Department of Commerce

National Oceanic and Atmospheric Administration

NOAA performs research in the high-latitude regions of the planet in connection with its environmental assessment, monitoring, and prediction responsibilities. Research programs focus on scientific questions that address the Arctic environment and its relation to the global environment.

Office of Oceanic and Atmospheric Research

Arctic Research Office

The Arctic Research Office was formed in FY 2000 to administer the Arctic Research Initiative and to build a NOAA program focused on Arctic science issues of national importance. For this purpose, the "Arctic" is defined loosely as the northern hemisphere land area underlain by permanent or discontinuous permafrost, and ocean areas subject to permanent or annual sea ice cover. Consideration of watersheds and airsheds that flow to the Arctic can extend the geographic boundaries significantly, as can consideration of the impacts of Arctic processes on hemispheric weather and climate. In FY 2003, newly appropriated funds became available to initiate a NOAA contribution to the interagency Study of Environmental Arctic Change (SEARCH).

Under the overall guidance of the NOAA Strategic Plan, the ARO has formulated more specific goals that relate to its specific mission:

- Characterize poorly known high-latitude marine habitats and understand and model factors controlling the populations of key marine species in the Arctic and sub-Arctic;
- Monitor ecosystem indicators of climate change;
- Understand ecosystem impacts of critical contaminants and human uses in the Arctic; and
- Understand the causes and impacts of atmospheric, oceanic, and climate variability and change in the Arctic.

Several projects are planned over the next few years to address these goals and contribute to the SEARCH Science Plan. These projects are:

- Retrospective Analysis of Ocean Climate and Populations of Key Living Marine Resources;
- Collaborative, international program of Arctic exploration;
- Bering Sea Ecosystem Study;
- Atmospheric and Cryospheric Change in the Arctic;
- Arctic/Sub-Arctic Ocean Fluxes;
- Arctic System Reanalysis;
- Arctic Climate Impact Assessment;
- Environmental Sources, Fate, and Impact of Mercury and Persistent Organic Pollutants in the Arctic;
- Assessment of Environmental and Economic Impacts of Oil and Gas in the Arctic; and
- Development of updated AMAP Strategic Plan.

To date NOAA has funded the following SEARCH programs.

Retrospective Analysis of Arctic Clouds and Radiation from Surface and Satellite Measurements. Recent studies have shown that Northern Hemisphere sea ice extent and thickness have been decreasing, while land surface air tempera-

	Funding (thousands)	
	FY 02	FY 03
Atmos Trace Constituents	800	300
Fisheries Assess/Manage	18,900	18,900
Marine Mammal Assessment	12,675	6,675
Ocean Assessment	15	10
Stratospheric Ozone	250	200
Data Management	357	331
Remote Sensing	388	273
Aircraft/Vessels	2,053	550
Weather Research	0	25
Western Arctic/Bering Sea Ecosys	7,507	2,050
Barrow Observatory	1,350	650
Ocean Exploration	808	250
Tsunami Warning/Env. Obs	250	250
Arctic Research Initiative	1,650	2,000
Ocean Observations/Arctic Fluxes	360	360
Arctic Climate Research (SEARCH)	0	2,000
CIFAR	0	350
Total	47,363	35,174

ture has increased markedly over the last 30 years. Arctic climate change has also been noted in the horizontal flux of precipitable water snowfall and in vegetation. While these studies indicate that the Arctic has been warming, it is not clear how other aspects of the climate system have forced the change. In particular, how do changes in surface and cloud properties interact and affect the surface radiation budget; that is, what is the cloud–radiation feedback?

Answers to these questions will only come through an analysis of multi-decadal data sets. Surface-based meteorological and radiation data have been collected at various locations across the Arctic for many years, with some observations dating back to the 1920s. However, surface stations are sparse, and many are scaling back operations. Satellite meteorological data sets that now span two decades provide a pan-Arctic perspective. While the measurement principles are very different, both types of observations offer the potential to detect and monitor climate change. For example, long-term measurements from meteorological stations have shown that the surface temperature of the Arctic land areas has been increasing over the past few decades. These trends have been verified by satellite data for the past 20 years, and trends in satellite-derived cloud amount and the cloud radiative effect have recently been reported. Similar trends found at surface stations corroborate the satellite findings.

Nevertheless, there is still much that can be learned from the historical surface and satellite data sets. Cloud and radiation fields need to be examined in more detail, other geophysical parameters should be examined, similarities and differences in surface and satellite-derived measurements need to be assessed, and regional trends must be explained. Furthermore, the interactions between parameters, such as the ice/snow albedo and cloud radiation feedbacks, are poorly understood. The objective of this element is to evaluate the degree to which historical and ongoing measurements can be used to answer SEARCH science questions and to aid in evaluating optimum locations for an expansion of the Arctic observing network. The task is to perform a retrospective analysis of coincident surface measurements and satellite-derived quantities, comparing one to the other and assessing the spatial and temporal variability in each parameter.

Atmospheric Observatory Site Selection Building National and International Linkages. This element contains three main objectives critical to the success of SEARCH. First, information on existing environmental monitoring in the Arctic will be compiled, and selected data sets will be analyzed for their usefulness in providing information on trend detection. The analysis is expected to yield information about the locations, time scales, and variables most likely to allow climate trends in the Arctic to be detected. Second, the combined information about current and optimal monitoring will help suggest strategic locations for atmospheric observing stations. The ability to build off or utilize existing measurements programs and infrastructure will be considered in developing recommendations for possible locations. Third, coordination and linkages will be developed between national and international polar programs and observing networks. This coordination will assist in maximizing the SEARCH measurement program goals.

Atmospheric Observatory. At present, the only continuous measurements of Arctic surface radiation, clouds, aerosols, and chemistry sufficient for detailed evaluation of interactive climate change processes in the lower atmosphere (0–15 km) are made in Barrow, Alaska. The Barrow facilities include the National Weather Service (with records from the 1920s), the NOAA/CMDL Baseline Observatory (in operation since 1972), and the DOE ARM North Slope of Alaska (NSA) site (in operation since 1998). It is the intention of the Atmospheric Observatory Element of the NOAA/SEARCH program to mirror the Barrow atmospheric measurements, first in northeastern Canada and at some later date in central Siberia.

The Canadian and Siberian regions have been selected based on the principal hypothesis of the SEARCH program that Arctic climate change is related to the Arctic Oscillation (AO). There have been observations of large-scale co-variability between a number of climatic variables (surface temperature, hydrological balances, cloud cover, winds) with the primary modes of the Arctic Oscillation. Analyses suggest that one of the most significant AO-related trends over the last 50 years is warming in eastern Siberia and cooling in the northeastern Canada–western Greenland region. The Barrow site appears to be in a region of lower variability with respect to the AO, so additional measurements in the regions where AO-related variability is expected to be the most pronounced are desirable. A coordinated set of intensive atmospheric measurements in Alaska, northeastern Canada, and Siberia will not only provide important observational records on regional variations

within the Arctic but will also provide key data sets for validating satellite measurements and improving model parameterizations.

Correction of Systematic Errors in TOVS Radiances. The TIROS Operational Vertical Sounder (TOVS) instrument has flown on NOAA polar-orbiting satellites since 1979 and has collected one of the longest and most complete satellite data records in existence. It was originally designed to serve the weather forecasting community by providing temperature and moisture profiles in regions of the earth that have few conventional meteorological stations. The TOVS data can also be used to retrieve cloud properties (coverage, cloud-top height, optical depth, and phase) and surface properties (skin temperature, surface type, and drag coefficient). While this instrument was intended for operational applications, many researchers have demonstrated its tremendous potential for studying a wide range of climate applications as well, particularly in regions with poor coverage of conventional measurements, such as the Arctic Ocean and adjacent seas.

A problem arises in using TOVS data for climate applications, however, as the radiances were not adequately calibrated for long-term accuracy. Consequently, substantial systematic errors from various sources greatly reduce the potential value of TOVS observations for monitoring and understanding climate change. The proposed work will attempt to identify, quantify, and mitigate these errors, with the ultimate goal of producing a 20-year (or more) record of TOVS radiances and retrieved products that are as error-free as practicable, given available resources. Many of the known errors should be regionally and seasonally independent, but some may be peculiar to or exacerbated by Arctic conditions. Thus, while the efforts will be global, the focus will be primarily Arctic. The expected product of this investigation will be a data set of tremendous value for geophysical retrievals with sufficient accuracy to identify changes since 1979, as well as for direct assimilation by numerical atmospheric models.

Observations for SEARCH: Data Integration for Arctic Reanalysis and Change Detection. Unaami, the changes in the Arctic that are the subject of the SEARCH program, became apparent to researchers in the context of long-term and pan-Arctic observations. In November 2001 the SEARCH Workshop on Large-Scale Atmosphere/Cryosphere Observations reached two related conclusions:

- There is no cohesion among various Arctic disciplines and data types to form a complete observation set of Arctic change; and
- Present data are vastly underutilized in understanding Arctic change.

The proposed work will address these conclusions by assessing what data are relevant to SEARCH reanalysis and change detection activities, collecting these data from a wide variety of sources, and facilitating the SEARCH research community's access to the data. The work will be carried out in cooperation with Jim Overland, PMEL, as a contribution to the NOAA SEARCH Arctic Change Detection and Reanalysis efforts.

There are many existing observational data sets that may be useful to SEARCH but that are underutilized for reasons that may include:

- They cover only a limited length in time or spatial extent;
- They have unknown accuracy and limited or no information about observing methods;
- They are not an ongoing record;
- They are inaccessible or costly to acquire; or
- The research community is unaware that they exist.

In addition to observational data sets, there are data streams that are underutilized. For example, only about 10% of the Russian national station network data are internationally exchanged over the GTS system and included in quality-controlled data sets available from U.S. national data centers.

These underutilized data sources are not optimal because of the effort required to use them, but at the same time they can be vitally important to reanalysis and change detection efforts. For example, the planned Arctic reanalysis will assimilate precipitation data in order to improve how the model treats moisture. Yet precipitation measurements are especially problematic in the Arctic, there are a number of data sets with differing characteristics, and a data stream for ongoing measurements has not been identified. Permafrost extent, borehole temperature, and active layer depth are sensitive indicators of climate change and therefore good candidates for climate indices. These observations reside in a number of institutions around the world, and here the challenge will be to obtain and combine data sets into useful Arctic-wide products.

Arctic Change Detection. A major task outlined in the SEARCH Science Plan is to determine how current and retrospective observations can be best used and enhanced to understand and anticipate the course of the ongoing changes in the Arctic. This project will address the highest prior-

ity identified in the SEARCH Implementation Plan, specifically, to understand the key characteristics of the multivariate change in the Arctic in space, time, and persistence.

There is a need for high knowledge return on existing and future data and for the capability to supply this information to nonspecialists and interdisciplinary researchers. This is a challenging task. It seeks to include operational weather and climate data rather than relying on a focused experimental design such as SHEBA. It is multidisciplinary, and its goal is knowledge extraction, a task beyond the development of data archives, or even data accessibility. The development of an Arctic Change Detection protocol is a necessary SEARCH startup activity.

While many SEARCH activities seek to documenting Arctic climate processes, this project will assume a larger role of providing the global change and broader communities with a clear understanding of the complex changes that are occurring in the Arctic. Communicating climate change information is a difficult process. NOAA's new role as a leader of the U.S. Climate Program makes this function all the more necessary, as NOAA has an explicit responsibility for communicating scientifically validated Arctic status and change information.

There is some recent help in this process. The field of data mining has now been extended to knowledge discovery, which recognizes the important step of consolidating information into knowledge and communicating the results. Certain guidelines for communicating climate change detection and ecological indicators to decision makers and the public are being articulated. Of particular importance is the issue of uncertainty. Methods for the rational use of environmental indices is also developing rapidly.

A broad review of recent changes in the Arctic has been accomplished. Of importance now is to reduce this information to a set of several key indicators of Arctic change and to relate the magnitude, location, and causes of current changes (the previous 30 years) to extremes in earlier historical and proxy records.

Initiation of an Arctic Reanalysis Activity in SEARCH. At the SEARCH Workshop on Large-Scale Atmosphere/Cryosphere Interactions (in Seattle, WA, in November 2001), the presentations and discussions provided several reasons why a compelling case could be made for an Arctic reanalysis. First, the reanalysis would produce long time series of temporally and dynamically consistent fields (subject to changes in observing system input) of Arctic upper-air and surface winds, humidities, and temperatures for studies of circulation variability, for budget studies, and for the driving of sea ice and ocean models. Second, the atmospheric component of the reanalysis would provide fields for which direct observations are sparse or problematic (such as precipitation, evapotranspiration, radiation, and clouds) at higher spatial and temporal resolution, and with greater reliability, than from existing reanalyses. Third, the system-oriented approach required for a reanalysis would provide a community focus, involving at least the Arctic terrestrial, sea ice, and atmospheric communities. Fourth, the reanalysis would leverage upon, and provide a synthesis of, Arctic field programs (SHEBA, LAII/ATLAS, ARM), capitalizing on prior investments by bringing field results to bear on the parameterizations used in large-scale models. Finally, the groundwork for an Arctic regional reanalysis can now be performed by capitalizing upon ongoing efforts such as ERA-40 and NCEP's North American Regional Reanalysis (NARR), as well as recently compiled Polar Pathfinder products from satellites. The coincidence of this groundwork and the spin-up of SEARCH provides a unique window of opportunity for an Arctic reanalysis. However, in addressing the viability of an Arctic system reanalysis, the recent workshop report notes that preliminary activities need to be undertaken now if SEARCH is to capitalize on this window of opportunity. For example, the reprocessing of the TOVS radiances will likely require several years. In addition, the momentum provided by ERA-40 and NCEP's NARR can be harnessed for SEARCH only if the Arctic output from these efforts is evaluated by the Arctic community, allowing for the implementation of parameterizations tailored to Arctic conditions. The enhancement of ERA-40's Arctic performance resulted from several years of such evaluation (and associated enhancements) of ERA-15 by a core of Arctic investigators.

Monitoring Ice Thickness in the Western Arctic Ocean. Recent studies indicate that the sea ice cover is undergoing significant climate-induced changes, affecting both its extent and thickness. For instance, satellite-derived estimates of maximum ice extent suggest a net reduction between 1978 and 1996, at an average rate of –3% per decade. A recent report indicates an even more rapid reduction in the perennial sea ice cover: –9% per decade. Data on the ice thickness, derived from submarine-based upward-looking

sonar, also suggest a net thinning of the sea ice cover since 1958. NOAA is continuing to monitor these changes to improve the fundamental understanding of the role of the sea ice cover in the global climate system and to take advantage of the sensitivity of the sea ice cover as an early indicator of the magnitude and impact of climate change.

The extent of the sea ice cover is effectively monitored from satellite platforms using passive microwave imagery. Monitoring changes in the ice thickness is more problematic. As with ice extent, the ideal platform for monitoring ice thickness is a satellite because it provides a full-basin perspective. However, to date, no technique has been adequately developed to obtain satellite-based measurements of ice thickness. Until satellite imagery can be used to monitor ice thickness, we must rely on measurements made from submarines, aircraft, seafloor moorings, and drifting buoys. As determined at the recent SEARCH Workshop on Large-Scale Atmospheric/Cryospheric Observations, this is most effectively done through a coordinated effort to establish a large-scale sea ice observing system. It is also necessary to disseminate the data collected from the various components of this system to the scientific community in a timely and consistent fashion. Once available, the data can be used to gain insight on the relationship between the characteristics of the sea ice cover and climatic forcing. Specific emphasis should be placed on efforts to work in tandem with those developing satellite-based assets designed to measure ice thickness. Data from the ice-based observing system can play a central role in assuring an optimal approach for obtaining accurate satellite-based measurements. Together, these platforms can provide an effective means of assessing the state of the sea ice cover over the entire Arctic basin.

The primary objective of this proposal and the related proposal "Monitoring the Eurasian Basin of the Arctic Ocean" is to establish and maintain a large-scale sea ice thickness observing system. The establishment of two distinct elements recognizes the different logistical challenges in the western and eastern sectors of the Arctic region. This proposal focuses specifically on measurements within the western sector of the Arctic. This sector of the Arctic is currently more accessible and therefore makes it feasible to conduct a program involving instrumentation that must be maintained after deployment. Within the western sector of the Arctic, this proposal seeks to initiate an array of moored upward-looking sonar (ULS) and drifting buoys. In the eastern sector of the Arctic, the focus of the proposal "Monitoring the Eurasian Basin of the Arctic Ocean," the instrumentation would be limited to the drifting buoys, which only need support during the deployment phase. Recently, it has been revealed that the Russians plan to establish a permanent, manned ice camp within the eastern sector of the Arctic, which will be available to the scientific community at large as an operational platform. If this resource becomes a reality, it may be possible to extend the deployment range of the moored ULS.

Instrumentation within the large-scale observing network will be located to complement existing measurement sites and activities and to take advantage of historical data records. Specifically, it will augment the data currently being collected at the North Pole Environmental Observatory (NPEO, http://psc.apl.washington.edu/northpole/), by the International Arctic Buoy Program (IABP, http://iabp.apl.washington.edu/), and from SCICEX cruises. Specific site locations will be determined using models of ice motion, which incorporate recorded observations. Data from the observation sites will be combined with data from other sources to produce annual reports on the state of the sea ice cover, including both its extent and thickness. A contextual setting for current data will be established by summarizing earlier western Arctic observations of sea ice mass balance over an annual cycle, beginning in 1957. The availability of data in the Russian literature, which is likely to cover the eastern Arctic, will also be investigated.

Monitoring the Eurasian Basin of the Arctic Ocean. NOAA has funded a network of automatic data buoys to monitor synoptic-scale fields of sea level pressure, surface air temperature, and ice motion throughout the Arctic Ocean as recommended by the U.S. National Academy of Sciences in 1974. Based on the Academy's recommendation, the Arctic Ocean Buoy Program was established by the Polar Science Center (PSC), Applied Physics Laboratory (APL), University of Washington, in 1978 to support the Global Weather Experiment. Operations began in early 1979, and the program continued through 1990 under funding from various agencies. In 1991 the International Arctic Buoy Program (IABP) succeeded the Arctic Ocean Buoy Program, but the basic objective remains—to maintain a network of drifting buoys on the Arctic Ocean to provide meteorological and oceanographic data for real-time operational requirements and research purposes, including support to the World Climate Research Programme

and the World Weather Watch Programme.

Dramatic changes in Arctic climate have been noted during the past two decades. Observations from the IABP have played a significant role in the detection of this change over the Arctic Ocean. For example, IABP data have shown that sea level pressure has decreased, surface air temperature has increased, and the circulation of sea ice and the ocean have changed so as to flow less clockwise. In addition to studies of Arctic climate and climate change, observations from the IABP are also used for validating satellites, for forcing, for validation and assimilation into numerical climate models, and for forecasting weather and ice conditions.

The continued success of the IABP, and our ability to monitor many aspects of Arctic climate change, depend on maintaining and further developing the buoy network. The buoys drift with the sea ice and have finite life spans, so a tremendous amount of resources are required to purchase and deploy buoys to maintain the buoy network. In the past the IABP was able to seed the buoy network in the Beaufort Sea, and the large, clockwise gyre circulation would carry the buoys out to cover the Arctic Ocean. However, given the changes in circulation, the Beaufort Gyre has shrunk, and maintaining the buoy network in the Eurasian Arctic has been more difficult. For example, the latest map of buoys on the Arctic Ocean shows that only 6 of the 26 buoys in the network are monitoring the Eurasian Basin.

Monitoring the Eurasian Basin is important, as this is the center of many of the changes in Arctic climate. For example, the decrease in sea level pressure, the warming in surface air temperature, and the thinning of Arctic sea ice are most significant in this area. One could ask, did the increase in surface air temperature act to thin sea ice, or did the thinner sea ice allow more heat to flux from the ocean to warm the atmosphere? It has been hypothesized that the dynamic thinning of sea ice driven by the changes in atmospheric circulation causes the increasing trends in surface air temperature. Enhanced buoys will be placed in the Eurasian Basin of the Arctic Ocean in 2004 to monitor the thickness of sea ice. Establishing a record of climate-induced changes in the thickness of the sea ice cover is essential to understanding the role of the sea ice cover in the global climate system and to using the sea ice cover as an early indicator of climate change in the polar regions. As explained in the recent report on the SEARCH Workshop on Large-Scale Atmosphere/Cryosphere Observations, buoys within the IABP network can play an important role in monitoring changes in ice thickness by enhancing their measurement system.

Oceanic Observations of Climate Change in the Arctic–Subpolar Zone. This is a new, multiyear project to observe water masses and fluxes of water, salt, heat, ice, and tracers between the Arctic Ocean and the sub-Arctic seas. The goal is to provide understanding of the changing state of the Arctic and anticipate its future. The logistic issues are severe and require innovative observational platforms as proposed here. The project will utilize sea-gliders and ice-hardened moorings to provide the physical data. A retrospective analysis of existing tracer data will provide context for the new data.

Ecosystem Change in the Northern Bering Sea. This project investigates the hypothesis that recent anomalous spring and summer productivity on the Northern Bering Sea shelf relates to decadal-scale atmospheric/sea ice/oceanographic processes, reflecting regime-induced climate changes in the western Arctic. Recent work shows that there are hot spots of biological productivity southwest of Saint Lawrence Island and that this productivity has been decreasing over the past decade. The Bering Sea is shifting to an earlier spring transition, based on ice melt and changes in atmospheric circulation patterns. Since changes in the north Pacific Ocean show little long-term trend while the trend in Arctic Oscillation appears to be a clearly increasing climate signal, the northern Bering Sea is an important location to monitor for ecosystem changes. The recent studies demonstrate the timeliness for increased focus on the ecosystem of the northern Bering Sea. Such a program would include the following tasks:

- A retrospective analysis of all northern Bering Sea data to put future changes into context and to provide an objective measure for change detection;
- Establishment of a northwest Bering Sea biophysical oceanographic mooring to document ongoing changes, similar to the successful multiyear FOCI mooring, M2, on the southeast Bering Sea shelf; and
- Process studies of the northern biological hot spots, primarily funded by non-NOAA sources.

Ice Dynamics and Oceanography

NOAA supports a program to carry out observations and modeling of the freshwater dynamics connecting the Arctic and Atlantic Oceans. Concentrated activity occurs where the Arctic and

Atlantic meet and interact. Increasing amounts of fresh water have been pouring out of the Arctic and, in combination with intensified winds, have altered the circulation of the Atlantic. Improved observations of water masses and fluxes of water, salt, ice, and tracers between the Arctic and the Atlantic will help us understand this changing state and anticipate its future. An investigator at the University of Washington is studying observational and modeling methods relevant to the intense flows linking the Arctic and Atlantic Oceans. He is examining the feasibility of an affordable but adequate long-term measurement program in the Canadian Archipelago and Davis Strait, the Labrador Sea, and the Labrador continental shelf.

NOAA is continuing to study the variability of thermohaline circulation and freshwater storage in the Arctic Ocean. The Arctic Ocean and its marginal seas are key areas for understanding the Arctic climate system and its change through time. Changes in the freshwater balance would influence the extent of sea ice cover; changes in surface albedo, energy balance, temperature, and the salinity of water masses; and biological processes in the Arctic.

Ocean and Coastal Ecosystems and Living Resources

NOAA has undertaken several programs focusing on ocean ecosystems, including analyses in the Bering Sea region to study climate variability and its impacts on ecosystems and a study of the trophic pathways on the Chukchi–Beaufort shelf. Microalgae grow on the undersurface of sea ice as well as within the sea ice matrix and are a well-known feature of Arctic ecosystems. They contribute a poorly known proportion of the total primary production in Arctic seas, and recent studies suggest that ice algal primary productivity has been greatly underestimated. Ice algae are important to microbial food webs and the dissolved and particulate carbon and nitrogen pools of the Arctic Ocean. Novel techniques are being used to quantitatively trace carbon fixed by ice algae and water column phytoplankton through pelagic and benthic food webs using conservative fatty acid signatures. The results of this work will help us understand trophic dependencies and carbon budgets in Arctic food webs and predict the effects of environmental change caused by global warming and further reductions in sea ice.

NOAA's Arctic Research Office has supported projects to examine possible connections between Arctic climate and oceanic change and the declining Steller's sea lion population. The areas of interest include the impacts of climate change on the Bering Sea ecosystem over the past 500 years, retrospective studies of climate impacts on Alaskan Steller's sea lions, the nature of North Pacific regime shifts and their impacts on Steller's sea lions, ocean climate variability as a potential influence on Steller's sea lion populations, north Pacific climate variability and Steller's sea lion ecology, interannual variability of biophysical linkages between the basin and shelf in the Bering Sea, and climate-driven bottom-up processes and killer whale abundance as factors in Steller's sea lion population trends in the Aleutian Islands. The National Marine Mammal Laboratory's Alaska Regional Office and Protected Resources Management Division are responsible for research on the management of 22 species of marine mammals that commonly occur in Alaska, including the Steller's sea lion.

NOAA's Resource Assessment and Conservation Engineering Division and Resource Ecology and Fisheries Management Division are promoting a full-scale program to provide information on the run characteristics of Yukon River Chinook salmon. Over 1,100 fish will be radio-tagged near the river mouth and tracked to upriver spawning areas to provide information on stock composition and timing, nation of origin, migration patterns, and the location of previously undocumented spawning areas.

NOAA's Pacific Marine Environmental Laboratory (PMEL) conducts fisheries oceanography and ecosystem studies in the Bering Sea and the western Gulf of Alaska. Fisheries–Oceanography Coordinated Investigations (FOCI) is a cooperative program among PMEL, NMFS's Alaska Fisheries Science Center, NOS's Coastal Ocean Program, and the University of Alaska. FOCI's goals are to increase understanding of the Alaskan marine ecosystem, to document the role of walleye pollock in the ecosystem, to determine factors that affect pollock survival, and to develop and test annual indices of pre-recruit pollock abundance. FOCI is also investigating decadal variability and climate change of the North Pacific and western Arctic, particularly in light of the declining Steller's sea lion population.

Underwater Research

In 2002 NOAA funded the development of an ROV, the *Global Explorer*, to investigate under-ice life, the water column, and the seafloor of the

deep Canada Basin and the Northwind Ridge. This program, called Arctic 2002, was a collaboration between NOAA's Ocean Exploration Office and Arctic Research Office, the Canadian Department of Fisheries and Oceans, JAMSTEC, and institutes in China. The objectives were to take censuses of marine life in unexplored regions of the Arctic. Baseline transects are needed to be able to quantify changes in the ecosystems over space and time.

As a follow-up to this mission, NOAA's Ocean Exploration Office and the Arctic Research Office supported a multibeam mapping expedition to the Chukchi Cap and the Northwind Ridge on the USCGC *Healy* during the summer of 2003. During this expedition, scientists from NOAA, the University of New Hampshire, and other partners discovered and mapped a new complex underwater seamount (larger than Mount Rainier) lying at the northernmost end of the Chukchi Plateau. The scientists mapped 1,530 nautical miles of the 2,500-m depth contour of the continental slope north of Alaska as they accomplished the U.S.'s first Law of the Sea ocean mapping surveys in the Arctic Ocean. Before the expedition, existing charts of the Arctic seafloor showed only a small knoll where the seamount was discovered. The team also discovered water depths of more than 4,000 meters, depths not previously measured anywhere in the Amerasian Basin of the Arctic Ocean. The expedition also added important information about ice age glaciation and past climates. Randomly oriented seafloor scours, mapped at depths of 300–400 m, provide evidence of large icebergs scraping the seafloor. In addition, large pockmarks discovered on the Chukchi Plateau seafloor sediments are indicative of active venting of gas from the seafloor. The expedition also obtained oceanographic data that will improve knowledge of the water masses and circulation in the Arctic.

Climate and Weather

NOAA is supporting a program to study the recent changes in sea ice and snow cover and their impact on the Arctic Oscillation (AO). Changes are occurring in the Arctic that appear to have begun in the late 1960s and increased in the 1990s. These include tropospheric warming, reduction in ice extent, and increased variability in snow cover. Ecological impacts of these changes are already being noted. Much scientific interest has focused on the AO, which represents an Arctic-wide increase in upper atmosphere winds and decrease in sea level pressure. A paradox is that the main shifts in the AO are seen in mid-winter, while many of the surface changes are seen in spring and summer. A second issue is whether the reductions in sea ice and snow cover in the western Arctic actually have an impact on the atmosphere. The goal of this project is to determine the impact of the AO on low-level wind and temperature fields in spring in the Arctic and to evaluate the magnitude of feedback from sea ice and snow anomalies to the atmosphere in spring and summer.

Glaciology and Hydrology

NOAA has supported a program to study the hydrologic response of Siberian major rivers to climate change and variation. Arctic rivers are an important component in global ocean and climate systems, and recent studies have shown remarkable changes in hydrologic regimes of the major rivers in Siberia over the past several decades. This project, at the University of Alaska Fairbanks, is a comprehensive assessment of change and variability in Siberian river systems and their connections to surface climate and atmospheric circulation.

Climate Monitoring and Diagnostics Laboratory

The Climate Monitoring and Diagnostics Laboratory (CMDL) conducts sustained observations and research related to source and sink strengths, trends and global distributions of atmospheric constituents that are capable of forcing climate change through modification of the atmospheric radiative environment, those constituents that may cause depletion of the global ozone layer, and those that affect baseline air quality. CMDL accomplishes this mission primarily through long-term measurements of key atmospheric species at 65 sites spanning the globe, including five well-instrumented and manned Atmospheric Baseline Observatories at Barrow, Alaska; Trinidad Head, California; Mauna Loa, Hawaii; American Samoa; and South Pole.

In the Arctic, CMDL measurements include carbon dioxide, carbon monoxide, methane, nitrous oxide, surface and stratospheric ozone, halogenated compounds including chlorofluorocarbon (CFC) replacements, hydrocarbons, sulfur gases, aerosols, solar and terrestrial UV, and broadband and infrared radiation. In addition, field campaigns in key regions, utilizing an array of platforms including aircraft, balloons, ocean vessels, and towers, complement the long-term measurements. The CMDL data are used to assess climate forcing, ozone depletion, and baseline air quality; to

develop and test diagnostic and predictive models; and to keep the public, policy makers, and scientists abreast of the current state of our chemical and radiative atmosphere.

CMDL Arctic Baseline Atmospheric Observatory Operations. CMDL has operated the Atmospheric Baseline Observatory at Barrow, Alaska, (BRW) for 30 years. In addition to the 24 core atmospheric baseline measurement projects, BRW supports 20 cooperative research projects, with the majority coming from universities or agencies in Alaska. As part of the Barrow Arctic Science Consortium (BASC) facilities upgrade, CMDL is in the design phase of a new observatory building at the present BRW site. Construction is set to begin in late 2004.

At Summit, Greenland, a National Science Foundation research site, CMDL initiated year-round carbon-cycle air flask sampling and in-situ surface ozone and black carbon measurements in the spring of 2003. CMDL collects weekly pairs of discrete samples from a 65-site global network that includes Arctic or near-Arctic sites at Barrow, Cold Bay, and Shemya, Alaska; Ocean Station "M"; Heimaey, Iceland; Alert, Canada; Pallas, Finland; and Ny Alesund, Spitzbergen, in addition to the sampling at Summit, Greenland. Vertical profiles of a large suite of trace gases are obtained over Poker Flats, Alaska, on a biweekly basis, with an aircraft flying profiles to 8,000 m above sea level.

Boreal Forest Fire Impact on Global Tropospheric Chemistry. Continued studies by CMDL and the University on Maryland on the transport and atmospheric effects of effluents from the 1998 and 2000–2003 fires in Siberia show that the effects of these fires are sensitive to their timing and location. While the 2003 boreal fires burned a greater area than any previous year on record, the hemispheric increase in CO was much smaller than that observed during 1998. The early-season fires of 2003 may have produced large amounts of CO, but seasonally high levels of photochemically derived OH efficiently removed the CO from the troposphere. In contrast, the late-season fires in 1998 occurred when OH production was decreasing towards its seasonal minimum, leaving less OH to react with the fire-produced CO. Several laboratories are using CMDL data in global chemical-transport models to better understand the factors that link forest fires with their broader impact on the global atmosphere.

Measurements of Ozone-Depleting and Climate-Forcing Gases in the Arctic Troposphere and Stratosphere. From January 2002 through February 2003, CMDL scientists participated in the NASA SAGE III Ozone Loss and Validation Experiment (SOLVE-II), a high-altitude airborne research campaign with deployments out of NASA Dryden Flight Research Center at Edwards Air Force Base, California, and Kiruna, Sweden. During SOLVE-II the CMDL PAN (peroxyacetylnitrate) and Trace Hydrohalocompounds Experiment (PANTHER) instrument, along with 13 other instruments onboard the NASA DC-8 platform, sampled air from the midlatitudes across the Arctic vortex edge and into the vortex core region. In January the northern vortex broke into two lobes and then rejoined, thereby trapping midlatitude air inside the vortex. The subsequent mixing of this air, coupled with the production of numerous polar stratospheric clouds (PSCs), allowed the mission scientists to conduct a suite of unique measurements leading to a highly successful mission. A major goal of calibration and validation comparisons between the aircraft instrumentation and remote NASA SAGE III satellite measurements was achieved.

Observations of Stratospheric Water Vapor During SOLVE II. During the winter of 2002–2003, balloon profile measurements were carried out in Sweden, Finland, and Norway using the CMDL cryogenic, chilled-mirror hygrometer to measure water vapor in the stratosphere up to altitudes of approximately 25 km. During this campaign, significant dehydration was not noted in the profiles, unlike several previous campaigns in which there was some dehydration of the stratosphere in the Arctic vortex. This lack of dehydration in the Arctic stratosphere is in contrast to the Antarctic, where extensive polar stratospheric cloud formation and subsequent dehydration takes place on a large scale.

Surface Ozone Observations in the Arctic. Sites operated by CMDL make surface ozone observations in three distinct regimes within the Arctic. Barrow represents an Arctic Ocean environment with seasonal ice cover. Summit, Greenland, is a high-altitude site on the permanent ice cap, while Westman Islands, Iceland, is representative of a high-latitude site on the permanently ice-free North Atlantic. At Barrow in the spring, there are numerous episodes of ozone depletion that may persist for several days and often completely remove ozone from the lower atmospheric boundary layer. At Summit and Westman Islands, on the other hand, events of this type are not seen. This demonstrates that both the ocean environment and sea ice formation are critical ingredi-

ents in the ozone-depletion process. Halogen compounds (primarily those containing bromine) processed on the Arctic ice pack, in the presence of increasing spring sunlight, are the primary catalysts for ozone loss in what appears to be a natural process.

Study of Environmental Arctic Change. Beginning in FY 2003, CMDL became involved in two elements of SEARCH funded through the Arctic Research Office: Retrospective Analysis of Arctic Clouds and Radiation from Surface and Satellite Measurements, and Expansion of the Arctic Network of Climate Monitoring Observatories. The following summarizes the CMDL involvement in SEARCH.

Trends in Sea Ice Extent and Snow Cover in the Western Arctic. The spring snowmelt date has been monitored at BRW for many years. Since 1940 the spring melt at BRW has advanced by about 10 days (±4.8 days). Most of the advance occurred after 1976, when a major regime shift occurred.

Incursions and Impact of Asian Dust Over Northern Alaska. Using an assimilation of data collected at BRW, the direct effects of atmospheric aerosols on the surface radiation budget in the Arctic are being monitored. In the past the focus has been on Arctic Haze, which is air pollution transported from Eurasia to BRW each spring. Spectral aerosol optical depth measurements are used to differentiate dust from haze; dust contains much larger particles and is often of higher optical depth. Because polar atmospheres are generally very clean, even small increases in aerosol concentrations can perturb the radiometric structure of the atmosphere and thus the surface energy balance.

During the spring of 2002, massive dust storms in the Gobi Desert region of Mongolia lofted dust into the atmosphere, where it was transported eastward in a broad plume that reached and crossed the continental U.S. Some of this dust was also blown over northern Alaska, passing over BRW. CMDL measurements show that when Asian dust is present in the Arctic atmosphere, the surface tends to cool but to a lesser extent than at lower latitudes that are free of snow. Even though these Arctic dust events are episodic and occur mainly in late winter through spring, their effect is not insignificant when they are present. Should the Arctic atmosphere become more turbid in the future, projections of enhanced warming in the the Arctic due to greenhouse gases could be episodically negated because of this negative feedback induced by dust and aerosols. On the other hand, should the dust contain high concentrations of carbonaceous particles that directly absorb sunlight, additional atmospheric heating could occur. More data and model simulations will be required before we fully understand the climatic impacts of these polar aerosols.

Enhancing the Network of Arctic Climate Monitoring Observatories. While SEARCH is addressing several complex issues related to climate change in the northern high latitudes, improving Arctic observational records is fundamental to the entire program. In collaboration with the NOAA Environmental Technology Laboratory (ETL), CMDL is taking a lead in efforts to expand or enhance the sparse network of observing stations now in existence. The combined facilities at BRW and the adjacent Atmospheric Radiation Measurement (ARM) Program site represent the state of the art in climate monitoring, especially for studies of cloud and aerosol effects on the surface radiation balance. One goal of SEARCH is to establish BRW-like observatories at other strategic Arctic locations to better characterize the Arctic climate system and to produce long-term data records that will help us understand the processes and feedbacks that drive the Arctic climate system. A component of this activity is to enhance atmospheric and radiation monitoring in the Canadian Arctic at Alert and Eureka at sites operated by the Meteorological Services Canada and possibly at two Siberian sites in conjunction with the Russian Academy of Sciences and Roshydromet.

Trace Gas Emissions Measured along the Trans-Siberian Railway. To study the trace gas emissions of a large sector of both Europe and Asia, a consortium of Russian, German, and U.S. scientists have instrumented a Russian railway car with a wide range of atmospheric measurement instrumentation, coupled the observatory carriage to regularly scheduled passenger trains, and conducted 17,000-km traverses from Moscow to Khabarovsk and back. These 13-day Trans-Siberian Observations Into the Chemistry of the Atmosphere (TROICA) missions have been conducted seven times since 1995. In the summer of 2001, CMDL Boulder scientists were the project leads on the program, as they were in early 2004 on a mid-winter journey during which temperatures as low as –40°C were encountered. This railway platform is ideal for atmospheric measurements because the railway is electrified between Moscow and Khabarovsk, minimizing the potential contamination of measurements by the train itself.

During the 2001 summer expedition (TROICA-7), emissions of six man-made, ozone-depleting substances were measured for the first time ever in Siberia. TROICA-8 occurred in the winter, when the emissions of biologically produced gases (such as carbon dioxide) and biomass burning gases from forest fires (such as carbon monoxide) are at a minimum.

Russia ended production of the chlorofluorocarbons (CFCs, used as refrigerants), chlorinated solvents (methyl chloroform, CH_3CCl_3, and carbon tetrachloride, CCl_4), and halons (used as fire extinguishing agents) at the end of 2000 as a result of the Montreal Protocol, but emissions persist from banks of these chemicals (in existing refrigerators, air conditioners, etc.). One goal of this program is to measure the reduction of the ozone-depleting substances between 2001 and 2004. Measurements on board the carriage include oxides of nitrogen (NOx), ozone, aerosols, radon-222, CO, CH_4, CO_2, and meteorological parameters, including vertical temperature profiles.

Measurements on the TROICA missions are supported by NOAA (Arctic Research, CMDL, OAR) programs, NASA (Atmospheric Chemistry Modeling and Analysis; Radiation Sciences; and Upper Atmospheric Research) programs, the Max Planck Institute for Chemistry in Mainz, Germany, and the Russian Railway Institute.

Cooperative Institute for Arctic Research at the University of Alaska Fairbanks

Arctic Climate Impact Assessment. The Arctic Climate Impact Assessment (ACIA) is an activity of the Arctic Council to assess the impacts of climate and UV radiation changes in the Arctic. An ACIA Secretariat, supported by the U.S. through NSF and NOAA, is located at the University of Alaska Fairbanks and is responsible for the conduct of the assessment. In 2002–2003 the 200 international authors of the assessment wrote several successively improved versions of the assessment in 17 chapters, and after internal review an extensive external review of the assessment by about 200 international experts took place. Final revisions are now occurring, responding to and taking the numerous reviewer comments into account. The length of the final document is expected to be about 1,500 printed pages and deals with impacts on the environment, on economic sectors, and on people's lives. A summary "Overview" report of about 80–100 pages has also been produced for a more general readership. The four-year ACIA project will conclude with a final scientific conference in Reykjavik, Iceland, on 9–12 November 2004, at which time the ACIA documents will be released.

Russian–American Long-Term Census of the Arctic. In 2003, NOAA and the Russian Academy of Sciences signed a Memorandum of Understanding for World Ocean and Polar Regions Studies. Also in 2003 both Russia and the U.S. requested proposals from investigators for participation in the first joint U.S.–Russia research cruise to the Bering and Chukchi Seas, including sampling and instrument deployment in both U.S. and Russian territorial waters. This is the first activity under the Russian–American Long-term Census of the Arctic (RUSALCA), a joint project of NOAA and the Russian Academy of Science. The cruise objectives are to support the U.S. interagency Study of Environmental Arctic Change (SEARCH) program (http://psc.apl.washington.edu/search/) and the NOAA Ocean Exploration Program (http://www.oceanexplorer.noaa.gov/). These seas and the life within are thought to be particularly sensitive to global climate change because they are centers where steep thermohaline and nutrient gradients in the ocean coincide with steep thermal gradients in the atmosphere. The Bering Strait acts as the only Pacific gateway into and out of the Arctic Ocean and as such is critical for the flux of heat between the Arctic and the rest of the world. Monitoring the flux of fresh and salt water and establishing benchmark information about the distribution and migration patterns of the life in these seas are also critical before the emplacement of a climate monitoring network in this region.

In November 2003 a workshop on the RUSALCA expedition mission was held in Moscow to define the main research topics and regions. In February 2004, after panelists met in Russia and the U.S., nine programs were funded. The primary study area will be the northern Bering Sea (north of 60°N) and the Chukchi Sea (Wrangel Island to Point Barrow and north toward the Chukchi Plateau to the extent that ice conditions permit). The cruise is expected to occur in the summer of 2004 on a Russian ice-strengthened (not icebreaking) research ship (the *Khromov*). The ship will depart from Vladivostok and make two or three port stops in Alaska before returning to Russia. The cruise length will be about 45 days, with intensive activities in the primary study area during the middle 20 days or so. Underway activities can be carried out during the entire 45 days.

Participants will include individuals from the following organizations: the University of Alaska

Fairbanks, the Smithsonian Institution, the University of Tennessee, the University of Texas, the University of Washington, the Woods Hole Oceanographic Institution, NOAA Fisheries, NOAA's Arctic Research Office, NOAA's Ocean Exploration Office, the U.S. Fish and Wildlife Service, the U.S. Army Cold Regions Research and Engineering Laboratory, the Shirshov Institution of Oceanology (Moscow), VNIIOkeangeologia (St. Petersburg), the Zoological Institute (St. Petersburg), the Institute of Microbiology (Moscow), the Arctic and Antarctic Research Institute (St. Petersburg), the Pacific Oceanographical Institute (Vladivostok), Roshydromet (Vladivostok), the Russian Federation Navy, and ECOSEA (group alliance). Funding is provided by NOAA and the Russian Academy of Sciences

NOAA's Undersea Research Program

NOAA's Undersea Research Program (NURP) has the responsibility to establish programs for the assessment, protection, development, and utilization of U.S. underwater resources. In meeting this responsibility, NURP has established six regional centers for support of in-situ research and technological development. The West Coast and Polar Regions Undersea Research Center serves the Arctic and Antarctic regions, as well as the entire west coast of the U.S. In FY 2002 the center supported development of next-generation equipment for studying the activities of marine mammals.

Although there have been significant advances in miniaturized video technology and virtual-reality data assessment, their use in the study of large marine animals has lagged considerably behind the applications for ROVs and other submersible platforms. There is great potential for using marine mammals as "biological autonomous underwater vehicles" to study their behavior and the ocean environment.

The first generation of video/data recorders designed to be mounted on marine mammals was developed under a 1998 NURP grant. It has been deployed on Weddell seals during NSF-sponsored research at McMurdo Sound, Antarctica. The use of this equipment has provided new insights into the behavior of both the seals themselves (while under water) and the behavior of their prey—several species of pelagic fishes. Both the seals and the fish are difficult to study by any other method because of the logistics of observing their activity under the Antarctic ice. The scientific results have been reported in several journals, including *Science* and *Marine Biology*.

In 2002 the West Coast and Polar Regions Undersea Research Center supported development of a next-generation version of this equipment. Modifications include digital video recording to a mini-hard drive, the use of on-the-fly MPEG video compression, incorporation of GPS for geolocation at the surface, extended data recording for up to 14 days, and a 50% reduction in size. The system records pressure, swim speed, compass bearing, ambient temperature, dissolved oxygen, ambient light, and tilt, pitch, and roll. The digital video/audio uses near-infrared LEDs and a low-light-sensitive, black and white camera. The equipment is powered by rechargable lithium batteries connected to solar panels. One factor that limited the use of the first-generation equipment to Weddell seals was the size and weight of the package. A 50% reduction in size now permits the new equipment to be used on smaller marine mammals. Tests have been conducted with Stellar's sea lions at the Alaska SeaLife Center in Seward, Alaska. This technology will yield new insight into the activities and habitat of these Arctic marine mammals at sea.

Alaska Fisheries Science Center

National Marine Mammal Laboratory

The National Marine Mammal Laboratory, Alaska Regional Office, and the Protected Resources Management Division are responsible for research on and management of 22 species of marine mammals that commonly occur in Alaska, including five endangered cetacean species (bowhead, fin, humpback, North Pacific right, and sperm whales), one pinniped species (Steller's sea lion) that is threatened in one portion of its range and endangered in another, and two depleted species (Cook Inlet beluga whale and northern fur seal). Field research by the NMML staff on marine mammals off central and northern Alaska focused on two pinniped and six cetacean species during 2002 and 2003: Steller's sea lions, harbor seals, Cook Inlet beluga whales, killer whales, and large cetaceans (fin, blue, humpback, and North Pacific right whales) in the Bering Sea.

Steller's Sea Lions. NOAA/Fisheries is the lead agency responsible for the management and recovery of the endangered western and threatened eastern populations of Steller's sea lions. The western population has declined by more than 80% in the last two decades, but it may have stabilized over much of its range during the last

two years. Conversely the eastern population appears to be recovering from severely reduced levels in the early part of this century and has exhibited consistent growth over the past three decades. Factors hypothesized for the dramatic decline in the western population include reduced prey availability leading to nutritional stress, poor juvenile survival, and decreased reproduction; disease; pollution; predation by killer whales; incidental mortality in groundfish fisheries; and legal and illegal shooting. The Steller's sea lion research program at NMML conducts scientific research on each of the potential factors that could have contributed to the decline of the western population. The core research program includes vessel and aerial surveys to quantify abundance, molecular and genetic studies to elucidate stock structure, assessment of predator–prey dynamics and foraging distributions to determine foraging ecology, and individual identification and tracking to provide the foundation of mortality and life history studies.

Alaska Harbor Seals. In recent decades, Alaska harbor seals have declined dramatically in some regions, while their numbers have increased in other regions. The primary objectives of NMML's research on this species are to obtain data on the abundance of the species throughout Alaska and to collect information on haulout patterns that can be used to better interpret abundance information. In 2002 and 2003 the NMML produced peer-reviewed papers describing the abundance of harbor seals in the Gulf of Alaska and the stability of harbor seal haulout patterns. In addition, research was undertaken to determine the response of harbor seals to cruise ships and the genetic relatedness of harbor seals via molecular genetic techniques. Obtaining information on Alaska harbor seals is critical, as they are an important component of the Alaska Native subsistence harvest. A comanagement agreement, signed by the Alaska Native Harbor Seal Commission and NMFS, has charged the Harbor Seal Comanagement Committee to prepare an annual action plan for this culturally important species.

Cook Inlet Beluga Whales. Research on the Cook Inlet beluga whale stock has been conducted annually since 1993. This stock was designated as depleted under the Marine Mammal Protection Act in 2000. Scientists from NMML, in cooperation with the Alaska Beluga Whale Committee, the Cook Inlet Marine Mammal Council, the Alaska Native Marine Mammal Native Hunters Committee, the Alaska Department of Fish and Game, and NMFS's Alaska Regional Office, have estimated the abundance of this relatively small and isolated population each year since 1994. Analyses of sighting data from aerial surveys indicated that the abundance of Cook Inlet beluga whales has declined by nearly 50% between 1994 and 1998. Distribution and abundance estimates from annual aerial surveys in 2002 and 2003 indicated that the population was stable but low in number. In 2002, research efforts were directed toward catching whales and outfitting them with radio and satellite tags to determine seasonal movement patterns and correction factors for aerial surveys. A Cook Inlet beluga habitat model is in development based on satellite tracking data and fatty acids analyses of blubber samples used to determine diet and contaminant burdens.

Killer Whale Surveys: Kenai Fjords to the Central Aleutians. To investigate the potential role of killer whales in the decline of the western population of Steller's sea lions, a vessel-based survey for killer whales extending from the Kenai Fjords to the central Aleutian Islands was initiated in 2001. The DART (Distribution and Abundance of Residents and Transients) surveys are designed to estimate the abundance of killer whales by ecotype. Three killer whale ecotypes have been identified in Alaskan waters thus far: the piscivorous (or resident) ecotype; the mammal-eating (transient) ecotype; and the offshore ecotype, which apparently preys mostly on fish. Biopsy samples are taken whenever possible to provide data for molecular genetic, prey isotopic and fatty acid, and contaminant analyses. When conditions permit, photographs and biopsies of sperm, fin, humpback, and Baird's beaked whales were also taken. These data augment sighting and biopsy sampling conducted in collaboration with the AFSC/RACE groundfish surveys.

Large Cetaceans in the Southeast Bering Sea and Northern Gulf of Alaska. NMML researchers were able to determine the abundance and distribution of large cetaceans (primarily fin and humpback whales) in the southeast Bering Sea and Gulf of Alaska because of new collaborations and the application of new technologies. A line-transect survey was conducted in 2002 in association with an AFSC/RACE groundfish stock assessment survey. These data provide a synoptic sample of large whale distribution and relative abundance in the southeast Bering Sea and northern Gulf of Alaska and are being used to update marine mammal stock assessment reports. In addition, cooperative research with Scripps Institute of Oceanography and NOAA's Pacific Marine Environmental

Laboratory (PMEL) has focused on using passive acoustic recorders to record calls from large whales in the southeast Bering Sea and northern Gulf of Alaska. These passive recorders remotely document the occurrence of calling North Pacific right whales and other baleen whale species during seasons in which conducting fieldwork is impractical due to short days or inclement weather. Information collected using passive acoustics will provide important insights into the seasonal distributions of large cetaceans and the relationships between large cetaceans and their environment.

Resource Assessment and Conservation Engineering Division and Resource Ecology and Fisheries Management Divisions

Marine Fisheries Assessment. The Alaska Fisheries Science Center (AFSC) of NMFS continued its long-standing commitment to assessment studies of U.S. living marine resources in the Bering Sea, Aleutian Islands, and Gulf of Alaska during 2002 and 2003. This effort included fishery-independent resource surveys, collection of data from commercial fisheries through fisheries observers, collection of recreational and commercial harvest statistics, and basic population biology and ecological research. The scientific information generated by these activities supports Federal fishery conservation and management responsibilities in the 200-mile U.S. Exclusive Economic Zone.

During 2002 and 2003, living marine resource populations in western U.S. Arctic waters were sampled at sea aboard NOAA ships, chartered fishing vessels, and cooperating foreign research vessels. Significant area-extensive survey efforts were conducted in the eastern Bering Sea, the Aleutian Islands, and the Gulf of Alaska. The principal survey methods included bottom trawls for demersal fish and crabs; hydroacoustic and midwater trawls for semipelagic fish; and special-purpose nets for eggs, larvae, and juvenile fish and shellfish. Trawl and acoustic surveys were used to estimate biomass and define community structure, and biological collections were taken to examine variability in growth, mortality, and stock recruitment.

Recruitment indices and processes that generate variations in abundance are being studied to improve prediction through the Fisheries–Oceanography Coordinated Investigations (FOCI) program. FOCI is a cooperative program between the AFSC and PMEL. To increase the accuracy and precision of these assessments, AFSC scientists conduct biological research to define recruitment processes, develop computer models to simulate interactions and dynamics of population change, and conduct or collaborate in extramural studies to improve sampling methods and survey designs.

Pacific Salmon: Bering Sea and Western Alaska. Pacific salmon runs to rivers emptying in the Bering Sea have been inconsistent and at times very weak. Low returns of chinook and chum salmon to the Yukon River, Kuskokwim River, and Norton Sound area (called the AYK region) of Alaska prompted the State of Alaska to restrict commercial and subsistence fisheries during 2000 and declare the region a disaster area. The weak AYK salmon returns follow several years of low sockeye salmon returns to Bristol Bay, which was declared a disaster region during 1998 by both the State of Alaska and the U.S. Department of Commerce. The cause of these disastrous returns is not fully understood but may be related to changes in the marine environment. To provide critical information on the marine ecology of Pacific salmon, scientists from the AFSC's Ocean Carrying Capacity (OCC) program conduct fall (August–October) surveys on juvenile salmon in the eastern Bering Sea shelf. The surveys are extensive, covering eastern Bering Sea shelf waters from the Alaska Peninsula to Kotzebue Sound. The research is conducted as part of a larger Bering Sea salmon ecology study conducted by the North Pacific Anadromous Fish Commission's Bering–Aleutian Salmon International Survey (BASIS) program. The goal of the OCC/BASIS salmon research is to understand the mechanisms underlying the effects of environment on the distribution, migration, and growth of juvenile salmon on the eastern Bering Sea shelf. The primary objectives of the survey are 1) to determine the extent of offshore migrations of juvenile salmon from rivers draining into the eastern Bering Sea; 2) to describe the physical environment of the epipelagic waters along the eastern and northeastern Bering Sea shelf occupied by juvenile salmon; and 3) to collect biological information of other ecologically important species.

Pacific salmon return to spawning areas in the Yukon River basin is of particular concern, as they support important commercial and subsistence fisheries in both the U.S. and Canada. These returns have been the focus of numerous harvest allocation disputes between the two countries, and returns have declined severely in recent years. A drainage-wide radio-tagging study was initiated in 2000 by the AFSC's Stock Identification and Assessment Program and the Alaska

Department of Fish and Game to provide information on the run characteristics of Yukon River chinook salmon. Returning adults were tagged in the lower river and tracked as they moved upriver to spawning areas. Work in 2000–2001 developed baseline information on the behavior and movement patterns. Large-scale, basin-wide tagging studies in 2002 and 2003 provided information on the stock composition and timing of U.S. and Canadian returns, movement patterns, and the location of undocumented spawning areas. These data have also been used to evaluate information from other assessment programs within the basin and to refine genetic stock identification baselines. An additional year of the basin-wide tagging study is planned for data collected during the late 1990s. Analyses include that of a remnant population of the endangered North Pacific right whale on the southeastern Bering Sea shelf. NWFSC scientists contributed input to the Science Steering Committee of NSF's Ocean–Atmosphere–Ice Interactions program. The importance of sea ice as critical habitat for polar marine mammals and birds is also being studied in collaborative efforts by NOAA scientists and other U.S. and Canadian researchers.

A paper detailing the analyses of 77 killer whale biopsy blubber samples for selected organochlorine compounds and lipid content has been published. The paper reported that concentrations of chlorinated biphenyls and DDT were relatively high compared to other marine mammal species that occur in Alaska. Furthermore, biological factors such as age, sex, reproductive status, and birth order were found to be important influences in the accumulation of organochlorine compounds in killer whales. A manuscript describing lipid and organochlorine contaminant profiles in gray whales was also published.

National Environmental Satellite, Data, and Information Service

National Ice Center

The National Ice Center (NIC) is a cooperative, interagency organization responsible for providing Arctic, Antarctic, and Great Lakes ice information to U.S. and allied armed forces, U.S. government agencies, and various segments of private industry. Manpower and fiscal resources for the NIC are provided by the U.S. Navy, NOAA/NESDIS, and the U.S. Coast Guard. The Office of Research and Applications (ORA) is the NESDIS research organization that, among other things, supports the NIC. Real-time global, regional, and tactical-scale ice guidance products are generated in support of mission planning, safety of navigation, and climate research. Routine products include satellite-derived sea ice analyses of current ice conditions and forecasts depicting future changes to the sea ice pack. Ice analyses are distributed in JPEG format and as geographic information system (GIS)-compatible files via the NIC web page (http://www.natice.noaa.gov). Metadata that detail the data sources integrated into routine ice analysis products are available on the NIC web page. As part of the Environmental Working Group, NIC released the High-Resolution Arctic Sea Ice Climatology in 2000, which encompassed historical data from 1972 to 1994. Work is nearing completion on extending the archive through 2003.

During 2002–2003 the NIC Science and Applied Technology Department expanded to include a new visiting scientist, a post-doctoral fellow, and increased support staff. The main goals of the department include:

- Improving the efficiency of data processing and analysis through the development of automated data fusion techniques;
- Automating the analysis and classification of data;
- Improving operational ice forecasting models;
- Optimizing Special Sensor Microwave/Imager (SSM/I) algorithms for operational sea ice analysis; and
- Developing new ice products by applying new techniques and incorporating data from new sensors.

The NIC science team evaluated the existing suite of sea ice concentration algorithms for the SSM/I and modified the operational sea ice algorithm. A passive microwave algorithm was developed using a principal components combination of SSM/I brightness temperatures and NIC-provided local ice conditions from visible and infrared data to provide improved global sea ice concentrations. Another accomplishment was the implementation of an algorithm to track ice motion using 85-GHz SSM/I. SSM/I and ice model products are available in near-real-time on the NIC experimental products web page (http://science.natice.noaa.gov). They have also recently completed the development of a new scatterometer ice edge algorithm.

The ORA is exploring the application of Cryosat altimetry data for estimating sea ice draft. Launch is expected in 2005. Other groups within ORA are exploring the application of cloud-tracked

winds and TIROS Operational Vertical Sounder (TOVS) data for improved Arctic wind products. Currently ORA cloud-tracked winds are being assimilated into the European Centre for Medium Range Weather Forecasts (ECMWF) forecast models. ORA is also continuing the Alaska synthetic aperture radar (SAR) demonstration (AKDEMO), which provides experimental high-resolution (1-km) SAR-derived winds and vessel positions for open water areas in the Bering Sea and other Arctic seas (http://www.orbit.nesdis.noaa.gov/sod/mecb/sar). Recent studies show that these winds are accurate to better than 2 m/s. The experimental wind product is useful for understanding gap winds, barrier jets, and wind shadowing by islands such as the Aleutians. Such knowledge can be beneficial to the safety of coastal transporation. AKDEMO SAR imagery and vessel positions are being evaluated in Alaska in an effort to provide improved guidance to fishing vessels operating near the ice edge. In addition, SAR imagery is being evaluated for use in monitoring river ice breakup in the larger Alaskan rivers such as the Yukon and Koskokwim.

NIC manages the U.S. Interagency Arctic Buoy Program (USIABP), which provides an important source of surface meteorological data and ice drift information in the Arctic. Since its inception in 1991, the mission of the USIABP has been to establish and maintain a network of 40 evenly spaced meteorological buoys on the drifting Arctic ice pack. NIC achieves this goal through coordinated deployments and international cooperation by participants in the International Arctic Buoy Program (IABP). During 2002–2003, nearly 95% of all Arctic drifting meteorological buoys reported data in real time over the Global Telecommunications System. Real-time buoy data are used to initialize operational weather and ice forecast models. All buoy data are quality controlled within six months of receipt and then assembled into a historical (1979–2003) database, which is archived by the Polar Science Center of the University of Washington (http://iabp.apl.washington.edu) and the National Snow and Ice Data Center (NSIDC). These data have been useful in initializing global circulation models and in climate change research. Buoy data are also used to generate a three-hour spatially and temporally interpolated data set of surface pressure and temperature.

National Snow and Ice Data Center

The National Snow and Ice Data Center and World Data Center for Glaciology, Boulder, (http://nsidc.org) was chartered by NOAA/NESDIS in 1982 to provide a focus for cryospheric data management activities. NSIDC is operated under an agreement between NOAA and the University of Colorado's Cooperative Institute for Research in Environmental Sciences and is affiliated with the NESDIS National Geophysical Data Center (NGDC), Boulder. NSIDC is home to the NSF-funded Arctic System Sciences Data Center and Antarctic Glaciological Data Center. The Frozen Ground Data Center (FGDC) at NSIDC is supported by the International Arctic Research Center, University of Alaska Fairbanks. Over 80% of NSIDC's funding comes from NASA for operating a Distributed Active Archive Center for Earth System Enterprise data sets. These include Geoscience Laser Altimetry System (GLAS), Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E), and Moderate Resolution Imaging Spectroradiometer (MODIS) products, as well as "heritage" data sets such as the nearly 30-year record of sea ice concentration from satellite passive microwave data.

More than 113 new data sets were made available through NSIDC's online catalog in 2002 and 2003. These included detailed maps of permafrost and soils from Russia and China, published in cooperation with the International Permafrost Association. Available in a variety of formats, including GIS-compatible files, these products contribute to a unified international depiction of frozen ground important for monitoring and hydrological studies.

Frozen soils and snow were the focus of the NASA/NOAA Cold Land Processes Field Experiment (CLPx), which took place in Colorado in 2002 and 2003. NSIDC data managers went into the field to work directly with researchers studying cold land processes over a wide range of conditions and spatial scales. NSIDC AMSR and MODIS snow cover products are being used with CLPx data to address the question of how uncertainties in remote sensing observations constrain data assimilation and prediction.

While new satellite sensors offer improvements in accuracy and resolution, NSIDC continues to archive and publish historical data records that provide the long view needed to assess climate change. Because glacier extent fluctuates in response to climate changes, historical glacier photos can be used to determine changes in glacier terminus location and to estimate changes in mass balance. The Glacier Photograph Collection database now provides over 1000 images of

glaciers on-line. Photographs, dating from 1883, were scanned through a joint National Geophysical Data Center/NSIDC project funded by NOAA's Climate Database Modernization Project.

In-house scientific expertise helps NSIDC improve the quality of research data sets and respond quickly to inquiries on snow and ice topics from the general public. The record minimum Arctic ice extent in September 2002 drew widespread media attention and was monitored at NSIDC using the Sea Ice Index (http://nsidc.org/data/seaice_index/), an easy-to-use source of information on sea ice trends and anomalies. Ice extent in September 2003 was similarly low, about 14% below the long-term (1978–2000) mean, and is the most recent evidence of a downward trend in Arctic sea ice in the three decades since passive microwave monitoring began. In a paper published in *Geophysical Research Letters*, NSIDC researchers attributed the record 2002 extent to an unusually warm summer over much of the Arctic Ocean, combined with stormy conditions that helped break up the ice.

On an international level, NSIDC is involved in setting directions for Climate and Cryosphere (CliC), a World Climate Research Programme core project established to coordinate research on the role of the cryosphere in the global climate system. NSIDC Director Roger Barry is seeking to establish a U.S. CliC committee in partnership with NOAA, NASA, and NSF.

National Oceanographic Data Center

NODC and the co-located World Data Center for Oceanography (WDC Oceanography) in Silver Spring, Maryland, continues to have an active data exchange program and engages in collaborative joint projects with many Arctic countries, academic institutions, other Federal agencies, and international organizations. In March 2002, NODC/Ocean Climate Laboratory (OCL) released the *World Ocean Database 2001* (*WOD01*), which contains 479,562 profiles in the Arctic region (60°–90°N) representing data of physical, chemical, and biological variables dating back to 1827. These profiles reflect data obtained from bottle, low-resolution CTD, and plankton instruments (Ocean Station Data); high-resolution conductivity–temperature–depth instruments (CTD); mechanical bathythermographs (MBT); expendable bathythermographs (XBT); surface-only instruments (bucket, thermosalinograph) (SUR); subsurface drifting floats (PFL); and surface drifting buoys with thermister chains (DRB). These last three instrument types were new additions to *WOD01* for the Arctic and did not exist in the 1998 version. Data continue to be added to the database on a daily basis, and there are now 485,088 profiles in the Arctic seas and oceans. The exchange of data is facilitated under the auspices of the Intergovernmental Oceanographic Commission (IOC) Global Oceanographic Data Archaeology and Rescue (GODAR) project and the World Ocean Database (WOD) project. These efforts are supported by NOAA's Office of Global Programs (OGP) and NOAA's Environmental Science, Data, and Information Management (ESDIM) program.

Data exchange and collaborative activities have been particularly fruitful with the Russian Federation for many years. In FY 2002, *Zooplankton of the Arctic Seas 2002* was released on CD-ROM. This product was prepared jointly by the NODC/OCL-WDC Oceanography, Silver Spring, Maryland, and the Zoological Institute, Russian Academy of Sciences. It includes physical and biological data for the Arctic and sub-Arctic regions, extending from the Barents Sea to the northwest Pacific. Samples were taken during 25 scientific cruises between 1903 and 1956.

In FY 2003, a three-year ESDIM grant was awarded to OCL to further its collaboration with Russian colleagues to develop an oceanographic database of the Arctic seas (Barents, Kara, Laptev, White, East Siberian, and Chukchi) for use in studying the Arctic climatic system. Two products have been prepared thus far, both of which are available online. The product *History of the Arctic Exploration 2003: Cruise Reports, Data*, released in October 2003, was prepared jointly with the P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences. It represents data collected from 1870 to 1940 at 3,936 stations from 62 cruises in the eastern Arctic seas as well as the Arctic Ocean. The second product, *36-Year Time Series (1936–1998) of Zooplankton, Temperature, and Salinity in the White Sea*, released in November 2003, was prepared jointly with the White Sea Biological Station (WSBS) of the Zoological Institute. This product presents an analysis of zooplankton data from the WSBS for the period 1963–1998 (2,436 plankton samples), as well as temperature and salinity observations at different depths for the period 1961–1999 (938 stations). In addition to being available online, this product is also available in manuscript form along with a CD-ROM of all the data. Another product is in progress and is expected to be released sometime in the spring or summer of 2004. This product, *Climatic Atlas of*

Further information about and access to the World Ocean Database and the products associated with the International Ocean and Atlas Information Series can be found at http://www.nodc.noaa.gov/OC5/indprod.html. The point of contact for the Ocean Climate Laboratory, the World Data Center for Oceanography, and the World Ocean Database is Sydney Levitus, U.S. Department of Commerce, National Oceanic and Atmospheric Administration/Ocean Climate Laboratory, 1315 East-West Highway (E/OC5), Silver Spring, MD 20910; 301-713-3290, ext. 194. For the Arctic databases, the points of contact are Renee Tatusko or Igor Smolyar, U.S. Department of Commerce, NOAA/OCL, 1315 East-West Highway (E/OC5), Silver Spring, MD 20910; 301-713-3295, ext. 206.

the Arctic Seas 2003: Part 1, Database of the Barents, Kara, Laptev, and White Seas, is being prepared jointly with the Murmansk Marine Biological Institute (MMBI), Russian Academy of Sciences. This atlas is expected to contain data from about 400,000 oceanographic stations from 1810 to 2002. There will be more than 20,000 plankton samples, including 260 collected during cruises of nuclear icebreakers in regions previously inaccessible for studies during the winter. The atlas will also include data from about 100 benthos samples collected along the Kola Meridian between 1921 and 1922 and in 1977. All of these data are or will be incorporated into the World Ocean Database and made available online.

The NOAA Central Library, located in Silver Spring, Maryland, is the largest oceanic and atmospheric sciences library in the Western Hemisphere and has extensive holdings related to Arctic exploration and Arctic science. The library's on-line catalog has over 1,800 entries related to Arctic activities and another 1,000 entries related to the oceanography and fisheries of Arctic marginal seas. The library's on-site collection is supplemented by 1,200 historical documents that can be found through the library's traditional card catalog. Through NOAA Library services, access can be gained to literally the full range of publications that are dedicated specifically to Arctic issues and science or have information relevant to Arctic issues. The library has also imaged thousands of pages of Arctic climate data for regions of Alaska, Canada, Norway, and Russia that are available on-line through the NOAA Library Climate Imaging Project. The library assists data rescue and recovery efforts of Arctic researchers, and its collections and services are particularly relevant to those studying climate issues and living resource issues. As an adjunct to textural material, the library also manages the NOAA Photo Library, which has over 600 on-line public domain images related to Arctic themes.

Further information about and access to the NOAA Library can be found at http://www.lib.noaa.gov/. The point of contact for the NOAA Library is Janice Beattie, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Central Library, 1315 East–West Highway (E/OC4), Second Floor, Silver Spring, MD 20910; 301-713-2607, ext. 139.

National Climatic Data Center

NCDC updates and maintains a 120-year-long mean monthly temperature time series zonally averaged over the Arctic. This work is done in collaboration with the Russian State Hydrological Institute. Long-term daily precipitation time series for the former Soviet Union have been rescued and homogenized. These data are available from NCDC and are being used in Arctic studies, including the Arctic Climate Impact Assessment. This work was done by NCDC in collaboration with the Russian Research Institute for Hydrometeorological Information and the Institute for Global Climate and Ecology.

National Ocean Service

From 1996 to 2002 the Coastal Ocean Program within the National Ocean Service supported the Southeast Bering Sea Carrying Capacity (SEBSCC) program, with a total of $5.5 million. The goals of SEBSCC were to increase understanding of the southeastern Bering Sea ecosystem, to document the role of juvenile walleye pollock and factors that affect their survival, and to develop and test annual indices of pre-recruit (age-1) pollock abundance. Four central scientific issues focused the research efforts: 1) How does climate variability influence the Bering Sea ecosystem? 2) What limits population growth on the Bering Sea shelf? 3) How do oceanographic conditions on the shelf influence biological distributions? and 4) What influences primary and secondary production regimes? These questions were addressed through collaborative research by NOAA scientists at the Pacific Marine Environmental Lab and the Alaska Fisheries Science Center and academic researchers at the University of Alaska, the University of California, and the University of Washington. The research effort included moored observations, process field cruises, modeling, retrospective studies, and syntheses.

In 2002, synthesis of SEBSCC results were published in two special journal issues with wide distribution to the oceanographic community. A special issue of *Progress in Oceanography* (vol. 55, no. 1–2, 2002) entitled "Variability in the Bering Sea Ecosystem" published 16 papers resulting from a session discussing the Bering Sea from 1991 to 2001 at the 10th annual meeting of the North Pacific Marine Science organization. A special issue of *Deep Sea Research II* (vol. 49, no. 26, 2002) on the ecology of the southeastern Bering Sea presented results of SEBSCC and an NSF-sponsored Inner Front program. Both of these programs were at work in the Bering Sea between 1995 and 2000. This was a time of great variability in the Bering Sea. An extremely warm year occurred in 1997, coincident with the first recorded observation of coccolithophore blooms on the Bering Sea shelf. Jellyfish increased in abundance, whereas salmon, shearwaters, northern fur seals, and Steller's sea lions declined. The collection of 21 papers in this volume present the current understanding of relationships between atmospheric forcing,

ocean circulation, phytoplankton growth, zooplankton dynamics, pollock abundances, and seabird diets. A new hypothesis about controlling factors on Bering Sea production and energy transfer was put forward by SEBSCC investigators.

Office of Marine and Aviation Operations

NOAA ship *Miller Freeman* conducted approximately 100 and 40 operating days in the Bering Sea during FY 2002 and FY 2003, respectively.

In FY 2002 the *Freeman* participated in a number of cruises that focused on echo integration-trawl (EIT) surveys of walleye pollock in the eastern Bering Sea near Bogoslof Island. The vessel succeeded in recovering and deploying various moorings that collect oceanographic and fisheries-related data for the Fisheries–Oceanography Coordinated Investigations (FOCI) program. The ship also accomplished a cruise that examined the community structure and transport of fish larvae and plankton on the continental shelf, slope, and deep water areas of the southeastern Bering Sea and Unimak Pass.

In FY 2003 the *Miller Freeman* continued to recover and deploy moorings in support of the FOCI program, as well as taking biological and physical ocean property samples at and near the mooring locations. Ongoing EIT surveys near Bogoslof Island and ichthyoplankton studies in the southeastern Bering Sea near Unimak Pass were also accomplished.