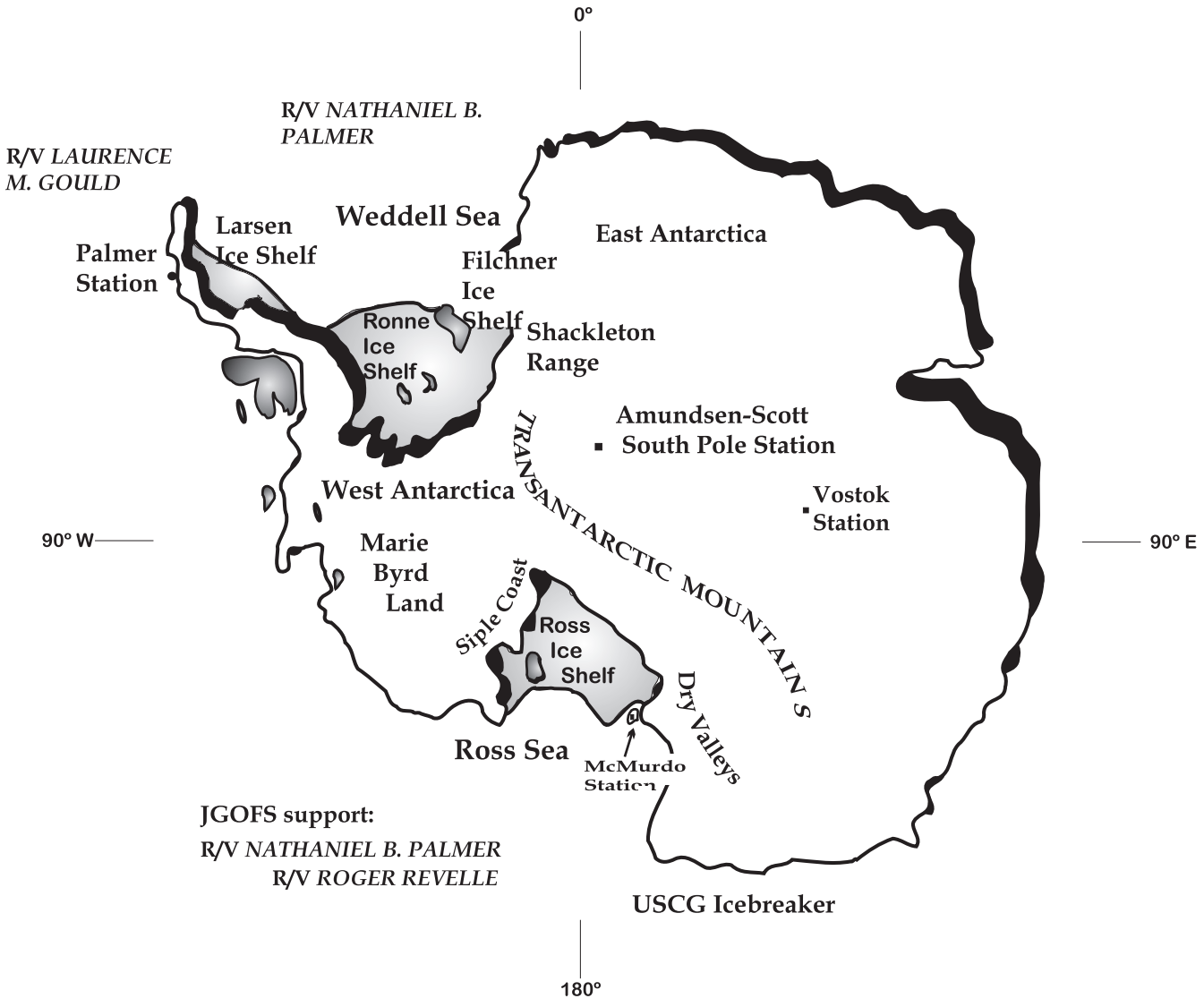
U.S. Antarctic Program 1997-1998

National Science Foundation
Office of Polar Programs

September 1997

U.S. Antarctic Program
1997- 1998
Sites of major activities



The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding grants for research and education in the sciences, mathematics and engineering.

To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Web site at:

http://www.nsf.gov

- Location: 4201 Wilson Blvd. Arlington, VA 22230
- For General Information (NSF Information Center): (703) 306-1234
- TDD (for the hearing-impaired): (703) 306-0090
- To Order Publications or Forms:
  - Send an e-mail to: pubs@nsf.gov
  - or telephone: (301) 947-2722
- To Locate NSF Employees: (703) 306-1234

The summaries that make up this publication are based on the abstracts provided by the senior investigators or NSF science program managers as part of the standard proposal. Each has been edited for grammar, style, and readibility but not content. Additional information about NSF awards, including awards for research in or pertaining to Antarctica, can be obtained at the NSF web site (http://www.nsf.gov).

U.S. Antarctic Program

1997-1998

National Science Foundation

Office of Polar Programs

4201 Wilson Boulevard

Arlington, Virginia 22230

U.S. Antarctic Program, 1997-1998

The 175 research projects that the U.S. Antarctic Program will field during the 1997-1998 austral summer and the 1998 winter are this year's U.S. contribution to the international effort to understand the Antarctic and its role in global processes and to support other research that can be best or only performed in Antarctica. This book, which describes each project, is intended by the National Science Foundation (NSF), as funding and management agency for the program, to keep scientists and others informed about research progress.

Most of the research described here is performed by teams of investigators from U.S. universities who have won NSF financial support of their work in response to *Antarctic Research: Program Announcement and Proposal Guide* (NSF 96-93), which describes research goals generally. Scientists from other Federal agencies also are supported by the operational resources in the Antarctic that are maintained by the Foundation.

These resources consist principally of the year-round research stations McMurdo—a coastal station and operational hub at 78°S at the southwest corner of the Ross Sea; Amundsen-Scott South Pole at 90°S in the antarctic interior; and Palmer on Anvers Island along the west coast of the Antarctic Peninsula at 64°S. The research icebreaker *Nathaniel B. Palmer* supports investigations in sea ice areas around the Antarctic, and a new ice-strengthened research and support ship—*Laurence M. Gould*—will debut during the 1997-1998 season to replace *Polar Duke*, in the program since 1984.

Heavy-airlift mobility comes from ski-equipped C-130 airplanes operated by the New York Air National Guard and the Navy's Antarctic Development Squadron 6. Smaller ski-equipped planes (Twin Otters under charter) and a fleet of contract helicopters headquartered at McMurdo also provide air support, and various ground vehicles are in use. A Coast Guard icebreaker provides operational and research support, and the U.S. Air Force Air Mobility Command provides airlift between New Zealand and McMurdo. The NSF contractor Antarctic Support Associates provides operations, maintenance, specialized science support, and other services.

With one exception, this book arranges the research projects in scientific discipline order. The order recalls the organization of the Antarctic Sciences Section of NSF's Office of Polar Programs, which funds projects in biology, environmental research, ocean sciences, climate systems, geology and geophysics, glaciology, aeronomy, astronomy, and astrophysics. The exception is the interdisciplinary southern ocean component of the Joint Global Ocean Flux Study, supported by the Office of Polar Programs and the Division of Ocean Sciences.

Projects that are not primarily scientific research are not described here. Such projects include those to integrate research and education, to enable representatives of the media to report on the program, and for artists and writers to help record the Nation's antarctic heritage. Maintenance and engineering infrastructure projects also are not addressed.

Related information products that are produced or funded by NSF include:

- Press releases issued by the Foundation's Public Affairs Office to describe specific research progress. See the NSF World Wide Web page at http://www.nsf.gov or call 703-306-1070.
- *Antarctic Journal of the United States*, which reports U.S. Antarctic Program news and related events, now online monthly at the NSF WWW site.
- *Antarctic Journal of the United States* annual review issues, which contain short reports by investi-gators about research recently performed in Antarctica. These large issues are online and are available in print from the Office of Polar Programs (dfriscic @nsf.gov).
- A Library of Congress bibliography covers the world literature back to 1951. Principal products are the monthly *Current Antarctic Literature*—online at http://www.crrel.usace.army.mil/library/aware/ antlit.htm—and annual *Antarctic Bibliography*—available from the Government Printing Office, Washington, D.C. 20402. National Information Services Corporation (410-243-0797 or sales@nisc.com) sells a CD-ROM holding this database and other polar bibliographies.

Short "highlights" e-mails can be sent to you when each month's *Current Antarctic Literature* and *Antarctic Journal* is posted. To be placed on the list contact dbeverst@nsf.gov.

Biology and medicine

Photochemical and optical properties of antarctic waters in response to changing UV-B fluxes. David Kieber, State University of New York, College of Environmental Science and Forestry; and Kenneth Mopper, Washington State University. The decrease in stratospheric ozone over the Antarctic results in an increase in the UV-B flux in the ocean surface waters where photosynthesis occurs (the euphotic zone). The increase leads to cellular damage to aquatic organisms, as documented by photo-inhibition, and decreased productivity. Cellular damage can occur either intracellularly or externally at the cell surface from biomolecular reactions with externally-generated reactive transient compounds. The extent of this extracellular damage will depend on the photochemistry of the seawater surrounding the cell. Until recently, nothing was known about the type of photochemical processes, rates, and steady state concentrations of transients in Antarctic waters. Our objective is to determine the dependence of UV-B and UV-A fluxes on photochemical production rates of formaldehyde, hydrogen peroxide, pyruvate, and the OH radical in antarctic coastal waters. We will collect and filter 40 liters of sea water. Aliquots of this water will be placed in quartz tubes and irradiated in a surface water bath each day. Using radiometers and spectral irradiance data available hourly at Palmer Station, we will measure the total daily UV-B and UV-A light fluxes. This experiment will be repeated for 2 - 3 separate 40-liter water samples. Concurrent with this long-term experiment, we will collect, filter, and irradiate coastal sea water daily to assess the variability in surface water photoproduction rates as a function of nitrate and nitrite levels (for the OH radical), DOC concentrations and the optical properties (absorbance and fluorescence) of these waters. Additionally we will collaborate with researchers from the Smithsonian's Environmental Research Center (S-010) to determine action spectra for phytoplankton photoinhibition and photoproduction of reactive oxygen species (the OH radical and hydrogen peroxide) in the same water samples and under the same light conditions. With these data we will be able to construct models of photochemical production rates in surface waters and at various depths and to predict the impact of varying levels of UV-B on the photoproduction and steady-state concentration of several key reactive transient compounds in the upper water column. (S-002)

Impacts of climate change on antarctic vascular plants: Warming and ultraviolet-B radiation. *Thomas Day, Arizona State University*. Evidence is strong that the climate of the Antarctic Peninsula has changed appreciably in this century. Weather records indicate that mean summer air temperatures have risen more than 10°C over the past 45 years at some peninsula locations. In addition to this warming trend, springtime ozone depletion events have resulted in well-documented increases in ultraviolet-B (UV-B) radiation levels. These rapid changes in regional climate provide a unique opportunity to assess the impacts of climate change on vascular plants.

Although the presence of only two native vascular plant species (*Deschampsia antarctica* and *Colobanthus quitensis*) and their sparse distribution in Antarctica attest to the severe conditions for plant survival, there are already indications that climate changes are exerting a strong influence on these species. Regional warming appears to be leading to rapid increases in populations of these species, based on censuses taken along the peninsula. The influence of enhanced UV-B levels on these species is less clear.

An experiment has been initiated in which temperature and UV radiation levels are manipulated around naturally growing *Deschampsia* and *Colobanthus* plants on the Antarctic Peninsula to assess their responses to these factors. Assessment involves examining changes in photosynthesis, growth, and reproduction of these plants following warming or exclusion of different UV components.

During the first field season, growth significantly improved under warming treatments. Exclusion of UV did not have any significant effects, although conclusions from this short-term assessment would be premature. Field manipulations will be continued and expanded in the current assessment of plant responses in four key areas: photosynthesis, general thermal adaptations, reproduction, and soils. These areas are critical to understanding plant responses to climate change in Antarctica. (S-003)

Role of antifreeze proteins in freezing avoidance in antarctic fishes: Ecological and organismal physiology, structure-function and mechanism, genetics, and evolution. *Arthur DeVries, University of Illinois.* Ongoing and new studies of the role of anti-

freeze glycopeptides (AFGPs) and peptides (AFPs) in freezing avoidance of antarctic fishes in five specific areas constitute this project:

- the relationship of the severity of environment and association of ice in fish,
- the uptake of endogenous ice and its fate,
- structure-function of antifreeze proteins including the molecular mechanism of AP adsorption and inhibition of ice growth,
- structures and organizations of AP genes and gene families and their relationship to protein characteristics and gene evolution, and
- tissue specificity of AFGP expression.

The extent of exogenous and endogenous ice will be determined for McMurdo area fishes, which experience the coldest and most ice-laden waters of the antarctic region. Similar experiments will be conducted for the less severe marine environment of the Antarctic Peninsula. These studies will correlate freezing extremes with circulating levels of AFGPs in the fishes associated with these two environments. (S-005)

Metabolic physiology during embryonic and larval development of antarctic echinoderms. *Donal T. Manahan, University of Southern California.* Feeding larvae of benthic marine invertebrates in the cold waters of McMurdo Sound are present in the water column for many months before the phytoplankton bloom, but scientists currently do not understand how these feeding larvae survive long periods under starvation conditions. Knowing the physiological mechanisms of this process is important for understanding the ecology of larvae from antarctic regions. For example, the results from recent studies of antarctic echinoderm larvae do not support the suggestion that feeding larvae use other food sources (bacteria or dissolved organic material) to survive this period of negligible phytoplankton abundance. Physiological data, however, suggest a possible survival strategy—potential larval life spans can be extended for about 1 year in the complete absence of food. Such life spans (without food) for feeding larval forms are unique to antarctic larvae. Our research focuses on the metabolism of this process in antarctic echinoderm larvae. We will test the hypothesis that the metabolic cost of development will be lower in antarctic echinoderms than for the same "unit of differentiation" (fertilized egg to feeding larval form) in comparable temperate larvae. Because such data on temperate larvae already exist, our investigation of antarctic larvae will enable us to compare stage-specific developmental metabolism rates. To obtain these metabolic data, we will use a novel technique called "coulometric respirometry," which permits continuous measurements of metabolic rate during development. In addition, we will examine the biochemistry of development to determine the mechanism(s) of low metabolism in antarctic larvae. Using data from these, we will test long-standing hypotheses on cellular mechanisms of low metabolism as these apply to invertebrate development in antarctic environments. The results from our research may also have implications for larvae developing under limited food conditions in other cold environments, such as the deep sea. (S-006)

Ultraviolet photobiology of planktonic development stages of antarctic benthic invertebrates. *Deneb Karentz, University of San Francisco.* Recently documented global decreases in stratospheric ozone have brought attention to the potential ecological consequences of increased ultraviolet-B (UV-B) radiation in marine communities. Even without ozone depletion, UV-B radiation penetration of ocean surface waters represents a biological hazard to many marine organisms. The most extensive destruction of ozone has been occurring over Antarctica and the southern oceans, where over 50 percent depletion is recorded each spring.

A major obstacle in assessing UV effects is that little is known about the UV photobiology of individual species. In the Antarctic, some of the ecologically dominant benthic invertebrate species occupy intertidal and shallow subtidal depths where researchers have already documented biological effects of UV-B. Because, for many of these species, their planktonic development and spawning season coincide with the period when ozone depletion is occurring, their microscopic embryos and larvae are exposed to increasingly higher levels of UV-B. Presently, no information is available on the potential short- or long-term effects of increased UV-B levels on populations of antarctic benthic invertebrates.

Our research focuses on the UV photobiology of three important antarctic invertebrate species—the limpet *Nacella concinna*, the sea urchin *Sterechinus neumayeri*, and the sea star *Odontaster validus*—which inhabit intertidal and subtidal areas in the region of Palmer Station, Anvers Island, Antarctic Peninsula. The adults of these species are dominant members of antarctic intertidal and shallow subtidal benthic communities, and their embryos and larvae develop for

months in surface waters from late austral winter through summer. To evaluate the impact of ambient UV-B on early stages (gametes, embryos, and larvae) in the life histories of these species, we will examine potential UV exposure levels; assess differential sensitivities; identify molecular, chromosomal, and morphological UV-B induced damage; and evaluate potential protection and recovery from UV-B exposure. Because these species have taxonomic equivalents at both temperate and tropical latitudes, our study will provide important biological parameters for increasing scientific knowledge about UV effects on both local and global scales. (S-007)

Polar T^3 Syndrome: Metabolic and cognitive manifestations and their hormonal regulation and impact upon performance. *H.L. Reed, Kathleen R. Kowalski, Kenneth D. Burman, and John Thomas, H.M. Jackson Foundation for Military Medicine.* People who live and work in Antarctica for longer than 4 to 5 months develop a characteristic constellation of symptoms and hormonal changes called the "Polar T^3 Syndrome." Earlier researchers have described these people as having a 40 percent increase in energy requirement; frequent mood disorders; doubling of the production, use, and tissue stores of triiodothyronine (T^3), the most active thyroid hormone; a decline in central nervous system thyroxine (T^4); and acquisition of physiologic cold adaptation.

To improve science's understanding of this syndrome, a team of experienced polar physiologists, endocrinologists, and psychologists will use a multidisciplinary approach to study these apparent discordant and compartmentalized tissue responses over 4 years. The possible cognitive and metabolic changes in performance related to declines in central nervous system T^4 and elevations in skeletal muscle T^3 content will be studied. Placebo-controlled T^4 replacement directed at the central nervous system deficit will be carried out and measured with cognitive instruments.

The team will evaluate T^3 content in the cardiovascular system by using submaximal exercise testing to differentiate resting from activity-mediated, energy-use contributions by the skeletal muscles. Additionally, tissue samples of skeletal muscle will provide information regarding the genetic coding for T^3 responsive proteins and, thus, will permit more accurate characterization of the thyroid status of these muscles. We will use moderate energy restriction along with T^4 supplementation to study the dependence of T^3 production, distribution, and tissue stores upon both pituitary generation of thyrotropin and energy intake and will analyze each subject's baseline, determined in the predeployment situation of California and compared with periods and standardized measures obtained during the antarctic summer and winter.

We believe that a correction of the low T^4 state in the central nervous system can be managed with T^4 supplementation without dramatically changing energy requirements, as suggested by researchers previously conducting human studies using cold-air chamber experiments. If this thesis is correct, characteristic declines in mood and memory during winter seasons in circumpolar regions may be attenuated by T^4 supplementation without affecting energy metabolism disadvantageously. Our project also expands information regarding the ultimate regulation and maintenance of the increased T^3 production, a central determinant of the Polar T^3 Syndrome. (S-008)

Possible linkages between ecosystem measures and the demographics of a Weddell seal population. *Donald Siniff, University of Minnesota.* The Weddell seal, an important upper-trophic-level species, has been the focus of long-term studies because this species congregates near antarctic support facilities. The most extensive investigations have involved the Weddell seal population near McMurdo Station where research and monitoring efforts began in the early 1960s and have continued to the present. The objectives of our project are

- to continue the long-term tagging studies by completing the fieldwork necessary to tag all pups born into the McMurdo Sound population and to replace tags on previously tagged individuals so they will not be lost from the tagged population
- to update estimates of population parameters annually and to continue the analyses and tests of hypotheses associated with this database
- to collect blood samples for DNA analysis, in support of anticipated future genetic work
- to attach radio transmitters to adult males to study breeding activity
- to study Weddell seal foraging ecology with scientists from Hubbs Marine Research Institute.

In support of these objectives, we will carry out mark-and-recapture surveys that are necessary to obtain all the estimates required for current capture-recapture models. (S-009)

New approaches to measuring and understanding the effects of ultraviolet radiation on photosynthesis by antarctic phytoplankton. *Patrick Neale, Smithsonian Institution.* Increases in ultraviolet-B radiation (UV-B, 280-320 nanometers) associated with the antarctic ozone hole have been shown to inhibit the photosynthesis of phytoplankton, but the overall effect on water column production is still a matter of debate and continued investigation. Investigations have also revealed that even at "normal" levels of antarctic stratospheric ozone, UV-B and UV-A (320-400 nanometers) appear to have strong effects on water column production. The role of UV in the ecology of phytoplankton primary production has probably been under appreciated in the past and could be particularly important to the estimation of primary production in the presence of vertical mixing. This research focuses on quantifying UV effects on photosynthesis of antarctic phytoplankton by defining biological weighting functions for UV-inhibition.

New theoretical and experimental approaches will be used to investigate UV responses in both the open waters of the Weddell-Scotia confluence and coastal waters near Palmer Station. In particular, measurements will be made of the kinetics of UV inhibition and recovery on time scales ranging from minutes to days. Variability in biological weighting functions will be calculated for pelagic and coastal phytoplankton in the southern oceans. The results will

- provide absolute estimates of photosynthesis under *in situ*, as well as under altered, UV irradiance;
- broaden the range of assemblages for which biological weighting functions have been determined; and
- clarify how kinetics of inhibition and recovery should be represented in mixed-layer models. (S-010)

The role and regulation of chloride cells in antarctic fish. *David Petrel, Creighton University.* Antarctic fish have the highest serum osmolarity of any sea water teleost. Maintenance of fluid balance is crucial for survival. Upon warm acclimation from -1.5° to 4°C, the fish lose 20 percent of their serum osmolarity through extrusion of sodium chloride (NaCl) across the gill. NaCl extrusion in fish is primarily performed by chloride-secreting cells located on the gill arches and gill opercula. The driving force for NaCl transport is the sodium/potassium-ATPase. To date, no information is available concerning the role and regulation of the elevated serum osmolarity in antarctic fish. Questions that arise include these:

- What role does the chloride cell play in mediating salt extrusion?
- Which hormones regulate chloride cell activity?

The chloride cell physiology and regulation in antarctic fish will be compared with a New Zealand fish that is eurythermal. The goals of the proposed research are to determine the plasticity of antarctic and New Zealand fish gill function at the physiological level (through studies of ion transport activity) and molecular level (through studies of the sodium/potassium-ATPase enzyme). Specifically, this research will

- determine the gill extrusion mechanisms underlying the increase in gill sodium/potassium-ATPase activity upon warm acclimation in antarctic fish and
- determine the hormonal regulation of the gill extrusion mechanisms.

The results of this research will, for the first time, describe in detail the underlying mechanism(s) mediating the enhanced hypo-osmoregulation observed in antarctic fish and will allow the comparison of these results to those observed in a eurythermal New Zealand fish. (S-012)

Weddell seal foraging: Behavioral and energetic strategies for hunting beneath the antarctic fast ice. *Randall Davis, Texas A&M University at Galveston.* To forage efficiently beneath the extensive, unbroken fast ice along the antarctic coast, Weddell seals (*Leptonychotes weddellii*) have adapted to an environment that is very challenging for an air-breathing predator. These adaptations enable Weddell seals to hunt for prey at depth while holding their breath for 20 minutes or longer. This feat is analogous to a lion or other large terrestrial predator holding its breath while it locates, pursues, and captures prey. In addition, Weddell seals must return to the same hole at the end of a dive or know the location of other breathing holes. Failure to locate a breathing hole will result in a seal's death by drowning.

This study will investigate the behavioral and energetic adaptations that enable Weddell seals to forage in the antarctic fast-ice environment. To achieve this goal, the underwater behavior, locomotor performance (swimming velocity, stroke fre-

quency and amplitude, and three-dimensional movements), and energy metabolism of Weddell seals will be measured during foraging dives. Hypotheses on general foraging strategies, searching behavior, searching mechanics, modes of swimming, metabolic costs of foraging, and foraging efficiency for different environmental conditions and prey type will be tested. Until now, it has not been possible to investigate the foraging behavior of marine mammals in detail. To accomplish this study, a small video system and data logger will be attached to the seals' backs, and oxygen consumption will be measured during voluntary dives from an isolated ice hole in McMurdo Sound, Antarctica.

Observing the foraging behavior and prey of marine mammals is a major means to advance studies of their foraging ecology. The Weddell seal may be the single best species in which to study the foraging behavior and energetics of deep-diving pinnipeds because

- data are available on its diving ability,
- the isolated-ice-hole protocol in McMurdo Sound enables recorders to be attached and recovered reliably, and
- it makes daily foraging dives when placed in the isolated ice hole. (S-017)

Population structure of key antarctic fish and invertebrate resource species. *Patrick M Gaffney, University of Delaware.* Characterizing the population structure of important antarctic species is essential to an improved understanding of antarctic ecology and the successful management of this ecosystem. The British Antarctic Survey (BAS) has initiated a collaborative international effort (Project Gene Flow) aimed at delineating population structure in several key species (fish, squid, and krill). A 1-month cruise in the Scotia Sea to obtain biological specimens and oceanographic data represents a unique opportunity to apply both established and novel molecular techniques to an important problem in antarctic resource management. Four commercially and/or ecologically important species will be the primary targets of the research: mackerel icefish, Patagonian toothfish, antarctic krill, and the seven star flying squid. A variety of molecular genetic techniques, including some that are well-established and others that are novel but extremely promising, will be applied to delineate genetic population structure in these species. This research will provide information on the whether separate "stocks" or genetically different populations of these species exist in antarctic waters. This information will be useful in the management of these species. (S-018)

Long-Term Ecological Research on the antarctic marine ecosystem: An ice dominated environment. *Maria Vernet, Scripps Institution of Oceanography; Eileen Hofmann, Old Dominion University; Langdon Quetin and Raymond C. Smith, University of California at Santa Barbara; William R. Fraser, Montana State University; David M. Karl, University of Hawaii*. The central hypothesis of the Palmer Long-Term Ecological Research (LTER) project is that the annual advance and retreat of sea ice is a major physical determinant of spatial and temporal changes in the structure and function of the antarctic marine ecosystem. Evidence shows that this dynamic variability of sea ice has an important, perhaps major, impact on all levels of the food web, from total annual primary production to breeding success in apex predators. For example, variability in sea ice may affect prey and predators directly (e.g., access to open water or preferred habitats) or indirectly (e.g., food availability, which in turn may be affected by the variability in sea ice). We hypothesize that sea ice is a major factor regulating

- the timing and magnitude of seasonal primary production;
- the dynamics of the microbial loop and particle sedimentation;
- krill abundance, distribution, and recruitment; and
- survivorship and reproductive success of apex predators.

The magnitude and timing of sea ice may have different consequences for different key species, and it is still unclear what the ramifications would be for the whole antarctic ecosystem. For example, high levels of survivorship and reproductive success of Adélie penguins appear to depend on high levels of availability of antarctic krill, which in turn appear to be correlated with greater ice coverage. On the other hand, high levels of breeding success of south polar skuas appear to be determined by the availability of antarctic silverfish, which in turn appear to be associated with lesser ice coverage. Thus, the overall objectives of the Palmer LTER project are

- to document not only the interannual variability of annual sea ice and the corresponding physics, chemistry, optics, and primary production within the study area but also the life-history parameters of secondary producers and apex predators;

- to quantify the processes that cause variation in physical forcing and the subsequent biological response among the representative trophic levels;
- to construct models that link ecosystem processes to environmental variables and which simulate spatial/temporal ecosystem relationships; and then
- to employ such models to predict and validate ice-ecosystem dynamics.

A key challenge for the Palmer LTER project is to characterize and understand the link between the different spatial and temporal scales of the various physical and biological components of the antarctic ecosystem. (S-016, S-021, S-028, S-032, S-035, and S-046)

The chemical ecology of shallow-water antarctic marine invertebrates. *Bill J. Baker, Florida Institute of Technology.* Our research is a continuation of an interdisciplinary approach to chemical ecology. The objectives are to characterize and quantify chemically mediated ecological relationships among antarctic benthic invertebrates. During two field seasons, we will investigate several specific objectives. We will evaluate the chemical defenses in adult antarctic marine invertebrates and also early life history stages. Investigators will evaluate lecithotrophic eggs, embryos, and larvae for bioactivity. This is particularly relevant because many antarctic invertebrates broadcast conspicuous lecithotrophic embryos and larvae, which require 2 to 6 months to develop. Because biologists have observed that colored sponges use their pigments as defensive agents, we will investigate the functional role of this coloring in sponges and in other colored invertebrates. Furthermore, bioactive metabolite concentration and sequestration will be investigated in invertebrates from which researchers have isolated secondary metabolites. Finally, we will continue to work on isolating and characterizing bioactive compounds from invertebrates to evaluate their functional role. Two significant aspects of this research are the use of ecologically relevant bioassays to guide the isolation of the active chemical agents while working on-site at McMurdo Station and, subsequently, the characterization of those metabolites at our home institutions. In summary, our research program will contribute significantly to the understanding of the nature and role of bioactive agents in the ecology of the antarctic marine benthos. (S-022)

Factors regulating population size and colony distribution of Adélie penguins in the Ross Sea. *David Ainley, Point Reyes Bird Observatory.* As part of this collaborative project, we will investigate the demographic mechanisms responsible for dramatic growth in existing Adélie penguin (*Pygoscelis adeliae*) colonies and will identify new ones in the Ross Sea region. We will also study the possibility that the growth of these colonies is related to documented climate change in the region by

- distinguishing the relative importance of the key resources that constrain colony growth—availability of nesting habitat vs. access to food and
- examining behavioral mechanisms (philopatry—the immigration/emigration balance, and/or breeding effort/success) that influence colony growth as a function of initial size and distribution.

This will be the first empirical *a priori* study to consider the geographic structuring of a seabird population. Results will increase scientific understanding of population regulation and patterns of dispersion and of the effects of climate change—mediated through changes in sea-ice cover—on penguin populations. In addition, results will provide a context in which to interpret conflicting data on penguin population trends from existing programs that use Adélie penguins as an indicator species for point source anthropogenic impacts on antarctic resources (e.g., fishery catches, disturbance by tourism). Our 7-year research effort includes intensive field study conducted at three Ross Island penguin colonies. As part of the study, we will quantify reproductive effort and success, food availability (access to food), diet quality, habitat use, and immigration/emigration relative to colony size and environmental conditions (i.e., pack-ice cover). Our methods bring together several well-established techniques that have been successfully but infrequently used in antarctic biology:

- aerial photography to evaluate availability of nesting habitat
- microwave images of sea-ice concentration to assess availability of feeding habitat
- analysis of stable isotopes to evaluate food quality
- radio telemetry to assess overlap in colony feeding areas
- automatic systems to log aspects of reproductive effort.

Our research builds on the efforts of Landcare Research New Zealand (LCRNZ), which conducted

two preliminary field seasons and is independently funded; LCRNZ activities include the testing of new equipment. LCRNZ will continue its efforts and collaborate with us throughout the project. Researchers from the University of California at Santa Cruz, University of Wisconsin, and Avid, Inc., will work with those from H.T. Harvey and Associates and LCRNZ to accomplish project goals. (S-031)

Penguin-krill-ice interactions: The impact of environmental variability on penguin demography. *Wayne Trivelpiece, Montana State University.* This study will focus on populations of Adélie, gentoo, and chinstrap penguins at Admiralty Bay, King George Island. These populations have exhibited fluctuations in abundance that have been related to long-term changes in environmental conditions, in particular sea-ice coverage and its possible effects on prey (krill) availability.

This research will test the following five hypotheses relating penguin demography to environmental variability via its effect on krill recruitment in the antarctic marine ecosystem.

- Krill population structure is strongly affected by pack ice extent through its impact on female fecundity and larval survival.
- Recruitment of penguins to their respective populations will be affected by the extent of pack ice cover during the winter prior to the breeding season.
- The survival of penguin fledglings will be correlated to the extent of pack ice cover the winter following the breeding season.
- Adélie penguins return to the pack-ice habitat during their first 2-week long foraging trips following clutch competition to recover from the prolonged fasting of the courtship period.
- Accessible pack ice in the early breeding season has led to the evolution of discreet population centers of Adélies from the Bellingshausen, Weddell, and Ross Sea populations.

The *Pygoscelis* species are the major predators of krill (*Euphausia superba*) in the Antarctic Peninsula region and are key species used to monitor the potential impacts of fishery activities in this area. To understand the structure and function of the antarctic marine ecosystem thoroughly, it is imperative to determine the impact of environmental variation on the structure and regulation of upper trophic level predators such as the *Pygoscelis* penguins. (S-040)

McMurdo Dry Valleys: A cold desert ecosystem. *Robert A. Wharton, Jr., University of Nevada, Desert Research Institute; Andrew Fountain, U.S. Geological Survey; Diana Freckman, Colorado State University; W. Berry Lyons, University of Alabama; John Priscu, Montana State University.* The McMurdo Dry Valleys, located on the western coast of McMurdo Sound, form the largest ice-free area (approximately 4,800 square kilometers) on the antarctic continent. This area was selected as a study site in the National Science Foundation's Long-Term Ecological Research (LTER) program. The dry valleys are among the most extreme deserts in the world—far colder and drier than any of the other LTER sites. The perennially ice-covered lakes, ephemeral streams, and extensive areas of exposed soil within the valleys are subject to low temperatures, limited precipitation, and salt accumulation. The biotic systems in the McMurdo Dry Valleys are composed of only microbial populations, microinvertebrates, mosses, and lichens. Nonetheless, complex trophic interactions and biogeochemical nutrient cycles exist in the lakes, streams, and soils. Solar energy produces glacial melt water in the austral summer, and in turn, this melt water exerts a primary influence on the soils, streams, and lakes by replenishing water and nutrients to these ecosystems. All ecosystems are shaped to varying degrees by climate and material transport, but nowhere is this more apparent than in the McMurdo Dry Valleys. The overall objectives of the McMurdo Dry Valleys LTER are to understand the influence of physical and biological constraints on the structure and function of dry valley ecosystems and to understand the modifying effects of material transport on these ecosystems. These objectives will be accomplished through a program of systematic environmental data collection, long-term experiments, and model development.

During the 1997-1998 field season, the following studies will be conducted in the McMurdo Dry Valleys as part of the LTER project:

- glacier mass balance, melt, and energy balance
- chemistry of streams, lakes, and glaciers
- flow, sediment-transport, and productivity of streams
- lake pelagic and benthic productivity—microbial food webs
- soil productivity
- Radarsat studies of aeolian transport processes
- ground penetrating radar (GPR) measurements

of glaciers and frozen lakes.

- meteorology.

Our efforts will focus on integrating the biological processes in and material transport between the lakes, streams, and terrestrial ecosystems in the dry valley landscape. This season, several experiments will focus increased attention on community structure and function within benthic microbial mats of the dry valleys lakes. Because experimental setup and sampling of lake sediments and microbial mats requires scuba diving, an additional goal this season is to evaluate quantitatively the potential impact of diving activities on lake systems. (S-042)

Buoyancy and morphological studies of antarctic notothenioid fishes. *Joseph T. Eastman, Ohio University.* Notothenioids, antarctic fishes of the perciform suborder Notothenioidei, are the dominant fishes by number and biomass in all inner shelf areas of the southern oceans. An evolutionary novelty—the only known example of a fish species flock—notothenioids, which are derived from a benthic stock lacking swim bladders, have diversified into most water-column habitats. They display a wide scope of organismal diversification in an ecosystem historically underused by non-notothenioid fishes and are a striking example of the nature of antarctic marine biodiversity. The primary objectives of our project, which centers on evaluating organismal diversification in these antarctic fishes, are

- to evaluate organismal diversification with emphasis on neutral buoyancy, reduced density (compared to the pleisomorphic benthic condition), and the associated morphology in members of the families Nototheniidae, Channichthyidae, and Bathydraconidae
- to explore the evolution of neutral buoyancy and reduced density by mapping these and other morphological features on cladograms independently derived from other information
- to determine whether the diversification of buoyancy (life history) types and the associated morphology are reflective of the phylogenetic history of various notothenioid classes or are related to environmental adaptation
- to add new buoyancy and morphological information to the existing suites of characters available for phylogenetic analysis of notothenioids.

We are also interested in elucidating the morphological basis for evolutionary changes in buoyancy and are hopeful that our study will provide insight into how notothenioids diversified to occupy a variety of water-column habitats in the southern oceans. (S-048)

Ecological studies of sea-ice communities in the Ross Sea, Antarctica. *David Garrison, University of California at Santa Cruz.* Coastal sea ice forms an extensive habitat in the southern oceans. Reports dating from the earliest explorations of Antarctica have described high concentrations of algae associated with sea-ice, suggesting that the ice must be an important site of production and biological activity. The magnitude and importance of ice-based production is difficult to estimate largely because the spatial and temporal distributions of ice communities have been examined in only a few regions, and the processes controlling production and community development in ice are still understood only superficially. This study will examine sea-ice communities in the Ross Sea region of Antarctica in conjunction with studies of ice physics and remote sensing. The specific objectives of the study are

- to relate the overall distribution of ice communities in the Ross Sea to specific habitats that are formed as the result of ice formation and growth processes;
- to study the initial formation of sea ice to document the incorporation and survival of organisms, in particular to examine winter populations within "snow-ice" layers to determine if a seed population is established at the time of surface flooding;
- to sample summer communities to determine the extent that highly productive "snow-ice" and "freeboard" communities develop in the deep water regions of the Ross Sea; and
- to collect basic data on the biota, activity, and general physical and chemical characteristics of the ice assemblages, so that this study contributes to the general understanding of the ecology of the ice biota in pack ice regions. (S-325)

Joint Global Ocean Flux Study

The objectives of the U.S. Joint Global Ocean Flux Study (JGOFS) are to quantify and understand processes controlling the time-varying fluxes of carbon and associated biogenic elements and to predict the response of marine biogeochemical processes to climate change. The JGOFS Southern Ocean Program, a 3-year effort south of the antarctic Polar Front Zone, is aimed at

- understanding better the fluxes of carbon, both organic and inorganic, in the southern oceans
- identifying the physical, ecological, and biogeochemical factors and processes that regulate the magnitude and variability of these fluxes
- placing these fluxes into the context of the contemporary global carbon cycle.

The southern oceans are critical in the global carbon cycle, as indicated by the region's size and the important physical processes that occur in it (e.g., deep and intermediate water formation), but its quantitative role in the contemporary global carbon cycle is uncertain. Because the broad continental shelf of the Ross Sea is characterized by relatively high biomass with large phytoplankton blooms in the austral spring and summer, this region has been selected for intensive process studies as part of the U.S. JGOFS comprehensive investigation of carbon and biogenic fluxes in the southern oceans.

Management and scientific services in support of the U.S. JGOFS Southern Ocean Program study: (1) Nutrients and (2) hydrography, coring, and site survey. *Robert F. Anderson, Columbia University; Walker Smith, University of Tennessee* . The JGOFS objectives for the southern oceans study include determining the response of the southern oceans to natural climate perturbations and predicting the response of the southern oceans to climate change.

To address these objectives successfully, a large field program has been designed to provide various investigators the opportunity to test specific hypotheses that relate to these broadly defined objectives. We expect the field test to last through March 1998 and use two U.S. research ships: the U.S. Antarctic Program's icebreaking research ship *Nathaniel B. Palmer* and a ship from the University National Oceanographic Laboratory System. Because most of the investigators will use hydrographic and nutrient data from these cruises, this project will support the analysis of nutrient concentrations during the 13 JGOFS cruises. A team of oceanographic experts representing various institutions has been assembled to complete these analyses. The data will be scrutinized for errors and provided in a timely fashion to all project investigators, as well as to the relevant oceanographic data-storage facilities. The hydrography and coring groups have been put together based on the successful model for the Arabian Sea JGOFS study. In conjunction with the nutrient data, the efforts of these groups will form a large portion of the southern oceans JGOFS database that both field investigators and modelers will use to clarify the role of the southern oceans in the global carbon cycle. (S-211 and S-255)

Mesoscale processes and primary productivity at the polar front. *Mark R. Abbott, Oregon State University.* The Antarctic Circumpolar Current (ACC) provides a pathway between the major basins of the Pacific, Atlantic, and Indian Oceans and has a critical role in the global redistribution of salt, heat, and other ocean properties between these basins. Although improved observations and more powerful numerical models have identified many critical processes, the scarcity of direct observations has greatly hampered our understanding of the physical environment. Scientific understanding of ocean biogeochemistry in this region is even worse. The challenge to understanding southern ocean dynamics (both physics and biogeochemistry) is exacerbated by the strong dynamic link between mesoscale processes and large-scale processes. The dynamic scales approach the scales typical of energetic coastal systems, yet the size of the southern oceans and the impacts on global biogeochemistry and climate make this an important region. Our JGOFS research focuses on the antarctic Polar Front Zone (APFZ) ecosystem, which behaves much like a coastal upwelling system and is characterized by episodic diatom blooms. These blooms result in high f-ratios, high preservation rates of biogenic silica, and relatively little vertical flux of particulate biogenic material. These processes are consistent with observations of bottom sediments.

The lack of meridional barriers leads to a "recirculation" of diatoms associated with frontal meanders. Phytoplankton would alternately upwell and then downwell in these meanders, creating a helical circulation path. Although such bloom events may be unimportant in the total productivity of the system, they do have a disproportionate role in carbon fluxes. To obtain data, we will use a high-resolution sampling array of moorings with bio-optical sensors and current meters. During the high-resolution surveys, we will also deploy Lagrangian drifters (some equipped with bio-optical sensors) to characterize the temporal and spatial scales of variability when coupled with the Eulerian observations from the moorings. These data will be analyzed in conjunction with high-resolution SeaSoar surveys and high temporal resolution sediment traps that other JGOFS investigators will use to study the effects of mesoscale processes on productivity and horizontal and vertical fluxes of biological properties. (S-212)

Distribution, sources, and sinks of dissolved organic matter in the southern oceans. *Edward T. Peltzer, Woods Hole Oceanographic Institution*. The five principal objectives of our project are

- to determine, via shipboard measurement, both dissolved organic carbon (DOC) and total organic carbon (TOC) and the spatial and temporal distribution of dissolved organic matter (DOM) in the southern oceans
- to identify the sites of net DOM production and export
- to estimate rates of net DOM production and export
- to estimate rates of bacterial remineralization of DOM
- to place these rates in the context of the global carbon cycle.

We will estimate the net rates of DOM production and consumption by a combination of *in situ* measurements and shipboard incubation experiments. Large-scale rates will be calculated from a combination of simple box and advection-diffusion models. We will routinely collect samples via small water samples drawn from 10-liter Niskin bottles on the conductivity-temperature-depth rosette. Our work emphasizes making large-scale surveys and repeating these surveys on a seasonal basis and will be conducted in collaboration with a complementary study that emphasizes process-oriented measurements of bacterial remineralization rates. Because the southern oceans constitute the only JGOFS study site where the vertical stability is low and where intermediate and deep water masses are being formed, we are able to observe directly the rate at which DOM is sequestered in the deep ocean. (S-213)

Measurements of carbon dioxide during the JGOFS Southern Ocean Program. *Taro Takahashi, Columbia University.* Water masses, such as Antarctic Bottom Water and Antarctic Intermediate Water, originate in the high-latitude southern ocean areas and spread through the interior of the major ocean basins, forming a major conduit for exchange of heat and such dissolved gases as carbon dioxide and oxygen between the atmosphere and the interior of the oceans. An improved understanding of the processes governing the physical and biogeochemical properties of the source waters in the southern oceans is important not only for gaining quantitative knowledge of the carbon-nutrient cycle in the global oceans but also for predicting the future course of atmospheric carbon dioxide and hence the climate of the Earth. Our research consists of three kinds of field observations. First, we will make continuous underway measurements of the total carbon dioxide concentration in surface waters throughout the JGOFS cruises to determine the seasonal and geographic variations and the causes of oceanic carbon dioxide sink/source conditions. Second, we will measure the partial pressure of gaseous carbon dioxide and total carbon dioxide in discrete sea water samples to observe depth profiles of the carbon chemistry (especially in the upper 500 meters) at hydrographic stations located at various latitudes during two seasonal cruises. Finally, high-resolution measurements of the hydrographic structure of the uppermost 250 meters and of nutrients will be conducted to document the mesoscale variability of biogeochemical properties within the antarctic Polar Front Zone. We will use a towed pumping system, designated as SeaSoar, on one of the cruises to the antarctic Polar Front Zone to make these measurements. (S-214)

Regulation of primary productivity in the southern oceans: Phytoplankton photosynthesis characteristics from individual cell measurements. *Robert J. Olson and Heidi M. Sosik, Woods Hole Oceanographic Institution.* Central to the mission of the U.S. JGOFS Southern Ocean Program is an understanding of the composition of the planktonic food web and the efficiency with which it transports carbon to the deep ocean. One of the specific questions being posed is the mechanism of regulation of phytoplankton growth and productivity in this area. Light

limitation, micronutrient availability, and grazing pressure all have been proposed to explain the persistence of high macronutrient concentrations and the relatively low productivity often observed. To distinguish among these mechanisms, we will examine photosynthetic characteristics of phytoplankton in natural populations under a range of environmental conditions. We will use chlorophyll-fluorescence induction measurements of individual cells to estimate photochemical efficiency and absorption cross-sections of photosystem 2 (PS2), as well as relative pigment content per cell for different groups of phytoplankton that can be distinguished either microscopically or flow cytometrically. These measurements, carried out on samples from depth profiles and experimentally manipulated assemblages of phytoplankton, should allow us to distinguish among limiting factors for phytoplankton growth. For example, limitation by micronutrients should result in low photochemical efficiency (reflecting the loss of functioning PS2 reaction centers), whereas low-light limitation (due to deep mixing) would be indicated by high fluorescence (i.e., pigment content) in near-surface cells. Grazing control would be implied if photosynthetic characteristics indicate no limitation of intrinsic growth rates. The individual cell nature of the proposed measurements will allow us to evaluate the condition of different groups of phytoplankton (or different cells) in a given water sample and to examine unambiguously the effects of environmental gradients or experimental treatments on given species. In addition, as a result of these measurements, we will be able to characterize the composition of the phytoplankton community by microscopic and flow-cytometric analysis. By observing the physiological state of cells in natural assemblages and experiments and combining this information with information on community structure, we will be able to evaluate the relative importance of light, iron, and grazing as limiting factors for productivity in the southern oceans and interpret more accurately bulk measurements of phytoplankton properties that can be obtained in a high-resolution survey with fast-repetition-rate fluorometry. (S-215)

Benthic cycling and accumulation of organic matter, biogenic opal, and $CaCO_3$ in the JGOFS southern ocean study areas. ***Frederick Sayles,*** *Woods Hole Oceanographic Institution.* Our JGOFS study focuses on benthic remineralization and burial and how these processes contribute to the cycling of the major biogenic components (organic matter, $CaCO_3$, and biogenic opal) in the southern oceans. (S-217)

Oxygen dynamics during the JGOFS southern ocean process study. *Michael L. Bender and Mary Lynn Dickson, University of Rhode Island.* Our research focuses on using oxygen to constrain carbon fluxes on three scales—large, meso, and local. For the large scale, we will collect air samples and measure the oxygen/nitrogen ratio. Because oxygen concentrations in the atmosphere vary on seasonal time scales as a result of primary production in the spring and summer months and ventilation of the ocean in the fall and winter, knowledge of the amplitude of the oxygen/nitrogen signal will provide a measure of the magnitude and timing of net production for the southern oceans. We collect air samples daily from ships that will participate in the JGOFS experiment to have high-resolution records of zonal and temporal variations of the atmospheric oxygen field. Similarly, we will determine net primary productivity from the mesoscale oxygen field in two ways: first by measuring oxygen/argon ratios and isotopic oxygen-18 from oxygen in sea water, which will be collected from the mixed layer, and second by continually measuring subsurface oxygen concentrations along the cruise track. These two approaches, together with the air-sampling program, will provide a temporally and spatially integrated estimate of net production. Finally, we will measure daily gross and net oxygen production and nitrate assimilation to constrain carbon flow. Gross oxygen production is calculated by spiking and incubating sea-water samples with oxygen-8 labeled water and measuring the isotopic oxygen-18 of the photosynthetically produced oxygen. Net oxygen production is measured by comparing the relative change in the oxygen concentration between initial and incubated samples by automated high-precision Winkler titrations. These measurements will provide daily depth-integrated gross and net production rates in addition to respiration rates. Furthermore, we will conduct photosynthetic irradiance experiments to measure gross and net production during cruises to extrapolate local measurements up to meso- and large-scale using bio-optical data from moorings and satellites. (S-218)

Iron in antarctic polar front zones. *Kenneth H. Coale, Moss Landing Marine Laboratory.* Our JGOFS project concerns the effect of iron on the productivity of the upper layers of the ocean. Dissolved iron concentrations in surface waters of the open ocean are often extremely low and have been shown to limit primary production in high-nitrate and low-chlorophyll regions of the global ocean. As a result of an earlier JGOFS study in the equatorial Pacific

Ocean, models describing the spatial and temporal variability in production and export now include the role of iron as a limiting micronutrient. The observed patterns of production in the equatorial Pacific were consistent with the supply and distribution of iron in this region. For the southern oceans, however, few data are available on iron concentrations and distribution of iron that could be used for such interpretations. For example, we do not know if iron concentrations are enhanced or depleted in southern ocean upwelled waters. Also, little is known concerning the concentrations, distributions, or sources of iron in the southern oceans and, as a result, correlating patterns of production in these waters with the distribution of iron is difficult. As part of our study, we will make systematic measurements of trace metal distributions in the Ross Sea and in the Antarctic Polar Front Zone with an emphasis on iron. These data will provide a base that will allow us to evaluate southern ocean biological processes in terms of a possible iron limitation. The results of this work will contribute significantly to our understanding of iron biogeochemistry in the southern oceans and of factors that control rates of new production in these regions, and they will have a direct bearing on our understanding of the global carbon cycle. (S-219)

Does copepod grazing control large phytoplankton in the HNLC region of the southern oceans? *Michael Dagg, Louisiana Universities Marine Consortium.* Large phytoplankton, especially diatoms, typically grow slowly in the permanently ice-free regions of the southern oceans, including the Antarctic Polar Front Zone (APFZ), because of limitations of micronutrients (Fe) or light or other limitations associated with deep mixing. Marine scientists believe that under these conditions the growth of large phytoplankton is balanced by grazing from the copepod community. When the growth of large phytoplankton is enhanced by increasing the amount of iron in the ecosystem or by improving light conditions, we believe that the additional growth is mostly absorbed by the functional response of the copepod community. The increased growth of phytoplankton, however, will saturate the grazing diatoms and increases the silicon-to-carbon ratio of sinking matter. This occurs because about 70 percent of ingested carbon is assimilated across the copepod gut wall but silicon is digestively inert. These relationships will be addressed by shipboard experiments designed to measure the feeding rates of large copepods on large phytoplankton of the APFZ and by measuring the ratio of carbon to biogenic silica in copepod fecal pellets and in sediment trap materials. (S-220)

Physical and biological controls of carbon dioxide levels in the southern oceans: A multitracer approach. *Paul D. Quay, University of Washington.* The southern oceans have been implicated, by ocean models, as an important region of oceanic uptake of anthropogenically produced carbon dioxide. Few data, however, are available to corroborate these model predictions. The three most likely characteristics of the southern oceans to have a major impact on global carbon-dioxide distribution are

- a carbon-dioxide sink that brings deep-water upwelling close to the surface
- high wind speeds that cause a rapid air-sea exchange of heat and gases
- biological productivity that occurs both in the open ocean and at the ice edge.

The interplay between these three processes controls the surface carbon-dioxide concentrations and, thus, the direction and magnitude of air-sea gas exchange. In our JGOFS project, we will use a combination of chemical measurements and a wind-driven circulation model to determine how deep water upwelling in this region exchanges carbon dioxide with the surface layer and how the air-sea exchange and biological productivity offset the effects of upwelling on surface carbon-dioxide levels. The measurement and modeling activities will yield a quantitative explanation of how the air-sea flux of carbon dioxide in the southern oceans is affected by circulation, gas exchange, and biological productivity. We will use the model results to predict how the surface carbon-dioxide levels and the ratio of carbon isotopes in the dissolved inorganic carbon pool of the ocean respond to changes in circulation rates and pathways caused by different atmospheric conditions. These results will help us to reconstruct past conditions of carbon-dioxide levels in the southern oceans, based on proxy measurements in marine sediments and continental ice cores. (S-221)

The role of particulate organic carbon, small particles, and aggregates in biogeochemical cycles in southern ocean fronts. *W.D. Gardner, Texas A&M University.* Our component of JGOFS concerns the role of particulate organic carbon (POC), small particles, and aggregates in biogeochemical cycling, and it makes use of optical techniques to quantify the flux of organic carbon. Specifically, the results of our investigation will help us to identify the factors and

quantify the processes that regulate the magnitude and variability of primary productivity and the fate of biogenic materials. We will use a suite of optical instruments to measure the *in situ* distribution of particles over the size range from microns to millimeters. To measure beam attenuation and light scattering, we will attach a transmissometer to over-the-side instruments at profiling stations. We will also make underway light transmission observations with the shipboard in-line sea-water system and will use an underwater video camera to define the *in situ* particle size distribution. The optical data will be correlated with measurements of particulate matter and particulate organic carbon and with discrete microplankton, chlorophyll, and primary productivity measurements made by others in the program. We will integrate these data with measurements of fluorescence, carbon dioxide, microplankton, mixed-layer dynamics, diel variations, frontal dynamics, nutrients, oxygen, light levels, wind mixing, and dissolved/particulate radioisotope distributions. The objective is to evaluate the role of particles in the packaging and export of carbon and particulate matter from the euphotic zone and the exchange between the large- and small-particle pools. (S-222)

Carbon and nitrogen in dissolved organics: A contribution to the U.S. JGOFS Southern Ocean Program. *Dennis Hansell, Bermuda Biological Station for Research.* We will collaborate with other researchers to evaluate microbial dynamics, carbon cycling, and the nitrogen cycle, particularly dissolved organic nitrogen (DON). Our goal is to determine the importance and role of dissolved organic carbon (DOC) as an intermediate in the oceanic carbon cycle. Nearly 1,000 gigatons of reduced carbon are estimated to reside in the DOC pool, which has a turnover time of 6,000 years. The average net oceanic carbon dioxide uptake is 2.1 gigatons, only a small fraction of the DOC pool. Although a perturbation in DOC production or sink could affect the balance between oceanic and atmospheric carbon, the dynamics of this large pool remain enigmatic. Our two specific objectives are to determine the concentrations of DOC and DON throughout the water column through an annual cycle and to measure the rates of DOC production by autotrophs and mineralization heterotrophs. (S-223)

Seasonal and spatial variations in the flux of particulate organic carbon derived from thorium-234 in the U.S. JGOFS southern ocean process study. *Ken O. Buesseler, Woods Hole Oceanographic Institution.* As part of the U.S. JGOFS Southern Ocean Program, we provide a quantitative estimate of upper ocean export fluxes of particulate organic carbon on spatial and temporal scales relevant to understanding biological and physical processes. We will measure the concentration of thorium-234 (a particle-reactive tracer with a half-life of 24.1 days) and its ratio to particulate organic carbon (POC) and particulate organic nitrogen (PON) to derive the appropriate export data. Our research includes collecting thorium-234 and POC samples on cruises spanning the seasonal production cycle in the antarctic Polar Front Zone. The results will be used to constrain the upper ocean sinking fluxes and to derive relationships between production and export across physical gradients (i.e., fronts) during seasonal transitions between low and high productivity. We will also examine the sensitivity of these rate estimates to model assumptions and data quality. (S-224)

The distribution of iron and other reactive trace metals in contrasting productivity zones of the Antarctic Polar Front during the U.S. JGOFS southern oceans study. *Christopher Measures, University of Hawaii.* Antarctic waters are generally characterized by low standing stocks of phytoplankton and low rates of primary production, despite the abundance of inorganic nutrients in the water column. Many researchers have speculated that the lack of in these waters explains this paradox but no one has presented conclusive evidence of the importance of iron or its mechanisms in stimulating productivity. The major goals of the JGOFS Southern Ocean Process Study are, in part, to unravel the factors and processes that regulate the magnitude and variability of primary productivity and use this knowledge to determine how the southern oceans respond to naturally occurring climate changes both in the past and in the future. In this study, we will measure iron and other reactive trace metals in the water column of various productivity regimes of the Antarctic Polar Front Zone. These measurements will be used to further our understanding of the supply and distribution of iron in antarctic waters and, in concert with the measurements taken by other investigators, the importance of iron in affecting the structure of the microbial food web and the dynamics of the various biogeochemical cycles in the water column. As the complex role that iron plays in the magnitude and sequence of biological processes becomes better understood, these measurements will gain importance in modeling the biological effects of iron on marine ecosystems and, indirectly, its impact in global biogeochemical cycles. (S-225)

Physics and recycling efficiency as factors controlling new (nitrate) production in the southern oceans. *Raymond Sambrotto, Columbia University, Lamont-Doherty Earth Observatory.* The vast size of southern ocean region together with its abundance of nutrients has led many scientists to speculate about its role in past and present exchanges of carbon with the atmosphere, as well as how this interaction may change in response to future climactic perturbation. To better understand the interaction between ocean and atmosphere, we will measure nitrate uptake and the uptake and regeneration of nitrogen from ammonium, urea, and dissolved amino acid sources in surface water. We also will measure how light affects nitrate uptake and analyze the size distribution to determine how vertical mixing can affect local rates of new production. Although we will sample all of the major physiographic regions of the southern oceans during this project, we will focus on the frontal systems at the northern portion of the study area, as well as the permanently ice-free region immediately to the south. This extensive region encompasses the largest, uninterrupted biogeochemical province in the world ocean. Thus, the work addresses the JGOFS goal of identifying the factors that regulate the magnitude and variability of biological production and its ultimate export from surface water and will be critical to the success of future models used to predict the response of the southern oceans to climate change. (S-226)

Latitudinal variations of particle fluxes in the southern oceans: A bottom-tethered sediment trap array experiment. *Jack Dymond, Oregon State University.* We will directly measure the downward flux of particulate matter through an array of bottom-mounted sediment traps. These traps will be maintained for 18 months and have a sampling resolution of 17 days with higher resolution during the intense summer phytoplankton bloom. The total export fluxes of organic carbon, nitrogen, biogenic silicates, and calcium carbonate that can be obtained from these measurements represent the basic core variables of the JGOFS program. (S-227)

Latitudinal variations of particle fluxes at the southern ocean: A bottom-tethered sediment trap array (U.S. JGOFS). *Susumu Honjo, Woods Hole Oceanographic Institution.* This project will make direct measurements of the downward flux of particulate matter through an array of bottom-mounted sediment traps. These traps will be maintained for an 18-month period and will have a sampling resolution of 17 days; during the intense summer phytoplankton bloom the resolution will be higher. The total export fluxes of organic carbon, nitrogen, biogenic silicates, and calcium carbonate that can be obtained from these measurements represent the basic core variables of the Joint Global Ocean Flux Study program. (S-228)

Primary production in the southern oceans. *Richard Barber, Duke University; John Marra, Columbia University; Walker Smith, University of Tennessee.* The southern oceans are critical to the global carbon cycle—as suggested by its size and the physical process that occurs there (e.g., deep and intermediate water formation)—but its present quantitative role is uncertain. To address the objectives of U.S. JGOFS effort successfully, measuring primary production is required for all process cruises planned for the southern oceans study. Three methods will be used: *in situ* incubations, deck incubations, and the photosynthetic irradiance response. The areas of study will be the continental shelf of the Ross Sea and the Polar Front region to the north of the Ross Sea. The controls on photosynthesis will also be investigated. We hypothesize that, on the continental shelf, irradiance limitation is the major factor controlling phytoplankton productivity, whereas in the Polar Front region, the availability of iron limits phytoplankton growth and influences the size distribution of the populations. The productivity data, in conjunction with hydrographic data, will form a large part of the southern oceans JGOFS database that at-sea investigators and modelers will use to clarify the role of the southern oceans in the global carbon cycle. (S-231, S-232, and S-233)

Silica cycling and the role of diatoms in the biological pump of the southern oceans (U.S. JGOFS). *Mark Brzezinski, University of California at Santa Barbara, and David Nelson, Oregon State University.* Our project will make use of the R/V *Nathaniel B. Palmer* and the R/V *Thompson*. This component of the Joint Global Ocean Flux Study (JGOFS) concerns the general topic of removal of organic carbon from the surface layers of the ocean and deals specifically with diatoms, a form of siliceous phytoplankton, as a major component of the biological pump of the southern oceans. Diatoms are known to be responsible for the majority of primary production in the Polar Front Zone (PFZ) and along the retreating ice edge in the Ross Sea.

Strong correlation between the fluxes of diatomaceous silica and organic carbon indicate that diatoms are also the autotrophic source of much of the

organic matter exported from the surface waters of the southern oceans. The role of diatoms in the biological pump may be especially important in the PFZ, since nearly all of the silica flux in the southern oceans occurs beneath the PFZ. As a result, this region and the waters to the south constitute the largest area of modern siliceous sediment accumulation in the world. Surprisingly, that immense opal accumulation is supported by very low rates of primary production near the surface. Within the water column and upper sediments, the regional cycles of carbon and silica are decoupled to a degree that does not occur elsewhere, and thus, opal-rich, but organic-poor, sediments are forming throughout much of the abyssal southern ocean.

The observational program is designed to reveal the fate of the silica produced and to help constrain the contribution of diatoms to carbon fixation and export in the region. The insights gained regarding the magnitude, fate of biogenic silica, and the factors controlling silica cycling and diatom productivity will help evaluate the role of diatoms in the biogeochemical cycling of elements in the region and explain the mechanisms producing high accumulation rates of diatom silica in the southern oceans. (S-234 and S-235)

Nitrogen and carbon isotope paleo-proxy verification and calibration in the southern oceans (U.S. JGOFS). *Mark Altabet, University of Massachusetts; Roger Francois, Woods Hole Oceanographic Institution.* Over the last decade, researchers have proposed and developed, to varying degrees, several new deep-sea sediment proxies for important oceanic properties. An urgent need has been recognized for verification and calibration studies, however, particularly in the southern oceans. The southern oceans have long been known as a region important to paleo-oceanography, not only because the region responds strongly to and contributes to the forcing of climate cycles but also because its remoteness makes it one of the least studied regions with regard to paleoproxy verification and calibration. In this respect, the Joint Global Oceans Flux Study (JGOFS) Southern Oceans Program provides paleo-oceanographers with a unique opportunity for seasonal access to a region that extends from the subtropical convergence to the Ross Sea.

Our effort focuses on sedimentary nitrogen and carbon isotopes, both of which, researchers have shown, exhibit large north/south gradients in the upper and surface portions of sediment cores during Quaternary climate cycles. The sedimentary record of these isotopes also indicates a systematic down-core shift associated with late Quaternary climate change. Our project has three objectives:

- to confirm and calibrate the relationships between nitrate use and levels of nitrogen isotopes and between surface-water carbon-dioxide levels/phytoplankton growth rates and surface-water levels of carbon isotopes;
- to determine the reliability of the transfer of the proxy signal of these isotopes to the ocean floor; and
- to determine the magnitude and consistency of any changes, caused by such environmental factors as water temperature, in the preserved proxy signal and identify sedimentary fractions for which these changes are minimized.

To accomplish our objectives, we will sample water seasonally in ocean areas between the subtropical convergence and the Ross Sea. Samples representing various aspects of surface-water chemistry, including nitrate-related compounds and dissolved isotopic carbon, will be collected at 1^{0} and 2^{0} latitude resolution along the cruise track. At each mooring, we will also take vertical profiles of the upper-water column. (S-236 and S-237)

New and regenerated production in the southern oceans: Ross Sea study (U.S. JGOFS). *William P. Cochlan, University of Southern California; Deborah Bronk, University of Georgia.* The broad continental shelf of the Ross Sea is characterized by relatively high biomass with large phytoplankton blooms in the austral spring-summer. This study is designed to assess the rates of new and regenerated production in the Ross Sea continental shelf regime during the productive growing season in Antarctica (spring, summer, autumn). The overall objectives of this study are to obtain accurate and quantitative estimates of the nitrogenous nutrition of the planktonic assemblages in this dynamic system and to understand the factors that control the magnitude and variability of primary production and the vertical flux of biogenic material from the euphotic zone (i.e., export production). A suite of core measurements will be made to estimate new and regenerated production over relevant spatial and temporal scales. New production in the Ross Sea is hypothesized as a function of the evolution of the ecosystems' development and thus regulated by

- the hydrodynamic properties of the water column (i.e., vertical stability from ice melt),

- the interaction of macronutrients (ammonium and urea), and
- the availability of the micronutrient iron.

Core measurements include determining the uptake rates of four nitrogen substrates (nitrate, nitrite, ammonium, and urea) using the ^{15}N-tracer technique at stations distributed along transects from the ice edge (marginal ice zone), across the shelf, slope and into the open ocean. Measurements will be taken at seven depths ranging from 100 percent to 1 percent of surface irradiance during morning, midday, and night. The degree of isotopic dilution will be quantified during nitrogen uptake experiments to determine more accurately the rates of uptake and to estimate rates of microheterotrophic nitrogen regeneration. In addition to the core measurements, additional experiments will answer specific questions about the system, and will refine our estimates of new and regenerated production. (S-238 and S-239)

Thorium isotopes as indicators of export flux and particle dynamics in the southern oceans: Joint Global Ocean Flux Study. *Michael P. Bacon, Woods Hole Oceanographic Institution; J. Kirk Cochran, State University of New York at Stony Brook*. We will use the U.S. Antarctic Program's icebreaking research ship *Nathaniel B. Palmer* and a ship from the University National Oceanographic Laboratory System on six process cruises between October to November 1996 and March 1998. Our effort focuses on the spatial and temporal variations in the distribution and particulate fluxes of thorium isotopes (thorium-234 and thorium-228). These isotopes serve as ocean tracers and yield fundamental information about the rates of biogeochemical processes that govern the production and fate of biogenic particles in the oceanic water column. While at sea, we will measure thorium-234 by beta and gamma-counting. Ashore, we will use alpha-spectrometry to measure thorium-228. The data will be interpreted within the context of biological rate measurements and other data to be collected during the study. We will use these data to estimate export fluxes of organic matter, carbonate, and silica from the euphotic zone; to quantify transformation processes such as aggregation and disaggregation in the water column; and to test biogeochemical models. Thorium is a particularly useful tracer in this context because its mode of production is well known; it is taken up quickly by biogenic particles; and its concentration can be measured quite precisely. The removal of thorium by falling particles can therefore be determined, and the inverse problem of inferring the integrated mass of falling particles (the particulate carbon flux) may be solved. (S-240 and S-241)

Bacterial production uncoupled from primary production: Implications for dissolved organic matter fluxes in the southern oceans. *Farooq Azam, University of California at Davis; Hugh W. Ducklow, Virginia Institute of Marine Sciences, The College of William and Mary; David L. Kirchman, College of Marine Studies.* Our investigation focuses on the role and quantitative importance of bacteria in transforming organic matter. Researchers hypothesize that extreme seasonal and spatial variation in the southern oceans leads to transient uncoupling between bacteria and primary producers, as mediated through the dissolved organic matter pool. The principal goal of our research will be comprehensive spatial and temporal coverage of core measurements (bacterial abundance, biomass, and production). This will allow an integrated quantitative assessment of the fraction of primary production consumed by bacteria. Equally important is the study of the mechanisms controlling the rate and time frame in which bacteria process primary production. This is critical to complement the core measurements and address these issues. Specifically, total bacteria counts will be complemented with counts of nucleoid-containing cells and respiring cells to determine the fraction of the bacterial assemblage that is active. In collaboration with other researchers, we will use incubation experiments to examine variation in dissolved organic matter lability and the growth yield of bacteria. This project will provide a quantitative and mechanistic understanding of variability in a major pathway of carbon flow, the microbial loop, in the southern ocean. (S-243, S-244, and S-245)

Organic geochemical studies in the southern oceans. *John I. Hedges, University of Washington; Cindy Lee, State University of New York at Stony Brook; Stuart G. Wakeham, Skidaway Institute of Oceanography.* Our JGOFS project is a cooperative study of organic-matter cycling in the water column and in the surface sediments of the southern oceans. The main goals of the effort are

- to determine how the composition and fluxes of organic material vary regionally and seasonally within the southern oceans
- to relate these variations to biological processing of the punctuated organic input and its siliceous matrix
- to follow the downward diagenetic fate of planktonic remains through the water column

and into the underlying sediments, with special emphasis on biochemical trends reflecting substrate quality or freshness

- to account holistically for total organic matter at all stages of degradation by carbon-13 analysis of bulk trap and sediment samples.

While onboard ship, we will collect suspended and raining particulate material within the water column and from the underlying sediment at several sites along the proposed study transect. We will use both plankton net tows and high-volume filtration of surface water to collect suspended particles. Modular sediments traps will be deployed in arrays of four to collect sinking particles. Specially designed individual traps will selectively collect sinking particles and reject swimming zooplankton without loss of sample or biocide. Two of the four traps on each array will be fitted with 12-tube subsampling carousels to study shorter term variations. We will analyze the collected trap- and sediment-core samples for their basic biochemical building blocks, such as carbohydrates, amino acids, lipids, lignins, and pigments. These biochemical components make up the bulk of the organic matter produced in the upper-water column and are an important fraction of the material buried in the sediment. At the molecular level, they can provide unequivocal information on the sources of organic matter and its decomposition at depth and on the pathways by which biogenic material is transferred to the sediment. We will combine these data with information obtained during prior JGOFS experiments to produce a global picture of the organic chemistry of particulate matter in the ocean. (S-246, S-247, and S-248)

Structure and dynamics of plankton communities in the antarctic front zone: Interactions of physical forcing, iron limitation, and microzooplankton grazing (U.S. JGOFS). *Michael Landry, University of Hawaii.* The southern oceans are a vast and variable environment with a potentially large role in global carbon cycling. The Joint Global Ocean Flux Study Southern Ocean Program seeks to advance the understanding of this region by investigating seasonal and spatial dynamics in two important subsystems: the Ross Sea shelf and the Antarctic Polar Front Zone. This project will contribute to this effort by determining microbial community structure and by assessing rates of phytoplankton growth and microzooplankton grazing on four cruises covering the spring, summer, and autumn seasons in the open-ocean front zone.

The overall goal of this research is to understand how physical processes (advection, mixing, and light), iron-limitation, and grazing interact to determine plankton community structure and production in the open oceans. Population abundances and biomasses of the plankton community will be assessed by analytical flow cytometry (bacteria and phytoplankton) and microscopy (nano- and microplankton) to determine their temporal and spatial patterns relative to physical features of the polar front. Growth rates of phytoplankton and bacteria and of microzooplankton herbivory and bacterivory will be measured with a suite of complementary methods including dilution, fluorescently labeled prey, size fractionation, and an Isozyme assay for bacterivory.

Results of this project will contribute to the general understanding of phytoplankton control mechanisms and trophic interactions in high-nutrient, low-chlorophyll regions of the world's oceans. They will also help to identify how potential global change affects water-column stability and how physical forcing in the southern oceans may alter food web structure, carbon storage, and export from the euphotic zone. (S-249)

U.S. JGOFS Southern Ocean Process Study: Zooplankton processes (U.S. JGOFS). *Mark Huntley, University of California at San Diego.* Making use of the R/V *Nathaniel B. Palmer* and the R/V *Roger Revelle,* this project will be a seasonal study of the mesoscale spatial distribution of the carbon utilization by zooplankton in the Antarctic Polar Front Zone and the Ross Sea. Evidence strongly indicates that the egestion of pellets by zooplankton can contribute significantly to a highly variable and episodic biogenic carbon flux in the southern oceans. The research approach used will quantify the rate of total fecal production by the meso- and macrozooplankton community at scales that dominate the variability—eddy-resolving spatial scales and seasonal time scales—in both the Antarctic Polar Front Zone and the Ross Sea study regions.

The process of quantification will depend upon measurements of zooplankton abundance and distribution using a SeaSoar-mounted Optical Plankton Counter (OPC) in the Polar Front Zone, a net-mounted OPC in the Ross Sea study area, and underway acoustic current measurements in both regions. Experimental measurements of ingestion rate will be directed at developing empirical relationships to body weight, food availability, and diel periodicity for the principal species of antarctic zooplankton

grazers. These relationships will then be combined with measurements of biomass and distribution to compute the rate of total fecal production. The approach addresses those factors that are most likely to produce the greatest variability in zooplankton-produced biogenic flux:

- variability in zooplankton biomass and in the food available to that biomass, on scales of tens of kilometers horizontally and tens of meters vertically,
- seasonal variability, and
- variability that is attributable to the size-frequency distribution of zooplankton .

The results will quantify the role of zooplankton in carbon flux processes of the southern oceans, leading to a better understanding of the southern ocean carbon cycle. (S-250)

Seasonal contribution of nano- and microzooplankton to antarctic food web structure in the southern ocean (U.S. JGOFS). *David A. Caron, Woods Hole Oceanographic Institution and Darcy Lonsdale, State University of New York at Stony Brook.* A major role for nanoplankton (2-20 ✳m) and microplankton (20-200 ✳m) protozoa in pelagic food webs of the world ocean has been firmly established in recent years. Neritic and coastal ocean ecosystems have been extensively studied in this regard, and considerable information is also accumulating on the microbial processes of tropical and temperate oceanic ecosystems. In contrast, the roles of nano- and microzooplankton in the flow of energy and elements through polar communities is less clear because of the difficulties associated with sampling and working in these environments and because of the prevailing dogma that microbial processes may be overshadowed by "classical" phytoplankton-zooplankton-fish food webs in these environments. Clearly, there is now a great deal of information that is contradictory to this dogma, and numerous studies in recent years have documented an abundant and active protozoan fauna in polar ecosystems. Nevertheless, there are still substantial gaps in our understanding of the overall importance of the microbial loop in polar environments.

We will examine questions concerning the ecological role of nano- and microplanktonic protozoa in the water column of the Ross Sea:

- Do nano- and microzooplanktonic protozoa constitute a significant fraction of the zooplankton community in the Ross Sea?
- Are these protozoa responsible for maintaining low phytoplankton and bacterial standing stocks in this environment?
- Is mixotrophy (i.e., combined phototrophic and phagotrophic nutrition) an important adaptive behavior for the survival of protists in this planktonic antarctic ecosystem?

Studies will be conducted over an annual cycle in the Ross Sea to examine the expected strong seasonal variability in these features of protistan ecology. (S-251)

The carbon dioxide system in the southern oceans. *Frank J. Millero, University of Miami*. Our experiment will be conducted aboard the research ships *Nathaniel B. Palmer* and *Roger Revelle*. The flux of gaseous carbon dioxide from the atmosphere to the ocean is controlled by the air-sea difference in the partial pressure of carbon dioxide. In the ocean, the dissolved carbon dioxide is in chemical equilibrium with carbonate and bicarbonate ions. The carbonate ion concentration controls the rate of dissolution and precipitation of calcium carbonate and the rate at which inorganic carbon is delivered to the sediment. What is not well known is how these inorganic relationships are affected by biological processes in a region where production and transformation processes are quite large. As part of our research, we will make direct measurements of the carbonate system on seven cruises between 1996 and 1998. This will involve measuring total inorganic carbon dioxide (TCO_2), the partial pressure of gaseous carbon dioxide (pCO_2), and total alkalinity (TA) in the surface waters, as well as the pCO_2 in atmosphere, continuously along the cruise tracks. We will also make complementary depth profiles of the oceanic parameters at some stations in cooperation with the carbon-related measurements planned by other groups participating in the experiment. The resulting carbon-based and nutrient measurements should provide the necessary field data that will be needed to examine the flux of carbon dioxide across the air-sea interface and the changes resulting from primary productivity and the oxidation of plant material. (S-253)

Ocean sciences

A survey of the variability in atmospheric oxygen in relation to the global carbon cycle. *Ralph F. Keeling, University of California at San Diego, Scripps Institution of Oceanography.* The abundance of oxygen in the atmosphere is sensitive at the part-per-million level to biological and anthropogenic activities over a wide range of spatial and time scales. Measurements of variations in atmospheric oxygen, detected through changes in the oxygen-to-nitrogen ratio, can address several important issues pertaining to the global carbon cycle:

- the magnitude of new production of organic matter in surface waters over expanses of the ocean where direct, *in situ* observations are lacking
- the magnitude of any terrestrial carbon sink at northern latitudes
- the relative importance of terrestrial ecosystems versus the oceans as a sink for anthropogenic carbon dioxide.

An improved understanding of these issues will be valuable for making more accurate forecasts of global climatic and biogeochemical changes in the decades ahead. We have recently measured the oxygen in air samples collected at several locations around the world, and the current project continues our effort to carry out a systematic global survey of the variability in the oxygen-to-nitrogen ratio. Measurements will be carried out using a newly developed interferometric technique for oxygen-to-nitrogen analysis and using gas-handling methods that obtain a precision of 1 part in 200,000 in the oxygen measurement. (S-204)

Research on ocean–atmosphere variability and ecosystem response in the Ross Sea. *Robert B. Dunbar, Rice University.* This interdisciplinary study, Research on Ocean–Atmosphere Variability and Ecosystem Response in the Ross Sea (ROAVERRS), focuses on atmospheric forcing, ocean hydrography, sea-ice dynamics, primary productivity, and pelagic–benthic coupling in the southwestern Ross Sea. The primary goal is to examine how changes in aspects of the polar climate system, in this case wind and temperature, combine to influence marine productivity on a large antarctic continental shelf. In the Ross Sea, katabatic winds and mesocyclones influence the spatial and temporal distribution of sea ice, as well as the upper ocean mixed-layer depth, and thus control primary production within the sea ice and in the open water system. The structure, standing stock, and productivity of bottom-dwelling biological communities are also linked to meteorological processes through interseasonal and interannual variations in horizontal and vertical fluxes of organic carbon produced in the upper ocean. During this 3-year study, we will investigate links among the atmospheric, oceanic, and biological systems of the southwestern Ross Sea ecosystem. Direct measurements will include

- regional wind and air temperatures derived from automatic weather stations
- ice cover, ice movement, and sea-surface temperatures derived from a variety of satellite-based sensors
- hydrographic characteristics of the upper ocean and primary productivity in the ice and in the water derived from research cruises and satellite studies
- vertical flux of organic material and water movement derived from oceanographic moorings containing sediment traps and current meters
- the abundance, distribution, and respiration rates of biological communities on the sea floor, derived from box cores, benthic photographs, and shipboard incubations.

Based on archived meteorological data, we expect that the atmospheric variability during the study period will be such that we will be able to monitor changes in air-flow patterns and their influence on oceanographic and biological patterns and to deduce the direct and indirect links, which are the focus of the research. Results from this study will contribute to our knowledge of atmospheric and oceanic forcing of marine ecosystems and lead to a better understanding of marine ecosystem response to climatic variations. (S-216A)

Research on ocean–atmosphere variability and ecosystem response in the Ross Sea. *James Barry, Monterey Bay Aquarium.* Our project is part of an in-

terdisciplinary study (Research on Ocean–Atmosphere Variability and Ecosystem Response in the Ross Sea, or ROAVERRS) of meteorologic forcing phenomena, sea-ice dynamics, ocean hydrography, primary productivity, and benthic-pelagic coupling in the southwestern Ross Sea, Antarctica. The primary goal is to examine how changes in aspects of the polar climate system—in this case wind and temperature—influence marine productivity on a large antarctic continental shelf. In the Ross Sea, winds off the continent and mesocyclones influence the spatial and temporal distribution of ice cover, as well as upper ocean mixed-layer depth. Consequently, they control primary production in sea-ice and open-water systems. The structure, standing stock, and productivity of bottom-dwelling biological communities are also linked to meteorologic processes through interseasonal and interannual variation in horizontal and vertical fluxes of organic carbon produced in the upper ocean. During a 2½-year field investigation, we will study links among atmospheric, oceanographic, and biological systems in the southwestern Ross Sea ecosystem. Direct measurements will include

- regional wind and air temperature
- ice cover, ice movement, and sea-surface temperature
- hydrographic characteristics of the upper ocean and primary productivity in sea ice and upper-water column
- vertical flux of organic materials and ocean circulation
- abundance, distribution, and respiration rates of biological communities on the sea floor.

Based on archived meteorologic data, we anticipate that atmospheric variability during the study will allow us to monitor changes in air-flow patterns in the southwestern Ross Sea and determine their influence on oceanographic and biological patterns. The study will contribute to our knowledge of atmospheric and oceanographic forcing of polar marine ecosystems and lead to a better understanding of the polar marine ecosystem response to climate variability. (S-216B)

Modeling primary production of the southern ocean for ROAVERRS. *Michael P. Lizotte, University of Wisconsin.* As part of the Research on Ocean–Atmosphere Variability and Ecosystem Response in the Ross Sea (ROAVERRS) program that will be conducted in the southwest Ross Sea between October 1996 and March 1997 and between October 1997 and March 1998, we will model primary production in the water column and sea ice. The focus of the initial modeling studies will be to derive estimates of primary productivity for the southern oceans. These initial estimates will be based on current understanding of the physiology, biochemistry, and ecology of southern ocean phytoplankton and sea-ice algae; climatologies for sea-ice cover, cloud cover, sea-surface temperature, and algal pigments; and existing modeling approaches for depth-dependent primary production in sea ice and water column. One of our primary goals is to make the first determination of the relative amounts of primary production in the water column and in the sea ice using a consistent, modern estimation method (bio-optical modeling) for both systems. Sensitivity analyses will then be performed to guide planning of the ROAVERRS program. These analyses will be directly applicable to planning for Joint Global Ocean Flux Study and for Global Ocean Ecosystem Dynamics activities related to estimating primary production in the southern oceans. Specifically, we will study model sensitivity to sampling scales (temporal and spatial) in the ROAVERRS study region and to variation in the parameters proposed for measurement during ROAVERRS (e.g., algal bio-optics, photosynthetic parameters, spectral quality of light, nutrient concentration, sea-ice thickness, snow cover, water-column mixing rates, and temperature). Following completion of this modeling study, the ROAVERRS program will make improvements to the models based on an expanded database—for example, tuning the model for different types of sea-ice habitat or phytoplankton blooms—and carry out testing of these models against field observations. (S-216C)

Drake Passage expendable bathythermograph program. *Ray Peterson, University of California.* This project will analyze data from bottom pressure gauges deployed across choke points for the southern ocean flow. Bottom pressure gauges were deployed between South Africa and the antarctic coast close to the Greenwich Meridian and at two locations spanning the Antarctic Circumpolar Current (ACC) south of Tasmania. Simultaneously, the British deployed similar instruments in the Drake Passage. The main scientific goal of these deployments was to determine the fluctuations in the transport of the ACC and to relate it to those in the subtropical and subpolar gyres and to the wind field over the southern oceans. (S-260)

Optical measurements and modeling to estimate concentration and fluxes of organic matter in the southern oceans. *B. Greg Mitchell, University of California at San Diego, and Dariusz Stramski, University of Southern California.* As predicted in the 1970s, the stratospheric ozone layer has been diminished as a consequence of anthropogenic release of chlorofluorocarbons. The thinning ozone layer results in increased surface flux of harmful ultraviolet-B (UV-B, 280■320 nanometers) radiation relative to ultraviolet-A (UV-A, 320■400 nanometers) and visible (400■700 nanometers) radiation. Although considerable effort has focused on evaluating the impacts of ozone depletion for antarctic marine communities, effects of increased UV-B radiation in the Antarctic remain virtually unexplored. In particular, few studies have addressed questions related to UV acclimation and photoprotection, questions whose answers are essential for predicting the long-term ecological effects of increased UV-B radiation.

This study will focus on the capacity of diverse marine polar phytoplankton species to acclimate to increasing UV-B levels by synthesizing potentially photoprotective UV-absorbing compounds, known as mycosporinelike amino acids (MAAs). Because convolution of known photo-inhibition action spectra with environmentally realistic spectral irradiance flux indicates that UV-A radiation represents the major portion of photo-inhibiting solar radiation, UV-absorbing compounds are likely to have evolved in response to UV-A wavelengths. If MAAs are to be effective at increased UV-B radiation levels, the cells must be able to synthesize compounds with UV-B absorption at shorter wavelengths of relevance to ozone depletion (e.g., less than 320 nanometers). To date, there is limited evidence as to the efficacy of MAAs in photoprotection or whether UV-B radiation alone can induce MAAs in phytoplankton. We will address the following questions:

- Is MAA production common among polar marine phytoplankton?
- How efficient are MAAs at absorbing UV, in particular the UV-B, radiation?
- What wavelengths are involved in the induction of MAA synthesis?
- Are MAAs effective UV photoprotectants, in particular for UV-B?

We will conduct several experiments with phylogenetically diverse arctic and antarctic isolates in monospecific cultures. Several approaches will be used in the course of this study where cultures will be exposed to ambient irradiance levels of UV-B, UV-A, and visible radiation in varying proportions to simulate present and enhanced UV-B radiation. The use of a single species in culture will allow controlled experiments to test our hypotheses. The results will allow development of predictions concerning the competitive advantage of various polar taxa with respect to alterations to their radiation environment. This effort will improve our understanding of mechanisms of photoprotection in marine polar phytoplankton in response to increasing levels of UV-B radiation. (S-261 and S-262)

Turbulent mixing near the Filchner-Ronne Ice Shelves. *Laurence Padman, Oregon State University.* This study concerns the formation processes of Weddell Sea Bottom Water, a very cold and saline water mass found at the continental shelf edge of the southernmost Weddell Sea. The formation process is believed to involve saline but warm Circumpolar Deep Water and extremely cold but relatively fresh Ice Shelf Water, but little is known about the process itself. Weddell Sea Bottom Water is important because it is a precursor to Antarctic Bottom Water, a dense, globally distributed water mass. The outflow of Ice Shelf Water from beneath the Filchner-Ronne Ice Shelf has been the subject of a continuing international field program.

In February and March of 1998, a British Antarctic Survey (BAS) cruise on board H.M.S. *Endurance* will focus on the oceanic and atmospheric exchange processes within the open water at the face of the ice shelf. This study is an integral part of the scientific program of the cruise and will concern the mechanisms responsible for the mixing of Ice Shelf Water with other regional water masses as it emerges from under the ice shelf. The measurements that will form the basis for the analysis include

- vertical profiles of temperature, conductivity, and velocity microstructure;
- acoustic doppler current profiles; and
- rapidly sampling temperature sensors mounted on BAS current meter moorings.

Datasets collected by other participants in the cruise will include

- atmospheric measurements,
- a regional survey of the hydrographic structure of the upper ocean, and
- satellite-based remote sensing products. (S-265)

Dynamic/thermodynamic processes and their contribution to the sea-ice thickness distribution and radar backscatter in the Ross Sea. *Martin Jeffries, University of Alaska at Fairbanks.* This project is a study of the effects of antarctic sea ice in the global climate system through an examination of how the spatial distribution of ice and snow thickness and of open water is reflected in satellite-based synthetic aperture radar (SAR) imagery. The field investigations will be carried out from the R/V *Nathaniel B. Palmer* in winter 1998 and summer 1999 and will produce observations of

- the snow and ice distribution;
- the crystal structure, stable isotopes, salinity, and temperature structure of ice cores; and
- the stratigraphy, grain size, and water content of the snow cover.

The SAR images from ERS-2 and RADARSAT will be acquired at the McMurdo ground station and processed at the Alaska SAR Facility. These images will provide information about the large-scale ice motion field and the small-scale ice deformation field, both of which contribute to the observed ice-thickness distribution.

In addition, a study of the spatial and temporal variation of the backscattered microwave energy will contribute to the development of numerical models that simulate the dynamic and thermodynamic interactions among the sea ice, ocean, and atmosphere. The surface data are vital for the extraction of environmental information from the radar data, and for the ultimate validation of interactive models. (S-286)

Environmental research

Impacts of tourism on wildlife populations at Palmer Station, Antarctica. *William Fraser, Montana State University*. Tourism in Antarctica has steadily increased since the late 1960s. Despite rising concern that human activity may adversely affect wildlife populations, studies designed to address this issue have been lacking. Our objective is to examine the feasibility of coupling research on the effects of tourism on Adélie penguin populations on Torgersen Island, Antarctic Peninsula, with two long-term ecosystem programs already in existence in the area. The rationale for this approach is that understanding and defining the natural variability inherent in the ecosystem are necessary prerequisites for identifying and interpreting the effects of human activity. By employing identical technologies and methodologies, we will attempt to develop identical, coincident databases at sites visited by tourists to compare with databases developed as part of the two ecosystem studies at sites not visited by tourists. The latter will thus provide the background ecosystem data needed to discern and interpret the former. If we are successful in developing this arrangement, our research will become one of the key studies addressing human impact in Antarctica and will serve as a model for future research of a similar nature. The results of this study will also help fulfill the National Science Foundation's responsibility and obligations for environmental protection under the Antarctic Conservation Act of 1978. (S-013)

Characterization of indigenous and introduced toxic phytoplankton in Antarctica. *Donald Anderson, Woods Hole Oceanographic Institution.* Of the thousands of species of marine phytoplankton only a few produce potent toxins. These species are found in the massive "red tides" or blooms of cells that discolor the water. More commonly, the organisms are present at low concentrations and are noticed only by the effects their toxins have on aquatic organisms and humans. The nature of the toxic phytoplankton problem has changed considerably in recent years: many areas that were previously unaffected are now subject to recurrent outbreaks. Therefore, it is alarming that marine algal toxins (saxitoxins) have been found in antarctic mollusks.

The implications of this discovery are profound given the low number of trophic levels between primary producers and top predators and the proven ability of the saxitoxins to alter the food web structure and dynamics. Saxitoxins can affect zooplankton, fish larvae, whales, porpoises, seabirds, and humans. A concern is that the saxitoxin-producing alga, presumably the dinoflagellates in the genus *Alexandrium*, has been introduced to antarctic waters, possibly by vessel traffic between South America and the Antarctic Peninsula. This mechanism of species dispersal has been implicated in the sudden appearance of toxic algae in other areas of the world. Short and frequent transport pathways do exist between Antarctica and the high-toxicity waters of southern Chile

and Argentina. It is also possible that the saxitoxins-producing organism is indigenous to Antarctica and was only recently noticed. In either case, the implications to the antarctic food web are significant.

The objectives of this project are to identify and characterize the possible source(s) of saxitoxins in Antarctica to determine whether the causative organisms are indigenous or introduced species, and if introduced, to identify the probable origin and transport pathway. (S-300)

Diagnostic indicators of biological community stress using benthic community analysis to tease apart impacts of organic enrichment and toxicity: An experiment in McMurdo Sound. *Charles Peterson, University of North Carolina at Chapel Hill.* Communities of benthic invertebrates are widely used to monitor and evaluate biological impacts of pollution in the marine environment because their sessile life styles, longevity, functional diversity, well-known taxonomy, and ecological significance render this system an ideal ecological template on which biological consequences are imprinted. Benthic communities have been used successfully in environmental assessments for convincing demonstrations that impacts of pollution are readily detectable at the level of family and phylum for macrofaunal invertebrates.

This project is designed to test the hypothesis that indices of abundance and production for individual phyla of macrofauna and/or meiofauna can be used as independent diagnostics to tease apart the typically confounded impacts of these two separate classes of marine pollution. The investigators will test the hypothesis that annelid worms and nematodes are enhanced by modest organic loading and arthropods and echinoderms are depressed preferentially by modest exposure to toxic contaminants (trace metals). This hypothesis will be tested near McMurdo Station because

- its relatively constant environment allows experimental work to proceed on the sea floor without compromise by confounding disturbances;
- previous benthic studies at this site have revealed significant confounded patterns of sediment contamination and benthic community degrad-ation; and
- low rates of natural bioremediation in cold polar oceans make study of pollution impacts especially critical at high latitudes.

The first objective will be to establish a field experiment near McMurdo Station where the investigators will manipulate organic loading and trace metal concentrations in sediment within colonization trays to test whether the separate taxa respond independently to the classes of pollution. Treatments will also include access of larger mobile predators and time for community development to assess whether biological interactions within the ecosystem with the diagnostic capability of the indices of pollution stress. Second, the investigators will complete a rigorous review and meta-analysis of all available data sets on effects of pollution on marine invertebrate communities to test the hypothesis using the wealth of pre-existing information from monitoring discharges, oil spills, and previous experimentation. (S-302)

The effect of dissolved organic matter on the photolysis and bioaccumulation of synthetic organic compounds in two lakes on Ross Island, Antarctica. *Yu-Ping Chin, Ohio State University.* The effect of persistent synthetic organic contaminants (SOCs) on the antarctic ecosystems is poorly understood. Dissolved organic matter (DOM) is ubiquitous to all surface waters in Antarctica, and these compounds may play an important role in the fate of SOCs. DOM is capable of acting as a quasisorbent, thereby altering the speciation of SOCs in the water column. DOM is also highly photoreactive and is able to form chemical transients that can transform SOCs. This dual-role nature of DOM could have pronounced effects on the bioavailability of SOCs to aquatic organisms.

This exploratory research will study processes that control the fate of SOCs in the presence of DOM from two small lakes on Ross Island. Bioaccumulation experiments using phytoplankton and cyanobacteria from these sites will be conducted in an effort to understand the effect of DOM on the bioavailability of SOCs. A chlorinated biphenyl congener and pyrene have been selected for study because they represent classes of contaminants found in Antarctica and because they possess a wide range of physiochemical properties. Photolysis experiments using artificial sunlight simulators will be studied to determine the role of DOM as photocatalysts in the transformation of the two target analytes. The results from this exploratory research will provide the groundwork for a much larger field project that will study these processes both *in situ* and *ex situ* using other SOCs. (S-305)

Measurement of combustion effluent aerosols from the Amundsen–Scott South Pole Station. *Anthony Hansen, Magee Scientific Company.* Anthropogenic activities in Antarctica have the potential of producing both contemporaneous and long-term environmental impacts on the nearly pristine surroundings. One of these impacts arises from the emission of "black" or "elemental" carbonaceous aerosols from the exhaust of diesel-powered generators and vehicles used to support antarctic operations. When deposited on the snow and ice cover, this pollutant may be preserved indefinitely. Its high optical absorption will alter the surface albedo and the radiative properties of surface cover. Its ability to promote catalytically certain chemical reactions may lead to modifications of snow and ice chemistry. Its absorbed content of fuel-derived organic species, such as polycyclic aromatic hydrocarbons and other toxics, may have a deleterious effect on marginal biota and near coastal stations.

Previous work showed that extremely small, but detectable, concentrations of black carbon aerosol are brought to the Amundsen–Scott South Pole Station in the background atmosphere in amounts consistent with models of long-range transport; however, the program that made this determination terminated in 1990. A 1986 study of surface snow and ice showed a clear plume of soot downwind of the station. Our objective is to install more modern equipment both upwind and downwind of the South Pole Station to reestablish the background aerosol measurements and to provide a direct assessment of the station's emissions. The results of our work will contribute to determining the station's environmental impact resulting from combustion-derived emissions. This information may be used as input to mitigation and abatement strategies. The upwind data will contribute to the global monitoring record and to assessments of the global circulation of anthropogenic emissions capable of influencing atmospheric optics and chemistry. (S-314)

Marine and terrestrial geology and geophysics

Cretaceous-Paleogene foraminiferida of the Victoria Land Basin (Cape Roberts Project). *Peter-Noel Webb, Ohio State University.* We will characterize the foraminifera in drill core recovered during the Cape Roberts Project (CRP). As part of the CRP, investigators will drill four holes from a sea-ice platform in up to 500 meters of water in the southwest Ross Sea. Geophysical site surveys suggest that the four drill holes will provide an aggregate thickness of about 1,500 meters of core and span about 100 to about 30 million years (Cretaceous-Paleocene). This interval of geological time is not yet documented by *in situ* stratigraphic sections in either the Ross Sea or East Antarctica. The nearest comprehensive data sources for the Cretaceous and Paleocene occur in New Zealand, the northern Antarctic Peninsula and the southern oceans. We will use benthic and planktonic Foraminiferida from the core, together with data from other fossil groups, to provide on-site age and stratigraphic control as drilling progresses. Age correlations will be made with biostratigraphy from southern ocean sites where drilling was conducted during Deep Sea Drilling Project/Ocean Drilling Project cruises and also with New Zealand planktonic and benthic zonal/stage schemes. Our initial objective is to make a comprehensive accounting of foraminiferal material present and to document this in the project's initial report in order to assist others who are planning post-drilling investi-gations. Basic information to be recorded on the foraminifera include

- presence, abundance, preservation, species dominance and diversity
- stratigraphic distribution, levels of endemism or cosmopolitanism in faunas
- completeness or fragmentation of population structures and related information

These data will be used to address various geological problems. Disconformities and acoustic reflectors that extend across the rift system basins and are also expected to be encountered in the drill hole will be dated. Major basin subsidence/uplift trends resulting from compaction and/or rift-margin faulting will be deduced from benthic foraminiferal bathymetric indicators. We will use more subtle cyclicity in the stratigraphic distribution of benthic species to recognize and document phases of transgression and regression, which in turn may indicate a relationship between sea-level oscillation and terrestrial glacial events. During the Cretaceous-Paleocene, the final disintegration of Gondwanaland occurred, specifically the northward movement of

New Zealand and Australia away from Antarctica. Foraminifera from the CRP drill holes will contribute to an understanding of the paleogeography and paleooceanography between the East Antarctic highlands and Pacific margin (the location of the proto-Transantarctic Mountains) and the West Antarctic rift system basins between this suspected island chain and the highlands of West Antarctica. This will help answer the question as to whether the marine margin of East Antarctica, near the planned drill holes, was located in a Cretaceous cul-de-sac or whether it occupied, at times, a position on a major oceanic circulation pathway between the southwest Indian, southwest Pacific, and southwest Atlantic Oceans. (S-049B)

Mapping and geodesy program. *Jerry L. Mullions and Tony K. Meaner, U.S. Geological Survey.* Accurate maps of Antarctica are essential for research and support of operational and logistical activities. They also provide a cartographic base for support of future antarctic scientific investigations and data collections. The U.S. Geological Survey (USGS) maps large portions of the continent to support U.S. research in Antarctica. Before publishing these maps, the USGS establishes geodetic control for topographic and satellite image-mapping at scales of 1:10,000 to 1:250,000.

USGS personnel will take aerial photography using airborne global positioning system (GPS) photogrammetry and geodetic surveys, operate GPS stations at various sites, support digital cartographic data applications, obtain absolute gravity measurement, and participate in the international GPS antarctic campaign. As part of the aerial photographic mapping program, we will photograph selected overland routes to South Pole Station, including the Leverett Glacier and Skelton Glacier. We will also do aerial-mapping photography in the Shackleton Glacier and McGregor Glacier areas in support of geologic research. Airborne GPS photogrammetry will provide mapping control for aerial photographs taken by a Wild RC-10 aerial mapping camera using the Twin Otter aircraft.

The GPS Continuous Operating Reference Station (CORS) will continue to operate year-round at McMurdo and Amundsen–Scott South Pole Stations. Data from these GPS base stations are used by other science groups to improve the accuracy of their GPS field observations. In addition, during the summer, we operate a CORS GPS receiver at the Crary Science and Engineering Center as a backup to the McMurdo system.

Digital cartographic data collection and application activities will continue both on and off the ice to support antarctic science. Applications will use data at scales ranging from 1:30,000,000 to 1:10,000. At McMurdo Station, USGS will provide access to the antarctic data through cooperative activities with individual scientists, production of graphic displays of selected research areas, data/analysis support to McMurdo logistic activities, and demonstrations of applications software packages with antarctic data.

Absolute gravity meter measurements will be obtained at McMurdo Station, Terra Nova Bay, along the McMurdo Dry Valley coast, and at one site inland along the coast. These measurements will be used to establish baseline gravity values in Antarctica. These data also support GPS technology by improving the vertical and horizontal geodetic control values.

The USGS maintains the U.S. Antarctic Map and Aerial Photography Collection at the USGS National Center in Reston, Virginia. This reference library is used by many antarctic scientists to obtain maps and aerial photographs used in planning their field activities each year. (S-052)

Tephrochronology applied to Late Cenozoic paleoclimate and geomorphic evolution of the central Transantarctic Mountains. *David R. Marchant, University of Maine.* Our project focuses on the geomorphic evolution of the McMurdo Dry Valleys. We will use isotopic ages and areal distribution of volcanic ash deposits to constrain the chronology and rates of landform development and to help quantify the age of geomorphic surfaces. The depositional setting and degree of weathering of the ash will help us to constrain regional paleoclimatic conditions during and after deposition of the volcanic ash. We will focus on the Quartermain Mountains, Asgard Range, Olympus Range, and McKelvey Valley because these regions are known to contain some volcanic ash deposits and because they contain a variety of geomorphic settings over a substantial elevation range. With the data collected in the field, we will attempt to test assumptions that underlie the hypothesis that the dry valleys region represents a relict, semiarid landscape that formed before the continental ice sheets developed during middle Miocene time and that subsequent slope modification has been limited to minor glacial scouring concentrated at valley heads, glacier

confluences, and deep-valley troughs. Among these underlying assumptions are the following:

- that present geomorphic processes are ineffective denudation agents
- that widespread land surfaces within tectonically uniform blocks reflect base-level changes at the Transantarctic Mountains front
- that geomorphic landforms of the dry valleys that superficially resemble box canyons, escarpments, mesas, and buttes of desert regions in the American southwest were formed by the same types of denudation processes now operating in the Colorado Plateau.

The isotopic-age information generated by this project will help constrain models of geomorphic evolution in cold-desert regions and will have implications for models of landscape development and uplift history of the Transantarctic Mountains. If the hypothesis of ancient semiarid erosion followed by minor glacial incision proves correct for the dry valleys region, then changes in base level, as defined by isotopically dated land surfaces in the McMurdo Dry Valleys, will provide a chronology of Late Cenozoic mountain evolution and uplift independent of thermochronological studies that have been completed. Answering these questions is important because the thermochronology studies, although well suited for determining long-term uplift rates, are not well suited for distinguishing early from Late Cenozoic uplift. The volcanic ash database developed during this study will also be useful for studies of the McMurdo volcanic province. (S-054)

Diatom biostratigraphy and paleoenvironmental history of Cape Roberts Project cores. *David Harwood, University of Nebraska at Lincoln.* This project will work to characterize the diatom fossils in drill core recovered by the Cape Roberts Project (CRP). The CRP is a major program within the international antarctic earth science community designed to sample antarctic continental margin strata of late Cretaceous through Paleogene age (30 million to 100 million years ago). Drilling operations will include continuous coring from a sea-ice platform at four sites on the flank of the Victoria Land basin in the western Ross Sea, during two drilling seasons. This particular project involves initial field-based paleontologic analysis of siliceous microfossils in Cape Roberts cores. Core sections will be ferried to the Crary Science and Engineering Center for immediate analysis. Diatoms and other siliceous microfossils will provide rapid age and paleoenvironmental information during drilling operations. Each season will include preparation of a preliminary biostratigraphic/ paleoenvironmental report based on siliceous microfossils. This report will become part of the *CRP Initial Reports* volume, which will include the preliminary results from other microfossil groups, lithostratigraphic, magnetostratigraphic, and other analyses.

Analysis of diatoms and other siliceous microfossils in CRP cores will greatly aid in the development of an integrated biostratigraphy for this poorly known interval in the southern high latitudes. Diatoms will provide evidence of, for example, environmental changes in water depth, primary productivity, and the presence or absence of sea ice. CRP cores will provide an excellent opportunity to study adaptation of diatoms to strong polar seasonality and diatom evolution. By integrating CRP studies with ongoing studies of Paleogene siliceous microfossils in Arctic strata (for example, Ocean Drilling Program Leg 151), the CRP cores will also offer the possibility of gaining a bipolar perspective on Paleogene high-latitude phytoplankton evolution. (S-051)

Downhole logging for the Cape Roberts Project. *Richard Jarrard, University of Utah.* Continuous-core and downhole logging will be done at the four planned Cape Roberts Project (CRP) scientific drill holes. The goal of CRP is to study the Early Tertiary and Cretaceous record of climate, tectonics, and sea-level change and to determine the time of onset of antarctic glaciation. Geophysical well logs will be converted into continuous records of variation, and these records can be interpreted as indicating variations in mineralogy and porosity. The detailed one-dimensional records at each hole will be integrated with available high-resolution seismic data to produce a two-dimensional interpretation of the stratigraphy. This geophysical logging program is an essential component of basic characterization of the drill site and is a fundamental part of the effort to produce a stratigraphic framework for interpretation of other scientific work on the core. (S-055)

Calcareous nannofossil biostratigraphy and paleoenvironmental history of Cape Roberts Cores. *David K Watkins, University of Nebraska at Lincoln, and Sherwood Wise, Florida State University.* The Cape Roberts Project (CRP), a major program within the international antarctic earth science community, is designed to sample the stratigraphic record, which spans the time interval 30 to 100 million years ago, by drilling four sites on the flank of the Victoria Land basin. Our effort focuses on basic characterization of

calcareous nannofossils as part of the development of the biostratigraphic framework for drill core recovered during the project and will support the drilling program by providing rapid-age and paleoenvironmental information through the study of calcareous nannofossils. To accomplish this, we will systematically sample the recovered sedimentary cores and analyze their calcareous nannofossil content at the Crary Science and Engineering Center at McMurdo Station, Antarctica. Initial reports volume to be prepared at the end of each of the two drilling seasons will include the results of this work as part of the initial characterization of the cores. The calcareous nannofossil biostratigraphic record spans the entire interval to be cored during CRP. Recent work on calcareous nannofossils from ocean drilling sites around Antarctica has yielded a refined zonation for the Paleogene and Upper Cretaceous of the southern oceans that will provide a high-resolution biostratigraphic framework for hemipelagic and pelagic sediments recovered by Cape Roberts drilling. Data from this research, when combined with other fossil data, magnetostratigraphic data, and other age-dating methods, will provide integrated age control that is essential for other geological investigations. In addition, calcareous nannofossils are excellent paleoenvironmental indicators for surface-water temperature and productivity. We will use statistical analysis of quantitative population census data to infer paleoenvironmental variations during the Paleogene and Cretaceous. These data, in combination with data from other fossil groups and sedimentological studies, will be useful for assessing climate change during the critical period of 30-100 million years ago. (S-057)

Antarctic search for meteorites. *Ralph Harvey, Case Western Reserve University.* The Antarctic Search for Meteorites (ANSMET) will continue during the 1997■1998, 1998■1999, and 1999■2000 austral summer field seasons in Antarctica. Since 1976, ANSMET has recovered more than 7,800 meteorite specimens from locations along the Transantarctic Mountains.

Over the next 3 years, systematic searches will be conducted in regions known to contain meteorites, and reconnaissance work will be conducted to discover new concentrations. During the 1997■1998 field season, work will be done in the Pecora Escarpment-LaPaz Icefields region, where several small icefields remain unsearched and earlier reconnaissance located significant concentrations. During the 1998■1999 field season, the southern Walcott Névé region will be visited, where more than 1,500 meteorites have already been recovered and many more remain. During the 1999■2000 field season, several icefields in the Dominion Range-Grosvenor Mountains-Scott Glacier region will be visited, where previous reconnaissance and incomplete systematic searching promise significant meteorite recoveries.

Antarctica is the world's premier meteorite hunting ground for two reasons.

- Although meteorites fall in a random fashion all over the globe, the likelihood of finding a meteorite is enhanced if the background material is plain and the accumulation rate of terrestrial sediment is low. Ice is a perfect medium.
- On the east antarctic ice sheet, ice flow can become blocked causing very old ice to be pushed to the surface. When the stagnant ice is deflated by the strong katabatic winds, a lag deposit of meteorites, over time in large concentrations, is left on the exposed surface of the ice.

Continued recovery of antarctic meteorites is important for several reasons. ANSMET samples

- have been the only reliable source of new, nonmicroscopic extraterrestrial material since the Apollo project;
- provide essential "ground truth" about the composition of asteroids, planets, and other bodies of our solar system;
- provide samples of many geological types of asteroids;
- have proved, against the conventional wisdom, that some meteorites actually represent planetary materials, delivered to us from the Moon and Mars; and
- have even promoted the discovery that meteorites can be used to do astronomy, through the study of isotopically anomalous grains that could have evolved only in a different stellar environment. (S-058)

Maestrichtian land mammals of Vega Island, Antarctic Peninsula. *Michael Woodburne, University of California at Riverside.* The Maestrichtian is considered to have been a key interval in the development of the land mammal fauna of southern Gondwanaland from Australia to Antarctica and South America. Until now, no Maestrichtian fossil land mammals have been found in any of these continents. The Lopez de Bertodano Formation of Vega

Island, Antarctic Peninsula, shows the best potential of yielding remains of land mammals of Maestrichtian age in any southern Gondwanaland location. This project is designed to grasp that opportunity as a collaborative venture between St. Mary's University, University of California at Riverside, and Argentine scientists.

Current theory predicts that the presently unknown Maestrichtian-age land mammal fauna in Antarctica should consist of

- a suite of non-therian taxa remnant from an Albian-Campanian fauna that occupied southern Gondwanaland from Australia to Antarctica to South America and
- a complex of marsupials composed of relict peradectids and more derived early members of australidelphians. The australidelphians should include early members of the (currently) South American *Microbiotheriidae* as well as early lineages of the (currently) Australian *Peramelina*, *Dasyuromorphia*, and *Diprotodontia*.

Investigators will test this hypothesis in terms of the composition of the Maestrichtian land mammal fauna by conducting field research on Vega Island of the James Ross Island basin, Antarctic Peninsula. The location has been chosen on the basis of its known productivity in yielding Maestrichtian-age vertebrates (presbyornithid birds and hypsilophodont dinosaurs) in near-shore fine-grained shallow-water marine sandstones of the Lopez de Bertodano Formation that are amenable to dry or wet sieving collecting methods. Such methods have proven successful in obtaining fossil mammals from similar facies in the medial Eocene La Meseta Formation of Seymour Island. (S-061)

Initial Characterization of Organic Matter in Cretaceous-Paleogene Sedimentary Rocks, Cape Roberts, Antarctica. *Richard M Kettler, University of Nebraska at Lincoln.* Our project focuses on organic geochemical characterization of Cretaceous-Paleogene sedimentary rocks to be recovered during the Cape Roberts Project (CRP). The CRP proposes to core four 500-meter holes from a fast ice drilling platform in the Ross Sea. The core recovered will be described, curated, and sampled for scientific re-search. The CRP has the potential to answer significant questions regarding the history of the West Antarctic rift system, the development of continental ice sheets in Antarctica during the Cretaceous and Paleogene, and the response of biota to climatic deterioration and the development of seaways. Because organic geochemical measurements are relevant to these issues, they are included in the initial core characterization studies. Our will include measuring whole-rock carbonate carbon, total carbon, total nitrogen and total sulfur; analyzing the elemental composition of kerogen in selected samples; and using gas chromatographic analysis of the solvent-soluble organic matter in selected samples. These data will be collected in the Crary Science and Engineering Center (CSEC) at McMurdo Station and will be reported as part of the initial core characterization study of the CRP. (S-064)

Thermal and fluid state of the lithosphere beneath South Pole region, East Antarctica, from magnetotelluric measurements. *Philip Wannamaker and John Stodt, University of Utah.* Our objective is to extend knowledge of the thermal and physico-chemical state (fluids, melts) of the deep crust and upper mantle of Antarctica with magnetotelluric (MT) geophysical profiling of the South Pole area. In the MT method, temporal variations in the Earth's natural electromagnetic (EM) field are used as source fields to probe the electrical resistivity structure in the depth range of 1 to 100 kilometers or more. The effort will consist of about 16 sites over a length of 90 kilometers, offset from South Pole Station a few kilometers and oriented grid NE-SW, normal to the Transantarctic Mountains (TAM). The method will test the cratonic character of the lithosphere of this part of East Antarctica to depths of 100 to 150 kilometers and compare its resistivity structure with that imaged in central West Antarctica (CWA) by the same research group. Second, there has been only one successful broadband MT campaign in the antartctic interior. Conditions around South Pole differ from those at CWA, and this project should make MT surveying more feasible over the entire continent. Third, the results will provide the crustal response baseline for possible long-term MT monitoring to lower mantle depths at South Pole. (S-068)

Initial sedimentological characterization of the Late Cretaceous-Early Cenozoic drill cores from Cape Roberts, Antarctica. *Lawrence Krissek, Ohio State University.* An international initiative to collect 1,500 meters of drill core from offshore of Cape Roberts, McMurdo Sound, Antarctica, is intended to provide a better understanding of antarctic history through the late Cretaceous and early Cenozoic. Events during this period, which extends from before the final breakup of Gondwanaland through the onset of antarctic glaciation, are ill-defined by existing data. The Cape Roberts Project (CRP) aims to

provide new data about the development of the west antarctic rift system, the subsidence history of the Ross Sea, and ice-sheet fluctuations on Antarctica through this critical time interval.

CRP is partly an extension of previous drilling efforts on the antarctic continental margin and is partly a new initiative to document more completely the developmental history of the Ross Sea sector of the Antarctic and southern Pacific region through the late Cretaceous-early Cenozoic. It will draw on the successes of previous drilling efforts to document regional and environmental development with good spatial and temporal resolution, and it will also draw upon newly compiled geophysical databases.

CRP is a collaborative endeavor and is currently being supported by six participating countries. Tasks involved in this segment of the project will include initial description and characterization of the stratigraphic successions; these results will be used as the fundamental database for other analyses. The stratigraphic sections will also be used as reference sections for modeling observed marine and geophysical events. Initial sedimentological characterization of the successions will allow the definition of facies, the construction of facies sequences, and the interpretation of depositional environments through time. The end result of the proposed work will be an Ocean Drilling Program-style initial report for each drilling season. These reports will include the stratigraphic log, initial facies and depositional system interpretations, sedimentary petrologic and petrogenetic analyses, and initial clay mineralogical analysis. Information provided by other specialists will also be included in the reports, including biostratigraphy, magnetostratigraphy, geophysical logs, and geochemical interpretations. The initial interpretations of regional history will be presented in these reports, and the regional and global ramifications of this history will be highlighted. (S-070)

Holocene paleoenvironment change along the Antarctic Peninsula: A test of the bipolar/solar signal. *Eugene Domack, Hamilton College.* This project is a multi-disciplinary, multi-institutional effort to elucidate the detailed climate history of the Antarctic Peninsula during the Holocene epoch (the last 10,000 years). The Holocene is an important, but often overlooked, portion of the antarctic paleoclimatic record because natural variability in Holocene climate on time scales of decades to millennia can be evaluated as a model for our present "interglacial" world.

This project builds on over 10 years of prior investigation into the depositional processes, productivity patterns, and climate regime of the Antarctic Peninsula. This previous work identified key locations that contain ultra-high-resolution records of past climatic variation. These data indicate that solar cycles operating on multicentury and millennial time scales are important regulators of melt water production and paleoproductivity. These marine records can be correlated with ice-core records in Greenland and Antarctica.

This project will focus on sediment dispersal patterns across the Palmer Deep region. The objective is to understand the present links between the modern climatic and oceanographic systems and sediment distribution. In particular, additional information is needed regarding the influence of sea ice on the distribution of both biogenic and terrigenous sediment distribution. Sediment samples will be collected with a variety of grab sampling and coring devices. Two additional objectives are the deployment of sediment traps in front of the Muller Ice Shelf in Lallemand Fjord and seismic reflection work in conjunction with site augmentation. The goal of sediment-trap work is to address whether sand transport and deposition adjacent to the ice shelf calving line results from melt water or aeolian processes. In addition, the relationship between sea-ice conditions and primary productivity will be investigated. The collection of a short series of seismic lines across the Palmer Deep basins will fully resolve the question of depth to acoustic basement. (S-072)

Paleomagnetic and mineral magnetic characterization of drill cores from the Cape Roberts Project. *Kenneth Verosub, University of California at Davis.* The goals of the Cape Roberts Project (CRP) are to elucidate the history of fragmentation of the Pacific margin of Gondwanaland and the history of antarctic glaciation from Cretaceous through Oligocene time. The CRP will operate with an integrated science plan in which all of the initial scientific characterization of the cores will be done at McMurdo Station during two drilling seasons over two successive years. The drilling seasons will each be 2 months long and will operate in much the same manner as 2-month cruises of the Ocean Drilling Program. The scientific activities associated with characterization of the cores will include magnetostratigraphy, biostratigraphy, petrography, mineralogy, and sedimentology. Age determination is of principal importance in such a project because a temporal framework is necessary to obtain a history of climatic and tectonic events.

This research will determine high-quality paleomagnetic stratigraphy, with the appropriate mineral magnetic studies, in support of the CRP. For the on-site magnetic studies, this project will

- undertake logging of the whole-core magnetic susceptibility, which will help correlate the several overlapping cores to be recovered during the CRP;
- determine a magnetostratigraphic framework for dating the cores;
- undertake mineral magnetic and environmental magnetic studies to assess the reliability of the paleomagnetic signal; and
- determine if environmental magnetic properties yield information concerning changes in the tectonic, sedimentologic, diagenetic, or climatic influences on the sedimentary record at Cape Roberts.

Detailed environmental and mineral magnetic studies will also enable evaluation of the sediments as recorders of the geomagnetic field. The Cape Roberts records provide the potential to obtain rare high southern latitude constraints on geomagnetic field behavior. Paleomagnetic studies should also provide important data concerning crustal movements and rift development in the Ross Sea sector. (S-075)

Jurassic floras of the Carapace Nunatak area: Evolution and paleoclimatic significance. *Thomas Taylor, University of Kansas.* This project will systematically collect and analyze the Jurassic fossil floras from three levels at Carapace Nunatak in southern Victoria Land and will complete reconnaissance for similar-aged deposits at Shapeless Mountain near the head of Wright Valley. These floras represent the most extensive deposits of Jurassic fossil plants that are known from the continental portion of Antarctica. They are poorly known, both from a biostratigraphic and floristic standpoint and, as such, are important not only to our understanding of floral changes in Antarctica but also to correlations with other Gondwanaland continents. In addition to impressions and compressions, the site also contains permineralized specimens. In this rare preservation type, cells and tissue systems are intact so that details about the anatomy and morphology of these Jurassic plants can be evaluated. The preservation of the permineralized floral elements at Carapace is identical to those of Permian and Triassic age that have been studied over the past 10 years. As a result, a continuum of structurally preserved plant fossils extending from the Permian into the Upper Jurassic of Antarctica is available for examination. In this context, it will be possible to examine details of seed plant growth, development, and evolution at high paleolatitudes during the latter stages of the Paleozoic and extending into the Jurassic.

The few specimens collected during an earlier reconnaissance at Carapace Nunatak suggest a flora rich in conifers and seed ferns. The conifer components will be important in evaluating basal character states within the major conifer families, whereas the seed ferns will be useful in evaluating the characters and relationships of these Mesozoic gymnosperms to the geologically younger flowering plants. The site also contains some woody specimens (small twigs, fragments of wood), in which the tree rings will be analyzed and compared with those from other high latitude sites, both older (Permian and Triassic) and younger (Cretaceous and Tertiary). (S-076)

Dry valleys seismograph project. *Bob Reynolds, U.S. Geological Survey.* The dry valleys seismograph project was established in cooperation with the New Zealand Antarctic Program to record broadband, high-dynamic-range digital seismic data at a remote site removed from the environmental and anthropogenic noise on Ross Island. The Wright Valley offers one of the few locations on the continent where bedrock can be accessed directly. The station consists of a triaxial broadband borehole seismometer at 100 meters depth and a vertical short-period instrument at 30 meters depth. These data are digitized at the remote location and then are radio-frequency telemetered via repeaters on Mount Newell and Crater Hill, eventually to the recording computer located in the Hatherton Laboratory at Scott Base. Although archived at Scott Base for backup purposes, the data do not stop flowing at this point. The data pass via a point-to-point protocol link to the Internet at McMurdo Station and then on to the Albuquerque Seismological Laboratory for distribution to the seismological community. This year's objectives are to refuel the remote station and the repeater site and to continue to enhance the performance of the radio link. Extra effort will go into the overhaul of the thermoelectric generators this season to improve their reliability over past seasons. This data set has beautifully complemented the data from the other seismic stations that the Albuquerque Seismological Laboratory operates on the antarctic continent at Amundsen-Scott South Pole Station, Palmer Station, and, next season, the Australian station, Casey. (S-078)

Stress field history, Cape Roberts, Antarctica. *Terry Wilson, Ohio State University.* This collaborative research program will obtain the first age-calibrated stress-field history within the west antarctic rift system of Antarctica. The opportunity to acquire the stress data is provided by the international drilling program planned at Cape Roberts, which is located along the margin between the uplifted Transantarctic Mountains and the rifted crust of the Victoria Land basin. Information on the paleostress history of the Mesozoic and Cenozoic rift-basin fill will be obtained from the core and downhole logging of natural fractures and faults.

To establish the contemporary stress state, the cores will be examined for coring-induced stress fractures and the borehole will be examined via downhole televiewer and dipmeter for any wellbore breakouts and fractures reactivated by the contemporary stress field. The stress data will be analyzed to address questions relevant to the paleo- and neotectonic evolution of the antarctic plate. The results will contribute to the resolution of outstanding questions such as the cause of the anomalous aseismicity of the continent, the geometry of stresses along the lithospheric boundary between the Transantarctic Mountains and the west antarctic rift system, and the evolution of the antarctic intraplate stress field and its relation to rifting episodes associated with Gondwanaland breakup. Contemporary stress data obtained from this research will be added to the global stress database and will help to fill the current void in the global stress coverage marked by the antarctic plate. (S-079)

Initial palynological characterization of Cape Roberts drill cores. *John Wrenn, Louisiana State University.* The Cape Roberts Project (CRP) is designed to core submarine deposits in the western Ross Sea that range in age from middle Late Cretaceous to early Miocene. Four 500-meter-long drill cores will be taken from a platform of annual sea ice floating in water depths ranging from 100 to 500 meters. The cores will sample a composite stratigraphic section 1,500 meters thick during two 45-day drilling seasons.

Shipboard geophysical surveys have identified a package of dipping sedimentary strata interpreted to be Cretaceous-Miocene. A thin blanket of younger sediments overlies these beds. Rocks of this age range are not known from the Ross Sea, the Transantarctic Mountains, or elsewhere in East Antarctica. Thus, recovered sediments of this age have prime importance for interpreting antarctic geologic, biologic, climatic, and tectonic history during the Cretaceous-Cenozoic. Objectives of CRP include

- obtaining a late Cretaceous-Cenozoic paleoclimatic record
- studying glacial-deglacial and eustasy cycles
- determining the Gondwanaland breakup and rifting history of the Ross Sea embayment.

Core description and downhole experiments will be conducted at each drill site. An international team of biostratigraphers, sedimentologists, magnetostratigraphers, petrologists, and others will conduct initial characterization of the cores and their constituents during and immediately following drilling.

Palynomorphs have proven to be invaluable tools for biostratigraphic and paleoenvironmental interpretation of younger Ross Sea sequences drilled in the Ross Sea embayment. They include both marine (dinocysts) and nonmarine (spores, pollen) types, record extensive and diverse geologic information, and are preserved in a wide variety of lithofacies formed in various paleoenvironments. This project will provide initial palynological characterization of the CRP drillcores in collaboration with New Zealand palynologists. Analyses will focus on providing palynological input for an integrated biostratigraphic and paleoenvironmental framework based on all microfossil groups present. This critical framework is of fundamental importance to all future geologic, geophysical, and paleontologic studies conducted on the cores and in the drilling area. (S-080)

Mount Erebus Volcano Observatory. *Philip R. Kyle, New Mexico Institute of Mining and Technology.* Mount Erebus, the most active volcano in Antarctica, has been in a continuous eruptive state throughout the 20th century. The volcano is unique because it contains a persistent, convecting lava lake composed of highly alkalic anorthoclase phonolite magma. During the time that the volcano has been observed, eruptive activity from the lava lake and adjacent vents has consisted of minor strombolian eruptions that rarely eject volcanic bombs to heights exceeding 500 meters. Recent work has also shown that Mount Erebus is an important source of aerosols to the antarctic atmosphere and most likely contributes significant quantities of chlorine, fluorine, and other trace components to the snow falling on the east antarctic ice sheet. These data have important consequences for chemists who are trying to decipher paleoenvi-

ronments from snow and ice-core analyses. Our objective is to continue seismic observations using the Mount Erebus Volcano Observatory at McMurdo Station. Year-round observations using eight seismic stations on Mount Erebus and one at McMurdo Station allow near real-time observations of the ongoing volcanic activity. Additional observations of the gas emissions and surveillance of the activity from an observatory near the summit of Mount Erebus will expand scientific understanding of the degassing behavior of this "open vent" volcano. Radiometric dating of lava erupted from Mount Erebus will contribute to an understanding of the development of the volcano. (S-081)

Global Positioning System (GPS) measurements of crustal motion in Antarctica. *Carol A. Raymond, Jet Propulsion Laboratory.* The objective of this project is to establish a Global Positioning System (GPS) geodetic network in the Transantarctic Mountains to measure vertical and horizontal crustal velocities. The vertical crustal velocities measured by GPS reflect the viscous, elastic response of the solid earth to antarctic deglaciation. We will use data from this GPS network to test models of late Pleistocene-early Holocene versus late Holocene deglaciation of Antarctica. These data will also help constrain the length of time over which the antarctic ice sheet disintegrated and the distribution of the peak glacial load. A mid-Holocene deglaciation model produces a predicted uplift pattern near the Transantarctic Mountains that we can measure using high-precision GPS geodetic measurements within a 4-year period. We will also measure horizontal deformation induced by rebound to help constrain present-day changes in antarctic ice mass by monitoring the elastic deformation of the lithosphere resulting from ongoing glacial loading and unloading. The lithospheric response to ongoing ice mass changes is predicted to be an order of magnitude less than the viscoelastic response to late Pleistocene-Holocene deglaciation. Tectonic uplift rates are also predicted to be small compared to the predicted rebound signal for this region. Baselines across faults in the Transantarctic Mountains may capture co-seismic motion if an earthquake or a seismic slip were to occur. (S-082)

Timing of retreat of the west antarctic ice sheet. *John B. Anderson, Rice University.* Our objective is to examine the timing of ice-sheet grounding and retreat from the continental shelf in the Ross Sea region during the past glacial episode. This type of analysis is needed to improve the understanding of the past behavior of the ice sheet and to provide an important basis for testing glaciological models that attempt to predict the future behavior of the ice sheet—for example response to global warming and subsequent sea-level rise. To accomplish this objective we will acquire a variety of different data sets. High-resolution seismic data acquired with air guns will provide a stratigraphic framework for recognizing deposits of the last glacial maximum. Very high-resolution seismic records acquired with both hull-mounted and deep-towed chirper systems will enable us to link cores to seismic data; these systems provide stratigraphic resolution on the order of tens of centimeters. Sediment cores provide sample material for dating glacial events and for establishing the source of ice that grounded on the continental shelf. The multibeam system provides direct images of features formed at the base of the ice sheet when it was grounded on the continental shelf, such as glacial furrows and drumlins. These features provide information about flow direction of former ice streams and the extent to which deformation of the bed on which the ice sheet rested contributed to ice sheet flow and retreat. (S-083)

The GPS campaign to measure rock motion in the Transantarctic Mountains and related volcanics. *Ian Whillans, Ohio State University.* In close cooperation with the U.S. Geological Survey, we will begin taking global positioning system (GPS) measurements of rock motion in southern Victoria Land and nearby areas. We will use the results to test some of the leading models for ice-sheet change and tectonic movement, particularly whether the continent is rebounding because of reduced ice load from East or West Antarctica and whether Terror Rift or Transantarctic Mountain uplift is producing tectonic motion. A modest program to measure ice motion will be conducted as well. Our objective is to test models for ice flow in the Allan Hills meteorite concentration region and to determine whether small glaciers in the McMurdo Dry Valleys are thickening or thinning. We will set monuments into rock and ice and will use GPS receivers to determine their locations. Measurements will be taken again in later years to determine further motion. (S-084)

Scotia Arc Global Positioning System project. *Lawrence A. Lawver and Ian W. Dalziel, University of Texas at Austin.* Antarctica is Earth's most isolated continent. It is surrounded by actively spreading ridges except in the South American sector. The motion of South America with respect to Antarctica is latitudinal and left-lateral at approximately 22 milli-

meters per year and is distributed along the boundaries of the intervening Scotia Plate. A prominent but discontinuous bathymetric high, known as the Scotia Ridge, surrounds the Scotia Plate on three sides. This feature includes some continental material detached from South America and Antarctica, but its eastern closure is a volcanically and seismically active group of islands, the South Sandwich Arc, which is separated from the Scotia Plate by a vigorously spreading back-arc ridge. The entire east-closing, locally emergent bathymetric feature joining the two continents, is known as the Scotia Arc. The D-shaped Sandwich Plate and Arc appear to be moving rapidly east with respect to both South America and Antarctica, thereby for the first time introducing a subduction system into the otherwise rift-bounded South Atlantic Ocean basin. This motion may constitute the best evidence for mantle return flow from the closing Pacific Ocean basin to the expanding Atlantic Ocean basin. The Scotia Arc is nonetheless one of the most poorly constrained of the major tectonic systems on Earth, although it is a critical and enigmatic link in global plate-motion circuits.

The Scotia Arc GPS Project (SCARP) will use the global positioning system (GPS) to measure the plate motions between South America, Antarctica, and Africa and around the Scotia Arc using a newly developed geodetic strategy known as a multimodal occupation strategy (MOST). This strategy involves setting up permanent GPS receivers at a small number of sites in South America and Antarctica and using additional receivers to position numerous stations relative to this continuously operating network. Two seasonally occupied stations in the South Sandwich Islands will be tied to permanent GPS sites in South America, Antarctica, and Africa, and to intervening stations in the Falkland, South Georgia, and South Orkney Islands, which British collaborators will occupy occasionally. During the initial 3 years, the South Sandwich arc motion will be easily resolved. Using roving stations in the Antarctic Peninsula/South Shetland Islands area, we should be able to determine if extension is occurring across Bransfield Strait.

We will also construct a relatively dense subnetwork in Patagonia/Tierra del Fuego and a moderately dense subnetwork in the Antarctic Peninsula network. Although we do not expect these subnetworks to achieve submillimeter-per-year velocity resolution in the initial 3-year project, we will be able to establish the baseline necessary for a follow-on suite of measurements in perhaps 6 to 8 years. The follow-on project will allow characterization of the slow motions and deformations that occur across and within the boundaries of the Scotia Plate.

The objectives of SCARP are to determine

- the relative motions of the Antarctic, South America, Scotia, and South Sandwich plates
- strain partitioning within the South America–Scotia Plate boundary zone, Tierra del Fuego
- the rate of extension across the volcanically active Bransfield trough and the present rate of uplift or subsidence of the extinct South Shetland Islands volcanic arc
- with our British colleagues, the rate of rollback of the South Sandwich Trench in a South American–African framework.

The results of these objectives in turn will

- make an important contribution to a geodetic assessment of the elastic displacement field associated with extension in Bransfield Strait and the accumulation or loss of ice on the antarctic continent
- help scientists determine why there is transpression along the northern boundary of the Scotia Plate and transtension along its southern boundary
- facilitate testing for motion between East and West Antarctica postulated as a source of error in global plate circuits
- enable researchers to assess what the South Sandwich trench rollback means in terms of mantle flow and the potential for transforming a passive rifted ocean basin into a subducting or disappearing ocean basin. (S-087)

IRIS: Seismology at the South Pole and Antarctic Peninsula. *Rhett Butler, Incorporated Research Institutions for Seismology (IRIS).* The IRIS Global Seismographic Network (GSN) operates two stations in Antarctica—SPA at Amundsen–Scott South Pole Station and PMSA at Palmer Station. Both SPA and PMSA provide key seismological coverage in the Southern Hemisphere and are critical stations in the GSN. Located on Earth's rotational axis, SPA is uniquely situated to measure long-period oscillations of the Earth without the effects of rotational splitting of modes. The Antarctic Peninsula station has a unique vantage for studies of the tectonics and seismicity of the Peninsula, South America, Scotia Sea, and Drake Passage. Near real-time access to the data is important to the seismological community. IRIS, a

nonprofit consortium of 87 U.S. universities, creates and manages research facilities for seismology. Currently, it provides funding to the University of California at Los Angeles to operate a long-period gravimeter at the South Pole. IRIS operates the SPA and PMSA seismic stations in cooperation with the Albuquerque Seismological Laboratory of the U.S. Geological Survey. (S-090 and S-091)

Collaborative investigation of earliest crayfish: Paleobiologic, paleoecologic, and paleoclimatic implications. *John Isbell, University of Wisconsin at Milwaukee; Molly Miller, Vanderbilt University; Loren Babcock, Ohio State University.* During the 1995■1996 austral summer field season, the oldest known fossil crayfish and one of the oldest known occurrences of fossil crayfish burrows were found in the Shackleton Glacier area of Antarctica. This collaborative, interdisciplinary study will expand on these discoveries.

The crayfish claw was found in the Upper Carboniferous to Lower Permian Pagoda Formation deposited in glacial environments 280 to 300 million years ago. The discovery pushes back the first occurrence of crayfish 65 to 75 million years. The crayfish burrows were found in the Lower Triassic Fremouw Formation deposited approximately 240 million years ago. Their abundance and complexity indicate that crayfish developed burrowing behavior early in their long history. The objectives of the study are to collect additional crayfish body and trace fossils from Antarctica, to use these fossils to develop further insight into the depositional conditions in parts of that continent during intervals of the Late Carboniferous-Early Permian and the Early Triassic, and to study the early evolutionary and burrowing history of freshwater astacoid decapods (crayfish). Specifically, the work plan is

- to search for more fossil crayfish and crayfish burrows in the Pagoda Formation;
- to interpret the way of life of the crayfish in the Pagoda Formation and relate it to the crayfish morphology;
- to reconstruct the depositional environment and paleoclimate recorded by the crayfish-bearing rocks;
- to search for crayfish within burrows in the Fremouw Formation;
- to describe quantitatively the burrows in the Fremouw Formation; and
- to compare the morphology and behavior of Late Carboniferous to Early Permian crayfish and burrows to those of the Early Triassic and later.

This study will elucidate the evolutionary and behavioral history of crayfish. Modern crayfish exert an important control on parameters such as energy flow, biotic species composition, and biotic abundance in many different aquatic ecosystems. This study will yield information about how and when this environmental and behavioral diversification took place, as well as increase understanding of the late Paleozoic and early Mesozoic paleoclimates. (S-094)

Contrasting architecture and dynamics of the Transantarctic Mountains. *Robin Bell, Columbia University.* Continental extension produces a great variety of structures. The cause of variable rift width and crustal thinning is fairly well explained by variable initial heat flow and crustal thickness. Mechanical stretching of the lithosphere has been linked to rift shoulder uplift, but the cause of variable rift flank uplift remains poorly understood. The Transantarctic Mountains are an extreme example of rift flank uplift, extending over 3,500 kilometers across Antarctica and reaching elevations up to 4,500 meters and thus constituting a unique feature of Earth's crust. The range was formed in the extensional environment associated with the Mesozoic and Cenozoic breakup of Gondwanaland. Geological and geophysical work has shown that the Transantarctic Mountains developed along the long-lived lithospheric boundary between East and West Antarctica reactivated by a complex history of extensional and translational microplate motions.

The motivation for studying the Transantarctic Mountains is to try to understand the geodynamics of their extreme elevation rift flank. Are the geodynamics of the area unique, or does the history of glaciation and related erosion contribute to the extreme uplift? Using the existing data sets, researchers find that it is difficult to be confident about constraining the geological architecture across representative sections of the Transantarctic Mountains. Any effort to refine geodynamic mechanisms requires this basic understanding of the Transantarctic Mountains architecture. The goal of this project is to

- constrain the architecture of the rift system as well as the distribution and structure of sedimentary basins, glacial erosion, and mafic igneous rocks surrounding the rift flank by acquiring three long-wavelength geophysical transects with integrated gravity, magnetics, ice-penetrating radar, and ice surface measurements;

- quantify the contribution of various geodynamic mechanisms to understand the geological conditions that can lead to extreme rift flank uplift; and
- use the improved understanding of architecture and geophysical data to test geodynamic models to improve our understanding both of the Transantarctic Mountains geodynamics and the general problem of the geodynamics of rift flank uplift worldwide.

This project will allow development of a generalized framework for understanding the development of rift flank uplift as well as address the question of the specific geodynamic evolution of the Transantarctic Mountains. (S-095)

A broadband seismic experiment for study of the tectonics and structure of the Antarctic Peninsula and Scotia Sea regions. *Douglas Wiens and Dapeng Zhao, Washington University.* The present-day tectonics and seismological structure of the Antarctic Peninsula and Scotia Plate region are among the most poorly understood of any location in the world. This region offers a unique and complex geodynamic setting, as illustrated by the recent cessation of volcanism along the South Shetland Trench and onset of volcanism and rifting in the Bransfield Strait, the possible presence of diffuse deformation and/or microplates in the Drake Passage region, and fast back-arc spreading behind the South Sandwich Arc. Our project is the U.S. component of an international effort to study the seismotectonics and seismic structure of the Antarctic Peninsula and Scotia Sea regions by using a large-scale deployment of broadband seismographs beginning during the 1996–1997 field season. We will deploy nine broadband PASSCAL seismographs for 2 years in the Antarctic Peninsula region, southernmost Chile, and South Georgia Island. Our research addresses the following questions:

- Is there seismological evidence, in the form of either subduction-zone earthquakes or seismic structure, for current subduction beneath the Antarctic Peninsula?
- Is there evidence from seismic anisotropy for large-scale mantle flow around South America into the South Atlantic?
- Are regional earthquakes and focal mechanisms consistent with current kinematic models for the Scotia Plate, which imply compressional deformation in the Drake Passage region?
- What is the deep structure of the South Sandwich subduction zone?
- What is the seismological structure of active back-arc spreading centers in the Bransfield Strait and South Sandwich regions?

Answering these questions will help to constrain important tectonic questions such as what causes plate motion changes, what processes initiate back-arc spreading, and what is the relationship between mantle flow and surface tectonics? (S-097)

Transantarctic Mountains aerogeophysical research activities (TAMARA). *Terry Wilson, Ohio State University, and Carol Finn, U.S. Geological Survey, Denver.* As part of the TAMARA program, we will conduct aeromagnetic surveying over the Transantarctic Mountains in the McMurdo region. Ground-based gravity measurements will be made near the Skelton Neve camp as time permits. The aeromagnetic data will be integrated with a GIS to be constructed as part of this program (geophysical and geologic data sets and satellite imagery) to obtain a comprehensive model of the Transantarctic Mountains architecture and evolution. The science objectives of this project focus on

- Mesozoic-Cenozoic Transantarctic Mountains rift-flank architecture and the kinematics and timing of rifting and uplift,
- Jurassic and Cenozoic rift-related magmatic architecture, and
- Paleozoic convergent margin trends within the Ross orogen. (S-099)

Antarctic network of unattended broadband integrated seismometers (ANUBIS). *Sridhar Anandakrishnan, Pennsylvania State University.* The antarctic crust and mantle composition and geometry are poorly known. The primary methods for studying the crust, upper mantle, and the deeper asthenosphere is interpretation of seismic data: either by "active" methods acquired through use of explosives or by "passive" means, using natural sources and interpreting various earthquake phase arrival times and amplitudes. Integrating passive and active seismology can result in efficient use of resources to produce detailed images of the lithosphere. This project will develop a passive seismic network for the antarctic interior.

The Antarctic is a gaping hole in the rapidly improving field of global seismic imaging and tomography. On this huge continent (surface area of 14

million square kilometers), there are only eight broadband seismic observatories. Further, with the exception of South Pole, all of those stations are along the margins of the continent and none are in West Antarctica. By contrast, there are 200 permanent stations worldwide in the FDSN (Federation of Digital Seismograph Networks) and on the order of 1,000 in national networks not yet integrated into the FDSN.

This project will develop and deploy 11 long-term broadband seismic stations on the continent itself. Because 98 percent of the continent is ice covered, these stations will be installed at the surface of the ice sheet. The body-wave data thus recorded from regional and teleseismic earthquakes can be analyzed at each station for local crustal thickness, lamination, Poisson's ratio (a measure of crustal composition), crust and mantle anisotropy (a measure of current and former stress regimes), and identification of rift zones and crustal block boundaries. In addition, the data from all the stations (including the existing peripheral ones) can be used for seismic tomographic analysis to detail lateral variations in these properties. Six of the stations will be installed at existing Automatic Geophysical Observatory sites (in East Antarctica), which will provide heat and power for the data loggers. The remaining five stations will be in West Antarctica and will be powered and heated by wind turbines during the austral winter. (S-180)

Glaciology and glacial geology

Recovery and science coordination of an ice core at Siple Dome, Antarctica. *Kendrick Taylor, Desert Research Institute.* This project, which will recover a 1,000-meter ice core from Siple Dome, Antarctica, and coordinate a science management office for the scientific program, is part of the West Antarctic Ice Sheet (WAIS) program, which seeks to understand the current behavior of the west antarctic ice sheet and to decipher its past climate history. Siple Dome is located between ice streams C and D and is well situated to investigate coastal climate conditions and the dynamics of the Siple Coast ice streams, which drain the west antarctic ice sheet. The annual accumulation at the site is 7 to 11 centimeters of ice per year, and it is anticipated that annual layers will be identifiable to an age of at least 6,000 years. The length of the usable climate record will extend to at least 80,000 years. This project provides the background for the Siple Dome drilling program, develops the opportunity for individual scientists to work on the ice core, and establishes a science coordination office to coordinate the activities of the various organizations involved in the project, including the National Science Foundation (NSF), the Polar Ice Coring Office (PICO), Antarctic Support Associates (ASA), and the National Ice Core Laboratory (NICL). (S-152)

Near-surface processes affecting gas exchange: West antarctic ice sheet. *Mary Albert, Cold Regions Research and Engineering Laboratory.* This project will examine the physical processes that affect the manner in which heat, vapor, and chemical species in air are incorporated into snow and polar firn. The processes include advection, diffusion, and the effects of solar radiation penetration into the snow. An understanding of these processes is important because they control the rate at which reactive and nonreactive chemical species in the atmosphere become incorporated into the snow, firn, and polar ice and, thus, will affect interpretation of polar ice-core data. Currently, the interpretation of polar ice-core data assumes that diffusion controls the rate at which chemical species are incorporated into firn. This project will determine whether ventilation, or advection of the species by air movement in the firn, and radiation penetration processes have a significant effect. Field studies at the two west antarctic ice sheet deep-drilling sites will be conducted to determine the spatial and temporal extent for key parameters and boundary conditions needed to model the advection, conduction, and radiation transmission/absorption processes. An existing multidimensional numerical model is being expanded to simulate the processes and to serve as the basis for ongoing and future work in transport and distribution of reactive chemical species. (S-155)

The evolution of a polar ice sheet in East Antarctica. *George Denton, University of Maine.* This study seeks to determine the sequence and chronology of events that led to the development of the antarctic ice sheet. A continental-scale ice sheet probably first developed in East Antarctica close to the Eocene-Oligocene boundary under temperate climatic conditions. The purpose of this project is to determine, from landscape analysis (with a numerical chronology), when (and why) these early temperate

conditions gave way to a polar environment in Antarctica. From previous fieldwork and recent photographic analysis, an extensive relict landscape (older than 17 million years) with landforms and erosional features characteristic of temperate glaciation has been delineated. This relict landscape has been called the "Sessrumnir erosion surface," and it extends over 3 degrees of latitude and covers almost 10,000 square kilometers in three fault blocks of the Transantarctic Mountains (Convoy, Dry Valleys, and Royal Society). It is on this relict land surface that data will be collected which record Middle and Early Miocene glacial history and paleoclimate. The results should allow an identification of the transition from temperate to polar conditions. This work will involve landscape analysis, stratigraphy of glacial deposits, and argon-40/argon-39 dating of volcanic ashfalls. Denudation rates will come from fission-track analyses and from exposure-age analyses of bedrock surfaces and erratic boulders. The overall results will elucidate the origin and stability of the polar antarctic cryosphere. (S-156)

Hot-water borehole drilling on Siple Dome to deploy vertical strain meters and to determine ice temperature and lateral continuity of climatic records at depth. *Barclay Kamb, California Institute of Technology.* The long-term objective of this project is to establish by direct observation in boreholes the physical mechanism of rapid motion of the West Antarctic ice streams, in relation to global climate change. In previous years, we have studied ice streams B and C and have developed techniques for rapid deep drilling with a hot-water jet and for obtaining ice cores by hot-water drilling. During the 1997-98 field season, we will apply the hot-water drilling technique to the problem of the vertical compression of ice at depth in the ice sheet at the Siple Dome deep-coring site and how this compression thins the annual layers of ice that accumulate each year on the surface of the ice sheet. Quantitative knowledge of this thinning process is necessary to evaluate an ice core's age at depth and the history of ice accumulation. Collaborating with investigators from the University of Alaska (S-164), we will drill 40 boreholes to various depths near the Siple Dome core site, while investigators from project S-164 install vertical strain meters in these holes to measure the vertical compression rate as a function of depth. Additional, this field season we will obtain a vertical profile of ice temperature near the strain-rate-measurement locations and drill a vertical sequence of ice cores near the main Siple Dome core site and at a location about 10 kilometers away. The temperature data are needed to interpret the strain-rate measurements in terms of an anisotropic flow for the ice at depth. The cores will be used to ascertain if the vertical profile of paleotemperatures and other climatic records is laterally continuous in the upper part and discontinuous at depth, as investigators found it to be in ice cores from Greenland (i.e., the GISP2 and GRIP cores). Lateral continuity of the records is important in demonstrating the reliability of climatic history inferred form the ice cores. (S-157)

Snow-atmosphere transfer function for reversibly deposited chemical species in West Antarctica. *Roger Bales, University of Arizona.* Measurements made by this project will help investigators improve their understanding of the relationship between formaldehyde (HCHO) and hydrogen peroxide (H_2O_2) in the atmosphere and the concentrations of the same species in antarctic snow, firn, and ice. This work aims to relate changes in concentrations in the snow, firn, and ice to corresponding changes in tropospheric chemistry. Atmospheric and firn sampling for formaldehyde and hydrogen peroxide at one or more of the WAIS (West Antarctic Ice Sheet) ice core drilling sites will be undertaken, and controlled laboratory studies to estimate thermodynamic and rate parameters will be performed. In addition, this work will involve modeling of atmosphere-snow exchange processes to infer the "transfer function" for reactive species at the sites and atmospheric photochemical modeling to relate changes in concentrations of formaldehyde and hydrogen peroxide in snow, firn, and ice to atmospheric oxidation capacity. This work will contribute to a better understanding of the relationship between atmospheric concentrations of various species and those same species measured in snow and ice samples. (S-158)

Passive microwave remote sensing for paleoclimate indicators at Siple Dome, Antarctica. *Robert Bindschadler, National Aeronautics and Space Administration.* Passive microwave data will be used in this project to validate key paleoclimate indicators used in glaciologic research. The specific contributions of this research are

- to define the timing and spatial extent of hoar complexes, which may serve as visible, annual stratigraphic markers in ice cores, through a combination of satellite passive microwave data and field observations and
- to monitor temperature trends at the site with calibrated passive microwave brightness temperatures and to correlate these trends to

proxy temperatures provided by oxygen and hydrogen stable isotope ratio profiles from snow pits and/or ice cores.

The work will take place at Siple Dome, Antarctica, as part of the field activities associated with the ice-core drilling program there. (S-159)

Digital imaging for ice core analysis. *Joan J. Fitzpatrick, U.S. Geological Survey, Denver.* Over 2 years we will develop the technology and methodology for digitizing the photographs and analyzing the thin sections from ice cores and will investigate the application of digital technology for whole-core stratigraphy, using digital photography, image enhancement and image processing. The thin section analysis will be tested using samples already in hand from the Taylor Dome ice core. If we are successful, we will apply these techniques to samples from the Siple Dome ice core, in cooperation with the investigators funded to retrieve and examine these sections. The original digital images with all original data annotation files will be distributed to Siple Dome investigators so they can use these files to interpret their own data. All software and hardware acquired for this project will become part of the permanent equipment inventory at the U.S. National Ice Core Laboratory and will be available for use by clients at the facility.

Antarctic ice core records of oceanic emissions. *Eric Saltzman, University of Miami.* This project will develop long-term records of the atmospheric deposition of aerosolborne, marine-derived elements to the antarctic ice sheet. The project includes the sampling of antarctic ice-core samples from the Vostok ice core and the laboratory analysis of soluble ions in the ice. The analyses include methanesulfonate, non-sea-salt sulfate, and several additional ions derived from gaseous emissions from the sea surface, from seasalt, and associated with continental dust. The principal emphasis of this work is on sulfur, because of its role as a major aerosol-forming constituent of the atmosphere and because of its potential importance to climate. The main goal of the project is to complete analyses of the Vostok ice core. (S-161)

Ice dynamics, the flow law, and vertical strain at Siple Dome. *William Harrison, University of Alaska at Fairbanks.* This 3-year project will measure the vertical strain rate as a function of depth at two sites on Siple Dome, Antarctica. Iceflow near a divide such as Siple Dome is unique because it is predominantly vertical. As a consequence, the component of ice deformation in the vertical direction, the "vertical strain rate," is dominant. Its measurement is, therefore, important for the calibration of dynamic models of iceflow. Two different, relatively new, high-resolution systems for its measurement in hot water drilled holes will be employed. The iceflow model resulting from the measurements and flow-law determination will be used to interpret the shapes of radar internal layering in terms of the dynamic history and accumulation patterns of Siple Dome over the past 10,000 years. The resulting improved model will also be applied to the interpretation of the thicknesses of the annual layers (to produce annual accumulation rates) and borehole temperatures from the ice core to be drilled at Siple Dome during the 1997■1998 field season. The results should permit an improved analysis of the ice core, relative to what was possible at recent coring sites in central Greenland. This is a collaborative project between the University of Alaska, the University of California at San Diego, and the University of Washington. (S-164)

Physical and structural properties of the Siple Dome Core. *Anthony Gow, Cold Regions Research and Engineering Laboratory.* This project will investigate the visual stratigraphy, index physical properties, relaxation characteristics, and crystalline structure of ice cores from Siple Dome, West Antarctica. This investigation will include measurements of a time-priority nature that must be initiated at the drill site on freshly drilled cores. This need will be especially pressing for cores from the brittle ice zone, which is expected to constitute a significant fraction of the ice core. The brittle zone includes ice in which relaxation, resulting from the release of confining pressure, is maximized and leads to significant changes in the mechanical condition of the core that must be considered in relation to the processing and analysis of ice samples for entrapped gas and chemical studies. This relaxation will be monitored via precision density measurements made initially at the drill site and repeated at intervals back in the United States. Other studies will include measurement of the annual layering in the core to as great a depth as visual stratigraphy can be deciphered, crystal size measurements as a function of depth and age, c-axis fabric studies, and analysis of the physical properties of any debris-bearing basal ice and its relationship to the underlying bedrock. Only through careful documentation and analysis of these key properties can we hope to assess accurately the dynamic state of the ice and the age-depth relationships essential to deciphering the paleoclimate record at this location. (S-165)

SOAR laser: Calibration and first measurement for ice-sheet change detection. *Ian Whillans, Ohio State University.* This 3-year study will make precise and accurate measurements of the elevation of the antarctic ice sheet to detect ongoing changes in the surface of the ice sheet. The location and pattern of change discovered may be used to deduce the causes of the changes. Suitable equipment for these measurements are part of the Support Office for Aerogeophysical Research in Antarctica (SOAR) facility. This project will evaluate the quality and calibrate the measurements to be made by SOAR. Tests will be made both while the aircraft is parked and during flights over ground-surveyed sites near the aircraft base camp. After the validation and calibration is complete, a limited measurement program to detect time changes in surface elevation of glaciologically interesting sites will be started. At the conclusion of the program, the capability of the SOAR facility to determine surface elevation accurately and precisely will be established. SOAR will then be useful to all investigators who are interested in precision mapping and detection of change in the antarctic ice sheet. (S-166)

Reconstruction of paleotemperatures from precision borehole temperature logging: A Transantarctic Mountains transect from Taylor Dome to Ross Sea. *Edwin Waddington, University of Washington.* As a part of this study, we will gather data to provide a direct thermal measurement of any climate warming in the Ross Sea sector of Antarctica. When combined with existing McMurdo Dry Valleys climate records and indicators, these data should provide information about past relationships in the region among such climate factors as cloudiness, air temperature, and wind patterns. To obtain the data, we will log temperature as a function of depth in preexisting boreholes on a transect from Taylor Dome through the McMurdo Dry Valleys to the Ross Sea. Paleotemperatures will be derived by applying formal inverse methods to the data. The oxygen-isotope proxy record from the Taylor Dome ice core will be compared with a true thermal record to calibrate the oxygen-isotope proxy record. Vertical strain rate will be measured in an existing 130-meter dry hole to allow correction for firn compaction and ice advection. (S-171)

West Antarctic Glaciology V. *Robert Bindschadler, National Aeronautic and Space Administration.* This 3-year project is designed to answer two questions of critical importance to understanding the ice-flow of the west antarctic ice sheet:

- Are the Ross ice streams (B, D, and E) currently surging?
- What has been the buttressing effect of an enlarging Crary Ice Rise on the flow of ice stream B?

Both questions will be answered based on a combination of data collected on the surface, from the air, and from space. Although many past indications of change in West Antarctica have been based on interpolations and calculations with large uncertainties, these measurements will be direct, making use of rapid and accurate global positioning system data to minimize field logistic requirements. Direct measurement of expected thinning in the upper portion of ice stream D and repeated satellite image measurements at the heads of ice streams B, D, and E to detect the inland migration of the onset area (as is required by sustained surging) will enable a test of a surge hypothesis developed by Bindschadler. The buttressing impact of Crary Ice Rise on ice stream B's flow will be studied by comparing new measurements of ice thickness, surface elevation, and velocity with data collected during the 1950s, 1970s, and 1980s, thus providing a multidecadal time series of change. (S-173)

Radar investigations of former shear margins: Roosevelt Island and ice stream C. *Charles Bentley, University of Wisconsin at Madison.* This 2-year project will perform radar investigations across former shear margins at Roosevelt Island and ice stream C to measure changes in the configuration and continuity of internal layers and the bed. The broad goal of these investigations is to gain an understanding of ice-stream flow and the timing and mechanisms of ice-stream shutdown. A high-resolution short-pulse radar system will be used for detailed examination of the uppermost 100 meters of the firn and ice, and a monopulse sounding-radar system will be used to image the rest of the ice column (including internal layers) and the bed. Changes in the shape and continuity of layers will be used to interpret mechanisms and modes of ice-stream flow including the possible migration of stagnation fronts and rates of shutdown. Variations in bed reflectivity will be used to deduce basal hydrology conditions across lineations. Accumulation rates deduced from snow pits and shallow cores will be used to estimate near-surface depth-age profiles. Improved understanding of ice-stream history opens the possibility of linking changes in the west antarctic ice sheet with the geologic evidence from northern Victoria Land and the

ocean record of the retreat of the grounding line in the Ross Sea. (S-176)

Determining ice-sheet mass balance using global positioning system measurements. *Gordon Hamilton, Ohio State University.* Over the course of 3 years, we will measure the rate of thickening or thinning of the antarctic ice sheets at selected sites in East and West Antarctica. To do this, we will measure vertical velocities of markers anchored at several depths in the ice sheet and retrieve shallow firn cores to determine density and long-term average accumulation. Precise, absolute marker positions will be obtained using global positioning system surveys. The three existing sites will be revisited, and 13 new sites in nine locations will be established on the east and west antarctic ice sheets. Although we will use the measured thickening or thinning rates to test various glaciological hypotheses, the results of the work will also be useful for calibrating data from satellite and airborne altimetry of ice sheets. (S-178)

The quantitative assessment of the Mount Pinatubo signal in antarctic snow. *Ellen Mosley-Thompson, Ohio State University.* This study will sample surface snow in pits and drill shallow cores near South Pole to look for evidence of the June 1991 eruption of Mount Pinatubo in the Philippines. Extensive measurements and observations by satellite and by ground-based and airborne atmospheric instruments are available regarding the amount of sulfur dioxide emitted from the eruption, as well as the global distribution and decay of the stratospheric aerosols derived from the volcanic sulfur dioxide. Ground-based and airborne measurements in Antarctica clearly indicate that the stratospheric sulfate aerosols from this eruption reached high southern latitudes in late 1991 and persisted in the antarctic atmosphere through 1993. Preliminary results from snow pit samples recently taken in the South Pole area indicate that the Pinatubo signal exists and can be separated from the signal of another volcanic eruption (Cerro Hudson), which occurred in mid-August 1991. Combined with the known total sulfate aerosol production from Pinatubo, the proposed sampling and analyses will yield the quantitative information necessary to establish empirical relationships between the explosivity of a low-latitude eruption and the amplitude of its corresponding signals in antarctic snow. (S-185)

Measurements and model development of antarctic snow accumulation and transport dynamics. *David Braaten, University of Kansas.* A more thorough understanding of annual ice-sheet snow accumulation is important for interpreting paleoclimatic ice-core records, and assessing the role of wind on the mass transport of snow is important in understanding the redistribution of snow on the continent and mass transport off the continent. Our research continues to quantify the year-round snow accumulation dynamics and wind-blown mass transport of snow in remote katabatic wind areas, providing new insights into these complex nonlinear processes. Using instrumentation that disperses colored glass microspheres at 14-day intervals throughout the year and a sonic snow depth gauge that makes hourly measurements of snow-surface height, we can reconstruct in detail the complex accumulation and transport dynamics. The microspheres dispersed at fixed times throughout the year act as both time markers within the annual snow-accumulation profile and as tracers of snow mass transport by the wind. These insights are essential in developing and validating numerical models that are concurrently being developed to simulate these processes.

Snow-core and snow-pit sampling of the annual accumulation will be conducted at Ferrell automatic weather station (AWS) on the Ross Ice Shelf and AGO-2 on the polar plateau. At each site, we will take snow samples with a depth resolution of up to 1 centimeter and will analyze these to identify microsphere horizons within the annual accumulation profile. Snow cores will be obtained along a line in the prevailing wind direction and will be analyzed to identify microspheres transported by the wind. The instrumentation located at Ferrell AWS will be moved to Marilyn AWS on the Ross Ice Shelf, an area with very strong katabatic winds. (S-190)

Climate studies

Antarctic Meteorological Research Center. *Charles Stearns and John T. Young, University of Wisconsin.* The Antarctic Meteorological Research Center (AMRC), one of three research centers in the Crary Science and Engineering Technology Center at McMurdo Station, is a resource for meteorological research and a test bed for improving operational synoptic forecasting. The Man-Computer Interactive

Data Access System (McIDAS), a versatile computer-based system for organizing, manipulating, and integrating antarctic environmental data, forms the basis of AMRC. McIDAS not only captures the flow of meteorological information from polar-orbiting satellites, automatic weather stations (AWS), operational station synoptic observations, and research project efforts, but it also receives environmental data products, such as weather forecasts, from outside Antarctica and serves as a repository for existing archived databases. Developed at the University of Wisconsin in the mid-1970s, McIDAS ingests meteorological data from various sources, standard synoptic observations, radiosonde profiles, satellite-based visible and infrared imagery, atmospheric profiles inverted from multispectral scanning sensors, and nonstandard sources such as total ozone mapping spectrometer data, synthetic aperture radar sea-ice information, and the AWS network observations. The system automatically registers, calibrates, and locates (by geographical coordinates) the ingested information and allows a user at a work station to manipulate the database. The manipulations, which include sectorization, false color, enhancements, brightness stretching, overlays, and looping, are quite definitely keyed to synoptic meteorological research and weather forecasting. The antarctic system is based primarily on data streams provided by polar orbiters (AVHRR/ HRPT and DMSP), because the angles of sight for geostationary satellites are extremely low. The full use of McIDAS capabilities to produce meteorological data products for forecasting and research will include data-transfer and communications capability to, for example, the Australian Bureau of Meteorology, the University of Wisconsin Space Science and Engineering Center, the Fleet Numerical Oceanography Center in Monterey, and the European Center for Medium Range Weather Forecasts in Reading, United Kingdom. (S-202)

Antarctic halos and ice crystals. *Walter Tape, University of Alaska.* Our project is an experimental and theoretical study of ice crystals in the antarctic atmosphere and the halos that they produce. For reasons that are not currently known, the antarctic interior experiences more frequent and better developed halos than any other location on Earth. Our objectives are to observe natural halos at Amundsen–Scott South Pole Station and to sample ice crystals to validate computer models of light refraction and reflection in ice crystals. Such models have the potential for the remote sensing of atmospheric conditions. Controlled experiments, such as seeding the atmosphere with dry ice, will produce artificially generated but simple and well-formed single-species crystals. Our research provides a unique mechanism for examining the crystal growth and evolution process in the natural atmosphere. By observing halos through polarizing filters, we will also be able to examine the atmospheric ice-crystal orientation, shape, and size. The results of our project will advance our understanding of why well-formed ice crystals grow in the antarctic atmosphere but are not generally observed elsewhere. (S-208)

Chlorine- and bromine-containing trace gases in Antarctica. *R.A. Rasmussen, Oregon Graduate Institute for Science and Technology.* We are collecting air samples year-round at Palmer Station to investigate seasonal trends in trace-gas concentrations. The samples are analyzed in our laboratories for a number of trace components, especially chlorine- and bromine-containing gases. These trace constituents, which come from both natural and human sources, can alter the Earth's climate. They have even been implicated in the chemical processes that contribute to the austral spring depletion of the ozone layer over Antarctica. Our work will contribute to a better understanding of the buildup of trace constituents, particularly those of high-latitude marine origin. (S-254)

South Pole monitoring for climate change. Amundsen–Scott South Pole Station: *David Hofman, Climate Monitoring and Diagnostics Laboratory;* **Palmer Station:** *James T. Peterson, Environmental Research Laboratories, National Oceanic and Atmospheric Administration.* The National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory team will continue long-term measurements of trace atmospheric constituents that influence climate. Four scientists will work at the Amundsen–Scott South Pole Station observatory during the austral summer, and two NOAA personnel will stay over the winter to measure carbon dioxide, water vapor, surface and stratospheric ozone, wind, pressure, air and snow temperature, and atmospheric moisture and other trace constituents from the station's clean-air facility. These measurements are part of NOAA's effort to determine and assess the long-term buildup of global pollutants in the atmosphere. The measurements will be used for time-series analyses of multiyear data records that focus on stratospheric ozone depletion, transantarctic transport and deposition, interplay of the trace gases and aerosols with solar and terrestrial radiation fluxes on the polar plateau, the magnitude of seasonal and temporal variations in greenhouse gases, and the development of polar stratospheric clouds

over Antarctica. Other objectives of our research are to determine the rate at which concentrations of these atmospheric constituents change and to examine their sources, sinks, and budgets. Working with climate modelers and diagnosticians, we will use these data to determine how the rate of change of these parameters affects climate, particularly when the data are included in climate model studies. In support of this project, Palmer Station personnel also will collect carbon dioxide samples. (S-257A and S-257C)

Operation of an aerosol sampling system at Palmer Station. *Gail dePlannque and Colin G. Sanderson, Environmental Measurements Laboratory, U.S. Department of Energy.* In March 1990, a team from the U.S. Department of Energy, Environmental Measurements Laboratory (EML) in New York City, installed a high-volume aerosol sampler, a gamma-ray spectrometer, and a satellite data transmission system at Palmer Station. This installation is part of EML's Remote Atmospheric Measurements Program, which is an extension of its worldwide surface air-sampling program. The system transmits data through the National Oceanic and Atmospheric Administration's ARGOS satellite system. The sampling station at Palmer provides significant input for EML's global database. (S-275)

Antarctic automatic weather stations: Operation and research. *Charles Stearns, University of Wisconsin at Madison.* Approximately 50 automatic weather stations measuring surface pressure, air temperature, wind speed and direction, and at some sites, humidity are located in remote areas of Antarctica. The data are transmitted to polar-orbiting satellites of the National Oceanic and Atmospheric Administration series and are rebroadcast for reception at McMurdo and Palmer Stations in Antarctica. The data from the weather stations are used to study the barrier wind along the Transantarctic Mountains; vertical motion and sensible and latent heat flux from the Ross Ice Shelf; warm west winds flowing from the Beardmore and Byrd Glaciers; katabatic flow on the Adélie Coast, Antarctica; and mesoscale systems around the South Pole. The data are used to establish long-term climate records at selected sites. Starting in the 1994–1995 field season, the data were used to study the meteorology of the west antarctic/Siple Coast region. During the 1995–1996 field season, automatic weather stations were installed in support of future ice coring; the first such location will be at Siple Dome. Data from the automatic weather stations are also used in support of aircraft operations in Antarctica. The data are available from the University of Wisconsin. (S-283)

Ozone-depletion studies

Ground-based and *in situ* monitoring of polar stratospheric clouds. *Alberto Adriani, Institute of Atmospheric Physics, Rome, Italy.* In cooperation with the U.S. Antarctic Program and in collaboration with the University of Wyoming, Italian scientists will make laboratory-based light radar (lidar) observations and *in situ* measurements by laser backscatter sondes of polar stratospheric clouds (PSCs) above McMurdo Station. These data add to the available information concerning the annual springtime depletion of ozone in the antarctic stratosphere and enhance scientific understanding of the role of PSCs in the depletion process. The lidar observations are also in the frame of the Network for the Detection of Stratospheric Change activity. (S-107)

***In situ* measurements of polar stratospheric clouds (PSCs) spanning the austral winter and of ozone from late winter to early spring.** *Terry Deshler, University of Wyoming.* The annual stratospheric ozone hole above Antarctica is driven by chlorine compounds that interact on the surfaces of polar stratospheric clouds, which form during the polar winter. It is for this reason that the hole appears in the austral spring and that ozone depletion is much more severe in polar regions than elsewhere. By using balloonborne instruments, this investigation provides detailed information on the actual cloud particles and the distribution of the clouds and the ozone. The measurements will provide vertical profiles of both the PSCs and ozone, size distributions of the PSC particles, and some information on their composition and physical state (liquid or solid). The project is enhanced by cooperation with an Italian investigator who operates a lidar system at McMurdo Station. The project contributes to the World Meteorological Organization/UNEP Network for the Detection of Stratospheric Change and the Global Change Initiative. (S-131)

Measurement of stratospheric chlorine monoxide and other trace gases over McMurdo Station in

the austral spring. *Robert deZafra, State University of New York.* Chlorine monoxide (ClO) is a product of the destruction of stratospheric ozone by chlorine, which is present in the stratosphere as a result of the breakdown of chlorofluorocarbons (CFCs). ClO, as well as other trace stratospheric gases that are important in the antarctic ozone hole, can be measured from the ground by microwave receivers, similar to those used in radio astronomy. This project will continue a decade-long series of such measurements to extend the climatology, but more important, to provide as well a cross calibration of a new Network for the Detection of Stratospheric Change (NDSC) ClO microwave instrument, which has recently been installed nearby at New Zealand's Scott Base. The NDSC instruments are being installed at a number of sites worldwide as part of a joint National Aeronautics and Space Administration/World Meteorological Organization/UNEP program, and it is quite important to provide as much correlative information as possible so that the NDSC can be relied upon in the future to monitor the health of the stratosphere. (S-137)

Trace gas measurements over the South Pole using millimeter-wave spectroscopy. *Robert deZafra, State University of New York.* Many atmospheric gases radiate energy in the millimeter wavelength region of the radio spectrum; each species has a unique spectrum. The shape of each individual species' spectrum provides information on the temperature and pressure of the gas; thus, one can use the millimeter-wave spectrum of the atmosphere to determine the relative abundances and height distribution of a number of trace species. In this particular investigation, millimeter spectroscopy will be used to monitor ozone, carbon monoxide, nitrous oxide, nitric acid, water vapor, and nitrogen dioxide above South Pole over the period of year. Several of these gases play important roles in the formation of the annual antarctic ozone hole, whereas others, particularly water vapor and carbon monoxide, can provide information of the dynamics, particularly vertical transport, of the upper stratosphere and mesosphere. (S-138)

Astronomy, aeronomy, and astrophysics

The operation of an extremely-low-frequency/ very-low-frequency radiometer at Arrival Heights, Antarctica. *A.C. Fraser-Smith, Stanford University.* During the 1997■1998 field season, this project will continue to operate an extremely-low-frequency and very-low-frequency (ELF/VLF) radiometer at McMurdo, Antarctica, to monitor radio noise from natural sources such as thunderstorms. The Arrival Heights site is one of a network of eight such radiometers operated by Stanford University for the Office of Naval Research. Characterizing the possible sources of radio interference is important for operational purposes. Additionally, the variations in global noise reflect variations in global thunderstorm activity and can, therefore, provide information on global climate change. The antarctic site was chosen about 15 years ago because it is unusually free from man-made electromagnetic interference. The ELF/VLF record of data collected by this project now extends unbroken for more than 10 years. (S-100)

Magnetometer data acquisition at McMurdo and Amundsen–Scott South Pole Stations. *Louis Lanzerotti, AT&T Bell Laboratories; Alan Wolfe, New York City Technical College*. Magnetometers installed at selected sites in both polar regions continue to measure the magnitude and direction of variations in Earth's magnetic field in the frequency range from 0 to about 0.1 hertz. Our project focuses on measurements of these variations using magnetometers installed at conjugate sites in the Northern and Southern Hemispheres, specifically at McMurdo and Amundsen–Scott South Pole Stations, Antarctica, and at Iqaluit, Northwest Territories, Canada. We are also analyzing these data in association with similar data acquired from several automatic geophysical observatories that are part of the polar experiment network for geophysical upper-atmosphere investigations (PENGUIN) program (S-112). Using these systems, we gather data on the coupling of the interplanetary medium into the dayside magnetosphere, including the magnetospheric cusp region, as well as the causes and propagation of low-frequency hydromagnetic waves in the magnetosphere. Because of unique climatic conditions at the South Pole, we are also able to correlate optical measurements with

particle-precipitation measurements and with hydromagnetic-wave phenomena recorded by the magnetometer. (S-101)

An investigation of magnetospheric boundaries using ground-based induction magnetometers operated at manned stations as part of an extensive ground array. *Roger Arnoldy, University of New Hampshire.* An array of induction coil magnetometers located at high geomagnetic latitudes in the Arctic and Antarctic is operated, and the data collected are analyzed, by this project. The sites are Sondre Stromfjord, Greenland, and Iqaluit, Northwest Territories, Canada, in the Arctic and at Amundsen-Scott South Pole and McMurdo Stations in the Antarctic. The sites also complement similar magnetometers in the U.S. and British automatic geophysical observatory (AGO) networks and the MACCS array in Canada. The measurements of magnetic pulsations at these high geomagnetic latitudes are used to study the plasma physics of some of the important boundaries of the magnetosphere, particularly those surrounding the area through which the solar wind enters the magnetosphere and where the magnetosphere transfers the solar wind's energy to the Earth's atmosphere in the form of aurora and similar phenomena. This project is jointly supported by the U.S. Arctic and Antarctic Programs. (S-102)

Antarctic auroral imaging. *Stephen Mende, Lockheed Palo Alto Research Laboratory.* In the past, space satellites have performed detailed exploration of the magnetosphere, and the average distribution of the energetic particle plasma content of the magnetosphere has been mapped. This form of measurement is unsuitable, however, for observing the dynamic behavior of the magnetosphere. Auroral phenomena are produced when particles from the magnetosphere precipitate into the atmosphere causing the atmosphere to fluoresce. Because particles preferentially travel along the magnetic field line, the aurora can be regarded as a two-dimensional projection of the three-dimensional magnetospheric regions. Thus, observing the morphology of the aurora and its dynamics provides an important way to study the dynamics of the three-dimensional magnetosphere. This method requires knowledge of which type of auroras represent which energy of precipitation and their connection to the various regions of the magnetosphere.

Amundsen–Scott South Pole Station is uniquely situated for optical observations of polar aurora. The specific advantage of South Pole is that during the winter the aurora can be monitored 24 hours a day unlike most other places, where the sky becomes too bright near local mid-day. An intensified optical, all-sky imager, operating in two parallel wavelength channels—4,278 and 6,300 Ångstroms—will be used to record digital and video images of aurora. These wavelength bands allow us to discriminate between more or less energetic electron auroras and other precipitation. From South Pole Station, we can observe the polar cap and cleft regions by measuring auroral-precipitation patterns and interpreting the results in terms of coordinated observations of magnetic, radio-wave absorption images and high-frequency, coherent-scatter radar measurements. Through this investigation, we hope to learn about the sources and energization mechanisms of auroral particles in the magnetosphere and other forms of energy inputs into the high-latitude atmosphere. (S-104)

A study of very high latitude geomagnetic phenomena: Continued support. *Vladimir Papitashvili, University of Michigan.* This joint U.S.-Russian project focuses on the structure of very-high-latitude ionospheric current systems, the integrated effect of which is observed at the earth's surface by magnetometers. Correlative data from antarctic and Greenland magnetometer arrays will be used to investigate symmetries and asymmetries in the electrodynamics of the northern and southern polar caps and auroral regions. Two Russian permanent magnetic observatories (Vostok and Mirnyy) and a remote autonomous magnetometer at Sude are operated jointly by the University of Michigan and the Russian Arctic and Antarctic Research Institute in 1997. Scientific objectives for the 1997-1998 field season are as follows:

- to collect and process magnetometer data for 1997 from Vostok, Mirnyy, and Sude (data from latter two stations will be delivered to Vostok by the Russian snow traverse in November 1997) and
- to update the second autonomous magnetometer system located at Vostok for the 1998 winter operation and coordinate its deployment at Komsomolskaya by the Russian snow traverse team.

The principal investigator, V. Papitashvili, and a Russian magnetician, A. Frank-Kamenetsky will be delivered from McMurdo to Vostok in November 1997 by the first flight of LC-130. Dr. Frank- Kamenetsky will stay at Vostok through winter of 1998 and operate digital magnetometer system; he will take a

snow traverse to Mirnyy in December of 1998 revisiting Komsomolskaya and Sude. Dr. Papitashvili will return to McMurdo from Vostok in December 1997 upon completion of the project objectives for the field season. (S-105)

Global thunderstorm activity and its effects on the radiation belts and the lower ionosphere. *Umran Inan, Stanford University.* Very-low-frequency (VLF) radio receivers at Palmer Station, Antarctica, operated by this project, study ionospheric disturbance caused by global lightning. The principal mode of operation is to measure changes in amplitude and phase of signals received from several distant VLF transmitters. These changes occur in the VLF signals following lightning strokes because radio (whistler) waves from the lightning can cause very energetic electrons from the Van Allen radiation belts to precipitate into the upper atmosphere. This particle precipitation in turn causes increased ionization in the ionosphere, thus affecting the propagating VLF radio waves. Because the directions to the VLF transmitters are known, it is possible to track remotely the path of the thunderstorms that cause the changes. The Palmer receivers are operated as a collaboration with the British and Brazilian Antarctic Programs, both of which operate similar receivers. This project contributes to the Global Change Initiative. (S-106)

Extremely-low-frequency/very-low-frequency (ELF/VLF) waves at the South Pole. *Umran S. Inan, Stanford University.* Advancing our understanding of the electrodynamic coupling of upper atmospheric regions and refining our quantitative understanding of the energy transport between the magnetosphere and the ionosphere are two important objectives of the U.S. Antarctic Program's automatic geophysical observatory program. Particle precipitation driven by extra-low-frequency/very-low-frequency (ELF/VLF) waves have a part in transporting and accelerating magnetospheric and ionospheric plasmas, processes that result from a variety of physically different wave-particle interactions. Because measuring ELF/VLF waves from multiple sites provides a powerful tool for remote observations of magnetosphere processes, we maintain a system at Amundsen–Scott South Pole Station that measures magnetospheric ELF/VLF phenomena. Data from this system are correlated with data from the automatic geophysical observatory system. During the 1997–1998 austral summer, our objectives are:

- to conduct ELF & VLF recording at magnetospheric cusp
- to correlate with the automatic geophysical observatory (AGO) project
- to support the University of Maryland narrowband VLF recording. (S-108)

South Pole Air Shower Experiment 2. *Thomas Gaisser, University of Delaware.* The South Pole Air Shower Experiment 2 (SPASE-2) consists of a sparsely filled array of scintillation detectors covering several thousand square meters at South Pole. It detects energetic charged particles (mostly electrons), which are produced in the upper atmosphere by cosmic rays. The experiment has several goals, the most important of which is to determine the elemental composition of the primary cosmic rays at energies above approximately 100 teraelectronvolts. To do this, SPASE-2 works in conjunction with the Antarctic Muon and Neutrino Detector Array (AMANDA), which has several hundred optical detectors so deep in the ice sheet that the only products of the cosmic ray interactions that can be seen by AMANDA are muons. The ratio of muons to electrons produced in a cosmic ray shower is a sensitive function of the mass of the original primary cosmic ray. Because SPASE can measure the number of electrons produced by a cosmic ray as well as its total energy and because AMANDA can determine the number of muons, the mass of an incident primary cosmic ray can be determined. The determination of the elemental composition of cosmic rays is one of the most important outstanding questions in cosmic ray physics, and such information will shed light on the origin of energetic cosmic rays. This project is cooperative with the University of Leeds in the United Kingdom. (S-109D)

High-latitude antarctic neutral mesospheric and thermospheric dynamics and thermodynamics. *Gonzalo Hernandez, University of Washington.* It is possible to deduce the temperature and wind speed of the atmosphere by measuring the emission spectra of certain trace gasses, especially the spectra of those that are confined to fairly narrow altitude regions. This project uses a Fabry-Perot infrared interferometer located at Amundsen-Scott South Pole Station, Antarctica, to look at the band spectra of several trace species, most importantly the hydroxyl radical (OH), in orthogonal directions. By determining the doppler shift of the lines, researchers can measure the winds. The brightness and line ratios within the bands provide density and temperature information. The OH in the atmosphere is primarily found in a narrow band near 90 kilometers altitude. The fact

that the measurements are being made at the axis of rotation of Earth significantly limits the types of planetary waves, thus simplifying the study of the large-scale dynamics of the atmosphere. (S-110)

Riometry in Antarctica and conjugate regions. *Theodore Rosenberg, University of Maryland*. We will use imaging and broadbeam riometers and auroral photometers to study the processes of energy transfer from the solar wind to Earth's magnetosphere and ionosphere at high geomagnetic latitudes. The emphasis will be on understanding the ionospheric signatures of dayside auroral phenomena associated with particle entry into the cusp and boundary layers, as well as the nightside substorm effects associated with the magnetotail and plasma sheet. Three imaging riometers, located at Amundsen–Scott South Pole Station (Antarctica), Sondre Stromfjord (Greenland), and Iqaluit (Northwest Territories, Canada, the magnetic conjugate to the South Pole) will provide continuous, simultaneous, conjugate measurements of polar auroral phenomena. All of the above data sets will also be used in conjunction with data obtained by automatic geophysical observatories. (S-111)

Correlative medium-frequency radar studies of large-scale middle atmospheric dynamics in the Antarctic. *David C. Fritts and Ben B. Balsley, University of Colorado at Boulder*. Using two medium-frequency radars, we will measure the dynamics of the mesosphere and lower thermosphere at high time and spatial resolution (2 minutes and 2 kilometers). The first of these systems was installed at McMurdo Station in January 1996; the second is planned for installation at the British base of Rothera (67.5°S) during January and February 1997. Using these instruments, we will be able to study in detail large- and small-scale motion fields and their latitudinal and temporal variability. When the results of these data are compared with similar products from Northern Hemisphere radars, we expect to be able to study interhemispheric differences in the behavior of the mesosphere and lower thermosphere, which preliminary studies indicate are quite substantial. (S-113)

Astrophysical gamma-ray spectroscopy with the high resolution gamma-ray and hard x-ray spectrometer (HIREGS) on long-duration balloon flights. *Robert P. Lin, University of California, Berkeley.* Our objectives are as:

- to determine the conditions for positron annihilation (511 keV) line radiation from the galactic center region,
- to study ^{26}Al line emission and search for ^{44}Tl emission from galactic nucleosynthesis, and
- to study transient positron annihilation radiation, both direct and indirect and compton-scattered, from black-hole sources in the galactic center region. (S-116)

All-sky-camera measurements of the *aurora australis* from Amundsen–Scott South Pole Station. *Masaki Ejiri, National Institute of Polar Research, Japan.* Amundsen–Scott South Pole Station, located at the south geographic pole, is a unique platform from which to undertake measurements of the polar ionosphere. Because of the configuration of the geomagnetic field in the Southern Hemisphere, the station is situated in such a way that dayside auroras can be viewed for several hours each day. Research has shown that they are caused by precipitation of low-energy particles, which enter the magnetosphere by means of the solar wind. Since 1965, data have been acquired at the South Pole using a film-based, all-sky-camera system. Using advanced technology, we can now digitize photographic images and process large amounts of information automatically. Besides continuing to acquire 35-millimeter photographic images with all-sky-camera system, U.S. and Japanese researchers will collaborate and use an all-sky-camera processing system developed at Japan's National Institute of Polar Research to analyze data. This system displays data in a geophysical coordinate framework and analyzes images over short and long intervals not possible with individual photographic images. The data will be used to investigate dayside auroral structure, nightside substorm effects, and polar-cap arcs. These studies can also be used to obtain further insight into the physics of the magnetosphere, the convection of plasma in the polar cap, and solar winds in the thermosphere. (S-117)

Solar and heliosphere studies with antarctic cosmic-ray observations. *John Bieber, University of Delaware*. Neutron monitors in Antarctica provide a vital three-dimensional perspective on the anisotropic flux of cosmic rays that continuously bombards Earth. At McMurdo and Amundsen–Scott South Pole Stations, year-round observations will continue for cosmic rays with energies in excess of 1 billion electronvolts. These data will advance our understanding of a variety of fundamental plasma processes occurring on the Sun and in interplanetary space. Neutron-monitor records, which began in 1960 at McMurdo Station and 1964 at South Pole Station, will play a crucial role in efforts to understand the nature and causes of cosmic-ray and solar-

terrestrial variations occurring over the 11-year sunspot cycle, the 22-year Hale cycle, and even longer time scales. At the other extreme, we will use new methods to study high time-resolution (10-second) cosmic-ray data to determine the three-dimensional structure of turbulence in space and to understand the mechanism by which energetic charged particles scatter in this turbulence. (S-120)

RICE—Radio Ice Cherenkov Experiment. *David Besson, University of Kansas.* Electromagnetic radiation (e.g., light, x-rays, gamma rays) cannot escape from inside the most active regions of the Universe, for instance from the nuclei of galaxies, nor can the highest energy gamma rays even propagate through intergalactic space because they will be absorbed by the cosmic background infrared photons. Neutrinos, however, can traverse a considerable amount of material unimpeded, and if they can be detected in such a way that their arrival direction and energy can be determined, they can be used to study high-density regions and highest energy events of the cosmos. When an electron-type neutrino does interact in a dielectric medium (such as the deep glacial ice beneath South Pole), it will produce a shower of electrons and positrons that will cause the energy of the original neutrino to radiate rapidly away as electromagnetic radiation. The probability of such interactions increases with increasing energy, so that a detector's sensitivity increases with energy. Thus, a modest sized (by neutrino detector standards) instrumented volume of ice, say a 100-meter cube, could have an effective volume of a cubic kilometer, a size which is deemed necessary to do astronomy. This project is a pilot to determine the feasibility of the radio detection of neutrino interactions in ice. (S-123)

Rayleigh and sodium lidar studies of the troposphere, stratosphere, and mesosphere at the Amundsen-Scott South Pole Station. *Jim Abshire, National Aeronautics and Space Administration, Goddard Space Flight Center.* The automated geophysical observatory (AGO) lidar is an ongoing, National Aeronautics and Space Administration (NASA) funded project to develop and demonstrate a compact, low-power, and autonomous atmospheric lidar for operation in the U.S. Antarctic Program's AGOs deployed to various locations in Antarctica. The primary science mission of AGO lidar is detecting, monitoring, and profiling polar stratospheric clouds (PSCs). These clouds form in the extremely cold polar stratosphere during the austral winter, and a particular type of PSC (type 1) has been implicated in the annual springtime destruction of stratospheric ozone. A secondary science mission is long-term continuous monitoring of atmospheric transmission and backscatter from the surface. These data will be compiled into a database that will provide statistics on atmospheric conditions for the Geoscience Laser Altimeter System (GLAS).

The first AGO lidar is scheduled to be deployed to AGO P1 by the AGO servicing crew in November 1997. This instrument will have redundant laser diode transmitters operating at 670 nanometers, producing 500 milliwatt peak power pulses, at 1- or 4-microsecond pulse lengths, and a pulse-repetition frequency of 4 kilohertz. The backscattered laser light will be collected by a 20-centimeter diameter telescope and detected by all-solid-state single-photon counting modules in a cross-polarized detection scheme. Type 1 PSCs will depolarize incident radiation. Because the laser transmitters in AGO lidar produce highly linearly polarized light, we expect to see a depolarization signal (up to several percent) in the backscattered light.

The lidar data will be archived in the lidar instruments' own flash memory as well as the optical drive provided by the AGO platform. The AGO lidar will also contain its own Argos transmitter, which will telemeter at least one atmospheric profile per day back to NASA's Goddard Space Flight Center in Greenbelt, Maryland. (S-126)

Rayleigh and sodium lidar studies of the troposphere, stratosphere, and mesosphere at the Amundsen-Scott South Pole Station. *George Papen, University of Illinois.* During the 1997-1998 field season, this project will continue the operation of a sodium resonance lidar at the South Pole to study the vertical structure and dynamics of the atmosphere from the lower stratosphere to the mesopause. During this third year of the project, an iron resonance lidar will be added and will extend the measurements of the dynamics and temperature structure to 100 kilometers altitude. Additionally, an airglow imaging camera will be used to study the horizontal structure. When used in conjunction with the normal balloon-borne radio sondes, which are flown regularly from South Pole, the final complement of instruments will provide extensive data on

- the temperature structure from the surface to 100 kilometers altitude;
- the nature of the polar stratospheric clouds, which are important to ozone chemistry;
- the variability and frequency of occurrence of

metallic layers in the mesosphere, which play a role in communications as well as chemistry;

- atmospheric gravity waves; and
- many other phenomena, some of which are unique to the South Pole. (S-127)

High-latitude electromagnetic wave studies using antarctic automatic geophysical observatories. *James LaBelle, Dartmouth College.* At radio frequencies between 0.05 and 5.0 megahertz (MHz), three types of radio phenomena related auroral origin can be detected: narrowband near 2.8 and 4.2 MHz, broadband noise bursts in the frequency range of 1.4–4.0 MHz, and broadband noise at frequencies below 1 MHz. An accepted physical theory explains the third type, called "auroral hiss," but the origin of the other two types is unknown. Although these radio emissions constitute a small fraction of the total energy of the aurora, they may provide important clues to the more energetic processes, analogous to the way in which solar radio emissions are used to infer the processes taking place in the solar corona. Using LF/MF/HF receivers, we hope to collect further clues about these emissions from antarctic auroral zone and polar cap sites, taking advantage of radio-quiet antarctic conditions. The receivers will be installed at Amundsen-Scott South Pole Station, in three U.S. automatic geophysical observatories, and in two British automatic geophysical observatories.(S-128)

Spectroscopic and interferometric studies of middle atmosphere dynamics and particle precipitation patterns over the South Pole. *Gulamabas Sivjee, Embry-Riddle Aeronautical University.* An infrared spectrophotometer, an eight-channel photon-counting photometer, and an infrared Michelson interferometer are maintained by this project at the South Pole to study the dynamics and chemistry of the upper atmosphere. By measuring the variations in the brightness and temperature of airglow band emissions, researchers can detect planetary, gravity, and tidal waves. Studying the horizontal wave structures by looking in several directions while making these measurements at several wavelengths, which come from different heights in the atmosphere, provides information on the vertical extent of the wave activity. Additionally, viewing the different altitude auroral emissions with the spectrophotometer provides insight into the nature of the sources of the auroral precipitating electrons and how these different sources vary as a function of time. (S-129)

The antarctic muon and neutrino detector array (AMANDA) project: The antarctic ice sheet as a high-energy detector. *Robert M. Morse, University of Wisconsin at Madison.* The primary objective of AMANDA is to discover sources of very-high-energy neutrinos from galactic and extragalactic sources. These neutrinos could be of diffuse origin coming from the contributions of many active galactic nuclei or point sources coming from super-nova remnants, rapidly rotating pulsars, neutron stars, and individual blazars or other extragalactic point sources. AMANDA consists of photomultiplier tubes imbedded at depths between 1 and 2 kilometers in glacial ice near the South Pole. This array uses natural ice as a Cherenkov detector for high-energy neutrinos of astrophysical origin that have passed through Earth. Recently, new sources of high-energy gamma rays have been discovered, such as the source Mrk-421 discovered by the CGRO and the Mount Hopkins Observatory. These sources, also believed to be copious emitters of high-energy neutrinos, are the type of objects that AMANDA has been designed to study.

To date, neutrino astronomy has been limited to the detection of solar neutrinos and one brief burst from the supernova that appeared in the Large Magellanic cloud in February 1987 (SN-1987a). Only now is building large neutrino telescopes becoming technically feasible, and as one of the first generation detectors, AMANDA promises to be a large contributor to this new branch of neutrino astronomy. The AMANDA project includes plans to install seven additional detector strings to complement the four strings that are already in place at depths of 1,500–1,900 meters. These strings, installed during the 1996–1997 season, will be positioned at a depth of 2,000 meters in the ice, and will each contain 36 photomultiplier tubes modules. The 2-kilometer-deep holes in the ice will be drilled by the Polar Ice Coring Office. (S-130)

Center for Astrophysical Research in Antarctica. *Doyal A. Harper, University of Chicago.* Infrared and submillimeter astronomy has the potential for answering major questions about the formation of the Universe:

- What are the processes by which stars form from interstellar gas?
- How did the planets form?
- What was the nature of primeval galaxies?
- How was matter and energy distributed in the early Universe?

Because of the cold temperatures and the near absence of water vapor in the atmosphere above the polar plateau, the infrared skies are consistently clearer and darker in Antarctica than anywhere else on Earth. These conditions enable researchers to make measurements that would be extremely difficult or impossible from other sites. To capitalize on these advantages, the University of Chicago and several collaborating institutions have established the Center for Astrophysical Research in Antarctica (CARA), which is one of 24 Science and Technology Centers funded by the National Science Foundation. To support its scientific mission, CARA is working to establish an observatory at the South Pole and to investigate the conditions for astronomy at the South Pole and other sites on the polar plateau. Currently, CARA supports research using three major telescope facilities.

- The Astronomical Submillimeter Telescope/ Remote Observatory (AST/RO) project uses a 1.7-meter-diameter telescope to conduct surveys of atomic and molecular line emission from interstellar gas in the galactic plane, the galactic center, and the Magellanic Clouds.
- The South Pole Infrared Explorer (SPIREX) project uses a 0.6-meter-diameter telescope to investigate the potential of the site for near-infrared astronomy and to conduct observations of distant galaxies, cool stars, and heavily obscured star-forming regions.
- The Cosmic Background Radiation Anisotropy (COBRA) project uses a 0.75-meter-diameter telescope (Python) to map the anisotropy in cosmic microwave background radiation at sufficient sensitivity to test current theories of the origin of the Universe.

In addition to projects using these three telescopes, the Center has undertaken the Advanced Telescopes Project to collect data on the quality of polar plateau sites for astronomical observations and to plan for future telescopes and facilities.

Projects included as part of CARA are

- CARA-wide operations and activities (S-132A),
- the AST/RO project (S-132B)
- the SPIREX project (S-132C)
- the Advanced Telescopes Project (S-132E)
- activities of the COBRA project related to preparation for deployment of the Viper telescope, a new, 2-meter class telescope that will extend the observations now being made with the 0.75-meter Python telescope to structures in the cosmic microwave background having smaller angular scales (S-132F).

Besides making measurements of "seeing" quality using the SPIREX telescope, the Advanced Telescopes Project also supports a number of other efforts including wide-field cameras, a near-infrared sky brightness monitor (in collaboration with the University of New South Wales), and an instrument for monitoring mid-infrared sky brightness and transmission (in collaboration with the National Aeronautic and Space Administration's Goddard Space Flight Center). (S-132)

Cosmology from Dome C in Antarctica. *Lucio Piccirillo, Bartol Research Institute, University of Delaware.* The thermal cosmic microwave background radiation (CMBR), left over from the Big Bang, carries the only available information about the distribution of matter in the very early universe. Generally, scientists believe that galaxies and other structures arose from the gravitational amplification of tiny density fluctuations. Detecting high energy cosmic neutrinos represents a unique opportunity to probe the distant universe. While the trajectories of protons, because they are charged particles, are likely to bend in galactic and intergalactic magnetic fields, neutrinos point directly back to their source. Using an array of radio receivers buried in the ice at the South Pole, we hope to detect high energy cosmic neutrinos in order to measure the cosmic neutrino flux at high energies and to determine sources of such a flux. During our first field season we will deploy a small number of dipole receivers and transmitters to measure ice properties and develop the technology needed for the efforts to follow. When completed our array will be complementary to the Antarctic Muon and Neutrino Detector Array (AMANDA). Both use antarctic ice to reconstruct the incident direction and energy of a cosmic neutrino, but AMANDA relies on phototube technology to probe the optical frequency range while our array will be tuned to radio frequencies. (S-140)

Long-duration ballooning—Launch and telemetry support. *Steven Peterzen, National Scientific Balloon Facility.* Wholly funded by the National Aeronautic and Space Administration, the National Scientific Balloon Facility (NSBF) is operated under contract by New Mexico States' Physical Science Laboratory. The effort in Antarctica, known as the Long-Duration Balloon Program, launches high-altitude

balloons carrying scientific payloads into the stratosphere. These large helium-filled balloons (804,199 cubic meters) circumnavigate the continent between 3 and 4 millibars for up to 24 days. For each circumpolar flight, NSBF performs the launch operations, designs and manages the telemetry links, and then terminates and recovers the flight system. (S-145)

Infrared measurements in the Antarctic. *Frank J. Murcray, Ronald Blatherwick, and Aaron Goldman, University of Denver.* For this project, we will use an infrared (IR) interferometer to monitor selected trace constituents in the atmosphere above Amundsen–Scott South Pole and McMurdo Stations. The measurements will be made in two modes: absorption and emission. The absorption mode uses the Sun, shining through the atmosphere, as an infrared source of IR radiation and allows us to measure a number of trace constituents, especially during the local springtime when the antarctic ozone hole is forming. The emission mode, using radiation emitted by the atmospheric gases themselves, is less sensitive than the absorption mode but does allow critical measurements during the long, dark polar night, when the chemistry that sets the stage for the springtime ozone depletion is taking place. The compounds we will measure include hydrogen chloride, nitric acid, chlorofluorocarbon-11 and -12, nitrous oxide, methane, ozone, and chlorine nitrate. Each of these gases plays a role in ozone depletion, and several are also important greenhouse gases. This project is a precursor to the establishment of an antarctic Network for the Detection of Stratospheric Change (NDSC) station. When the NDSC station is established (presumably at Dome C), we will extend our project to this site and begin making similar measurements there. This project is jointly funded by the National Science Foundation's Office of Polar Programs and Division of Atmospheric Sciences and also by the National Aeronautic and Space Administration's Office of Earth Sciences and Applications. (S-148)