its Labrador field program across Hudson Strait and began archeological surveys and excavations in Frobisher Bay, southeast Baffin Island. The project involves studies of early Inuit history in relation to the voyages of Martin Frobisher in 1576–1578 and seeks to amplify the historical record of this early English enterprise in the New World with new information from archeology, historical archives, Inuit oral history, archeometry and environmental sciences. The project also explores the impact of Frobisher and later European contacts on the development of Baffin Island Inuit culture from 1500 to the present. Research is being conducted by the Smithsonian and other American and Canadian institutions as a collaborative effort of the Canadian Meta Incognita Project.*

The Frobisher project exemplifies the need for international collaboration in Arctic research. The voyages are documented by massive archival holdings in London, including detailed bankruptcy inventories, while the Kodlunarn Island site, an archeological resource, is located on Canadian soil.

* Meta Incognita is chaired by a ministerially charted interagency committee chaired by Dr. Thomas Symons of Trent University.



James Beare's map of Frobisher's discoveries.

Smithsonian involvement began when the site's discoverer, the American explorer Charles Francis Hall, gave his notes and half of his archeological finds to the Institution in 1863. The other half went to the Royal Geographical Society in London and was later transferred to the British Museum. Visits to Kodlunarn Island by American and Canadian archeologists earlier in this century resulted in collections being returned to museums in Chicago and Toronto. After 1964 research on Hall's artifacts and records at the Smithsonian produced new information requiring field verification, and artifacts collected during a 1981 expedition organized by the Smithsonian were studied in Washington before being transferred to Yellowknife, N.W.T. As a result the Frobisher research program must be organized as a collaborative international effort between Canada, the United States and Britain.

Historical background is of particular importance to the project. Frobisher, although little known in the United States, is a legendary figure in British and Canadian history, a pirate and personal friend of Queen Elizabeth who earned fame for his heroic attempt to discover a route to China via the Northwest Passage. He is also known, less nobly, for promoting a gold mining venture that ended in financial ruin for stockholders of the Cathay Company, one of the first joint stock companies of the western world.

At the time Frobisher's discoveries were considered state secrets and for this reason were never mapped precisely. Following the voyages, knowledge of the location of the *Countess of Warwick Island* was lost for three hundred years until Charles Francis Hall, at the suggestion of Inuit hunters, visited Kodlunarn Island in 1861 and identified it as Frobisher's base camp. Hall published his finds and, for safe-keeping, split his collections between the Smithsonian and the Royal Geographical Society in London. Both institutions lost track of the collections, but one of the Smithsonian objects, an iron "bloom," was later relocated.

Despite its historic importance Kodlunarn Island failed to attract attention as an important archeological site until recent years. In 1980 a large lump of bloomery iron (smelted and partially processed

Excavations at Inuit site at Kamaiyuk described by George Best in 1578.

iron ore) from the Hall collection at the Smithsonian was radiocarbon-dated to the 12th and 13th centuries. These dates raised questions about Hall's attribution and led to a Smithsonian field study of Kodlunarn Island in 1981. This project produced the first maps and detailed description of the Frobisher mines and workshops and recovered archeological data including ceramics (roof tile, crucibles, utilitarian wares), wood, charcoal, slag and other materials—all of apparent Elizabethan origin. Particularly important was the discovery of three new iron blooms found buried in Frobisher site contexts but which produced pre-Frobisher dates comparable to those from the Hall bloom. Fieldwork also revealed the presence of Inuit sites containing English artifacts dating from the Frobisher voyages, suggesting either direct or indirect contact with Frobisher or his sites.

To date, two field seasons have been devoted to preliminary research at Kodlunarn Island and neighboring areas of outer Frobisher Bay by Canadian and American teams. Work at the Kodlunarn Island sites has been conducted by archeologists from the Canadian Museum of Civilization and Laval University. Their results amplify our earlier 1981 studies. Hall's "ship's trench" seems to have been one of Frobisher's earliest mine trenches and was later used as a supply cache at the end of the 1578 season. Materials found here include two iron blooms, lumber, ceramic tiles and foodstuffs, including hardtack and lentils. Excavations in the foundation of "Fenton's watchtower" failed to produce the toy soldiers, metal bells, mirrors, beads and fresh-baked bread Frobisher's men left there for the Inuit, but ceramics, flint-tempered mortar and other remains were found, and the foundation's measurements closely match Fenton's "little watch tower" of 8 × 14 ft.

While recent research at Kodlunarn Island has been directed at producing data for developing conservation and management plans for this important Canadian national monument—the first English establishment in the New World—"off-island" research by a Smithsonian-coordinated team of American and Canadian scientists recovered archeological and environmental data from throughout the outer Frobisher Bay region. These surveys have identified mines worked by Frobisher's men and a site answering the description of the Inuit camp at "Bloodly Point" attacked by Frobisher's men in 1576. Future surveys will search for sites noted in the narratives and for traces of Frobisher's "lost sailors" captured by the Inuit in 1577. A few days before this event, Frobisher himself barely escaped capture after being chased and wounded in the buttocks by an Inuit arrow.

These surveys have also resulted in the discovery of prehistoric and historic Inuit sites spanning the 4000 years of human occupation in southeastern Baffin Island. Over fifty sites representing Pre-Dorset, Dorset and Thule cultures have been found. But the largest number of sites occur in the historic era, which begins with the Frobisher voyages. These sites, dating from 1500 to 1840, contain only Elizabethan (and possibly Dutch) artifacts, suggesting that European goods, though rare and hard to come by, were commodities important to Inuit people. The prevalence of these sites suggests that the Inuit expanded their coastal settlement to increase their opportunities for obtaining Elizabethan or later European goods by trade or by scavenging the remains of wrecked ships and whaling flotsam. Many of the sites contain Frobisher ceramics, roof tile fragments (converted to grindstones, polishing implements and sources of ocher) and English flint. More remarkable finds have included an iron arrow point and another iron bloom. Elizabethan materials are especially common at Kamaiyuk, a site near Kodlunarn Island that was occupied in Frobisher's time, where the sod-covered "poor caves and houses" were described by one of Frobisher's captains, George Best, in what is probably the first description of an archeological site in the New World. It appears that Inuit scavenging from the Kodlunarn Island site continued for centuries, until the beginning of the whaling period in 1840, when massive amounts of European goods became available to the Frobisher Bay Inuit from whalers, traders and Inuit middlemen.

These preliminary results suggest that continued research in the Frobisher region will yield important results on regional prehistory and the development of Baffin Inuit culture under varying types of European influence. More importantly,

much is being learned about the response of Inuit culture to episodic waves of European contacts, adaptations to environmental change resulting from the onset of the Little Ice Age, and the effects of these developments on other Inuit cultures in the Eastern Arctic. Frobisher–Inuit contact provides an important focal point for this research because it occurred at an extremely early date in the history of New World exploration and can be isolated archeologically because the next wave of European contacts did not begin until 250 years later with the onset of the Scots–British whaling era in the 1840s.

Finally, as noted previously, the Frobisher voyages offer a fascinating topic for international scientific study, a requirement mandated by the dispersed nature of the records, finds and relevant specialists. As important as existing archeological resources are, this research cannot be accomplished without the active collaboration and assistance of Native Inuit peoples, who retain local knowledge, including tales of Elizabethan explorers and the whalers, traders, missionary and military people who followed the earliest European explorers to these shores.

A monograph presenting the history of the Frobisher voyages and the results of research to date will be published by Smithsonian Press in the fall of 1992.

Labrador Inuit Archeology and History

In addition to research in Baffin Island the Center continues to maintain several research programs in Labrador, including a long-term study of Labrador cultures and environments. These studies have produced a large archeological and paleoenvironmental database on the history of cultural and environmental change along an 800-mile Arctic–subarctic frontier for the past 8000 years. Responses of Indian and Eskimo cultures to fluctuations in the forest–tundra boundary have been identified, and regional geological uplift curves have been developed, permitting researchers to model cultural, environmental and climatic interactions. Recent results indicate that glacial ice may have had a major impact on the vegetation and early human history in central and northern Labrador. In addition, we have found that crustal subsidence and coastal erosion have resulted in the destruction of many archeological sites during the past 3000–4000 years.

In keeping with increasing interest among Native peoples, research has also been conducted on the recent history of Labrador Inuit (Eskimo) and Innu (Indian) cultures. The results from these studies indicate a 1500-year ancestry of Innu peoples and document the origins of early Labrador Indian cultures in the Maritime Archaic period from 8000 to 4000 years ago. At the modern end of Labrador history, excavations at Inuit sites in Nain and Hebron document changes in Labrador Inuit culture as it responded to European contacts and influence during the past 300 years. This later project is co-directed by Gary Baikie, the Inuk director of the Torngasok Cultural Centre in Nain, and heralds a new era of cooperation between Smithsonian researchers and local native groups. The results of these projects are being prepared for publication.

Ethnology of Bering Strait

Political rapprochement and the opening of borders has resulted in new opportunities for contacts, research on cultural relationships and the development of joint scholarly and heritage programs across the Bering Strait. These developments are signaled by progress toward creation of a Bering Strait International Park and by new joint Russian–American exhibition and research programs at the Smithsonian. Among these are several projects in the ethnography and ethnohistory of the Bering Strait area. The first study, "Divided Nations of the Arctic," concerns the political implications of the recent history of ethnic and cultural relationships for three Native groups in the Bering Strait/North Pacific area:

- The Yupik Eskimos of St. Lawrence Island and the southeast Chukchi Peninsula;
- The Inupiat Eskimos of the Diomede Islands and Seward Peninsula and the Yupik Eskimos and Chukchis of northeastern Chukotka; and
- The Aleuts of the Commander and Aleutians islands.

All these groups share similar histories of extensive cultural, marital and trade connections across the Russian–American border, ties that were abruptly terminated with the start of the Cold War and building of an "Ice Curtain" between Siberia and Alaska after 1947–1948. This project will produce a comprehensive summary of human relations for each of the three study areas through genealogical search, archival and other historical inquiries, Native oral tradition and other data. Several aspects of this work have already been completed, including a history of the migration patterns at the Diomede Islands, a demographic study of St. Lawrence Island from 1880 to 1940, a study of the reactions of Siberian Natives to the rise of circumpolar native politics and cultural experience, and a study of the Alaskan impact on ethnic revival among the Siberian Eskimo.

Another study continues an earlier research effort on the history and ecology of indigenous whaling in the western Arctic. This research will be augmented by multidisciplinary studies integrating prehistoric and modern whaling and cultural heritage issues in the Bering Strait area. A reconnaissance survey of archaeological sites and of recent bowhead and gray whale remains at two study areas in Alaska and in the Chukchi Peninsula is planned for July 1992. This and the following surveys are seen as parts of National Park Service and Smithsonian activities to protect native cultural resources in both Siberian and Alaskan sections of the proposed Beringian International Park.

A third project includes the production of a major synthesis on the contact history of Asiatic Eskimos from 1900 to 1990. This project analyzes the survival of a Siberian Arctic minority exposed to enormous cultural shock and acculturation pressure during the 20th century. The Asiatic or Siberian Eskimo example provides a unique opportunity to compare governmental strategies, patterns and results of Native transitions within the varying political systems of the major Arctic states, for example, the former Soviet Union, the U.S., Canada and Denmark. The study concerns the period from 1900 to 1932, from the decline of American whaling in the Arctic to the establishment of full-scale Soviet administration system on the Siberian side of the Bering Strait. The second part of the project concerns later Siberian Eskimo developments under Soviet paternalistic policies from 1933 to 1990.

Exhibitions

During the past two years the Smithsonian's exhibition "Crossroads of Continents: Cultures of Siberia and Alaska" has been seen in Seattle, New York, Indianapolis, Los Angeles, Anchorage and Ottawa. Each venue has provided opportunities for Soviet scholars, sponsored by IREX (International Research and Exchanges Board), to travel to North America to assist with exhibition programs, to conduct research and to meet and exchange information with colleagues. A tour of Russia was scheduled but has been postponed pending the resolution of financial and security arrangements.

In the meantime, work progressed on a small version of the Crossroads exhibition being prepared by American curators and Russian specialists from the museums of the Russian Far East. "Crossroads of Continents—RFD Alaska" is designed for travel to Alaskan rural communities and Siberian cities from the Bering Strait to Vladivostok, locations where facilities do not exist for displaying the larger parent exhibition. The show includes archeological and ethnographic artifacts from North Pacific and Beringian peoples together with photo albums, videos and 20th century art and is being developed in consultation with Native groups. This project is a multi-agency effort with National Park Service and University of Alaska–Fairbanks.

The National Museum of Natural History hosted a traveling exhibition titled "Darkened Waters: Profile of an Oil Spill," a thoughtful exploration of the ecological, economic and cultural impact of the *Exxon Valdez* oil spill in Alaska. The exhibit was produced by the Pratt Museum in Homer, Alaska.

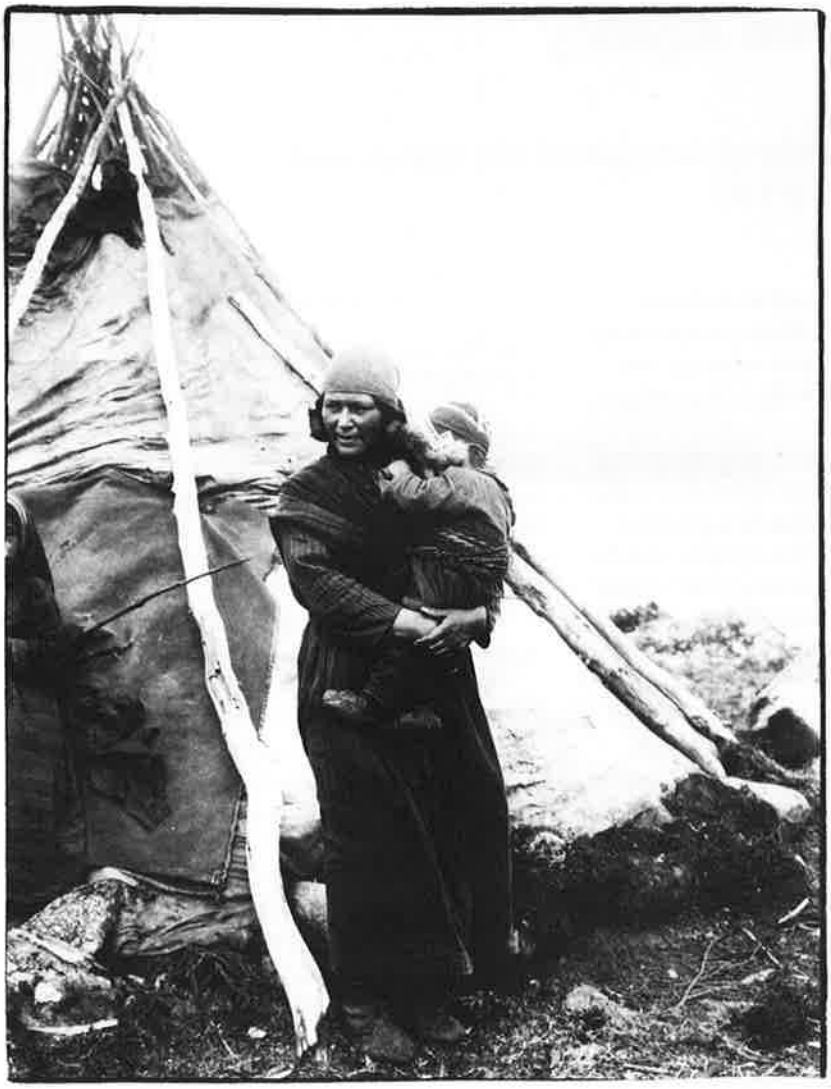
Planning is also underway for a major new North American Indian exhibit for the National Museum of Natural History in Washington. This exhibit will feature Alaskan Native groups in traditional and modern settings and will emphasize ways in which these cultures have adapted to forces affecting them in the 20th century.

Film and Media Programs

Arctic Center film and media projects continued to gain momentum during the past two years. "Mysteries of the Lost Red Paint People" documenting the early maritime Indian peoples of northeastern North America was broadcast frequently on PBS and other stations in the U.S. and Canada. A film on Viking exploration and archeology in the New World has been completed, and production continues on films on Labrador prehistory, the ethnohistory of the Innu peoples of Labrador, Crossroads of Continents, and Bering Sea ethnography. A film documenting the life and vision of Andris Slapins, the Latvian filmmaker killed by Soviet snipers during the repression of Latvia in January 1991, is being planned. An annual Smithsonian film program and an international prize for Native filmmakers, established together with the Parnu Visual Anthropology Society of Riga, Latvia, have been established in Slapins' name.

Repatriation

The National Museum of the American Indian Act (P.L. 101–185), enacted in 1989, requires the Smithsonian to inventory and identify the origins of all American Indian and Native Hawaiian human remains and funerary objects in its possession. In response to this mandate the National Museum of Natural History established a Repatriation Office charged with inventorying the Museum's collections, notifying affected tribes of culturally affil-



Innu (Indian) woman and child at Tshinutvish, Indian House Lake, northern Quebec, 1910

iated remains or funerary objects, and facilitating any requested returns. Given the archaeological nature of these materials, questions of cultural affiliation and cultural continuity are key issues in repatriation cases. As stated in the National Museum of the American Indian Act, the Smithsonian shall return human remains if they can be identified as culturally affiliated with a particular Indian tribe, upon the request of that tribe.

The first body of Arctic materials to come under consideration for repatriation was a collection of archeological materials from the Uyak Bay site, located near the village of Larsen Bay, Kodiak Island, Alaska. This site was excavated by Smithsonian physical anthropologist Ales Hrdlicka in the 1930s. After over four years of negotiations and expert testimony, the Institution decided to return the Uyak site human remains and funerary objects to the people of Larsen Bay. Skeletal remains from approximately 756 individuals were returned for interment in September 1991. In January 1992 the Museum also returned 176 artifacts identified as associated funerary objects from these burials.

Conferences

Arctic Center staff participated in many workshops, symposia and conferences during the past two years. Research was conducted in Russian Far East and Alaskan museums with "mini-Crossroads" exhibit curators, and meetings and workshops were held in connection with the Frobisher project in Ottawa, Iqaluit, St. John's, Newfoundland and Washington, D.C. Staff presented research results at numerous professional meetings. A major meeting was held in March 1992 with Native Alaskan groups to plan local participation in the "Crossroads—RFD Alaska" exhibition.

Future Research: Jesup 2 and a Smithsonian Office in Alaska

The Arctic Studies Center plans to continue developing its research and educational programs in Alaska and elsewhere in the circumpolar North. In the next two years the Center expects to add a western Arctic archeologist to its staff. In addition, plans are being developed for an interdisciplinary Beringian and North Pacific research program with U.S. and Russian scientists following research themes explored in the Crossroads exhibit. The program will include joint Russian–American projects in archeology, ethnology, geology and biology, both in Siberia and in Alaska. This program takes advantage of new opportunities for joint research that have not been available since the Jesup North Pacific Expedition of the American Museum of Natural History conducted the first international, interdisciplinary project in this region in 1897–1903, nearly a hundred years ago.

The growth of these and other plans has resulted in discussions about the need for providing the Arctic Studies Center with direct access to the Alaskan research organizations and other constituencies. The most efficient method to do so would be to establish a Center office in Alaska. Research in particular would benefit from access to collections and field work opportunities in Alaska and adjacent regions. Such a move would also benefit the Center's educational programs and would facilitate Alaskan access to a variety of Smithsonian resources.

Environmental Protection Agency

EPA's Arctic research focuses on the effects of atmospherically transported pollutants. Funding totaled $500,000 in FY 91.

The goal of the EPA program in Arctic research and monitoring is to address two questions:

- To what extent are Arctic ecosystems contaminated by atmospherically transported pollutants?
- What effects are atmospherically transported pollutants likely to have on Arctic food webs?

These questions are prompted by a growing body of international literature suggesting that the Arctic environment is an important global repository for toxic materials, both metals and persistent organics, released by industrial and agricultural practices, not only in the Arctic but also in the lower latitudes. This body of literature was most important in leading to the formulation and endorsement of the Arctic Environmental Protection Strategy in June 1991 by the eight Arctic nations. This strategy identified environmental monitoring and assessment reports as important needs for decision making to protect the Arctic environment. To pursue these needs, the strategy established the Arctic Monitoring and Assessment Program (AMAP). While the design and implementation of AMAP are evolving, with strong U.S. participation, it is clear that monitoring the levels of toxics in the environment is one of the highest priorities of the EPA's Environmental Monitoring and Assessment Program (EMAP). This program is designed to play a lead role in meeting these needs, not only domestically but also in the international discussions that will lead to internationally harmonized networks.

FY 91 FUNDING (thousands)

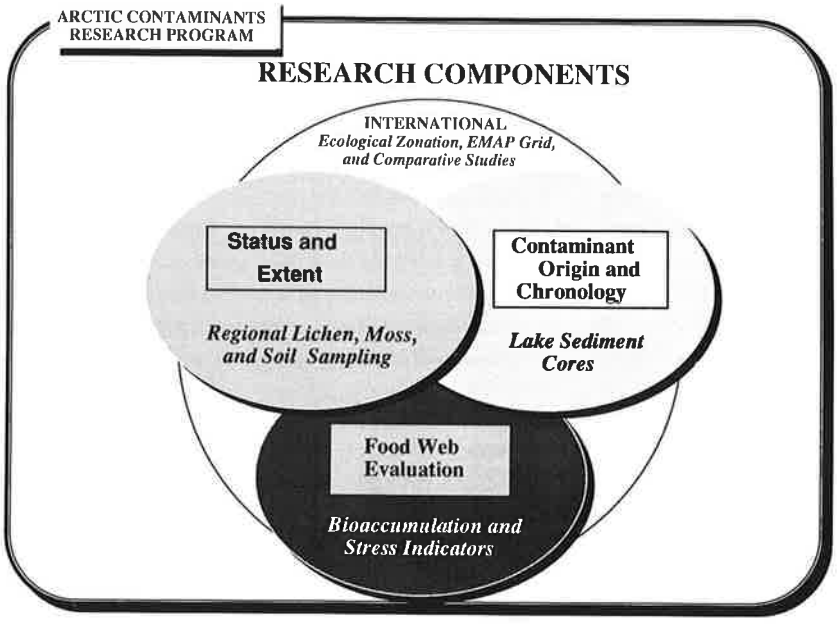
Arctic Research Program (ALERT)	250
High-Latitude Methane	250

Within these two goals the EPA program has developed four specific objectives:

- Document the levels of Arctic contaminants;
- Evaluate the recent history of deposition and possible sources of contaminants;
- Determine the possible food web effects; and
- Interpret the results from an international perspective.

EPA will address these objectives by examining the levels of contaminants in the terrestrial environment. The four specific goals have led to the design of a program with three major components:

- Status and Extent, which will determine the status and extent of contaminants using regional lichen, moss and soil sampling. This component will include sample collection from regionally representative locations within the U.S. Arctic.
- Contaminant Depositional History and Source, which will be evaluated using lake sediment cores. The lake sediment cores will help to separate background or natural contributions from those arising from long-range transport. Lake sediment cores can provide a contaminant history for the pre-industrial and post-industrial periods. If specific contaminant concentrations are high in both periods, then the contaminants found in the moss and lichens in that region are less likely to have arisen from long-range transport.
- Food Web Evaluation, which will be addressed through bioaccumulation studies, stress indicator analyses, and studies involving physiological biomass. This research will examine the possible sublethal effects in two fish and a small terrestrial mammal.



Department of Transportation

DOT supports Arctic research through the U.S. Coast Guard, which provides icebreaking capability for government and nongovernment research and performs iceberg reconaissance, and through the Federal Highway Administration, which is studying a variety of highway problems in the Arctic. Funding totaled $4.5 million in FY 91.

U.S. Coast Guard

Historically the Coast Guard has been assigned four primary roles: maritime law enforcement, national security, maritime safety and marine environmental protection. In the Arctic these roles focus on:

- Protecting national economic interests relating to fisheries and other resources in the Exclusive Economic Zone;
- Providing polar icebreaker capability in support of national logistics and scientific requirements;
- Responding to calls for assistance and reducing the loss of life and property through preventive programs; and
- Preventing the discharge of oil, chemicals and other hazardous materials into the marine environment and ensuring the quick, effective detection and cleanup of discharges that do occur.

Under the umbrella of promoting national security interests, the Coast Guard provides icebreaking capability in support of Arctic research. When they were built in the late 1970s, the Coast Guard's Polar-class icebreakers incorporated only limited space and equipment for research support. These deficiencies became particularly evident as research projects became more interdisciplinary and research teams became larger. A program was initiated in 1987 to expand and modernize the research support capabilities. As this project has progressed, the Coast Guard has sought and partially subsidized appropriate missions to exercise and evaluate the new facilities.

In August 1990, following the annual resupply mission to Thule, Greenland, the Coast Guard Cutter *Polar Sea* was used by researchers from the Navy's Arctic Submarine Lab (ASL) as well as personnel from the International Ice Patrol (IIP), a Coast Guard unit. The purpose of the project was twofold: an ASL bathymetric survey of a region off Greenland that had not been extensively surveyed and a hydrographic survey of the Polar Front, an ASL project supported by IIP. The bathymetric survey was entirely successful, and the IIP team collected data from 122 hydrographic stations in 20 days, completing one of the first hydrographic surveys of the Polar Front. This project continued work started in 1984.

FY 91 FUNDING (thousands)

International Ice Patrol	630
Test and Evaluation	1070
Extramural Support	55

After the ASL project, the *Polar Sea* returned to its home port of Seattle via the Northwest Passage. During that transit the vessel supported engineering tests of an ice buoy produced by the Woods Hole Oceanographic Institute under the sponsorship of the Office of Naval Research (ONR); field tests of an ultrasonic ice thickness sensor designed by the California State University–Northridge were also conducted. Since they were conducted during a routine transit, these projects were accomplished without incurring additional vessel operating costs.

In August 1991, again following the annual Thule deployment, the *Polar Star* was used by a party of researchers for participation in the International Arctic Oceanographic Expedition (IAOE), a three-ship, multinational, multidisciplinary research project in the deep Arctic. The other two vessels were the Swedish icebreaker *Oden* and the German icebreaking research vessel *Polarstern.* Unfortunately the *Polar Star* experienced mechanical problems and was forced to curtail its work three weeks into a 70-day expedition after completing approximately 25% of the planned research. The major funding agencies for this project were the Office of Naval Research, the Naval Oceanographic Office, the Canadian Centre for Remote Sensing, the German Meteorological Office, the Naval Research Laboratory and the National Science Foundation.

As part of its mission to promote the safety of life and property at sea, the Coast Guard manages and operates the International Ice Patrol (IIP). This organization, founded in 1914 in response to the sinking of the *Titanic*, provides mariners in the

International Ice Patrol air deployment of a TIROS oceanographic drifter over the North Atlantic from a Coast Guard HC-130 fixed-wing aircraft.

Grand Banks area off Newfoundland, Canada, with information on the location of icebergs and the sea-ice edge. To improve the effectiveness of their models, research is routinely conducted on the drift and deterioration of icebergs. In FY 90 and 91 the IIP conducted field tests of new types of oceanographic drifting buoys for use in predicting iceberg drift and melt. In FY 91, preliminary tests were conducted of an airborne radar being added to the Coast Guard's inventory, examining that sensor's ability to detect and identify icebergs.

Federal Highway Administration

The goals and objectives of the Federal Highway Administration (FHWA) in the Arctic are to develop and maintain cost-effective surface transportation facilities, primarily for highways and vehicles, just as anywhere else in the U.S. In the Arctic, however, there is a need to assure that highways are compatible with the severe constraints imposed by weather conditions and the fragile ecology of the area, as well as other normal environmental compatibility concerns.

The FHWA has been monitoring and conducting research in the Arctic for many years; in addition the numerous investigations conducted elsewhere in the United States are often relevant to highway problems in the Arctic. These projects have been primarily in collaboration with state highway agencies, especially Alaska and the states with more severe winter conditions. Together with state highway agencies, the FHWA sponsors and monitors work done under the auspices of the National Academies of Science and Engineering through the Transportation Research Board, the National Cooperative Highway Research Program (NCHRP) and the Strategic Highway Research Program (SHRP). Some of this work includes funding from and collaboration with other agencies, such as the U.S. Geological Survey and the Army Corps of Engineers' Cold Regions Research and Engineering Laboratory, as well as university and private contractors. The highway studies related to the Arctic that received funding during FY 90 and 91 are summarized below.

FY 91 FUNDING (thousands)	
Stream-crossing hydraulic problems	100
Pavements	1549
Weather monitoring/Storm forecasting	316
Snow control	90
Pavement treatments for snow and ice	673

Stream-Crossing Hydraulic Problems

Arctic streams typically have highly variable discharges and flood levels and are plagued by erratic and highly variable floating and blocking ice. To deal with these conditions the USGS has for decades been contracted to measure the varying water discharge rates and the flood stages of the Yukon River and numerous other streams. The results of these measurements have been used in structural and hydraulic designs of bridges and culverts. A combined ecological and hydraulic study has addressed the optimal design of culverts to pass flood waters efficiently yet at velocities compatible with the upstream migration needs of slow-swimming fish. During FY 91, studies began on the sources of debris loads on bridges; Arctic streams can have heavy debris loads of loose ice, brush, trash and even trees, usually during the late spring and summer.

Pavement Studies

Since FY 91 there has been an unusually high level of effort in pavement investigations of inter-

est to the Arctic, primarily due to the SHRP program on pavements. A study of the freeze–thaw durability of portland cement concrete is investigating the thermal and freeze–thaw behavior of the aggregates, the behavior of hardened cement pastes and the effects of air entrainment.

Of the $50 million spent on the Long-Term Pavement Performance studies in the SHRP, approximately $5 million for FY 88–92 ($1 million FY 90 and $1 million FY 91) have been used for pavement test sections under conditions applicable to Arctic conditions. Both portland cement and asphalt concrete pavement test sections have been placed in adequate lengths. Various mix designs, thicknesses and base conditions were used. Atmospheric and ground temperatures and moisture conditions for the test pavements are being monitored seasonally. The various test pavements are then evaluated for integrity, deflections, rideability and surface defects such as spalling.

The Alaska Department of Transportation and Public Facilities, in collaboration with FHWA, has been involved in three studies directed toward Arctic conditions, namely, permafrost control features, limiting longitudinal cracking, and evaluating AC 1.75 asphalt. The study of permafrost control features is evaluating the possible long-term benefits of insulated embankments, air-cooled ducts, thermal syphons and snow sheds in controlling roadway distress related to thawing permafrost. In another investigation that combines a theoretical study, laboratory testing and observations of field installations, a scheme is being developed for using reinforcing materials in road embankments to limit longitudinal cracking caused by the lateral movements of the embankment. The third study is evaluating 1.75 asphalt, either alone or in combination with Chem-Crete, as a means of alleviating problems with thermal and map cracking.

Sixteen-foot-high snow fence, which traps snow more effectively than traditional four-foot-high slat fences.

Weather Monitoring and Storm Forecasting

SHRP investigations are being pursued to help highway maintenance operations respond quickly and strategically to problems resulting from ice and snow storms. The studies are evaluating means to adequately and representatively sample current weather and road temperature conditions at selected sites throughout a local region (typically 200–2000 square miles in urban areas) and rapidly and reliably communicate these measurements and short-term weather forecasts. Short-term strategic predictions based on rapid computer calculations are then made available for highway maintenance decisions. Artificial intelligence based on meteorological concepts and historical records of area storms is used to improve the predictive programs.

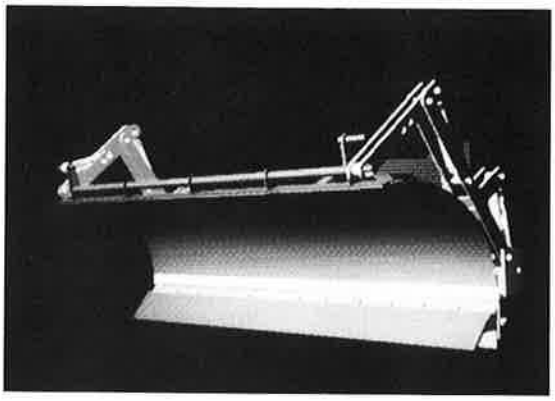
The goal of these investigations and parallel efforts done elsewhere is to allow more strategic, economic, timely and properly sized highway maintenance responses to snow and ice storms. Expected cost savings come from smaller or more timely responses to storm threats. Weather monitoring and storm forecasting systems can also be used to help with decisions to close or not close travel on highway sections for storm conditions.

Snow Control

An investigation dealing with reducing the impacts of snow by improving snow fence designs and controlling snow drifting around highway fixtures such as guard rails and sign posts has produced significant guidance through reports, manual and videotape. Two smaller investigations have dealt with the use of plastic netting and living snow fences (tree shelter belts) in place of wooden snow fences. Living snows fences are not effective until the trees are high and dense enough, which can take 10–20 years. An investigation is focusing on snow stability and other snow properties during storm and warming conditions that could lead to avalanches. Included are simulations, field observations and assessments of snow properties and meteorological conditions for avalanches in the Cascade Range of Washington. The results should have applications for Arctic conditions.

Pavement Treatments for Snow and Ice

Eighteen investigations dealing with pavements treatments for snow and ice removal were active for all or part of FY 90 and 91. Four of these deal with probing the physics of bonds between ice and pavements and possible means of reducing these bonds by surface modifications or disturbances to the ice. One investigation is examining the mechanics of cutting edges for dislodging ice from pavements. Another study has been analyzing



Experimental snowplow for investigating the optimum moldboard shape for reducing energy consumed in plowing.

more energy-efficient and versatile snowplows designed to be modified for large variations of snow loads due the differences in snow wetness, density and depth.

Twelve studies have been evaluating various aspects of chemical and abrasive treatments to snow- and ice-covered highways. The objectives of these efforts are to develop improved technologies and materials for attaining bare pavements, or at least improved traction, on snow- and ice-covered roads. The evaluations have included sources, costs, availabilities, deicing behaviors and possible deleterious effects of chemical treatments on highways, including environmental impacts and corrosion to highway pavements and structural and reinforcement steel. One of the main efforts addresses the procedures that should be used for deciding on deicing chemicals and establishes the bases for future work on developing deicing materials.

Special attention has been paid to the total costs of using calcium magnesium acetate (CMA) instead of common salt (primarily sodium chloride). For several types of locations CMA is clearly a better and lower-cost alternative. Studies are examining the use of several chemical applications to highway pavements shortly before snow and ice storms are expected. These treatments already show promise that CMA will inhibit snow or ice from bonding to pavements and thus will improve traction for highway vehicles and greatly ease blading or plowing.

Department of State

The Department of State continues its involvement in several multilateral and bilateral activities related to environmental protection and scientific research in the Arctic. The most significant of these are the Arctic Environmental Protection Strategy, the International Arctic Science Committee and the U.S. Man and the Biosphere Program.

Within the past year the Department of State coordinated U.S. participation in the successful conclusion of the negotiations to establish the Arctic Environmental Protection Strategy (AEPS), signed by the eight Arctic nations at a June 1991 meeting in Rovaniemi, Finland. The AEPS is a nonbinding legal agreement that provides for cooperation and coordination of the participating countries' efforts to protect the Arctic environment. The strategy document is based on State of the Arctic Environment reports prepared by the participants. Its objectives include preserving environmental quality and natural resources, accommodating environmental protection principles with the needs and traditions of Arctic Native peoples, monitoring environmental conditions, and reducing and eventually eliminating pollution in the Arctic environment.

The strategy prescribes specific actions to control six types of pollutants: persistent organic contaminants, oil, heavy metals, noise, radioactivity and acidification. It also calls for cooperative steps in four areas: an Arctic Monitoring and Assessment Program (AMAP), protection of the marine environment, emergency preparedness and response, and conservation of Arctic flora and fauna.

The first AMAP organizational meeting of experts was held in Tromsø, Norway, on December 2–6, 1991. The meeting established a framework for coordinating existing and future monitoring efforts and developing an Arctic data directory. Similar events were hosted in early 1992 by Canada on flora and fauna protection and by Sweden on emergency preparedness. The Arctic countries will hold their next general meeting on the strategy in Greenland in 1993. The Department of State will continue to play a coordinating role in the AEPS, while other agencies take responsibility for expert-level activities, such as EPA for AMAP and the Fish and Wildlife Service for flora and fauna protection.

The Department of State, working with the Polar Research Board, continues to follow the activities of the International Arctic Science Committee (IASC), a nongovernmental scientific organization that encourages and facilitates international consultation and cooperation in all aspects of Arctic research. Since the IASC Founding Articles were signed in August 1990, the Committee has made significant progress in arranging its operations and its scientific program.

FY 91 FUNDING (thousands)	
MAB: Arctic Directorate	60

The IASC Secretariat was established in Oslo. The IASC Council held its first meeting in January 1991 (see *Arctic Research of the United States*, Vol. 4, Fall 1991, p. 54), at which operating rules and procedures were developed, four non-Arctic countries conducting substantial research in the northern polar areas were admitted as IASC members, and an Executive Committee was created to provide leadership and oversight between Council meetings. Representatives to the IASC Regional Board, which ensures that IASC activities are consistent with national and regional interests, have been named by most of the Arctic member countries. The Board met in March 1992.

The scientific program of IASC is set by the Council. In January 1991 the Council established a working group on Arctic global change studies, with instructions to conduct a small workshop and consider a regional program of global change research. Ad hoc working groups have been set up to advise the Council on data systems, human and social sciences, and possible uses of an inventory of Arctic research programs. In addition, IASC is investigating ways to cooperate in the execution of the Arctic Environmental Protection Strategy.

A meeting of the IASC Council was held in Reykjavik in April 1992, following a workshop on Arctic global change studies. In addition to evaluating existing activities, the Council considered several new proposals for scientific working groups.

The Department of State also administers the U.S. Man and the Biosphere Program (U.S. MAB), through a MAB secretariat located within the department. The High-Latitude Ecosystem Directorate is one of five MAB Directorates funded by State and other agencies. The level of support

depends on the number and quality of proposals awarded for each Directorate in any given year (with an average of $30,000 per grant). In both 1990 and 1991 the overall U.S. MAB program was funded at over $900,000, with the Department of State contributing $395,000 each year.

The High-Latitude Ecosystem Directorate aims to enhance the understanding and rational management of resources and ecosystems in the high-latitude regions of the United States and other northern circumpolar lands. This is accomplished through support of integrated research in biological, physical and social sciences, and other cooperative international endeavors. MAB is particularly concerned with applying scientific advances to societal needs, including those of multicultural communities and indigenous peoples. MAB also promotes informed policy formulation on societal issues, such as sustainable development, global climate change and maintenance of biological diversity and stability in high-latitude ecosystems.

The Directorate currently supports a study of existing northern circumpolar research sites in the context of global climate change programs. The Directorate serves as the U.S. link to the MAB Northern Sciences Network (NSN), and U.S. MAB, through the Directorate, supports a U.S. scientist assigned to the NSN secretariat, located at the University of Lapland, Rovaniemi, Finland.

In addition to these activities the Department of State coordinates U.S. participation in two other Arctic events. The first is an annual meeting in Copenhagen with the Danish Commission for Scientific Research in Greenland, where proposals for research in Greenland by U.S. scientists are reviewed. The Department's Division of Polar Affairs compiles the list of proposals and leads the U.S. delegation to the Commission meeting.

Also, the Division of Polar Affairs and its counterpart in the Canadian Ministry of External Affairs organize a bilateral meeting every 1–2 years to discuss environmental, scientific and technical issues arising from hydrocarbon and other development activities in the Beaufort Sea.

Revision of the U.S. Arctic Research Plan

Readers of *Arctic Research of the United States* are invited to comment on the U.S. Arctic Research Plan and suggest improvements. The Second Biennial Revision of the Plan was published in this journal, Vol. 5, Spring 1991, p. 3–89.

The first U.S. Arctic Research Plan was published in 1987. Biennial revisions of the Plan were published in 1989 and 1991. In accordance with Section 109 of the Arctic Research and Policy Act, the next biennial revision of the Plan is to be prepared by July 1993, in consultation with the Arctic Research Commission, the Governor of the State of Alaska, the residents of the Arctic, the private sector and public interest groups. Please send your comments to Charles E. Myers, Interagency Arctic Research Policy Committee, Division of Polar Programs, National Science Foundation, Washington, D.C. 20550.

Boreal Ecosystem–Atmosphere Study (BOREAS)

The U.S. and Canada are planning a major field experiment to be conducted in the boreal forest biome of Canada. The boreal forest constitutes one of the earth's largest circumpolar biomes. There has been much conjecture and debate regarding the boreal biome's sensitivity to global change. Modeling results differ regarding the nature and severity of potential ecological and biogeochemical perturbations imposed by anticipated global climate warming. Understanding the current ecological and climatological functioning of this circumpolar ecosystem and its sensitivity to environmental change is therefore crucial to understanding and predicting larger-scale global dynamics.

The goal for the Boreal Ecosystem–Atmosphere Study (BOREAS) is to improve our understanding of the interactions between the boreal forest biome and the atmosphere in order to clarify their roles in global change. The agencies involved in planning and executing BOREAS are the U.S. National Aeronautics and Space Administration, the U.S. National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the U.S. National Science Foundation, the Canada Centre for Remote Sensing, Forestry Canada, Agriculture Canada, Environment Canada, the National Research Council of Canada and potentially the Natural Sciences and Engineering Research Council of Canada.

The specific objectives of BOREAS are:

- To improve our understanding of the processes that govern the exchanges of energy, water, heat, carbon and trace gases between boreal ecosystems and the atmosphere, with particular reference to those that may be sensitive to global change; and
- To develop and validate remote-sensing algorithms for transferring understanding of these processes from local to regional scales.

A wide array of disciplinary and interdisciplinary experiments will be needed to make this study successful. Relevant study areas include terrestrial ecology, hydrology, land surface climatology, trace gas biogeochemistry, atmospheric chemistry, boundary layer meteorology, energy and water fluxes, and integrative modeling. Two sites of 400–600 km^2 will serve as the foci of the experiment. Pending successful environmental impact review, they will be in Prince Albert National Park, Saskatchewan, Canada, and near Nelson House, Manitoba, Canada.

BOREAS is a short-term experiment. There will be initial monitoring, pilot and planning activities at the field sites during 1993. However, the concentrated observational effort for this experiment will occur throughout 1994. A series of intensive field campaigns spanning the annual cycle are planned, along with continuous monitoring. Afterwards some continued monitoring activities and limited revisits may be required. Within the experiment's time frame, BOREAS will provide the opportunity to pursue a wide range of investigations into the boreal forest's ecological, hydrological and biogeochemical dynamics and its coupling to the regional and global physical climate system.

To obtain additional information, write to Dr. Diane E. Wickland, Acting Chief, Ecosystem Dynamics and Biogeochemical Cycles Branch, Code SEP03, NASA Headquarters, Washington, DC, 20546, or call (202) 453-8195, or write to Dr. Josef Cihlar, Head, Applications Development Section, Canada Centre for Remote Sensing, Energy Mines and Resources Canada, 1547 Merivale Road, 4th Floor, Ottawa, Ontario, Canada, K1A OY7.

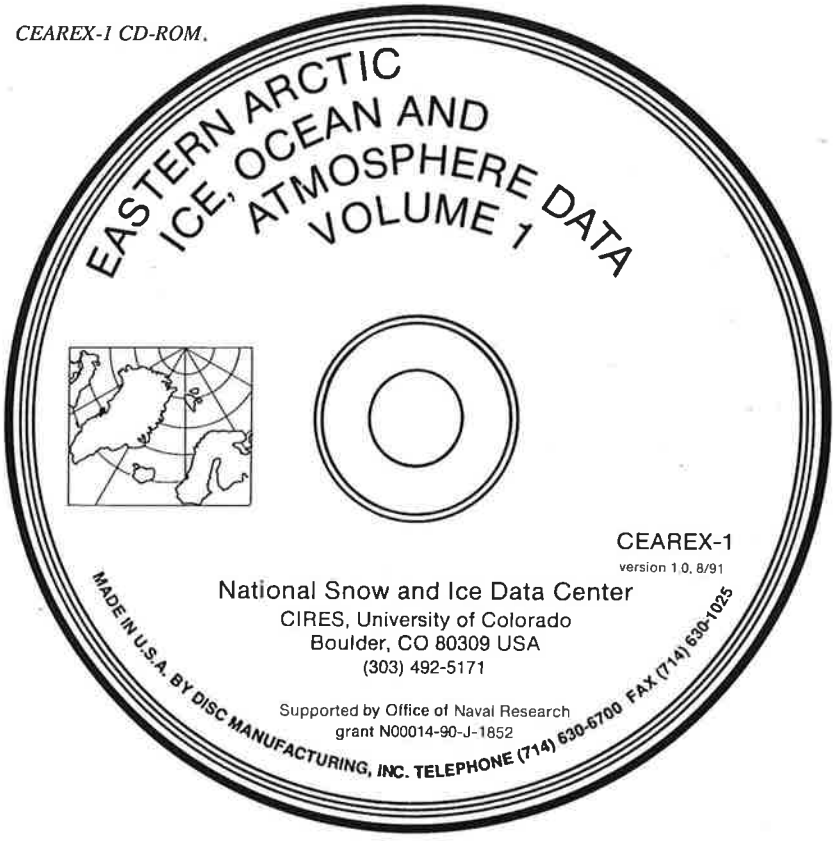
CD-ROM of CEAREX Data

Prepared by
Claire S. Hanson

The National Snow and Ice Data Center (NSIDC), as part of its data management services for the Coordinated Eastern Arctic Experiment (CEAREX), has produced a CD-ROM containing a sampling of CEAREX data. This is the first in a planned CD-ROM series titled Eastern Arctic Ice, Ocean and Atmosphere Data, which will contain sea-ice- and ocean-related data sets, including imagery, from CEAREX, the Marginal Ice Zone Experiment (MIZEX) and other sources, as well as selected data collected during the spring 1992 LEADEX project. Volume 1, titled CEAREX-1, includes data related to meteorology; hydrography; biophysical measurements; station and buoy positions; bathymetry; sea ice acceleration, stress and deformation; and ambient noise and acoustics.

CEAREX field experiments, which were carried out in the Arctic Ocean and the Greenland and Norwegian seas between September 1988 and May 1989, examined the structure and function of the meso- to small-scale processes in the exchange of momentum, heat and biomass between the Arctic Ocean and the Nordic seas. The experiment included two camps located on drifting ice floes and was supported by ships, helicopter and fixed-wing aircraft. With the Office of Naval Research as the principal sponsor, the field work involved 210 participants from seven countries. Most of the experiments took place in an area just north of Svalbard. (See *Arctic Research of the United States*, Fall 1988, p. 44; Spring 1989, p. 14; Spring 1990, p. 55; and Fall 1991, p. 5, for a series of progress reports on the field program and data analysis.)

CEAREX-1 CD-ROM.



The goal of the CD-ROM pilot project at NSIDC is to assure the long-term availability of the data collected during CEAREX, as well as other relevant Eastern Arctic data, for use in research that will improve our understanding of Arctic processes.

Data sets were transferred to NSIDC by designated data set managers at Scripps Institution of Oceanography, the Naval Postgraduate School, McPhee Research, Inc., and the Naval Research Laboratory, who received data from each investigator in the hydrography, biophysical, meteorology, station and buoy position, and bathymetry groups and provided uniform, quality-checked files to NSIDC. Individual investigators in the remaining subject areas provided quality-checked files directly to NSIDC. Review, editing and augmentation of documentation files was completed at NSIDC.

Data were placed on the CD-ROM in ASCII format so that they can be used on a wide variety of existing computers (for example, IBM-PC, Apple Macintosh, DEC VAX and Unix workstations). Whenever possible, existing "standard" or widely used data formats were employed. There is no executable software on the CD-ROM, although some source code in C supporting the use of the station and buoy position files was provided by the investigator and is included on the CD-ROM.

Data in the final form were transferred to nine-track magnetic tapes and shipped to a commercial CD-ROM mastering facility on August 23, 1991. A test master was received at NSIDC on September 12. Because of some incorrect assumptions made by the mastering facility, the test disk was found to be incorrectly formatted. NSIDC decided to seek local resources for mastering to allow the data integrity to be monitored at each step of the process.

Fortunately a CD-ROM mastering facility had recently been installed at the NOAA/National Geophysical Data Center (NGDC). NGDC made the CD-ROM facility available to NSIDC for this project, continuing its practice of sharing resources with NSIDC (NSIDC is operated for NGDC as part of NOAA's Cooperative Agreement with the University of Colorado). NSIDC transferred the CEAREX data files to the PC-based hardware and

Further information on obtaining the CD-ROM CEAREX-1 is available from Data Request Services, National Snow and Ice Data Center, University of Colorado, Boulder, Colorado 80309-0449. Telemail: NSIDC/Omnet. Internet: "hanson@kryos.colorado.edu".

produced what is known as a "one-off," a write-once laser disk suitable for replication onto CD-ROM disks for distribution. The "one-off" was tested at NSIDC on IBM-PC and Apple Macintosh computers. All files were readable and had consistent formats and correct file sizes. The mastering process was thereby shortened from nearly three weeks (including mailing tapes and processing at the mastering vendor location) to two hours, with complete control over the process.

The first CD-ROM volume, replicated from the "one-off" by a commercial CD-ROM facility, was distributed to CEAREX investigators in November 1991. The remainder of the currently funded CEAREX Data Management project at NSIDC will be devoted to defining the level of effort required to obtain and format selected current-meter and other velocity data sets from CEAREX and other Eastern Arctic campaigns for inclusion on a future CD-ROM.

First Meeting of the Arctic Monitoring and Assessment Task Force

The Arctic Environmental Protection Strategy (AEPS) was signed on June 14, 1991, in Rovaniemi, Finland, by the Arctic-rim countries: Canada, Denmark, Finland, Iceland, Norway, Sweden, the Union of Soviet Socialist Republics and the United States of America. Although nonbinding, the Strategy committed the Arctic countries to take joint steps towards implementing the Arctic Environmental Protection Strategy, an action plan for protecting the Arctic environment. It also established an "Arctic Monitoring and Assessment Programme (AMAP) to monitor the levels of, and assess the effects of, anthropogenic pollutants in all components of the Arctic environment. To this end, an Arctic Monitoring and Assessment Task Force will be established."

The first meeting of the Arctic Monitoring and Assessment Task Force (AMATF) was held on December 2–6, 1991, in Tromsø, Norway. The following were the key issues on the United States' agenda:

- The focus of AMAP monitoring activities should remain on the original priority pollutants; in particular, the collection of data related to global climate change, included in the May 1991 AMAP proposal, should not be a part of AMAP deliberations.
- Assessments are an important part of AMAP and should be discussed during the Task Force meeting.
- Key questions should be formulated to focus the AMAP approach.
- The AMAP approach should be pollutant specific, rather than medium by medium.
- Data management and quality issues need to be considered carefully to ensure easy access to all participating or interested countries.

The Task Force's objective was to set the guidelines for the future operation of AMAP. The meeting was chaired by Lars Reierson and co-chaired by Carola Bjorklund, both of Norway. In addition to the issues that the United States brought up, key agenda items were to develop the mandate, rules and procedures for AMAP; discuss cooperation between AMAP and IASC; discuss the contents and harmonization of existing programs and the initiation of additional work, including the development of an assessment program; define the practical work that needed to be undertaken; discuss quality control and data archiving; and elect a Chair and Vice-Chair, each to two-year terms.

The AMATF carefully considered the key agenda items that the United States brought to its attention, and for the most part they agreed. However, instead of the United States' suggestion of a pollutant-specific approach, it was decided that AMAP would be developed under the following themes (with the lead countries identified): emissions and sources (Secretariat; to be chosen), atmosphere (Canada), marine (Norway), fresh water (Finland), terrestrial (Sweden), human health (Denmark) and remote sensing and modeling (U.S.). Furthermore, in keeping with the Strategy document, it was decided that the initial emphasis would be on persistent organic contaminants, radionuclides and heavy metals. Expert reports from these groups are due by early May, with final drafts to be completed by September 1992.

A working group on key questions and assessment, chaired by both the United States and Canada, concluded that the planning process should include:

- An examination of relevant ongoing activities, existing data and knowledge;
- A consideration on how this information can contribute to answering the key questions; and
- An AMAP project recommendation.

The key questions governing both program planning and the assessment process were formulated as follows:

1. What are the levels and trends in the Arctic environment?
2. What are the sources?
3. What are the transport mechanisms?
4. What are the biological mechanisms?
5. What are the human health effects?
6. What are the implications for sustainable resources, socioeconomic and cultural resources and significance?
7. What are the required actions?
8. What changes are required in AMAP?
9. How effective are remedial measures?

Questions 1–3: How do media programs contribute to answering the key questions?

Questions 4–5: How do media programs contribute to knowledge of effects?

Questions 6–7: To be answered during the assessment process.

Questions 8–9: Management and future actions to be finalized by the Task Force.

With regard to data management the United States made a presentation on the Arctic Environmental Data Directory and the Arctic Data Interactive. This approach was well received by the other countries; in fact, some of the other countries are already involved with these programs. Further consideration of these formats would be considered.

To conclude the meeting, Heikki Sissula of Finland was elected Chair of AMAP and David Stone of Canada the Vice-Chair. It was also agreed that Norway would examine the applications that had been received for the position of Secretariat, to be located in Oslo and supported by Norway, and make a recommendation to the Chair. The applications and Norway's recommendation would be sent to the various heads of the delegations to seek concurrence or comment.

Canada offered to host the next Task Force meeting in November or December 1992; the exact location is yet to be determined. This meeting would help to organize AMAP for the next ministerial meeting, to be held in Greenland in 1993.

Fourth Biennial Report of the Interagency Arctic Research Policy Committee to the Congress

February 1, 1990, to January 31, 1992

Prepared by the National Science Foundation for the Interagency Arctic Research Policy Committee

Section 108(b) of Public Law 98-373, as amended by Public Law 101-609, the Arctic Research and Policy Act, directs the Interagency Arctic Research Policy Committee (IARPC) to submit to Congress, through the President, a biennial report containing a statement of the activities and accomplishments of the IARPC. The IARPC was authorized by the Act and was established by Executive Order 12501, dated January 28, 1985.

Section 108(b)(2) of Public Law 98-373, as amended by Public Law 101-609 directs the IARPC to submit to Congress, through the President, as part of its biennial report, a statement "dealing with particularity the recommendations of the Arctic Research Commission with respect to Federal interagency activities in Arctic research and the disposition and responses to those recommendations." In response to this requirement the IARPC has examined all recommendations of the Arctic Research Commission since it was established in 1985. The required statements follow on page124.

During the period February 1, 1990, to January 31, 1992, the IARPC has:

- Prepared and published the second biennial revision to the United States Arctic Research Plan, as required by Section 108(a)(4) of the Act. The President transmitted the Plan to Congress on July 23, 1991.
- Published and distributed four issues of the journal *Arctic Research of the United States*. The journal reviewed all Federal agency Arctic research for FY 1989 and 1990 and included summaries of the IARPC and Arctic Research Commission meetings and activities. The Spring 1991 issue contained the full text of the second biennial revision to the U. S. Arctic Research Plan.
- Consulted with the Commission on policy and program matters described in the Section 108(a)(3), was represented at all meetings of the Commission, and responded to Commission reports on goals and objectives, logistics and data.
- Continued the processes of interagency cooperation and coordination required under Section 108(a)(6), (7), (8) and (9).
- Provided input to an integrated budget analysis for Arctic research for the President's budget, which identified $116 million in Federal support for FY 1990 and $128 million in FY 1991.
- Provided for public participation as required in Section 108(a)(10), which culminated in public involvement in the development of the recommendations and the second biennial revision to the Plan at a meeting in Anchorage in March 1991.
- Prepared a strategy report, published in January 1991, for an FY 1992 interagency Arctic program that identified four key science elements for future research and coordination (Western Arctic Ocean Circulation and Productivity; Arctic Basin Geodynamics; Arctic Environmental Monitoring; and the Bering Land Bridge Program).
- Participated in the development of testimony on Federal Arctic research for hearings on April 24, 1991, by the National Ocean Policy Study of the Senate Committee on Commerce, Science, and Transportation, and hearings on May 13, 1991, by the Science, Technology, and Space Subcommittee of the Senate Committee on Commerce, Science, and Transportation.
- Prepared and updated the Arctic Environmental Data Directory, which now contains information on 350 Arctic data sets, and published Arctic Data Interactive (ADI), a prototype CD-ROM (compact disc–read only memory) product containing Arctic environmental data and information.
- Established an Interagency Social Sciences Task Force and prepared a coordinated social sciences and health research plan. Of special concern is research on the health of indigenous peoples and research on the Arctic as a unique environment for studying human–environmental adaptation and sociocultural change.
- Approved an Interagency Statement of Principles for the Conduct of Research in the Arctic to encourage communication and scientific partnerships with northern indigenous peoples (published in the second biennial revision to the United States Arctic Research Plan).
- Participated in the establishment of the nongovernmental International Arctic Science Committee.

- Participated in policy formulation and official endorsement of the June 1991 international agreement for an Arctic Environmental Protection Strategy. This strategy contains a set of principles and objectives for the protection of the Arctic environment. It also established the Arctic Monitoring and Assessment Program (AMAP) to provide a forum for international harmonization of Arctic monitoring programs. IARPC's Environmental Monitoring Working Group serves as a U.S. focal point for AMAP and coordinates domestic monitoring efforts.
- Convened two formal meetings of the Committee, in June 1990 and June 1991.

IARPC's Response to Recommendations of the Arctic Research Commission

The full text of the Commission's recommendations appear in a series of publications, which are referred to in the column headed "Source" in the following table and listed on p. 128. Recommendations have been summarized and combined where appropriate. The Interagency Arctic Research Policy Committee's responses to the recommendations appear in the column headed "Response." Many of these responses refer to the second biennial revision to the U.S. Arctic Research Plan, published in this journal, Volume 5, Spring 1991 (abbreviated as USARP 1991). The U.S. Arctic Research Plan was sent to the Congress by the President on July 23, 1991.

Recommendation	*Source*	*Implementing Agencies*	*Response*
Arctic as a Component of Global Earth System			
Conduct research to understand the Arctic Ocean, especially the Bering and marginal sea, sea ice and sea bed.	1, 4	DOC, DOD, DOI, NASA, NSF	Programs being implemented in accordance with Sections 2.1, 2.2, 3.1, USARP 1991. See also *Arctic Oceans Research: Strategy for an FY 91 Program,* published by IARPC, January 1990.
Support research program to determine the role of sea ice in controlling Arctic living resources	2	DOC, DOD, DOI, NASA, NSF	Programs being implemented in accordance with Section 2.1, 3.6.3, USARP 1991.
Support research to understand the coupled land and atmosphere components of the Arctic system.	1, 4	DOC, DOD, DOE, DOI, NASA, NSF	Programs being implemented in accordance with Section 3.4, USARP 1991.
Support systematic long-term monitoring of Arctic atmosphere, land and sea-surface parameters, sea ice and glacier behavior, and other sensitive climate indicators.	4	DOC, DOD, DOE, DOI, EPA, NASA, NSF	Arctic Monitoring and Assessment Program under development in accordance with Section 2.3, USARP 1991.
Support assessment of the full extent and causes of stratospheric ozone depletion in the Arctic.	4	DOC, NASA, NSF	Programs being implemented in accordance with Sections 2.3, 3.2.3, USARP 1991. NASA observations have verified depletion in the Arctic.
Support research to understand the high-latitude upper atmosphere and its extension into the magnetosphere.	1, 4	DOC, DOD, DOE, DOI NASA, NSF	Programs being implemented in accordance with Section 3.2, USARP 1991.
Support research in the health–culture–socioeconomic system to identify and resolve the major health,	1, 4	DOC, DOD, DOI, HHS, NSF, SI, State, USDA	Programs being implemented in accordance with Section 3.6, USARP 1991. Beringia

Recommendation	*Source*	*Implementing Agencies*	*Response*
behavioral and cultural problems that derive from distinctive characteristics of the Arctic environment.			program initiated (see Section 2.4, USARP 1991). Federal (HHS)–Alaska research cooperation.
Support four areas of Arctic health research: injury control, cancer, diet, and infectious diseases.	2	DOD, HHS	Programs being implemented in accordance with Section 3.6.3, USARP 1991.
Support research on the Arctic as a component of the global economic system.	9	DOC, DOE, DOI, EPA, NSF	NSF Arctic Social Sciences Program established, 1990. First research awards made in 1991. Also see Section 3.3, USARP 1991.
Support research to develop a deeper understanding of the Bering Sea marine ecosystem as a rational basis for prudently managing biotic resources and safeguarding U.S. interests in this area.	4	DOC, DOI, NSF, SI	Programs being implemented in accordance with Sections 2.1, 3.1.2 and 3.6.2, USARP 1991.
Develop a program of enhanced science education at the elementary and high school levels in Arctic Alaska.	4	DOI, NSF, SI	Federal support is available through NSF for Native American curriculum development. Other programs being implemented in accordance with Sections 3.6.1 and 3.6.2, USARP 1991.
Environmental Impact Statement Process			
Establish impartial external scientific and engineering review mechanisms (for environmental reviews).	6	All IARPC agencies	Policy already exists under CEQ regulations, 40 CFR, Parts 1500–1508.
Carefully select external reviewers for their expertise in the relevant fields.	6	All IARPC agencies	Agency policy.
Protect external reviewers from litigation.	6	All IARPC agencies	Reviewers of public documents usually do not face direct litigation.
Make full text of all reviews part of the public record.	6	All IARPC agencies	Required under Section 102(2)(C) of National Environmental Policy Act.
Stipulate that new scientific or technical information obtained during the EIS process should be published in the refereed literature.	6	All IARPC agencies	Agency policy.
Channel the identification, review and resolution of environmental issues through a single coordination team.	6	All IARPC agencies	Most major EIS's are coordinated by agency interdisciplinary teams.
Set guidelines for the implementation of the external review process.	6	CEQ	Guidance already exists in CEQ regulations. CEQ has offered to host an interagency discussion regarding applying these recommendations in the context of a particular EIS.

Recommendation	*Source*	*Implementing Agencies*	*Response*
Arctic Engineering			
Develop an Arctic engineering research plan with special emphasis on the following items: • Oil spill prevention technology, including containment and spill cleanup. • Waste disposal and air pollution control. • Power generation and energy storage. • Improved Arctic construction techniques. • Transportation systems for Arctic conditions. • Materials and processes with properties for Arctic operations.	7	DOD, DOI, DOT, EPA, NSF	Engineering research being implemented; see Section 3.5, USARP 1991. Private industry research programs complement Federal research.l
Promote applied scientific research in the following priority areas, whose results are crucial for Arctic engineering: • Physical properties of ice and snow. • Physical and chemical behavior of Arctic soils.	7	DOD, NSF	Research being implemented in accordance with Section 3.1.1, USARP 1991 for physical properties of ice and snow; Section 3.4.2 for Arctic soils.
Develop more extensive communication and cooperation between the various government agencies and the professional societies.	7	All IARPC agencies	Most communication and cooperation is on the basis of individual participation in professional society activities.
Give high priority at U.S. universities to improving existing engineering courses and programs and developing new ones.	7	DOD, NSF	Federal support is available for curriculum development.
Support a strong component of cooperative Arctic engineering research in the programs of the International Arctic Science Committee (IASC).	7	DOC, DOD, NSF	IASC programs are under development.
Arctic Data and Information			
Take the lead in developing U.S. policy directives for managing Arctic data and information.	5	All IARPC agencies	Data Policy Statement developed in context of Global Change Research Program.
Base Arctic data policy and guidelines on the needs of the user community.	5	All IARPC agencies	Prototype Arctic Environmental Data Directory Working Group (AEDDWG) involves agency, academic, international Arctic community.
Set aside an adequate portion of Federal Arctic research funds	5	All IARPC agencies	Some IARPC agencies share funding for AEDDWG; each operates inde-

Recommendation	*Source*	*Implementing Agencies*	*Response*
for successfully managing data and disseminating information.			pendently with respect to preservation of and access to Arctic data and information.
Plan and develop an Arctic Data and Information System (ADIS) under the guidance of IARPC to handle publicly available scientific and technical data and information.	4, 5	All IARPC agencies	Preliminary effort is joint development of Arctic Environmental Data Directory, linked to Earth Science Data Directory. Arctic data are referenced but data reside in host agencies.
Address the following in the policy and plans for an ADIS, listed in order of decreasing priority: 1. Interlinking data and information; 2. Defining needs for environmental monitoring and long-term data; 3. Ensuring quality control of data; 4. Devising strategies to arrest the proliferation of "gray literature;" 5.Improving the mechanisms for international exchange of Arctic data and information; 6.Providing for standardization of data and information; 7. Minimizing the cost to the user of data and information services; 8. Safeguarding confidentiality; 9. Providing for recording of historical and proxy data; 10. Protecting data and information from environmental and human hazards.	5	All IARPC agencies	Programs being implemented in accordance with Section 2.5, USARP 1991. OSTP policy addresses priorities 1, 3, 5, 6, 7 and 9. Interagency plans for the prototype Arctic Environmental Data Directory address the first steps for priorities 1, 2, 3, 5, 6, 7, 9 and 10. Agency and interagency plans for the Arctic Data and Information System are preliminary, viewing development of the Global Change Data and Information System as the model to follow.
Consider a cooperative interagency agreement as the vehicle for the implementation of Arctic data and information policy.	5	All IARPC agencies	OSTP Data Policy Statement provides policy guidelines for "full and open sharing" of scientific data and information.
Arctic Logistics			
Provide Arctic research vessel with ice-breaking capabilities	1, 3, 4, 9	DOT, NSF	Began acquisition of replacement Coast Guard polar icebreaker. Bids opened Oct. 11, 1991. Contract award expected Feb./March 1992. Multi-year upgrade of scientific support capabilities of USCG Polar-class icebreakers near completion. Additional Arctic research vessel under consideration by NSF. Conceptual design completed for class 3 ice-capable ship.
Support land-based logistics centers	1, 3, 4	DOD, DOE, DOI, NSF	Many land-based centers exist. See Section 4 of USARP 1991. State of

Recommendation	*Source*	*Implementing Agencies*	*Response*
			Alaska has published a directory of Federal and state research sites and facilities.
Provide high-latitude sounding rocket launch facility	1, 3, 4	DOD, NASA, NSF	Poker Flat Rocket Range, Alaska, is being upgraded to state-of-the-art capability.
Provide central logistics coordination	1, 3, 4	DOD, NSF	See Section 4, USARP 1991.
Logistics Support of U.S. Research in Greenland			
Give careful consideration to the continuance of an adequate logistic support capability at Sondrestrom Air Base	8	DOD	Department of Defense will terminate operations at Sondrestrom Air Force Base by September 30, 1992. Air National Guard flights will continue for transport of passengers and cargo.
Consider alternative scenarios of Danish takeover of Sondrestrom Air Base.	8	DOD, NSF	Currently under negotiation with Greenland Home Rule Government.
Design new modes of research operations for the major projects in Greenland.	8	NSF	The NSF-funded Polar Ice Coring Office will consider new operational modes as projects require.
Develop closer research ties with Danish and other European researchers.	8	DOD, NASA, NSF	Process is on-going. Agencies attend annual meeting with Danish Commission for Research in Greenland.
Alert the U.S. scientific community concerned with research in Greenland and provide them with details on the ongoing U.S./Denmark negotiations regarding Sondrestrom.	8	All IARPC agencies	Information being provided on an on-going basis.
International Activities			
Continue vigorous participation in the planning process for the establishment of an International Arctic Science Committee.	4	All IARPC agencies	IASC was established, 1990. U.S. participation is through the Polar Research Board.

Sources of Arctic Research Commission Recommendations

1. *National Needs and Arctic Research: A Framework for Action* (May 1986)
2. *Entering the Age of the Arctic* (Annual Report, January 1988)
3. *Logistic Support of Arctic Research* (July 1988)
4. *Goals and Objectives to Guide United States Arctic Research* (December 1988)
5. *Arctic Data and Information: Issues and Goals* (June 1989)
6. *Improvements to the Scientific Content of the Environmental Impact Statement Process* (December 1989)
7. *Arctic Engineering Research: Initial Findings and Recommendations* (April 1990)
8. *Logistic Support of United States Research in Greenland: Current Situation and Prospects* (December 1990)
9. *Goals, Objectives and Priorities to Guide United States Arctic Research* (January 1991)

United States Arctic Research Commission

Twenty-Fifth Meeting
December 5–6, 1991

Commission Members Present: *Donald D. O'Dowd, Chairperson; John H. Steele, Vice Chairperson; Ben C. Gerwick; Clifford J. Groh; Elmer Rasmuson; Fred Bernthal representing the Ex-Officio Member;*

Staff: *Philip L. Johnson, Executive Director; and Lyle D. Perrigo.*

Advisors: *Jerry Brown, Arthur Grantz and George Newton*

Visitors: *Eddie Bernard, NOAA/PMEL, Seattle; Ted DeLaca, Charles Myers and Peter Wilkniss, National Science Foundation; Robert H. Bourke and Alan Thorndike, Naval Postgraduate School, Monterey; Martin Bozeman, ARCO, Anchorage; Walter Bugno, Chevron; LCDR Tom Cameron, PATROL WING FIVE, USN; Lou Codispoti, Monterey Bay Aquarium Research Institute; Greg Dreyer, Space, Naval Warfare System; RADM W.J. Ecker, LCDR Paul Luppert and CPT Alan Walker, U.S. Coast Guard; David Garman, Senate Intelligence Committee; Richard Hayes, U.S. Navy; Carla Helfferich, University of Alaska Press; Albert W. Johnson and Laura Lee McCauley, ARCUS; Leonard Johnson, Office of Naval Research; Waldo Lyon and CDR Carl Wales, Arctic Submarine Laboratory; C. Peter McRoy, University of Alaska–Fairbanks; David Orr, Alaska Division of Economic Development; RADM Ralph West, Superintendent, Naval Postgraduate School.*

The Arctic Research Commission held its meeting at the Naval Postgraduate School, Monterey, California, on December 5–6, 1991.

RADM West summarized the role and scope of the Naval Postgraduate School since its establishment in 1909. It now enrolls 1900 students who seek master's degrees in 37 fields in 11 academic departments. A dozen or so Ph.D. degrees are awarded each year. There are 350 faculty members, most of whom are civilians. There is a strong Oceanography Department with an Arctic program.

Chairperson O'Dowd summarized activities since the last Commission meeting in August. In September he addressed the Alaska State Chamber of Commerce in Kenai, Alaska. As the theme was environment and business relationships, he emphasized the Commission's recommendations for improving the environmental impact statement process.

The Chairman and the Executive Director attended the Polar Research Board meeting in October in Washington and participated in discussions with the Board on developing a U.S. position on the International Arctic Science Committee (IASC).

Plans to develop and recommend an agenda for research on oil spills in ice-infested waters have been developed. This issue emerged strongly at the Barrow meeting. Advisors Will Nelson and Walt Parker working with Lyle Perrigo have prepared an initial draft for comment.

Jerry Brown, Will Nelson and Juan Roederer have accepted the Commission's invitation to serve as Advisors for a two-year period.

Dr. O'Dowd has written Governor Hickel urging continued support and development of research potential at the University of Alaska.

In response to a request from the Danish Polar Center, the ARC staff conducted an inquiry of U.S. science interests and plans for rocket or balloon launches at Sondrestrom, Greenland, in support of atmospheric research. This information has been forwarded to Denmark and is part of the planning process to provide logistic support for science and engineering after withdrawal of the U.S. Air Force next summer.

Chairperson O'Dowd has written Secretary of Energy Watkins requesting information on DOE's research programs in the Arctic and observed their declining Arctic budget over the past five years.

Alaska Congressional Delegation

Dave Garman of Senator Murkowski's staff reported that the outlook for ANWR legislation is not good. As a staff member of the Senate Intelligence Committee (Senator Murkowski is co-chair), he indicated great interest in the logistic and human assets of the military as they may be applied to civilian problems in the far North. As military budgets are to be downsized by as much as 25% in coming years, some decrease in the intelligence budget is also likely. Mr. Garman distributed copies of the Senate Commerce Committee hearing on Arctic Ocean research on April 24, 1991.

Alaska Governor's Office

David Orr, Office of Economic Development, representing Governor Hickel, reported on the November 6–8, 1991, meeting of the Northern Forum hosted by the Governor. Fifteen regional governments agreed to establish a secretariat in Anchorage to facilitate "a mechanism for regular interactions among those who are northern leaders by virtue of the office they hold or by virtue of their ability to represent views of significant northern publics." The Forum adopted a resolution expressing great interest in expanded commercial shipping via the Northern Sea Route and commissioned an analysis of its potential. Mr. Orr indicated that such commercial ventures must be compatible with environmental concerns. He observed that research would be needed on sea ice conditions and movement, improved shallow draft vessel design, and impacts on marine mammals and sea birds.

Interagency Arctic Research Policy Committee

Fred Bernthal, Deputy Director, NSF, indicated that a report to the President for Congress summarizing the Federal response to recommendations by the Commission is being reviewed by the various agencies and will be part of the biennial report filed by January 31, 1992, as required by legislation.

Arctic Marine Research

A series of presentations on marine research and logistic capabilities in the Arctic by Navy personnel was briefly summarized.

Robert Bourke, Naval Postgraduate School, described the Arctic program within the Oceanography Department as focused on polar oceanography and meteorology. Research has concentrated on physical oceanography of the marginal ice zone, ice thickness, acoustic propagation, ambient noise and applications of remote sensing. Meteorological studies include momentum, heat flux and wind stress in the boundary layer over sea ice.

Arthur Horbach described on video how the Naval Air Development Center, Warminster, Pennsylvania, has obtained environmental acoustic data remotely by using data acquisition and recording systems aboard P-3 aircraft over the past seven years. These planes can remain aloft for 9–10 hours in the Arctic and can carry instruments, data-logging equipment and up to six scientists in addition to crew. Studies of various parameters of atmosphere, ice and ocean, as well as deployment of buoys, were discussed as examples appropriate to civilian science. LCDR Tom Cameron, COMPATWING FIVE, Brunswick, Maine, described the specific systems and methods for using P-3 aircraft for Arctic research. In addition to radio communication and navigation systems, he discussed sensors for underwater sound signatures, ambient sea noise, ocean water temperature gradients, acoustic analysis, magnetic anomalies and passive infrared heat detection.

Gregory Dreyer, Arctic Systems Division, Space and Warfare Systems Command, Washington, D.C., reported that this was the first time in 30 years that there are not manned Soviet ice camps in the Arctic Ocean. U.S. Navy ice camps are operated during March and April supported from Thule, Greenland, and Danish Station Nord. A camp on shore-fast ice is established off northeast Greenland (RUBY), and a high-Arctic science camp near the North Pole (CRYSTAL) and a small midway camp for refueling (JACKPOT) are established each year. All camp locations and logistics are unclassified, and scientific work can be scheduled such that no security clearances are required.

CDR Carl Wales, Arctic Submarine Laboratory, San Diego, California, discussed and illustrated the concept, advantages and limitations of using a submarine for research. Data and samples can be obtained within the water column and on the surface. In addition to the physical and chemical properties of water, under-ice and bottom topography profiling is often recorded. CDR Wales also discussed the Navy field station at Cape Prince of Wales, Alaska, on the westernmost tip of the Seward Peninsula on the Bering Strait. It has been operated by the Arctic Submarine Laboratory for over 40 years.

Peter McRoy, Institute of Marine Science, University of Alaska–Fairbanks, presented data showing the circulation of Pacific waters through the Bering Strait into the Beaufort Sea. Such water circulation has been traced and is confined to the U.S.–Canadian half of the Arctic Basin. In part, nutrients in this water account for high biological productivity ranging up to 500 g/m^2.

Waldo Lyon, Arctic Submarine Laboratory, discussed the development of this facility since 1941. Deep experimental pools and a model basin are used to study ice mechanics and other properties such as acoustical propagation. Dr. Lyon also discussed the problems associated with the operations of submarines under sea ice canopies and the attendant information needs of the military in this environment.

RADM William Ecker, Chief of the Office of Navigation Safety and Waterways Services, U.S. Coast Guard, acknowledged shortcomings of the recent science deployment of the icebreaker *Polar Star*, which led to the failure of an important part of the mission near Svalbard in 1991. As a result of post-deployment discussions, the Coast Guard, up to and including the Commandant, have instituted improvements for the future support of science.

Three Arctic projects are scheduled:

- A USGS project in the Beaufort and Chukchi seas in 1992;
- An NSF-sponsored project of the Northeast Water Polynya in East Greenland in 1992; and
- A Canadian–U.S. deployment with researchers from both nations from the Bering Strait to the Pole and exiting Denmark Strait.

RADM Ecker asked the Commission to support a request to OMB to waive the requirement for a user agency charge ($15,000 per day) because it has been shown to be ineffective and interferes with proper scheduling of both research and ship time.

Leonard Johnson, Office of Naval Research, Arlington, Virginia, described the Arctic research activities supported by ONR. In the Ocean Science Division, research is focused on processes of air–ice–ocean interaction, marginal ice zone processes, shelf-basin dynamics and structure, ice–acoustic interaction, ice–electromagnetic interaction and instrument development. Arctic science funding in FY 91 was about $10.32 million but is likely to decline after 1993. Interagency coordination is very well advanced in Arctic marine activities. Much of the ONR interest in Arctic processes is centered on time scales of less than a year, whereas USGS,

NSF and NASA are more concerned with time frames of years to centuries. NOAA activities concern both short- and long-term events. A number of ONR Arctic activities have multiple agency participants.

Richard Hayes, Office of the Oceanographer of the Navy, Washington, D.C., reported that as a result of Senator Gore's interest there had so far been two releases of upward-looking sonar data from nine under-ice deployments. A Federal consortium of NSF, ONR, NOAA and NASA has agreed to a national Arctic data buoy program that plans to support up to 28 drifting buoys. Data will be filed with the Joint Ice Center operated by the Navy. Similarly new data from the Alaska SAR Facility will be provided to the Joint Ice Center in support of sea ice analyses and forecasts.

Priorities in Arctic Geoscience

Art Grantz, USGS, Menlo Park, California, reported in his capacity as chairman of a committee on Arctic geosciences of the Polar Research Board. He summarized the recently published PRB report on research priorities in Arctic earth sciences.

There is broad agreement in the geosciences community that the floor of the Arctic Ocean Basin contains potential answers to major unsolved problems in the earth sciences and that many of them pertain to questions that are of global scientific significance or pressing social concern. However, because of the perennial sea ice, harsh climate, high field costs and absence of research platforms suitable for many types of investigations, this region is also one of the least known on earth. The Committee on Arctic Solid-Earth Geosciences believes that a three-part program of solid-earth studies in the basin would address the identified opportunities for geoscience research in the Arctic Ocean region and would serve societal needs by increasing understanding of the earth's crust beneath the Arctic Ocean, thereby expanding the database on resources, climate and basic geologic processes.

Part one, the Geologic Framework and Tectonic Evolution, concentrates on the less-understood Amerasian Basin, includes selected problems in the Eurasian Basin and proposes extensive studies of Arctic continental margins. Part two of the program, The Sedimentary Record and Environmental History, proposes a detailed exploration of the 200-million-year-old record of Arctic climate, oceanographic conditions and faunal evolution and migration that is incorporated in the circumarctic sedimentary record. Part three, Arctic Geologic Processes and Environmental Indicators, examines a variety of processes and conditions that are either unique or well developed in the Arctic and that, if better understood, would improve our ability to interpret the environmental history of the Arctic and therefore to predict climate change.

If a sufficiently strong commitment were made to an augmented Arctic geosciences program, nuclear submarines could map the Arctic seabed with side-scan sonar and echo sounders, record its potential field with gravimeters and magnetometers, and probe its subseabed geologic structure and stratigraphy with continuous seismic reflection profiling methods.

Pilot Research Projects at PMEL

Eddie Bernard, Director, Pacific Marine Environmental Laboratory, NOAA, reported that in general Arctic initiatives at PMEL consisted of small pilot projects, as they had not been able to fund any large Arctic initiatives. However, in 1990 and 1991 PMEL deployed and recovered a series of moored data buoys in the Chukchi Sea in collaboration with the Arctic and Antarctic Research Institute in St. Petersburg. The data demonstrate rather dramatic reversals of current flow within a few days. Such data are important in understanding the exchange of water through the Bering Strait and its flow along ocean shelves into the Arctic Basin.

A second project is obtaining data on pollack age and population dynamics in the eastern and western shelves of the Bering Sea as a basis for numerical modeling. Such model projections are needed for understanding and managing fishing in the central Bering Sea by foreign vessels. The project is in collaboration with the National Marine Fisheries Laboratory.

AOGA Lease Planning and Research Priorities

Walter Bugno, Chevron Corporation, reported on behalf of the Lease Planning and Research Committee of the Alaska Oil and Gas Association. He is also one of the oil company representatives on the ONR review committee. Mr. Bugno indicated that current Arctic research priorities as viewed from the oil industry are:

- An expanded database of available Arctic information, particularly for offshore environments;
- Further refinement of satellite remote sensing methods and applications;
- Sea ice studies, especially their impact on structures; and
- Further development of alternative drilling and production technologies.

Mr. Bugno described the Alberta Underground Test Facility, which consists of 700-ft shafts and 6 miles of tunnels in oil sands. In this facility, techniques for drilling, tunneling and oil extraction are

being tested. It now appears that Canada's large reserves of bitumen can be commercialized competitively at a $21–22 West Texas crude price.

Alaska Clean Seas is planning a 1000-barrel in-situ oil burning experiment in August or September 1992, probably off Prudhoe Bay, Alaska. It is seeking needed Federal and state permits, as well as collaboration with interested agencies. Elmer Rasmuson observed that the Commission recommendations to improve the EIS process appeared to be relevant to this project.

Oil Spill Prevention, Containment and Cleanup Research

Lyle Perrigo summarized the status of the Commission's task to develop and recommend a research agenda to guide Arctic oil spill research. The Commission's experience, strongly supported by the public meeting at Barrow last August, is that the potential for oil spills in ice-laden Arctic waters is among the major reasons for public opposition to offshore oil exploration and production in the Arctic. The draft for discussion, *Research Needed for Response to Oil Spills in Ice-Infested Waters*, is a status report of the issue, including recommendations for research priorities. Staff are to incorporate comments and solicit reviews from a variety of experts before final review and publication.

Criteria for Selection of IASC Programs

The Polar Board (PRB) asked the Commission (July 9, 1991) for suggestions for specific programs and criteria for selecting the activities of the International Arctic Science Committee (IASC). Accordingly the staff prepared a statement recommending for IASC discussion four research themes: climate change in the Arctic, circumarctic environmental monitoring and assessment, Arctic Basin and margins geology and ecology, and comparative mortality, morbidity and treatment effectiveness among Arctic residents. Criteria for screening and operating projects were proposed, as well as suggestions on organizational linkages for IASC and the limitations of inventorying current Arctic research.

Other Business

The planned facility upgrade of the Poker Flat facility was discussed with Dr. Akasofu, and the funds appropriated have been transferred from the Air Force to NASA. The NSF FY 92 appropriation included up to $7.5 million for additional Arctic research support. The Commission continues to press for funding of an Arctic research vessel via NSF. In the area of Arctic health, discussions with Dr. Middaugh and the University of Alaska indicate that establishment of a research center for accidental injury by the Public Health Service is under active consideration for 1992.

Ben Gerwick called attention to the recently published reference text, *Construction in Cold Regions*, by T. T. McFadden and F. L. Bennett (John Wiley and Sons), as well done and responsive to the Commission's concerns in the area of Arctic construction problems.

Forthcoming Meetings

Listed here is a compilation of recent and forthcoming meetings, workshops and conferences on Arctic or northern topics and activities. Readers are invited to submit information on upcoming meetings, as well as reports on national or international meetings attended, to Editor, Arctic Research, *National Science Foundation, Room 620, 1800 G St., NW, Washington, D.C. 20550.*

1992

14th Polar Libraries Colloquy—International Sharing of Polar Information Resources
3–8 May 1992, Columbus, Ohio
Contact: Lynn Lay, Byrd Polar Research Center, The Ohio State University, 125 South Oval Mall, Columbus, Ohio 43210-1308
Phone: (614) 292-6715
Fax: (614) 292-4697
OMNET: BYRD.POLAR

Second Circumpolar Symposium on Remote Sensing of Arctic Environments
4–6 May 1992, Tromsø, Norway
Contact: The Roald Amundsen Centre for Arctic Research, University of Tromsø, N-9000 Tromsø, Norway
Phone: +47 83 45 240
Fax: +47 83 80 705

The Impacts of Climate Change on Resource Management of the North
12–14 May 1992, Whitehorse, Yukon Territories, Canada
U.S. Contact: William Bolhofer, NOAA, 1825 Connecticut Avenue, Washington, D.C. 20235
Phone: (202) 606-4360
Fax: (202) 606-4355

Symposium on Remote Sensing in Glaciology III
17–22 May 1992, Boulder, Colorado
Contact: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, United Kingdom
Phone: +223 355974
Fax: +233 336543

Symposium on Fish Ecology in Arctic North America
19–22 May 1992, Fairbanks, Alaska
Contact: Sharon Oren, Conferences and Special Events, 117 Eielson Building, University of Alaska, Fairbanks, Alaska 99775-0540
Phone: (907) 474-7800
Fax: (907) 474-5592

Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting
25–27 May 1992, Wolfville, Nova Scotia, Canada
Contact: Wolfville '92, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada
Phone: (902) 542-1902
Fax: (902) 542-1454

Symposium on the State of the Environment and Its Monitoring in Northern Fennoscandia and the Kola Peninsula
8–10 June 1992, Rovaniemi, Finland
Contact: Raija Kivalahti, Arctic Center, University of Lapland, P.O. Box 122, 96101 Rovaniemi, Finland
Phone: (60) 324 278
Fax: (60) 324 270

Arctic and Marine Oilspill Program, 15th Technical Seminar
10–12 June 1992, Edmonton, Alberta, Canada
Contact: Susan Clarke, Seminar Coordinator, Technology Development Branch, Environmental Protection, Unit 100, Asticou Centre, 241 Cité des Jeunes Blvd., Hull, Quebec K1A 0H3, Canada
Phone: (819) 953-5227
Fax: (819) 953-9029

Second (1992) International Offshore and Polar Engineering Conference
14–19 June 1992, San Francisco, California, U.S.A.
Contact: ISOPE-92, P.O.Box 1107, Golden, Colorado 80402-1107
Phone: (303) 273-3673
Fax: (303) 420-3760

BOSS 92—International Conference on Behaviour of Offshore Structures
7–10 July 1992, Imperial College, London
Contact: BOSS 92 Secretariat, BPP Technical Services Ltd., 2 Tavistock Place, London, WC1H 9RA, England
Phone: 071-837-6362
Fax: 071-837-0822

Specialty Meeting on Airborne Radars and Lidars
7–10 July 1992, Toulouse, France
Contact: Jean-Pierre Chalon, CNRM/METEO-FRANCE, 42 Avenue Coriolis, 31057 TOULOUSE Cedex, France
Phone: (33) 61 07 93 69
Fax: (33) 61 07 96 00
or
Warren Johnson, NCAR, Atmospheric Technology Division, P.O. Box 3000, Boulder, Colorado
Phone: (303) 497-8848
Fax: (303) 497-8770

Sixth Inuit Circumpolar Conference (ICC) General Assembly and Elders Conference, "One Arctic—One Future"
20–24 July 1992, Inuvik and Tuktoyaktuk, Northwest Territories, Canada
Contact: Peggy Jay, ICC Conference Coordinator, P.O. Box 2120, Inuvik, Northwest Territories, Canada X0E 0T0
Phone: (403) 979-2737
Fax: (403) 979-2135

27th Congress of the International Geographical Union
9–14 August 1992, Washington, D.C.
Contact: IGU Congress Secretariat, 1145 17th and M Street NW, Washington, D.C. 20036
Phone: (202) 828-6688

Third International Conference on Ice Technology
11–13 August 1992, MIT, Cambridge, Massachusetts
Contact: Sue Owen, Conference Secretariat, Wessex Institute of Technology, Ashurst Lodge, Ashurst, Southampton SO4 2AA, United Kingdom
Phone: 44 703 293223
Fax: 44 703 292853

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