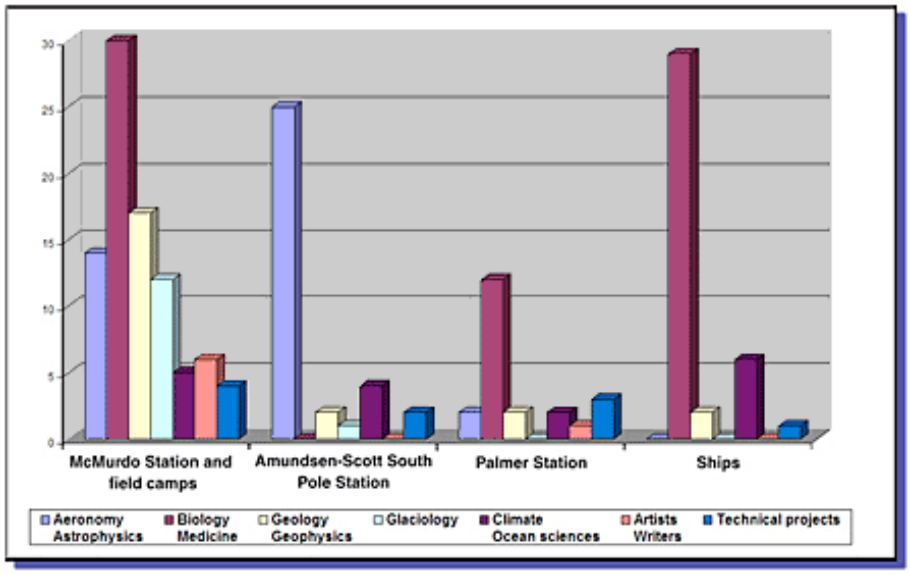
National Science Foundation
WHERE DISCOVERIES BEGIN

U.S. ANTARCTIC PROGRAM, 2005–2006

As part of the U.S. Antarctic Program, more than 800 researchers and special participants will conduct 165 projects during the 2005–2006 austral summer, with some projects continuing through the austral winter. Supported by over 2,000 civilian contract employees and U.S. military personnel, these researchers and special participants (writers, artists, and teachers) will work at the three year-round U.S. stations (McMurdo, Amundsen–Scott South Pole, and Palmer), at remote field camps, with other national antarctic programs at locations around Antarctica, and in the waters of the Southern Ocean aboard the U.S. Antarctic Program's two research ships—Nathaniel B. Palmer and Laurence M. Gould. These projects, funded and managed by the National Science Foundation (NSF), are part of the international effort to understand the Antarctic and its role in global processes. NSF supports research that can best be performed or can only be performed in Antarctica. The scientists conducting these projects come primarily from U.S. universities and have won NSF support by responding to the Antarctic Research Program solicitation (NSF 05–567; http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf05567&org=NSF). Operational resources in Antarctica are also used to support scientists from other Federal agencies.

The flags of the original 12 signatory nations of the Antarctic Treaty fly next to a bust of Admiral Richard Byrd at McMurdo Station. (*NSF/USAP photo by Rob jones*)

U.S. Antarctic Program Science Projects by Discipline and Research Site



During the 2005–2006 austral summer, 88 projects will be based at McMurdo Station or at remote field sites, 38 will be supported on research ships, 34 will operate at Amundsen–Scott South Pole Station, and 22 will do work in and around Palmer Station.

Science highlights

The following projects are among those supported during this austral summer and winter. Where appropriate, links for additional information have been added. NSF-funded science awards can also be found in the online NSF awards database. To access this information, search the database at http://www.nsf.gov/awardsearch/. Each NSF award listed here, as well as in the other sections of this document, includes the award number, which can be used to do a keyword search.

Biology and medicine

- **International Graduate Training in Antarctic Biology.** This month-long NSF-sponsored international course will be held at McMurdo Station, starting in January 2006. Up to 20 graduate students, postdoctoral fellows, and other research scientists interested in studying extreme environments and the biology of antarctic organisms will participate. The course emphasizes integrative biology, with laboratory- and field-based projects focused on adaptations in an extreme polar environment. A diverse teaching faculty will offer students the chance to work on a wide range of antarctic organisms (bacteria, algae,

invertebrates, and fish) and at several levels of biological analysis (molecular biology, physiological ecology, species diversity, and evolution). (NSF/OPP 05–04072; http://antarctica.usc.edu/)

- **Weddell seal population dynamics.** The Weddell seals that live in McMurdo Sound have been studied since 1968 in one of the longest intensive field investigations of long-lived mammals anywhere. More than 15,000 animals have been tagged, and 145,000 resightings have been recorded. This project is a resource for understanding the population dynamics not only of Weddell seals, but also of other species of terrestrial and marine mammals. New work this season includes assessing the role of food resources in limiting the population. (NSF/OPP 02–25110; www.homepage.montana.edu/~rgarrott/index.htm)

- **Genomic study of invertebrates.** Cold-ocean ecosystems constitute 72 percent of the Earth's biosphere by volume, yet they are sparsely inhabited and relatively unexploited. Environmental adaptations of the few animals that manage to exist on this verge of intracellular freezing are ideal subjects for exploring at the genomic level. This project is quantifying gene expression in sea stars and sea urchins to determine whether it is more or less difficult for an organism to grow in a polar extreme. To interest students in the developing field of environmental genomics, the project has an internship program for minority students and a K–12 education program. (NSF/OPP 02–38281; http://marsh.cms.udel.edu/~amarsh)

Ocean and climate systems

- **Maud Rise Nonlinear Equation-of-State Study.** When layers of sea water with similar densities but strong contrasts in temperature and salinity interact, a number of possible nonlinear instabilities can convert existing potential energy into turbulent energy. In the Weddell Sea, a cold surface mixed layer is often separated from the underlying warmer, more saline water by a thin, weak pycnocline (a layer of water where density changes rapidly with depth due to changes in temperature or salinity), making the water column particularly susceptible to an instability associated with thermobaricity (the process by which the thermal expansion coefficient increases with depth). The project is a collaboration between New York University, Earth and Space Research, the University of Washington, the Naval Postgraduate School, and McPhee Research Company. The investigation will contribute to understanding the Weddell Polynya, a 300,000-square-kilometer area of open water that existed within the seasonal sea ice of the Weddell Sea from approximately 1975 to 1979. This polynya has not recurred, although indications of much smaller and less persistent areas of open water do occur in the vicinity of the Maud Rise seamount. (NSF/OPP 03–37159; www.oc.nps.navy.mil/~stanton/thermo/Maudness/MaudnessMainHome.html)

- **Surface carbon dioxide in the Drake Passage.** The Southern Ocean is an important part of the global carbon budget, and the Drake Passage is the narrowest place through which the Antarctic Circumpolar Current goes. This chokepoint is an efficient site to measure the latitudinal gradients of gas exchange, and the ice-strengthened research ship Laurence M. Gould will support a project to measure dissolved and total carbon dioxide, providing data that, together with satellite images, will enable estimates of the net production and export of carbon by oceanic biota. (NSF/OPP 03–38248; www.ldeo.columbia.edu/res/pi/CO2)

Aeronomy and astrophysics

- **Infrared measurement of the atmosphere.** Winter measurements of atmospheric chemistry are providing data for predicting ozone depletion and climate change. Since most satellites do not sample the polar regions in winter, these ground-based measurements are expected to make an important contribution. (NSF/OPP 02–30370)

- **A 10-meter telescope for South Pole Station—South Pole observations to test cosmological models.** Much of the mass in the Universe is made up of dark matter, which emits little or no light or other electromagnetic radiation and makes its presence known only through the gravitational force it exerts on luminous matter. The University of Chicago will lead a consortium of six institutions to design and operate a 10-meter off-axis telescope located at Amundsen–Scott South Pole Station to survey galaxy clusters. Such a survey will allow them to study integrated cluster abundance and its red shift evolution and will give precise cosmological constraints, completely independent of those from supernova distance and cosmic microwave background anisotropy measurements. A foundation was built for the new telescope at the South Pole during the 2004–2005 austral summer. Construction of the support facility for the telescope will continue during this austral summer. (NSF/OPP 01–30612)

- **IceCube.** Work will continue on the world's largest neutrino detector, which—after 6 years of work—will occupy a cubic kilometer of ice beneath South Pole Station. The detector will deploy 4,800 photomultiplier tubes into holes created in the ice by a hot water drill. Neutrinos are special but hard to detect astronomical messengers that can carry information from violent cosmological events at the edge of the Universe or from the heart of black holes. The history of astronomy indicates that work in new energy regions has invariably led to the discovery of unexpected phenomena. By peering through a new window on the universe, IceCube could open new frontiers of understanding. During the 2005–2006 austral summer, participants will drill 10 ice holes and deploy 10 IceCube strings and 20 Ice-Top tanks. (NSF/OPP 03–31873; http://icecube.wisc.edu/)

- **Cosmic microwave background (CMB) polarization measurements.** The combined QUEST/DASI (or QUaD), a major upgrade to the DASI (degree angular scale interferometer) telescope, is a bolometric array receiver that is being used to search for polarization in the CMB. The spatial distribution of polarization contains important information about cosmological parameters and about the origin of temperature anisotropies (variations) in the CMB. Although the signal is tiny (1 to 10% of the temperature fluctuations), the scientific rewards are great. A measurement of polarization has the potential to distinguish between inflationary models by measuring the amount of primordial gravitational waves that are a relic of the inflationary epoch. The South Pole site for QUaD offers the advantages of altitude and cold that lead to little overhead water vapor, atmospheric stability that allows long observation periods, the ability to perform observations of the same areas of the sky throughout the year, and limited interference by the Sun and Moon. (NSF/OPP 03–38138, NSF/OPP 03–38238, and NSF/OPP 03–38335; http://astro.uchicago.edu/dasi and www.stanford.edu/~schurch/quad.html)

Glaciology

- **West Antarctic Ice Sheet divide.** This 5-year science program, involving a dozen research teams, will develop a detailed record of greenhouse gases for the past 100,000 years, determine whether changes in the Northern and Southern Hemispheres initiated climate changes over the past 100,000 years, investigate past and future changes in the West Antarctic Ice Sheet, and study the biology of deep ice. During the 2005–2006 austral summer, the camp infrastructure for the drilling program will be assembled at a site on the West Antarctic Ice Sheet divide. Construction crews will establish a skiway and a camp capable of supporting the science and drilling teams (approximately 45 people) that will collect a 3,400-meter ice core

to bedrock. A 200-foot steel arch will be constructed to house the drilling and core processing facilities for this deep drilling project. (NSF 04–40817; NSF/OPP 04–40759, NSF/OPP 04–40498, NSF/OPP 04–40509, NSF/OPP 04–40602, NSF/OPP 04–40615, and NSF/OPP 04–40701; http://waisdivide.unh.edu/) **[WINNIE: The summary has only the first event number. Okay? Add there? I think for this season there was only one number because there wasn't any field work conducted – just camp construction. I don't think we need the even number here, though.]**

- **A mobile sensor web for Polar Ice Sheet Measurements (PRISM).** PRISM research aims to develop innovative sensors (imaging and sounding radars), supported by wireless communications, intelligent systems, robotics, and ice-sheet modeling, to image the ice-bedrock interface, measure ice thickness, and map internal layers in the ice to provide key measurements for studying the contribution of the polar ice sheets to the rise in sea level. Researchers integrate and operate the sensors from an autonomous rover and a tracked vehicle equipped with communication and navigation systems. An intelligent system determines an optimum sensor configuration for imaging the ice-bedrock interface and the operational requirements for the rover. (NSF 01–22520; http://www.ku-prism.org/)
- **Tidal influence on ice stream flow.** Ice from the West Antarctic Ice Sheet flows to the sea through a number of ice streams, but the factors controlling the flow of these streams are not well understood. Earlier work at the Whillians Ice Stream on the Siple Coast demonstrated that their flow is surprisingly sensitive to changes in the tide beneath the Ross Ice Shelf. By measuring the rise and fall of the tide, researchers hope to improve their understanding of the controls on ice streams and gain information important for modeling the ice sheet. (NSF 02–29629; www.geosc.psu.edu/~sak/Tides)

Geology and geophysics

- **Old buried ice.** Ice has covered Antarctica for millions of years, but the ice itself is not that old; most of it arrives as snow and leaves as icebergs within a few hundred thousand years. Buried ice in the McMurdo Dry Valleys is thus a rare archive of atmosphere and climate potentially extending back millions of years. This project will study the surface processes that preserve ice, test ways of dating tills above buried ice, assess ways to date buried ice, and use these data to help resolve a debate over whether the deposits are as old as some scientists think they are. (NSF 04–40711; http://people.bu.edu/marchant/themesBuriedIce2.htm)
- **ANDRILL—Investigating Antarctica's role in Cenozoic global environmental change.** ANDRILL, an international program representing over 150 scientists from Germany, Italy, New Zealand, the United Kingdom, and the United States, is focused on Antarctica's role in Cenozoic global environmental change. Over the course of the project, ANDRILL researchers will obtain a record of important Eocene, Neogene, and Holocene stratigraphic intervals in high southern latitudes to address four themes—the history of the antarctic climate and ice sheets, the evolution of polar biota, antarctic tectonism, and Antarctica's role in the Earth's ocean-climate system. During this field season, teams will collect data to identify sites in southern McMurdo Sound for drilling. Field activities include an over-ice seismic survey to collect 20 kilometers of new seismic data, a transect of sea-floor sediment samples gathered by using a grab sampler, and an over-ice gravity survey along the seismic survey line. The teams will also use two Acoustic Doppler Current Profiling devices to make oceanographic measurements and will obtain data on currents to model sea-rise behavior at the probable drilling sites. (NSF 03–42484; http://andrill.org/)
- **Shallow drilling along the antarctic continental margin (SHALDRIL)—Demonstration ocean-bottom drilling in the James Ross Basin.** Scientists exploring the shallow shelves along the margins of Antarctica have been consistently frustrated by the inability to penetrate through the overcompacted glacial diamictons found at shallow sub-bottom depths. Advanced seismic reflection techniques show that older sections of Neogene and Paleogene sequences lie just beneath this thin veneer of diamictons. Four years of testing have demonstrated that a diamond coring system can be used on the U.S. research ship Nathaniel B. Palmer for drilling along the antarctic continental margin. During this austral summer, the research team will conduct a demonstration cruise near Seymour Island on the west coast of the Antarctic Peninsula. Here, the well-defined geologic section is estimated to range in age from Eocene to Quaternary, spanning the "Greenhouse-Icehouse" transition of global climate change. If successful, the mobile drilling system will be available to the scientific community for further exploration of the continental shelves. (NSF/OPP 01–25922, NSF/OPP 01–25480, and NSF/OPP 01–25526; http://www.shaldril.rice.edu/ and and www.arf.fsu.edu/shaldril.cfm)
- **Seismograph.** The world's quietest earthquake detector lies 300 meters beneath the surface of the ice sheet 8 kilometers from the South Pole. Completed in 2002, the station is detecting vibrations four times smaller than those recorded previously. Other seismographs have been there since 1957, and long-term, high-latitude data have helped prove that the Earth's solid inner core spins faster than the rest of the planet. Also, Antarctica is the continent with the fewest earthquakes, so the new station will record small regional earthquakes, thereby leading to new insights into the Antarctic Plate. (NSF/EAR 00–04370; www.iris.washington.edu/about/GSN)

Artists and writers program

This program, which records the Nation's antarctic cultural heritage and extends understanding of the region and the U.S. Antarctic Program within the research community and beyond, will support the following eight projects.

Artist/Writer	Project Title	Event Number
Henry J. Kaiser	Shooting Video in McMurdo to Supplement a 2001 Project	04–39708
Kathleen M. Heideman	*The Scientific Method: Poems of Antarctic Inquiry*	04–40619
Joseph F. Montaigne	A Season at Palmer	04–40659
Sarah Andrews	*In Cold Pursuit* (working title)—A Science-Based Mystery Novel Set in the Antarctic	04–40665
J. Allan Campbell	Antarctica—Images from a Frozen Continent	04–40702
Gabriel P. Warren	Examination of Crevasses and Other Iceforms as Artistic Sources	04–41979
Lawrence J. Conrad and Ann Hawthorne	Field Guide to Antarctic Features: McMurdo Sound Region	no award number*
George Steinmetz	Antarctica: The Frozen Desert	no award number*

* These awards have no electronic record because they were made before proposals were submitted via FastLane to the Antarctic Artists and Writers Program.

U.S. Antarctic Program, 2005–2006: Sites of Major Activities

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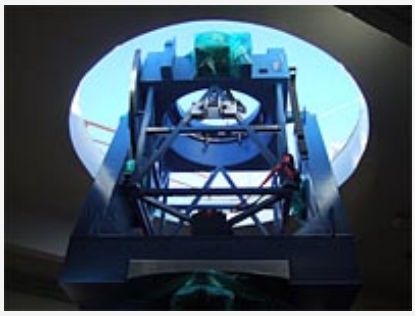
AERONOMY AND ASTROPHYSICS



The mount for the new Background Imaging Cosmic Extragalactic Polarizaiton (BICEP) telescope being installed at Amundsen-Scott South Pole Station. The BICEP telescope will measure the polarization of the cosmic microwave background (CMB) to unprecedented precision in search of answers to questions about the beginnings of the universe. (*NSF/USAP photo by Yuki Takahashi*)

In this section:

Overview

The polar regions have been called Earth's window to outer space. Originally, this term applied to dynamic events like the aurora, staged as incoming solar plasmas encountered the Earth's geomagnetic fields. Unique properties create a virtual screen of the polar

upper atmosphere on which the results of such interactions can be viewed (and through which evidence of other processes can pass). During the mid-1980s, Earth's window was extended to refer to the "ozone hole" in the polar atmosphere. As scientists have verified an annual loss of ozone in the polar stratosphere, a window previously thought closed (stratified ozone blocking the Sun's ultraviolet rays) is now known to "open," consequent to chemical cycles in the atmosphere.

For astronomers and astrophysicists, the South Pole presents unique opportunities. Thanks to a minimum of environmental pollution and anthropogenic noise, the unique pattern of light and darkness, and the properties of the geomagnetic force field, scientists staging their instruments here can probe the structure of the Sun and the Universe with unprecedented precision. Studies supported by the Antarctic Aeronomy and Astrophysics Program explore three areas of research:

- **The stratosphere and the mesosphere:** In these lower regions, current research focuses on stratospheric chemistry and aerosols, particularly those implicated in the ozone cycle.
- **The thermosphere, the ionosphere, and the magnetosphere:** These higher regions derive many characteristics from the interplay between energetically charged particles (ionized plasmas in particular) and geomagnetic/geoelectric fields. The upper atmosphere, particularly the ionosphere, is the ultimate sink of solar wind energy transported into the magnetosphere just above it. This region is energetically dynamic, with resonant wave-particle interactions and joule heating from currents driven by electric fields.
- **The galaxy and the Universe beyond, for astronomical and astrophysical studies:** Many scientific questions, including a particular interest in the Sun and cosmic rays, extend beyond the magnetosphere. Astrophysical studies are conducted primarily at Amundsen–Scott South Pole Station or on long-duration balloon flights launched from McMurdo Station. The capability of such balloons is expanding dramatically.

All research projects sponsored by this program benefit from (indeed, most require) the unique physical conditions found only in the high latitudes, yet their ramifications extend far beyond Antarctica. High-latitude astrophysical research contributes to the understanding of Antarctica's role in global environmental change, promotes the interdisciplinary study of geosphere/biosphere interactions in the middle and upper atmosphere, and improves the understanding of the critical processes of solar energy in these regions.

An example of the unique conditions that can be exploited for science is the IceCube Neutrino Observatory (under construction). This observatory relies on photo detectors buried up to 2.5 kilometers deep in the ice sheet at South Pole Station to detect high-energy neutrinos that can be used to image portions of the Universe normally obscured to light and ordinary electromagnetic radiation. Another example is the Center for Astrophysical Research in Antarctica (CARA), which was active at South Pole in the 1990s and phased out in 2001. However, the center's outstanding research activity led to the development of the 10-meter South Pole Radio Telescope, which will study cosmic microwave background radiation—the residual energy from the Big Bang—with unprecedented accuracy.

The 20th-century expansion of traditional astronomy to the science of astrophysics, coupled with the emerging discipline of atmospheric science (see also the Antarctic Ocean and Climate Systems Program), is nowhere better exemplified than in Antarctica.

Background imaging of cosmic extragalactic polarization (BICEP).

Andrew E. Lange and James J. Bock, California Institute of Technology; William L. Holzapfel, University of California–Berkeley; and Brian G. Keating, University of California–San Diego.

The cosmic microwave background (CMB) provides three strong but circumstantial pieces of evidence that the visible Universe was created by the superluminal inflation of a tiny volume of space: namely,

- the near isotropy (homogeneity) of the horizon,
- the flatness of space, and
- the phase-synchronicity of acoustic oscillations in the early Universe.

To better understand the origins of the Universe, we must probe this epoch of inflation directly. The most promising probe is the unique signature that the gravity wave background (GWB) imprints on the polarization of the CMB. The amplitude of this signature depends on the energy-scale of inflation.

Detection will require only modest angular resolution (about 1 degree), but long integration (about a year) on a restricted and contiguous patch of sky. The 6-month night, the extremely dry and stable weather, and the precise rotation of the sky about the zenith make South Pole Station the ideal terrestrial site for this ambitious project. A CMB polarimeter (BICEP) uniquely capable of detecting the signature of the GWB was deployed and commissioned during 2004–2005. After BICEP was unpacked and prepared for initial cooldown, the optical loading, bandpass, and noise characteristics of the detector array and modulation systems were tested under realistic conditions. The next steps will be erecting the groundshield, refining the pointing model of the mount, and mapping the beams of the 96 detectors before testing on galactic sources and dark fields begins.

BICEP operates simultaneously at 100 and 150 gigahertz (GHz) to both minimize and recognize confusion from polarized astrophysical foregrounds. At these frequencies, a modest (and thus relatively easy to deploy and maintain) 20-centimeter primary aperture will provide a resolution of 1 degree at 100 GHz and 0.7 of a degree at 150 GHz.

By combining a new polarization-sensitive bolometric detector technology developed for the European Space Agency's Planck satellite (to be launched in 2007) with four independent levels of signal differencing and a carefully optimized observing strategy, BICEP will reach the current limit on CMB polarization in the first hour of integration, reach the sensitivity of Planck over 1 percent of the sky in the first week, and precisely measure CMB polarization on the critical angular scales of 1 degree to 10 degrees.

Observational cosmology is enjoying a renaissance that has captured the public imagination and serves as one of the most effective vehicles for stimulating interest in science in general. Detecting the signature of the GWB in the CMB would represent a triumph of fundamental physics and cosmology that would revolutionize our understanding of the origins of the Universe. (A–033–S; NSF/OPP 02–30438)

The operation of an extremely-low-frequency/very-low-frequency

(ELF/VLF) radiometer at Arrival Heights, Antarctica.

Antony C. Fraser-Smith, Stanford University.

Since it was discovered in the 1930s that natural phenomena emit the lowest form of electromagnetic energy (radio waves), the field of radio astronomy has joined the effort to analyze both atmospheric and extraterrestrial signals. The extremely-low-frequency and very-low-frequency (ELF/VLF) record of data collected at Arrival Heights, Ross Island, Antarctica—chosen because it is unusually free from human electromagnetic interference—now extends unbroken since the austral summer of 1984–1985. An identical system has been operating at Stanford University for almost the same period, thus providing a mid-latitude comparison data set.

Because the Arrival Heights radiometer has been operating for so many years, studies of longer-term variations can now be done. The data also help improve the statistical reliability of shorter-term variations. The difficulty of making long-term observations, particularly at remote locations, means that the Arrival Heights measurements increase in scientific value as the radiometer continues to operate.

Since the predominant source of ELF/VLF radio noise is thunderstorms occurring in the tropics, the Arrival Heights and Stanford systems provide alternate views of this activity. If thunderstorm activity depends on the temperature of the tropical atmosphere, as has been argued, the long-term statistical measurements of ELF/VLF radio noise made by the Arrival Heights and Stanford systems can provide independent information about global warming. Moreover, our radiometer measurements supplement those made by automatic geophysical observatories.

Because of its remote location, Arrival Heights has such a low background noise level that important new measurements are being made on weak ELF signals. The Schumann resonances, for example, which are so weak that observation is severely affected by the noise usually encountered in developed areas, are easily measured at Arrival Heights.

Since the 2001–2002 austral summer, our program has provided new information on the long-term variations in the noise at various frequencies throughout the ELF/VLF range, while at the same time providing an opportunity for more detailed studies of phenomena such as the Schumann resonances and the propagation of ELF radio waves from the few human sources around the world. There is also a possibility that the longer-term observations will prove useful in studies of global change. (A–100–M; NSF/OPP 01–38126)

Conjugate studies of ultra-long-frequency (ULF) waves and magnetospheric dynamics using ground-based induction magnetometers at four high-latitude manned sites.

Mark J. Engebretson, Augsburg College, and Marc R. Lessard, University of New Hampshire.

The Earth's magnetic field arises from its mass and motion around the polar axis, but it creates a powerful phenomenon at the edge of space known as the magnetosphere, which has been described as a comet-shaped cavity or bubble around the Earth, carved in the solar wind. When that supersonic flow of plasma emanating from the Sun encounters the magnetosphere, the result is a long cylindrical cavity, flowing on the lee side of the Earth, fronted by the blunt nose of the planet itself. With the solar wind coming at supersonic speed, this collision produces a "bow shock" several Earth radii in front of the magnetosphere proper.

One result of this process is fluctuations in the Earth's magnetic field, called micropulsations, which can be measured on time scales between 0.1 second and 1,000 seconds. It is known that magnetic variations can significantly affect power grids and pipelines. We plan to use magnetometers (distributed at high latitudes in both the antarctic and arctic regions) to learn more about how variations in the solar wind can affect the Earth and anthropogenic systems.

We will study these solar-wind-driven variations and patterns at a variety of locations and over periods up to a complete solar cycle. Since satellite systems are now continuously observing solar activity and also monitoring the solar wind, it is becoming feasible to develop models to predict the disruptions caused by such magnetic anomalies. And while our work is geared specifically toward a better understanding of the world and the behavior of its anthropogenic systems, it will also involve space weather prediction. (A–102–M/S; NSF/OPP 02–33169)

A search for extrasolar planets from the South Pole.

Douglas A. Caldwell, Laurance R. Doyle, and William Borucki, SETI Institute, and Zoran Ninkov, Pixel Physics, Inc.

We will operate a small optical telescope at the South Pole to search for and characterize extrasolar planets by continuously following a southern galactic star field with a charge-coupled device photometer and searching for the periodic dimming that occurs as a planet transits its parent star.

The recent discovery of many close-in giant exoplanets has expanded our knowledge of other planetary systems and has demonstrated how different such systems can be from the solar system. However, their discovery poses important questions about the effects of such planets on the presence of habitable planets. To date, only one extrasolar planet—HD 209458b—has been observed to transit a parent star. This project has the potential for a 10-fold increase in the number of extrasolar planets for which transits are observed. The South Pole is an excellent location for detecting such planets because randomly phased transits can most efficiently be detected during the long winter night. Also, the constant altitude of a stellar field at the pole avoids large daily atmospheric extinction variations and allows for higher photometric precision and a search for smaller planets.

Specifically, we will establish an automated planet-finding photometer at the South Pole for two austral winters. The statistics of planetary systems of nearby solar-type stars would indicate that about 10 to 15 extrasolar planets should be detected. There is also the possibility of finding planets that have a lower mass and have not previously been detectable. Combining the transit results (which give the size of the planet) with Doppler velocity measurements (which give the mass) will allow the planetary density to be determined, thus indicating whether the planet is a gas giant like Jupiter, an ice giant like Uranus, or a rocky planet like the Earth. These data will provide basic observational information that is vital to theoretical models of planetary structure and formation. (A–103–S; NSF/OPP 01–26313)

Dayside auroral imaging at South Pole.

Stephen B. Mende and Harald Frey, University of California–Berkeley.

We plan to operate two ground-based imagers at South Pole Station and combine their observations with simultaneous global auroral observations by the IMAGE (Imager for Magnetopause to Aurora Global Exploration) spacecraft investigating temporal and spatial effects in the ionosphere from the reconnection processes at the magnetopause. The South Pole has advantages for auroral imaging because the continuous darkness during the winter allows 24 hours of optical observations and because the ideal magnetic latitude permits observation of the dayside aurora. The reconnection (merging) region of the magnetosphere provides the most significant entry point for solar wind plasma. It is now widely accepted that the dayside region contains the footprint of field lines that participate in reconnection processes with the interplanetary field.

Although a body of literature about the auroral footprints of the dayside reconnection region has been derived from ground-based observations, it has not been possible to relate those results to simultaneous global auroral images. Global observations of proton auroras from the IMAGE spacecraft have provided direct images of the footprint of the reconnection region, showing that reconnection occurs continuously and that the spatial distribution of the precipitation follows theoretically predicted behavior as a function of the interplanetary field. The apogee of the IMAGE spacecraft orbit is slowly drifting south, and during the austral winter of 2004, the apogee was over the Southern Hemisphere. Thus, it was possible to obtain simultaneous global images of the aurora by IMAGE and of the high-latitude dayside region by two ground-based imagers (electron and proton auroras) at South Pole Station.

Our main goal is to capitalize on this unique opportunity by using the IMAGE satellite as the telescope and the ground-based imagers as the microscope for these observations in an attempt to better understand substorms and related phenomena. Understanding the Earth's electromagnetic environment is key to predicting space weather and to determining how geoactive magnetic storms are. We will continue to involve students in every phase of the program, thereby encouraging some of them to start a career in upper-atmospheric research. (A–104–S; NSF/OPP 02–30428)

A very-low-frequency (VLF) beacon transmitter at South Pole.

Umran S. Inan, Stanford University.

This 3-year project to establish and operate a very-low-frequency (VLF) beacon transmitter at the South Pole will measure solar effects on the Earth's mesosphere and lower ionosphere. Relativistic electrons, measured at geosynchronous orbit to have energies of more than 300 kiloelectronvolts, appear to fluctuate in response to substorm and solar activity. During such events, these highly energetic electrons can penetrate as low as 30 to 40 kilometers above the Earth's surface. At that altitude, they can wreak havoc in the atmosphere; they ionize chemical species, create x rays, and may even influence the chemistry that produces ozone.

By comparing how the South Pole VLF signal varies in both amplitude and phase when it arrives at various antarctic stations, we can calculate the extent of relativistic electron precipitation. The transmitter will also produce other data on solar proton events, relativistic electron precipitation from the Earth's outer radiation belts, and the joule heating components of high-latitude/polar cap magnetosphere/ionosphere coupling processes. (A–108–S; NSF/OPP 00–93381)

Austral high-latitude atmospheric dynamics.

Gonzalo Hernandez, University of Washington.

Observations of atmospheric dynamics in Antarctica help us better understand the global behavior of the atmosphere in high-latitude regions. Compared with lower latitude sites, the South Pole is a unique spot from which to observe the dynamic motion of the atmosphere. Its position on the Earth's axis of rotation strongly restricts the types of wave motions that can occur.

We will use high-resolution Fabry-Perot spectrometers at South Pole Station and Arrival Heights to make simultaneous azimuthal observations of the individual line spectra of several upper-atmospheric trace species, specifically the hydroxyl radical and atomic oxygen. The observed Doppler shift of the emission lines provides a direct measure of line-of-sight wind speed; wind field structure can also be derived from these measurements. Simultaneously observed line widths provide a direct measurement of kinetic temperature.

Our goal is to observe, characterize, and understand high-latitude mesospheric and thermospheric motions, as well as the thermal structure of these regions. In particular, we are interested in the strong coupling between the lower and upper atmosphere and the existence of persistent upper-thermospheric vertical winds.

At both South Pole Station and Arrival Heights, we make observations during the austral winter, when the instruments operate in 24-hour data-acquisition mode. At this time, station technicians perform routine maintenance and monitor operations. During the austral summer, project team members deploy to both stations to perform calibrations, maintenance, and upgrades. (A–110–M/S; NSF/OPP 02–29251)

Studies of the polar ionosphere and magnetosphere from measurements in Antarctica and conjugate regions.

Allan T. Weatherwax, Siena College; Louis J. Lanzerotti, New Jersey Institute of Technology; and Theodore J. Rosenberg, University of Maryland.

We will continue our studies of the polar ionosphere and magnetosphere from Antarctica and nominally conjugate regions in the Arctic. High-frequency cosmic noise absorption measurements (riometry) and auroral luminosity measurements (photometry) form the basis of our investigations. However, our research also involves extensive collaboration with other investigators using complementary data sets. Our previous work has provided insights into high-latitude substorm dynamics, magnetic variations, day- and night-side absorption spike events, traveling convection vortices, pulsating auroral particle precipitation, ionospheric transient and cusp-latitude absorption events, the origin of auroral radio emissions, and the possible application of riometry to the study of the Martian ionosphere.

Riometers measure the relative opacity of the ionosphere. Working at both McMurdo and South Pole Stations, we maintain and use a system called IRIS (Imaging Riometer for Ionospheric Studies), broad-beam riometers, and auroral photometers. These instruments, which work synergistically with other instruments operated at various sites by other investigators, also provide the data acquisition systems for the common recording of geophysical data at South Pole and McMurdo Stations and the provision of these data to collaborating investigators. To enhance their usefulness and timeliness to the general scientific community, data are made available in near real time on the Internet.

We will also continue imaging riometer measurements at Iqaluit in the Arctic, the nominal magnetic conjugate point of South Pole Station. Further, we will participate in, and contribute to, several major science initiatives and National Space Weather programs. A primary focus of our analysis over the next year will be coordinated ground- and satellite-based studies of Sun-Earth connection events. Specifically, we will be able to combine ground-based data sets with IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite data when the spacecraft is ideally situated at apogee over the Southern Hemisphere. These disparate activities have the common goal of enhancing scientific understanding of the relevant physical processes and forces that drive the observed phenomena, both internal (magnetospheric/ionospheric instabilities) and external (solar wind/interplanetary magnetic field variations). From such knowledge may emerge an enhanced forecasting capability. Many atmospheric events can have negative technological or societal impacts that accurate forecasting could ameliorate. (A–111–M/S; NSF/OPP 03–38105)

Polar Experiment Network for Geospace Upper-Atmosphere Investigations: PENGUIn—A new vision for global studies.

Allan T. Weatherwax, Siena College.

Since the advent of space flight, we have witnessed the importance of understanding the Earth and its space environment. Such an understanding requires a deep knowledge of the atmosphere-ionosphere-magnetosphere system—knowledge based on upper-atmosphere physical processes in the polar regions in both hemispheres. Only from the surface of Earth can many of the critical coupling processes and feedback systems that define this global system be studied with high temporal and spatial resolution.

We will investigate, from Antarctica and nominally conjugate regions in the Arctic, the multiscale electrodynamic system that comprises Earth's space environment. Our plan entails

- the phased development of a new and comprehensive upper-atmosphere geophysical measurement program based on distributed autonomous instruments operating in an extreme antarctic environment,
- real-time data collection via satellites,
- a methodology to build synergistic data sets from a global distribution of Southern and Northern Hemisphere instrument arrays, and
- an analysis and data distribution/outreach program tied to modeling and computer simulation to link measurement and theory.

Over the next 5 years, we will investigate dayside phenomena such as magnetic impulse events and traveling convection vortices, substorms at the highest latitudes, auroral zone poleward boundary intensifications, and magnetic reconnection and ion flows.

We will also study the causes of space weather processes that affect technologies on Earth and in near-Earth space, including charged particle energization and loss and the effects of solar particles on the polar cap ionosphere. Having the IMAGE (Imager for Magnetopause to Aurora Global Exploration) satellite at apogee in the Southern Hemisphere provided unprecedented opportunities for unraveling processes involved in internal and external driving forces in the global system. From such research will ultimately emerge an enhanced capability to predict the likely occurrence of events that might have deleterious effects on technology or people.

We will make our data and data acquisition tools widely available, and our research will be integrated with all levels of education from high school through postdoctoral study. Also, the development of new low-power sensors and innovative approaches to extreme environment engineering will benefit other disciplines. (A–112–M/S; NSF/OPP 03–41470)

All-sky imager at South Pole.

Yusuke Ebihara, National Institute of Polar Research, Japan.

The South Pole is an unparalleled platform for observing aurora during the austral winter. As a point on the Earth's rotational axis, the pole provides a unique vantage point from which to observe the airglow and discern the characteristics of acoustic gravity waves in the polar region as they vary in altitude and wavelength. Observing aurora continuously over 24 hours allows us to collect data on

- the dayside polar cusp/cleft aurora (due to the direct entry of the solar wind);
- afternoon aurora that are closely associated with the nightside magnetospheric storm/substorm activities; and
- the polar cap aurora, which depends on the polarity of the interplanetary magnetic field.

Research has shown that these auroras develop from precipitating low-energy particles entering the magnetosphere from the solar wind.

Though data have been gathered at the South Pole with a film-based, all-sky camera system since 1965, newer technology now produces digital images and permits us to process large amounts of information automatically. Currently, we are using the all-sky imager, a digital charge-coupled device imager monitored and controlled by the National Institute of Polar Research in Japan.

These international collaborations should enhance knowledge of the magnetosphere, the ionosphere, and upper/middle atmosphere physics. The high-frequency radar installations at Halley Bay, Sanae, and Syowa Stations provide the vector velocity of ionospheric plasma over the South Pole. These studies should provide further insight into the physics of the magnetosphere, the convection of plasma in the polar cap, and solar wind effects, specifically dayside auroral structure, nightside substorm effects, and polar cap arcs. (A–117–S; U.S./Japan agreement)

Solar and heliospheric studies with antarctic cosmic rays.

John W. Bieber, William H. Matthaeus, and K. Roger Pyle, University of Delaware, Bartol Research Institute, and Evelyn Patterson, U.S. Air Force Academy.

Cosmic rays—penetrating atomic nuclei and electrons from outer space that move at nearly the speed of light—continuously bombard the Earth. Colliding with the nuclei of molecules found in the upper atmosphere, they create a cascade of secondary particles that shower down. Neutron monitors, which are deployed in Antarctica and are part of a global network of nine stationary monitors and two transportable ship-borne monitors, provide a vital three-dimensional perspective on this shower and how it varies along all three

axes. Accumulated neutron-monitor records (begun in 1960 at McMurdo Station and in 1964 at Amundsen–Scott South Pole Station) provide a long-term historical record that supports efforts to understand the nature and causes of solar/terrestrial and cosmic ray variations as they are discerned over the 11-year sunspot cycle, the 22-year Hale cycle, and even longer time scales. Data from the neutron monitors in this network will be combined with data from other ground-based and spacecraft instruments in various investigations of cosmic rays in relation to the Sun and solar wind. Specific objectives include the study of acceleration and transport of solar energetic particles, the scattering of cosmic rays in the solar wind, and the use of cosmic-ray observations for space weather forecasting.

This project at McMurdo and Amundsen–Scott South Pole Stations continues a series of year-round observations recording cosmic rays with energies in excess of 1 billion electron volts. These data will advance our understanding of a number of fundamental plasma processes occurring on the Sun and in interplanetary space. At the other extreme, we will study high time-resolution (10-second) cosmic ray data to determine the three-dimensional structure of turbulence in space and to elucidate the mechanism by which energetic charged particles scatter in this turbulence. (A–120–M/S; NSF/ATM 00–00315)

RICE: Radio-Ice Cherenkov Experiment.

David Z. Besson, University of Kansas–Lawrence.

We live at the dawn of the era of ultra-high-energy astronomy. Celestial accelerators, achieving energies 109 times higher than previously possible, can produce protons, photons, and neutrinos. Neutrinos are elementary particles with no electrical charge and very little mass. At the highest energies, neutrinos are the only particles that can elude the cosmic microwave background and penetrate, undeflected by magnetic fields, to Earth.

RICE is aimed at measuring high-energy neutrinos by detecting Cherenkov radiation, which is visible as a blue glow and results from collisions of very-high-energy neutrinos with ice or rock. RICE is designed to detect the compact electromagnetic cascades that produce Cherenkov radiation. At such high energies, radio detection of cascades is more efficient than optical-based detection.

We will work with the researchers on the IceCube drilling project, which began in 2004 (see A–333–S); specifically, we will deploy radio receivers in IceCube holes, thereby increasing RICE's sensitivity to neutrinos by at least two orders of magnitude. Deploying three radio receiver clusters (with two dual-polarization, high-bandwidth antennas per cluster) per hole will allow us to conduct radioglaciology measurements, in addition to astrophysics experiments. We will design the radio array for coincident (RICE plus IceCube) electromagnetic cascade detection, and special hardware will allow microsecond time-scale elimination of the surface anthropogenic backgrounds that have proved a problem in the past.

RICE data from the past 4 years have allowed the most detailed study of *in situ* radio detection systematics thus far; we have presented these data in two recent publications on the electrodynamics of the expected radio frequency pulse and two publications on RICE simulation and calibration and limits on the neutrino flux. Those limits were based on just 3 percent of the RICE data set. Expanded results based on 50 percent of the data set and improving on those limits by an order of magnitude, as well as results on the first *in situ* measurements of the polar dielectric constant, are being prepared for journal submission. Other studies are well underway. Our data and results will contribute greatly to the knowledge of astrophysics and ultra-high-energy astronomy. (A–123–S; NSF/OPP 03–38219)

Direction-finding measurements of low-frequency/medium-frequency/high-frequency (LF/MF/HF) auroral radio emissions at South Pole Station.

James W. LaBelle, Dartmouth College, and Allan T. Weatherwax, Siena College.

The Earth's aurora naturally emits low-, medium-, and high-frequency (LF/MF/HF) radio waves that are signatures of the interaction between the auroral electron beam and the ionospheric plasma. Yet some of the mechanisms that generate plasma waves are not well understood. Using an electromagnetic waveform receiver that we designed and constructed at South Pole Station, we will focus on several types of signals detectable at ground level, including auroral hiss, which occurs primarily at very low frequencies but often extends into the LF/MF range, and auroral roar, a relatively narrow-band emission generated near or at the second and third harmonics of the electron cyclotron frequency.

Because the broadcast bands found in the Northern Hemisphere are lacking in Antarctica, automatic wave-detection algorithms are more effective. Auroral roar has been found to be occasionally modulated (a phenomenon called flickering auroral roar). Our receiver will enable us to discover how common flickering auroral roar is, the conditions under which it occurs, what the frequencies are, and how the amplitude and frequency vary. Between 15 and 30 percent of auroral hiss events cannot be observed at very low frequencies. The receiver will determine whether LF auroral hiss consists exclusively of relatively unstructured broadband impulses or whether it sometimes displays a fine structure like that of auroral kilometric radiation and whistler-mode waves in the same frequency range detected in the lower ionosphere.

Despite its extensive application for communications, the LF/MF/HF band has not been extensively investigated as a source of natural radio emissions detectable at ground level. A complete knowledge of our geophysical environment requires understanding the physics of these emissions. Further, electron beam/plasma interactions analogous to the terrestrial aurora occur in many space physics and astrophysics applications. Often, the electromagnetic radiation emitted by these systems is our only source of knowledge about them. The local auroral plasma provides an opportunity to view some radiation processes at close range. (A–128–S; NSF/OPP 04–42369)

The antarctic investigations of upper atmospheric disturbances over the South Pole Station.

Gulamabas G. Sivjee and Syed Azeem, Embry Riddle Aeronautical University.

While variations in the Sun's energy affect people in obvious ways by driving the weather and the seasons, there are actually many cycles and variations of deeper interest to science, on scales from seconds to centuries to eons. One of the most basic is the 11-year cycle when the Sun's magnetic poles reverse direction (since reliable observations began, 23 of these have occurred and the last recently peaked) and sunspots and other solar activity wax to peak levels. The National Aeronautics and Space Administration is using this opportunity to conduct its TIMED (thermosphere-ionosphere-mesosphere-energetics and dynamics) satellite study, which will focus

on the region between 60 and 180 kilometers above the Earth's surface.

Taking advantage of the timing of both of these events, we will use observations in the visible and near-infrared ranges of upper-atmospheric emissions above South Pole Station to study the heating effects of auroral electrical currents in the ionosphere, as well as planetary waves and atmospheric tides.

As it passes overhead, TIMED will provide data on the temperature, winds, and tides of the Earth's upper atmosphere, especially above the poles. Since tracking satellites often have difficulty differentiating between variations in location or time, ground-based observations from the South Pole will be valuable in sorting out the time-location question. (A–129–S; NSF/OPP 03–37618)

Measurements addressing quantitative ozone loss, polar stratospheric cloud nucleation, and large polar stratospheric particles during austral winter and spring.

Terry Deshler, University of Wyoming, and Marcel Snels, Instituto di Fisica dell'Atmosfera, Rome, Italy.

The stratospheric ozone layer provides life on Earth with an essential shield from solar ultraviolet radiation. The discovery in 1985 of large ozone losses above Antarctica each spring took the world and the scientific community by surprise. Since that time, the cause of this unprecedented ozone loss has been determined to be chlorine compounds interacting on the surfaces of clouds that formed when temperatures dropped below –78°C the previous winter [polar stratospheric clouds (PSCs)]. This interaction helps explain why ozone depletion is so severe in the polar regions. However, many details still must be clarified before we can comprehensively model the stratospheric ozone balance.

Observations of vertical ozone profiles from McMurdo Station will add to our database of annual measurements and will be completed as stratospheric chlorine levels are peaking to provide a baseline to detect the first signs of ozone recovery. In addition, we will extend our observations of PSCs. We use balloon-borne *in situ* instruments and an optical light detection and ranging radar (lidar) to study PSCs, stratospheric aerosol, and the thermal behavior and dynamics of the atmosphere above McMurdo Station. Continuous lidar observations and comparison of lidar and *in situ* measurements provide insight into the nature of these PSCs. Specifically, measurements of the size, concentration, and optical properties of the particles that form in these clouds provide estimates of the surfaces available for heterogeneous chemistry (the activation of chlorine so it can destroy ozone), the rates of denitrification and dehydration, and particle composition.

Measurements of vertical ozone profiles and lidar aerosol profiles are archived in the database of the Network for the Detection of Stratospheric Change, a global set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the atmosphere (see www.ndsc.ws). This project represents a collaboration between Italian researchers and the University of Wyoming. (A–131–M; NSF/OPP 02–30424 and U.S./Italy agreement)

Measurement and analysis of extremely-low-frequency (ELF) waves at South Pole Station.

Marc R. Lessard, University of New Hampshire, and James W. LaBelle, Dartmouth College.

We aim to detect and record magnetic field fluctuations in the extremely-low-frequency (ELF) range, specifically auroral ion cyclotron waves, which have been well correlated with flickering aurora, at South Pole Station. Theory predicts that these waves modulate precipitating electron fluxes, thereby causing the flickering in luminosity emissions. Substantial evidence now supports this theory, although the excitation mechanism responsible for the ion cyclotron waves is uncertain. The most well developed theory suggests that the waves result from an electron-beam instability. In any case, the frequency of the flickering or, equivalently, the frequency of the ground-based observations of ion cyclotron waves can be used to infer the altitude of the excitation mechanism, since the wave frequency depends on the strength of the background magnetic field, which is a known quantity. As such, the information that will be acquired can be used to test models of auroral acceleration mechanisms, as well as study dispersive ELF waves, a type of wave that has been reported in the literature only a few times but may provide important information on substorm onset or, perhaps, the boundaries of open and closed magnetic fields.

A first step is to identify the wave mode and to determine the location and geomagnetic conditions under which these waves can be observed. The equipment used to make these observations consists of an induction coil magnetometer and data acquisition system. The induction coil is a commercially available device that was originally designed for geophysical exploration. Data will be returned to Dartmouth College for analysis. (A–136–S; NSF/OPP 01–32576)

Cosmic Ray Energetics and Mass (CREAM).

Eun-Suk Seo, University of Maryland; Simon Swordy, University of Chicago; James Beatty and Stephane Coutu, Pennsylvania State University; Michael Duvernois, University of Minnesota; Il Park, Ewha Woman's University; and Pier Simone Marrocchesi, University of Siena.

The Cosmic Ray Energetics and Mass (CREAM) project is a joint National Science Foundation/National Aeronautics and Space Administration (NASA) endeavor that will use a series of long-duration balloon flights to study the origin of cosmic rays. The CREAM instrument is configured with state-of-the-art particle detectors to measure the composition of cosmic rays from protons to iron nuclei over the energy range of 1 to 10^3 tera electron volts. The goal is to observe cosmic ray spectral features and abundance changes that might signify a limit to supernova acceleration.

To minimize the effect of backscatter from the calorimeter, particle charge measurements will be made with a timing-based detector and a pixelated silicon matrix. Particle energy measurements will be made with a transition radiation detector and a sampling tungsten/scintillator calorimeter. In-flight cross-calibration of the two detectors allows better determination of particle energy. Measurements of the relative abundance of secondary comic rays, as well as primary spectra, will allow us to determine ultra-high-energy cosmic rays for which measurements are not available.

The instrument has been tested and calibrated with a series of beam tests. It will be integrated with a command data module support system that was developed for the NASA Wallops Flight Facility and is attached to the bottom of the instrument to provide CREAM with power and communications. The power system consists of 10 solar panels and 4 batteries that will provide 28 volts of power to

the instrument and 5, 12, and 28 volts of (regulated and unregulated) power to the support system instrumentation. Flight computers provide the communication interface between the science instrument and the command data module via an Ethernet connection using the universal datagram protocol. Real-time data will be downlinked continuously. All data will also be recorded on two hard drives, so anything that is not downlinked during real time can be retrieved. Other communication platforms serve as backups. (A–137–M; NSF/NASA agreement)

Wallops Flight Facility Component of the Cosmic Ray Energetics and Mass (CREAM) Balloon Payload.

Linda D. Thompson, National Aeronautics and Space Administration.

The National Aeronautics and Space Administration (NASA) Wallops Flight Facility developed the command data module and its external systems to support the science instrument for the Cosmic Ray Energetics and Mass (CREAM) project, which will use a series of long-duration balloon flights to investigate high-energy cosmic rays over the elemental range from protons to iron. These support systems provide the CREAM instrument with power, telecommunications, command and data handling, mechanical structures, thermal management, and attitude control. The power system consists of 10 solar panels and 4 batteries that will provide 28 volts of power to the instrument and 5, 12, and 28 volts of (regulated and unregulated) power to the support system instrumentation.

An Ethernet connection using the universal datagram protocol provides the communication interface between the science instrument and the command data module. The balloncraft is instrumented to provide relay switch status, current, voltage, and temperature for telemetry health and status. The Tracking and Data Relay Satellite System serves as the prime over-the-horizon communications system and has a downlink capability of 100 kilobits per second. All data and system monitoring is both downlinked and stored on two hard drives on board so anything that is not downlinked during real time can be retrieved. Attitude control points solar panels toward the sun within ±2 degrees. (A–138–M; NSF/NASA agreement)

Advanced Thin Ionization Calorimeter (ATIC) Long-Duration Balloon Flight.

John P. Wefel, Louisiana State University–Baton Rouge.

Cosmic rays are the only sample of matter from distant regions of the galaxy, and possibly elsewhere in the Universe, that can be directly observed by space experiments in the solar system. This high-energy matter consists of atomic nuclei that travel at speeds very close to the speed of light. In fact, the highest energy cosmic rays observed are more than 10,000,000 times more energetic than those that can be produced in the largest particle accelerators on Earth. Cosmic rays, which include electrons, the natural elements from hydrogen and helium to iron and beyond, and antimatter in the form of positrons and antiprotons, play an important role in galactic dynamics and can be used to probe astrophysical conditions throughout our galaxy. They appear to gain their very high energy as the result of supernova explosion shock waves traveling through interstellar gas. The supernova shock wave acceleration model makes specific predictions about the cosmic ray energy spectrum as a function of elemental charge. The Advanced Thin Ionization Calorimeter (ATIC) project is designed to measure the energy spectrum of individual cosmic ray elements to study the validity of this model.

The ATIC balloon flight program will concentrate on measuring the cosmic ray proton and helium spectra from below 5×10^{10} electron volts to more than 10^{14} electron volts, with statistical accuracy of better than 30 percent at the highest energy. This unique coverage will enable us to investigate the spectral difference between hydrogen and helium and identify any spectral breaks over a broad energy range. In addition, ATIC will fill an existing gap in measurements of the proton/alpha ratio and concurrently will measure the spectra of nuclei up to iron, with individual element and superior energy resolution.

To achieve these objectives, ATIC will depend on a series of long-duration balloon flights that will be launched near McMurdo Station. During these flights, a large-volume helium-filled balloon will carry the experiment to the very edge of space (about 120,000 feet) for between 10 and 15 days. (A–143–M; NASA grant)

Long-Duration Balloon Program.

David W. Sullivan, National Scientific Balloon Facility.

The National Scientific Balloon Facility will launch two stratospheric balloons between 10 December 2005 and 10 January 2006. The balloons have a volume of 40 million cubic feet and will ascend at a rate of approximately 900 feet per minute to a float altitude of 125,000 feet. Both balloons will be launched at the Long-Duration Balloon site near Williams Field, reach float altitude, and circumnavigate the continent between 70°S and 80°S.

Balloons are terminated and recovered on the Ross Ice Shelf or on the Polar Plateau. For termination, an aircraft flies within line-of-sight of the balloon, and a radio command is sent to the payload. At the point of release, the payload descends with a parachute to a predicted impact site. Air or ground support (depending on the location) is used to recover the payload instruments, which are then returned to the home institutions to be refurbished and float another day. (A–145–M; NSF/NASA agreement)

Infrared measurements of atmospheric composition over Antarctica.

Frank J. Murcray, University of Denver.

We will use passive infrared instruments to measure year-round atmospheric chemistry for the photochemical transport models used to predict ozone depletion and climate change. The ozone hole has shown how sensitive the southern polar stratosphere is to chlorine, and although gradual healing of the hole is expected in response to the Montreal Protocol, models indicate a possible delay in recovery because of the impact of global warming on the catalytic ozone destruction process. Since most satellite instruments do not sample the polar regions in the winter, ground-based instruments can make an important contribution, and our data will also validate data from new satellite sensors.

We have installed two Fourier Transform Spectrometers, one at South Pole Station and the other at McMurdo Station, for year-round operation and a solar spectrometer at South Pole Station for summer operation. Also, we are collaborating with and receiving data from the New Zealand National Institute for Water and Air Research, which operates a similar spectrometer at Arrival Heights. During

the polar night, two instruments provide information on nitric acid and denitrification, as well as dehydration, and high-resolution spectra from which we will derive vertical profiles, vertical column amounts of many molecules important in the ozone destruction process, and atmospheric tracers. Specifically, we will derive year-round column abundance measurements of nitric acid, methane, ozone, water, nitrous oxide, the chlorofluorocarbons (CFCs), and nitrogen dioxide.

We will use the data to determine the state of nitrogen oxide partitioning; to measure denitrification, vapor profiles in the stratosphere, and dehydration; to determine CFC and stratospheric chlorine levels; and to gain more insight into vortex-related chemical and dynamic effects. In addition, our data will allow photochemical transport modelers to compare outputs with actual measurements, especially at intermediate stages. As the recovery from ozone destruction begins, it is important to have a comprehensive data set that covers the major constituents of both the catalytic ozone destruction sequence and global warming, in order to place the relative influence of these two mechanisms in perspective. Also, the data will be available on a Web site for high school instruction. (A–255–M/S; NSF/OPP 02–30370)

Dynamics of the antarctic mesosphere–lower-thermosphere (MLT) region using ground-based radar and TIMED instrumentation.

Scott E. Palo, James P. Avery, and Susan K. Avery, University of Colorado–Boulder.

The mesosphere–lower thermosphere, which is found between 80 and 120 kilometers above the surface of the Earth, is a highly dynamic region that couples the lower atmosphere (troposphere/stratosphere) with the upper atmosphere (thermosphere/ionosphere). Of particular importance in this region are both the upward propagating, thermally forced atmospheric tides and global planetary waves. Both of these phenomena transport heat and momentum from the lower atmosphere into the upper atmosphere.

Studies in recent years have indicated that the high-latitude mesosphere–lower thermosphere has a rich spectrum of previously undiscovered planetary waves that can interact with the sun-synchronous migrating semidiurnal tide, thereby modifying its spatial and temporal structure while giving rise to the nonmigrating semidiurnal tide. Understanding the structure and variability of the semidiurnal tide is an important step toward understanding the global heat and energy balance of the mesosphere–lower thermosphere.

We will observe and model the spatial-temporal structure and variability of the semidiurnal tide, with a focus on the horizontal wind and temperature fields in the arctic and antarctic mesosphere–lower thermosphere. Previous observations have indicated that planetary waves play a significant role in the variability of the semidiurnal tide. We will therefore estimate the structure of the semidiurnal tide and the planetary waves simultaneously. These estimates will be analyzed in conjunction with both linear mechanistic and global circulation models to help interpret the observations. The data for this project will also include horizontal wind measurements from a global network of 30 ground-based meteor and medium-frequency radars. (The radar data are collected by colleagues in Australia, Canada, Japan, Russia, the United Kingdom, and the United States.) Moreover, wind and temperature measurements from the National Aeronautics and Space Administration's TIMED (thermosphere-ionosphere-mesosphere-energetics and dynamics) satellite will be combined with the radar data and incorporated into existing databases.

Teaching, training, and learning will be advanced by the inclusion of graduate students, especially underrepresented minorities, in this research. All of the students involved in this project will be encouraged to present their results and participate in professional meetings. (A–284–S; NSF/OPP 03–36946)

Extremely-low-frequency/very-low-frequency (ELF/VLF) observations of lightning discharges, whistler-mode waves, and electron precipitation at Palmer Station, Antarctica.

Umran S. Inan, Stanford University.

Although tracking dynamic storms is a challenge, the lightning associated with thunderstorms can provide an indirect way of monitoring global weather. We will use very-low-frequency (VLF) radio receivers at Palmer Station to study thunderstorm coupling to the Van Allen radiation belts, the characteristics of lightning flashes that lead to upward electrodynamic coupling, ionospheric variability and parameters, and global lightning and climatology. In collaboration with the British and Brazilian Antarctic Programs, both of which use similar receivers, we will contribute data to the Global Change Initiative.

Our VLF receivers measure changes in the amplitude and phase of signals received from several distant VLF transmitters. These changes follow lightning discharges 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 increases ionization in the ionosphere, through which the propagating VLF radio waves must travel. Because the orientations to the VLF transmitters are known, we can triangulate the lightning sources that caused the changes. Once the direction of the source is known, it can be subjected to waveform analysis and used to track the path of thunderstorms remotely.

In addition, our VLF observations at Palmer Station will provide crucial support to a program involving the establishment and operation of a VLF beacon transmitter at South Pole Station. The reception of the beacon signal at Palmer Station will allow the continuous measurement of relativistic electron precipitation from the outer radiation belts, an important component of worldwide efforts to assess space weather.

The data we derive will be correlated with data from the antarctic automatic geophysical observatory network and used by scientists studying the magnetosphere and the ionosphere. (A–306–P; NSF/OPP 02–33955)

IceCube.

Francis Halzen, University of Wisconsin–Madison.

We are building the IceCube Observatory, which will be installed at the South Pole. IceCube, a neutrino telescope that will be buried 1.4 to 2.4 kilometers below the surface of the ice, will be constructed during the austral summers over the next 4 years. The detector will consist of 4,800 optical modules deployed on 80 vertical strings. The now-completed AMANDA (Antarctic Muon and Neutrino Detector Array project) served as a prototype for this international collaborative effort. Last season, we shipped the remaining components, began drilling in the ice sheet, and started to assemble and test systems. During this austral summer, drilling

will continue and additional optical modules will be deployed.

Using neutrinos as cosmic messengers, IceCube will open an unexplored window on the Universe and will answer such fundamental questions as what the physical conditions in gamma ray bursts are and whether the photons originating in the Crab supernova remnant and near the supermassive black holes of active galaxies are of hadronic (derived from subatomic particles composed of quarks) or electromagnetic origin. The telescope will also examine the nature of dark matter, aid in the quest to observe supersymmetric particles, and search for compactified dimensions.

Since many parts of the Universe cannot be explored using other types of radiation (protons do not carry directional information because they are deflected by magnetic fields, neutrons decay before they reach the Earth, and high-energy photons may be absorbed), IceCube will fill a gap in our knowledge and occupy a unique place in astronomical research. (A–333–S; NSF/OPP 03–31873)

Extending the South American Meridional B-field Array (SAMBA) to auroral latitudes in Antarctica.

Eftyhia Zesta, University of California–Los Angeles.

We intend to install 2 additional magnetometer stations in Antarctica and thus extend the South American Meridional B-field Array (SAMBA), which now comprises 10 stations, to higher latitudes. The 2 additional magnetometers will be at Palmer Station, a year-round U.S. research station in the Antarctic Peninsula region, and at Patriot Hills, a more remote, nonpermanent Chilean base. The Patriot Hills installation will be done with the logistical support of the Chilean Antarctic Institute.

More specifically, we intend to

- extend the SAMBA chain to auroral latitudes and increase the spatial resolution of the effective cusp-to-cusp chain comprising MACCS (Magnetometer Arrays for Cusp and Cleft Studies), MEASURE (Magnetometers Along the Eastern Atlantic Seaboard for Undergraduate Research and Education), SAMBA, the automatic geophysical observatories, and a few other individual stations;
- extend the number of conjugate pairs of stations between MEASURE in the Northern Hemisphere and SAMBA in the Southern Hemisphere, thus increasing the size of the inner magnetospheric region that can be remotely monitored from the two hemispheres;
- establish an auroral latitude station conjugate to the Canadian Poste de la Baleine and study the conjugate differences in substorms and general auroral activity;
- determine, with the addition of other antarctic auroral stations, a Southern Hemisphere auroral electrojet (AE)-type index and compare it with the standard AE index; and
- provide the scientific community with near-real-time data from Southern Hemisphere low- and auroral-latitude stations that can be used to validate models that up to now have been tuned primarily with data from the Northern Hemisphere. (A–357–M/P; NSF/OPP 03–41861)

Strateole-Vorcore.

François Vial, École Polytechnique, Laboratoire de Météorologie Dynamique.

The Strateole-Vorcore experiment was designed to examine the dynamics of the stratospheric antarctic polar vortex, the transport of minor constituents, and the interaction with ozone chemistry during late winter and spring.

We will launch a series of superpressure, long-duration balloons from McMurdo Station. These balloons are equipped with lightweight instrumented gondolas containing two temperature sensors, a pressure sensor, a global positioning system receiver, and an ARGOS transmitter to document wind and temperature horizontal fields inside the vortex core. This will permit us to study

- the dynamic structure of the polar vortex and its evolution up to its final breakdown,
- the influence of tropospheric forcing on the stratospheric circulation at high latitudes,
- the role of small-scale movements (gravity waves and turbulence) on the horizontal diffusion processes,
- the different regimes of horizontal transport around the isentropic layer (below which the exchange with mid-latitudes should be relatively free), and
- the temperature history of air masses—key to understanding the formation of polar stratospheric clouds. (A–360–M; U.S.–France agreement)

Development of an autonomous real-time remote observatory (ARRO).

Marc R. Lessard, University of New Hampshire, and James W. LaBelle, Dartmouth College.

We will develop an autonomous real-time remote observatory (ARRO), which will be designed to accommodate at least a dozen instruments, with the goal of enabling reliable observations from several sites on the antarctic plateau. We will build two prototypes of this observatory and test them for extended periods in cold chambers on Mount Washington and at the South Pole.

Significant outstanding issues in diverse fields drive the need for a network of reliable autonomous observatories capable of operating in the polar regions. ARRO will contribute to the pursuit of a broad scientific agenda by a large group of institutions and investigators in fields ranging from solar-terrestrial physics to seismology. In solar-terrestrial physics, the geomagnetic polar cap—the region of geomagnetic field lines connected to interplanetary space—forms a key window on the interaction between the solar wind and the Earth's magnetosphere. Continued progress in understanding the Sun's influence on the structure and dynamics of the Earth's upper atmosphere depends on increasing knowledge of the role that the polar cap plays in coupling the solar wind with the magnetosphere, ionosphere, and thermosphere. Furthermore, a network of observatories at high latitudes will contribute significantly to studies of energy input into the magnetosphere, reconnection, nightside energization of particles and auroral substorms, subauroral and inner magnetospheric physics, and development of a new polar cap index of solar-terrestrial activity.

Also, because the seismic character of Antarctica is not well known, a central goal is to determine crustal and mantle structure from seismic signals. This requires a network of receiving stations. In atmospheric science, one vital object of study is nitric acid trihydrate polar stratospheric clouds, which are implicated in the annual springtime destruction of stratospheric ozone over Antarctica.

In addition, ARRO development includes several different layers of research and training. Students will be directly involved, from the initial design stages to deployment. Finally, ARRO includes significant connections to industry and Government units outside the academic community, and participation will sharpen the capabilities of these units to serve the Nation in applying technology to challenging environments of cold weather and high altitudes. (A–362–S; NSF/OPP 02–16279)

Next-generation cosmic microwave background polarization measurements with the QUEST experiment on the degree angular scale interferometer (DASI).

Sarah E. Church, Stanford University; Clement L. Pryke, University of Chicago; and Andrew E. Lange and James J. Bock, California Institute of Technology.

We deployed QUEST, a 2.6-meter Cassegrain telescope equipped with a next-generation polarization-sensitive bolometer array, to South Pole Station and will operate it for another austral winter. We mounted the telescope on the existing degree angular scale interferometer (DASI) platform and reused large parts of the DASI infrastructure and control system. We will use the combined QUEST/DASI (or QUaD) system to make maps of the polarization of the cosmic microwave background (CMB) with unprecedented sensitivity and angular resolution.

The CMB—the faint, relic heat from the Big Bang—offers a snapshot of the Universe at the point where it transitioned from hot plasma to neutral gas. The statistics of the expected sky pattern for a given cosmological theory can be accurately calculated, and a host of experiments have now measured the variation of the total intensity, or temperature, of the CMB. Taken together, these measurements have begun to reveal the origin, composition, evolution, and ultimate fate of the Universe.

The polarization of the CMB results from bulk motions of material at the time of the plasma–neutral gas transition. Several experiments are either running or under construction to improve measurements of CMB polarization. QUaD has raw sensitivity similar to that of the European Space Agency's planned Planck satellite (to be launched in 2007) and in fact shares much of the same technology. However, while Planck plans to survey the whole sky, QUaD will go very deep on small patches selected for extremely low foreground contamination. QUaD's maps will have dramatically higher signal-to-noise per pixel and will prove crucial to disentangling the cosmic signal from instrumental and foreground effects.

The enterprise of modern cosmology is one with which almost everybody can identify. QUaD project members communicate with the public in both formal and informal settings. Outreach and education related to the project are disseminated through established structures and mechanisms that reach out to local and distant K–12 schoolteachers and students to inform and to help attract women and minorities to science. Also, graduate and undergraduate education and research are being integrated into QUaD construction and data analysis. (A–366–S; NSF/OPP 03–38138, NSF/OPP 03–38238, and NSF/OPP 03–38335)

Continued operation of the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO).

Antony A. Stark and Adair P. Lane, Smithsonian Institution Astrophysical Observatory; Christopher K. Walker, University of Arizona; and Jacob Kooi and Richard Chamberlin, California Institute of Technology.

Astronomy is undergoing a revolutionary transformation, where for the first time we can observe the full range of electromagnetic radiation emitted by astronomical sources. One of the newly developed and least explored bands is the submillimeter, at frequencies from about 300 gigahertz up into the terahertz range. Submillimeter-wave radiation is emitted by dense gas and dust between the stars, and submillimeter-wave observations allow us to study the galactic forces acting on that gas and the star formation processes within it in unprecedented detail.

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) is a 1.7-meter, single-dish instrument that has been operating since 1995 in several submillimeter bands. It has made position-position-velocity maps of submillimeter-wave spectral lines with arcminute resolution over regions of sky that are several square degrees in size. AST/RO provides a valuable complement to the planned arrays, which are inefficient when observing large areas because of their small field of view. AST/RO can observe molecular clouds throughout the fourth quadrant of the Milky Way and the Magellanic Clouds to locate star-forming cores and study in detail the dynamics of dense gas in our own galaxy. AST/RO studies are showing how molecular clouds are structured, how newly formed stars react back on the cloud, and how galactic forces affect cloud structure. Also, these studies

- have shown that the structure of molecular clouds is affected by their heavy element content and their proximity to spiral arms,
- have examined the gradient of heavy elements in the galaxy, and
- have produced extensive, high-sensitivity maps of several atomic and molecular transitions toward the Galactic Center and an unbiased survey of molecular and atomic gas in the fourth quadrant of the Galaxy.

Location at Amundsen–Scott South Pole Station is essential to AST/RO's capabilities. Most submillimeter radiation is absorbed by irregular concentrations of atmospheric water vapor before it reaches the Earth's surface. The desiccated air over South Pole Station allows an accurate intercomparison of submillimeter-wave power levels from locations on the sky separated by several degrees. This is essential to the study of submillimeter-wave radiation on the scale of the Milky Way and its companion galaxies.

This will be the last austral summer that we will operate the telescope. (A–371–S; NSF/OPP 01–26090)

Wide-field imaging spectroscopy in the submillimeter: Deploying SPIFI on the Antarctic Submillimeter Telescope and Remote Observatory

(AST/RO).

Gordon J. Stacey, Cornell University.

SPIFI (South Pole Imaging Fabry-Perot Interferometer), the first direct detection imaging spectrometer for use in the submillimeter band, was designed for use on the 1.7-meter Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) at the South Pole in the far-infrared and submillimeter windows. After having developed and extensively field-tested SPIFI, our primary goals are to

- image the inner regions of the galaxy, in particular submillimeter lines that characterize excitation conditions in the Central Molecular Zone (CMZ), and trace the dynamics of the gas. Questions to be answered are, among others, Can we trace neutral gas flowing through the CMZ? Are there shocks from cloud-cloud collisions in this flow? What is the connection between the CMZ molecular clouds and the circumnuclear ring?
- map the Large Magellanic Cloud and Small Magellanic Cloud in these lines. The low metalicity environment in these dwarf galaxies may mimic that of protogalaxies, so investigating the interaction between star formation and the interstellar matter in these galaxies is key to understanding the star formation process in the early Universe.
- characterize and map the physical conditions of the interstellar matter in nearby galaxies. These data are unique and will be essential to understanding the relationships between density waves, bar potentials, and galaxy-wide star formation.

These projects can be undertaken only with the high sensitivity and mapping capabilities of the SPIFI AST/RO combination. SPIFI is much more sensitive than the best heterodyne receivers, which do not have the sensitivity or (often) the bandwidth, to detect the broad, weak lines from galaxies or the spatial multiplexing capability necessary for wide-field mapping projects. We plan to gradually upgrade SPIFI by a factor of 10. We will also make modest optical and cryogenic modifications to improve it in ways important to successful polar operations. The result will be better spatial resolution, with a wider field of view, and a large improvement in system sensitivity. Moreover, the new cryogenic system will require servicing only every 5 days instead of the current 40 hours. This is helpful for outdoor polar operations. This new system also reduces helium consumption (by a factor of 2) and therefore reduces cost.

Our observations this austral summer will complete the SPIFI-AST/RO program, begun during the 2005 austral winter. When our observations are completed, we will remove SPIFI from AST/RO and prepare it for shipment back to Cornell University. (A–377–S; NSF/OPP 03–38149)

High-resolution observations of the cosmic microwave background (CMB) with the Arcminute Cosmology Bolometer Array Receiver (ACBAR).

William L. Holzapfel, University of California–Berkeley.

We will continue our observations with the Arcminute Cosmology Bolometer Array Receiver (ACBAR), a 16-element 230-micro-Kelvin bolometer receiver designed to produce high-resolution images of the cosmic microwave background (CMB) in 3-millimeter wavelength bands. Mounted on the 2.1-meter Viper telescope at the South Pole, ACBAR has a sensitivity that rivals balloon-borne experiments and an angular resolution that they cannot hope to achieve. Making full use of the excellent atmospheric conditions during the austral winter at the South Pole, ACBAR is producing images of CMB radiation with a sensitivity and resolution that exceed the capabilities of even the European Space Agency's proposed Planck satellite (to be launched in 2007).

Observations of the CMB provide a unique window on the early Universe; moreover, these data play a key role in transforming cosmology into a precise science. In particular, small angular-scale observations of the CMB are a new frontier about which comparatively little is known. On these angular scales, contributions from secondary anisotropies introduced by intervening structures are expected to become dominant. For example, the scattering of photons by hot gas bound to clusters of galaxies results in a spectral distortion of the CMB known as the Sunyaev-Zel'dovich Effect (SZE). Observations of the SZE can provide important new constraints on theories of how the Universe grew.

The unique capabilities of ACBAR, which was deployed to the South Pole in December 2000, allow it to address a broad range of science focused on measuring primary and secondary CMB anisotropies. Our observations and analysis will help realize the full potential of this powerful instrument for the study of cosmology. Four institutions will continue to collaborate on the maintenance and operation of ACBAR and Viper and participate in the data analysis.

The results will serve as a vital complement to the large-scale Microwave Anistropy Probe (MAP) spacecraft data set and provide an essential check of the fine-scale excess power reported by other single-frequency experiments. The novel instrumentation, observation techniques, and analysis developed for ACBAR are generally applicable to future ground-based millimeter astronomy experiments. In addition, this project has provided hands-on research experience to several undergraduate and graduate students. (A–378–S; NSF/OPP 02–32009)

South Pole observations to test cosmological models.

John E. Carlstrom, University of Chicago; Antony A. Stark, Smithsonian Institution Astrophysical Observatory; John Ruhl, Case Western Reserve University; Joseph J. Mohr, University of Illinois–Urbana-Champaign; and William L. Holzapfel, University of California–Berkeley.

One of the most important discoveries in cosmology is that much, if not most, of the mass in the Universe is apparently made up not of stars and glowing gas, but of dark matter, which emits little or no light or other electromagnetic radiation and makes its presence known only through the gravitational force it exerts on luminous matter. There is some indication that dark matter may in fact not even be baryonic (baryons are subatomic particles that are built from quarks and interact via strong nuclear force). Determining just what fraction of the mass is in the form of noninteracting nonbaryonic particles is of great interest to cosmologists and physicists.

The University of Chicago leads a consortium of six institutions in designing and using a 10-meter off-axis telescope at Amundsen–Scott South Pole Station to survey galaxy clusters. Such a survey will allow us to study integrated cluster abundance and its red shift evolution and will give us precise cosmological constraints that are completely independent of those from supernova distance and cosmic microwave background (CMB) anisotropy measurements.

Measuring the mass in baryons along with the total mass in a region of the Universe that could be considered a fair sample would provide a direct determination of the dark matter content. In recent years, just such a test-bed has been found in massive clusters of galaxies, which contain large amounts of gas (baryons) in the form of a highly ionized gas atmosphere that emits x rays. Nearly all of the baryons in the clusters are believed to be in the hot phase (millions of degrees), so it is likely that we are truly measuring the baryonic mass in the cluster.

In addition to emitting x rays, the hot cluster gas also scatters CMB radiation. This scattering, called the Sunyaev-Zel'dovich Effect (SZE), can be measured by using radio telescopes. The SZE is important to the study of cosmology and the CMB for two reasons:

- The observed hotspots created by the kinetic effect distort the power spectrum of CMB anisotropies. These need to be separated from primary anisotropies to probe inflation properties.
- The thermal SZE can be measured and combined with x-ray observations to determine the values of cosmological parameters, in particular the Hubble constant. (A–379–S; NSF/OPP 01–30612)

Measurements of the surface layer turbulence at Dome C.

Tony Travouillon, California Institute of Technology.

Over two austral winters, we will study surface layer turbulence to fill the gaps in knowledge about the total turbulence profile at Dome C. We will use sonic anenometers placed along an existing 30-meter (m) mast to measure the C_N^2 parameter at four different heights within the first 30 m of the atmosphere (3, 10, 20, and 30 m). This parameter describes the strength of the optical turbulence at any given point in the atmosphere. By interpolating and integrating these measurements, we will be able to calculate the surface layer component.

A complete understanding of the spatial and temporal evolution of the turbulence above Dome C is important in comparing this site with other existing or potential observatory sites. This section of the atmosphere is particularly crucial for small and intermediate-size projects that are currently proposed for this site and will be affected by the turbulence.

Other fields, notably geophysics, will be greatly interested in these measurements. Other parameters, such as temperature, wind speed and direction, and surface heat flux, will be derived from them and will help us understand the structure of the airflow on the antarctic continent.

The data we derive will be made available to the international community in semi–real time on a dedicated Web site. (A–442–E; NSF/OPP 04–40874)

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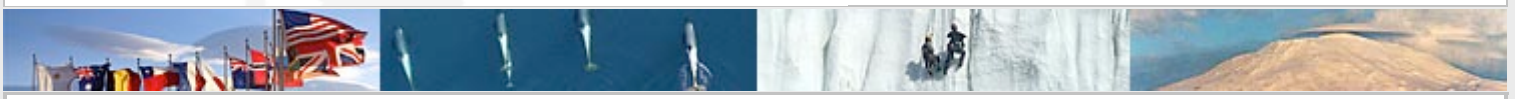

BIOLOGY AND MEDICINE

Four killer whales swim in McMurdo Sound. Researchers from NOAA Fisheries, Southwest Fisheries Science Center are studying the whales to determine if there are three separate species of Antarctic killer whales. They took aerial photos of the whales, such as this one taken in January 2005, as part of their work. (*NSF photo by Donald LeRoi, NOAA Southwest Fisheries Science Center*)

In this section:

- What limits denitrification and bacterial growth in Lake Bonney, Taylor Valley, Antarctica?
- Improving acoustic estimates of antarctic krill populations.
- Establishing a Polar Remote Interactive Marine Observatory (PRIMO) near Palmer Station on the western Antarctic Peninsula.
- Temporal variability in natural and anthropogenic disturbances at McMurdo Station, Antarctica.

Overview

Antarctica is a place like no other; as an intriguing habitat, it is a scientist's dream. It is a land where water is scarce—truly a desert—despite having more than two-thirds of the world's freshwater supply trapped in ice. Though it borders the world's major oceans, the Southern Ocean system is unique; it is a sea where average temperatures do not reach 2°C in summer, where even the water is so unusual that it can be identified thousands of kilometers away in currents that originated here. As the Earth, tilted on its rotational axis, makes its elliptical journey around the Sun each year, the Sun "sets" in April, not to be seen again until September. And the ice—an unimaginable, incomparable vastness of ice—appears in a dozen different varieties, at times and in places several thousand meters thick. There are two major ice sheets that change all the time. (One of them, the East Antarctic Ice Sheet, is larger than most countries.)

Adaptations and behavior developed in response to these extreme conditions provide insight into the intricacies, as well as the fundamental processes, of evolution. These extremes have also driven the development of ecosystems simple enough to reveal wonderfully clear pieces of the web of life on Earth.

The Antarctic Biology and Medicine Program funds research to improve understanding of antarctic ecosystems and life forms—their physiology, genetics, behavior, adaptations, and relationships. Projects range across all organizational levels, from the molecule, gene, cell, and organism to relationships within communities and ecosystems, to the level of global processes and the biosphere. This is another area of inquiry where scientific goals and benefits extend far beyond learning (in this field, about flora and fauna) in the high latitudes. Support is focused on the following areas:

- **Marine ecosystem dynamics:** Among the research topics are understanding the natural variability of marine ecosystems, correlating the structure and function of the marginal ice-zone ecosystem with oceanic and atmospheric processes, exploring the sources of nutrition and their influence on prey and on primary production, and examining the role of marine phytoplankton in carbon-dioxide cycling.
- **Terrestrial and limnetic ecosystems:** Organisms in ice-free areas and in perennially ice-covered lakes show remarkable adaptations to extreme environments. The fact that relatively few species thrive here facilitates the study of ecosystem dynamics and the interpretation of experiments, although much more remains to be learned about adaptive mechanisms and evolutionary processes.
- **Population biology and physiological ecology:** At the next level, looking at relationships among organisms, studies have focused on the variability and dynamics of populations of krill and other zooplankton. Ecological relationships among and between fish species, marine mammals, and birds have also been the object of much research, with many issues still to be further explored. Advances in genetic testing now permit scientists to establish relationships that were previously unverifiable between individuals and species in the wild. As organized programs of antarctic science enter their fifth decade (some have been in existence even longer), data sets and ongoing observations are elucidating manmade as well as natural changes.
- **Adaptation:** The extremes of light, temperature, and moisture have resulted in unusual adaptations. Research includes low-temperature photosynthesis and respiration, enzymatic adaptations, and adaptive physiology, such as the development of antifreeze compounds in fish and modifications to the circulatory system in seals. There is also continuing interest in the response of organisms to increased ultraviolet-B radiation from the ozone hole (as well as its impact on them). Here, too, new molecular DNA advances have had a profound impact on the types of studies that can be mounted.
- Genomics. "Genome-enabled" biology provides opportunities to examine polar questions related to structure and function in the environment and to do so with extraordinary depth and precision.
- **Human behavior and medical research:** Antarctica's extreme climate and terrain impose a spartan and unconventional existence on scientists and others who live and work there. As people are subjected to social, psychological, and physiological stresses (exacerbated during the winter isolation), opportunities for research arise. Studies focus on epidemiology, thermal regulation, immune system function, individual behavior, and group dynamics.

Impact of solar radiation and nutrients on biogeochemical cycling of dimethylsulfoniopropionate (DMSP) and dimethylsulfide (DMS) in the Ross Sea, Antarctica.

Ronald P. Kiene, University of South Alabama, and David J. Kieber, State University of New York–Syracuse.

Areas of the Southern Ocean have spectacular blooms of phytoplankton during the austral spring and early summer. One of the dominant species, the haptophyte Phaeocystis antarctica, is a prolific producer of the organic sulfur compound dimethylsulfoniopropionate (DMSP), and Phaeocystis blooms are associated with some of the world's highest concentrations of DMSP and its volatile degradation product, dimethylsulfide (DMS). Sulfur, in the form of DMS, is transferred from the oceans to the atmosphere, where it oxidizes and can affect precipitation chemistry and influence cloud properties and, possibly, climate. DMSP and DMS are also significant components of the carbon, sulfur, and energy flows in many marine food webs, although very little information is available on these processes in high-latitude systems.

We will therefore study how solar radiation and iron cycling affect DMSP and DMS production by phytoplankton and the subsequent use of these labile forms of organic matter by the microbial food web. Four interrelated hypotheses will be tested in field-based experiments and *in situ* observations:

- that solar radiation, including enhanced ultraviolet-B due to seasonal ozone depletion, plays an important role in determining the net ecosystem production of DMS in the Ross Sea;
- that development of shallow mixed layers promotes the accumulation of DMS in surface waters because of enhanced exposure of plankton communities to high doses of solar radiation;

- that DMSP production and turnover represent a significant part of the carbon and sulfur flux through the food webs of polar waters such as the Ross Sea; and
- that bloom development and resulting nutrient depletion (e.g., iron) will result in a high production of DMSP and high DMS concentrations and atmospheric fluxes.

The results of this study will greatly improve our understanding of the mechanisms controlling DMSP and DMS concentrations in polar waters, thereby enhancing our ability to predict DMS fluxes to the atmosphere from this important climatic region.

We actively engage high school, undergraduate, and graduate students in our research and are involved in formal programs that target underrepresented groups. The information gained from this research will also be used in teaching undergraduate and graduate courses. (B–002–N and B–266–N; NSF/OPP 02–30497 and NSF/OPP 02–30499)

Response of terrestrial ecosystems along the Antarctic Peninsula to a changing climate.

Thomas A. Day and Jeffrey M. Klopatek, Arizona State University–Tempe.

The striking increases in air temperatures and ultraviolet-B (UV–B) radiation documented along the west coast of the Antarctic Peninsula over the past 50 years represent a profound climatic change, arguably greater than has been experienced by any other region on Earth during this time. Along with these well-documented changes, annual precipitation and the depth of the winter snow pack along the Peninsula also appear to be increasing. These rapid changes provide a unique opportunity to examine the effects of climate change on terrestrial ecosystems.

Building on past work that focused on the impact of warming and UV–B radiation on terrestrial vascular plants on the Peninsula, we will examine how climate change alters nutrient (carbon and nitrogen) pools and cycling among plants, litter, and soils in vascular-plant-dominated communities, with the overall goal of predicting long-term effects on plant productivity. We will use two complementary approaches.

In the first approach, we will study shorter term responses to climate change by manipulating temperature, water availability, and UV–B exposure of vascular-plant microcosms over three growing seasons. We will assess how these manipulations influence plant growth and primary productivity, carbon dioxide fluxes, litter quality and decomposition, pools and turnover rates of carbon and nitrogen, and the structure of soil microbial and arthropod communities. These realistic manipulations will allow us to accurately assess the effects of different future warming scenarios, as well as the effects of solar UV–B radiation.

In the second approach, we will examine longer term responses to warming by measuring pools of carbon and nitrogen in plants, litter, and soils in plant communities along transects that represent gradients of long-term temperature regimes. Analyzing the results from short-term warming manipulations in the context of patterns found along these gradients will make it possible to develop a conceptual model of warming impacts over time.

The broader impacts of this project include

- recruiting and training undergraduate students from underrepresented minorities;
- disseminating findings to the general public; and
- contributing to society at large by improving our understanding of how climate change affects plant productivity and ecosystem carbon storage, as well as whether ecosystem responses to climate change will mitigate or promote continued buildups of greenhouse gases. (B–003–P; NSF/OPP 02–30579)

Patterns and processes: Dynamics of the Erebus Bay Weddell seal population.

Robert A. Garrott and Jay J. Rotella, Montana State University–Bozeman, and Donald Siniff, University of Minnesota–Twin Cities.

The Erebus Bay Weddell seal (Leptonychotes weddellii) population study in eastern McMurdo Sound was initiated in 1968 and represents one of the longest intensive field investigations of a long-lived mammal in existence. Over more than 35 years, a total of 16,809 animals have been tagged, with 161,994 resighting records logged in the database. This study is a valuable resource for understanding the population dynamics not only of Weddell seals, but also of other species of terrestrial and marine mammals. We are pursuing two lines of investigation that combine the long-term database with new field initiatives.

The continuity of the demographic data will be maintained by annually marking all pups born, replacing lost or broken tags, and performing censuses. We will combine these new data with the existing database and perform a complex series of demographic analyses that will allow us to test specific hypotheses about population regulation and evaluate previously determined temporal and spatial patterns of variation in vital rates among colonies.

The primary new field initiative is an intensive study of the mass dynamics of both pups and adult females to assess annual variation in marine resources and its potential role in limiting or regulating the population. In addition to collecting data on body mass dynamics, we will use satellite imagery to develop an extended time-series of sea ice in McMurdo Sound. (The extent of sea ice affects both regional primary productivity and availability of haul-out areas.) Increased primary productivity may increase marine resources, which would be expected to have a positive effect on foraging efficiency, leading to increased body mass. Understanding the mechanisms that limit or regulate Weddell seal populations and the specific linkages between climate, oceans, ice, and antarctic food webs can make important contributions to the knowledge of pinniped population dynamics, as well as the theoretical understanding of populations, communities, and ecosystems.

Such knowledge can enhance the ability of natural resource managers to effectively maintain assemblages of other large mammal species and the ecological processes they facilitate. Continuation of this long-term study may also contribute to understanding the potential impact of human activities such as global warming and the commercial exploitation of antarctic marine resources. (B–009–M; NSF/OPP 02–25110)

Drinking and sodium/potassium–ATPase alpha-subunit isoform expression and antarctic fish.

David Petzel, Frank Dowd, Margaret Scofield, and Philip Brauer, Creighton University.

Notothenioid fishes inhabiting the near-freezing (–2°C) waters of McMurdo Sound have some of the highest serum and cellular sodium concentrations and the lowest gill sodium/potassium-ATPase (Na/K-ATPase, the sodium/potassium pump) activities of any marine teleost. The enzyme Na/K-ATPase regulates the sodium concentration in the cells of many organisms. Maintaining a high salt content in the cells of these fish lowers the freezing point to allow them to inhabit cold antarctic waters and reduces the salt gradient between them and sea water.

On the basis of previous studies of temperature effects, we hypothesize that compared with New Zealand notothenioids that inhabit warmer waters, antarctic notothenioids have lower drinking rates, lower salt excretion rates, and a higher proportion of the low intracellular sodium affinity for a specific subunit of the Na/K-ATPase (a3-isoform). These unique osmoregulatory properties explain the high serum and cellular sodium concentrations found in notothenioids south of the antarctic Polar Front.

We will compare and contrast the unique osmoregulatory mechanisms of antarctic and New Zealand notothenioids with respect to

- sea water drinking rates and the serum and cellular chemical composition of the fish,
- enzymatic properties and the expression pattern of mRNA and protein, and
- temporal and spatial localization of the Na/K-ATPase a3-isoform subunit in the gills.

To accomplish these objectives, we will study four species of notothenioids, representing ecologically diverse habits above and below the Polar Front.

The information we gain will increase our knowledge about the role of Na/K-ATPase in the cellular function in many organisms, strengthen our understanding of the biochemical and physiological adaptations that allow antarctic notothenioids to survive and thrive in the icy waters south of the antarctic Polar Front, provide field and laboratory research experience for graduate and undergraduate students, and contribute to significant outreach activities in science education for elementary and high school students and teachers. (B–012–M; NSF/OPP 02–29462)

Remotely operable microenvironmental observatory for antarctic marine biology research.

Samuel S. Bowser, New York State Department of Health, and Anthony D. Hansen, Magee Scientific Company.

Research diving over the past two decades has yielded important insights into the ecological importance of giant (larger than 1 millimeter) foraminifera in McMurdo Sound. Unfortunately, the *in situ* behavior of these single-celled organisms and their interactions within the food web can be observed only in "snapshots" during summer dives, when algal production is at a maximum under 24-hour light. Much would be learned by observing foraminifera over extended periods, to study mobility, response to food availability, and other directed behaviors. It would be valuable to be able to extend observations to the winter months to study these organisms in the dark, with no algal production, and to experimentally manipulate *in situ* conditions and observe the behavioral response.

Research diving requires costly support and cannot provide extended observation of individual organisms. Moreover, the logistical requirements, costs, complexities, and risks of winter diving at remote locations in Antarctica are prohibitive. However, human diving is not required to make long-term *in situ* observations. Technology and communications have advanced to the point where it is feasible and practical to install video macro- and microview cameras in a submersible enclosure; they can transmit both live and sequential time-lapse images over the Internet to a remote user throughout the year. Such an instrumentation platform could then be used for experimental manipulation of the environment.

We will develop a submersible, remotely operable underwater observatory for the study of foraminifera and associated benthic fauna. This observatory will be connected to a shoreline unit by fiberoptic cable and linked by radio to the Internet for year-round access. The design and operation of this observatory will function as a technology template to meet other year-round antarctic research requirements by means of telescience rather than personnel deployment. (B–015–M; NSF/OPP 02–16043)

The molecular signals that regulate the ontogeny of aerobic capacity, lipid metabolism, and elevated myoglobin concentrations in the skeletal muscles of Weddell seals.

Shane B. Kanatous, University of Texas.

What are the molecular signals that regulate the changes in skeletal muscle physiology as young Weddell seals *(Leptonychotes weddellii)* develop into elite divers? We will address this broad question during a 3-year study that builds on our previous work, which characterized the enzymatic and structural adaptations for diving that occur in the skeletal muscles of newly weaned, juvenile, and adult Weddell seals and began to define the molecular signals that regulate these ontogenetic changes in skeletal muscles. We will proceed as follows:

- First, we will use enzymatic, immunohistochemical, and myoglobin assays to further characterize the ontogenetic changes in muscle aerobic capacity, lipid metabolism, and myoglobin concentration and distribution in newly weaned, subadult, and adult seals.
- Second, we will determine the molecular controls that regulate these changes in aerobic capacity, fiber type distribution, and myoglobin in skeletal muscles during maturation.

Through subtractive hybridization and subsequent analysis, we will determine the differences in mRNA in the swimming muscles of the different age classes of seals. These techniques will allow us to identify the proteins and transcription factors that influence the ontogenetic changes in myoglobin concentration, fiber type distribution, and aerobic capacity. The results will increase our

understanding of the ontogeny and molecular mechanisms by which young seals acquire the physiological ability to make deep (up to 700 meters) and long (about 20 minutes) aerobic dives.

This study will advance our knowledge of the molecular regulation of adaptations that enable active skeletal muscle to function under hypoxic conditions; this has broader applications for cardiac and pulmonary disease in humans. The project will involve a postdoctoral fellow and two graduate students and also has a significant outreach component. In addition to interviews, e-mail exchanges with high school and middle school students, public seminars, and presentations at meetings, we will continue to support our Web site in collaboration with the Science Teachers Access to Resources at Southwestern (STARS) Program (www.swmed.edu/stars/02antarcticexpedition), where we supply weekly updates about our research during the field season, answer questions from students and teachers, and supply periodic off-season updates on our results. (B–018–M; NSF/OPP 04–40713)

Genomic networks for cold-adaptation in the embryos of polar marine invertebrates.

Adam G. Marsh, University of Delaware.

Although the cold ocean ecosystems comprise 72 percent of Earth's biosphere by volume, they remain sparsely inhabited and relatively unexploited, particularly the metazoan phyla. Consequently, the few animals that can exist at this border of intracellular freezing are ideal for exploring genomic-level processes of environmental adaptation. Understanding life at the margin will convey significant insights into the processes essential for survival under intense selection pressures.

Our study of adaptive mechanisms in genomic networks focuses on a system that faces a formidable challenge at cold temperatures: embryonic development of two antarctic echinoderms, the seastar *Odontaster validus* and the sea urchin *Sterechinus neumayeri,* at sea water temperatures of –1.8°C. We will quantify temperature effects on gene expression and protein turnover networks during early development by using a Bayesian network analysis (a method of statistical analysis) to identify clusters of genes and proteins whose levels of expression are associated in fixed, synergistic interactions. Ultimately, the question to be addressed is whether it is more or less difficult (complex) for an embryo to develop in an extreme environment. To answer this question, we will decipher network topologies and subnet structuring to uncover gene connectivity patterns associated with embryonic development in this polar environment. We also intend to interest students in the developing field of environmental genomics by increasing the awareness of career opportunities within the field and increasing the racial diversity of those attracted to it.

Working in a remote, extreme environment such as Antarctica is always a challenge, but the adventurous nature of the work can be used to establish educational and outreach components of high interest to both undergraduate students and the public. We will bring the experience of working in Antarctica to a larger audience by

- incorporating environmental genomics into a new bioinformatics curriculum being developed at the University of Delaware,
- implementing an intern program to involve minority undergraduates in summer research in the United States and then to bring them to Antarctica to participate in research, and
- creating a K–12 education program that will bring the excitement of working in Antarctica to the classrooms of thousands of children (in the United States and around the world) through a program produced in conjunction with the Marine Science Public Education Office at the University of Delaware. (B–029–M; NSF/OPP 02–38281)

Geographic structure of Adélie penguin populations: Demography of population expansion.

David G. Ainley, H.T. Harvey and Associates, and R. Glenn Ford, RGFord Consulting.

In collaboration with scientists from New Zealand, Italy, and France, we are investigating the mechanisms responsible for the geographic structuring, the founding of new colonies, and the recent population expansion of the Adélie penguins *(Pygoscelis adeliae)* of Ross and Beaufort Islands. Similar expansion has been occurring throughout the Ross Sea, where 38 percent of the world's population of this species resides, and is in some way related to ameliorating climate. We continue to examine

- the relative importance of resources that constrain colony growth;
- aspects of natural history that might be affected by exploitative or interference competition among neighboring colonies;
- climatic factors that influence the latter;
- behavioral mechanisms that influence colony growth; and
- foraging effort, as a function of diving and swimming capabilities and food availability.

We have shown how sea ice affects diet, foraging, and winter survival. In addition, the large colony at Cape Crozier, in concert with minke and killer whales, affects the foraging patterns of penguins at the smaller colonies and, perhaps, their size. Emigration also appears to be constrained by sea ice, with reasonable concentrations of ice favoring the growth of smaller colonies where foraging competition is minimal.

We will use 10 cohorts of marked penguins from each colony to assess juvenile survival, recruitment age, and age-specific fecundity and subsequent survival. These data will be compared with another demographic study, the only one for this species, conducted at Cape Crozier during the 1960s and 1970s, when populations were declining. Satellite tags are providing information on local, foraging movements, and geolocation tags are providing information on the winter journeys of southern Ross Sea penguins.

Information will be related to sea ice as quantified by satellite images. Global climate is changing the fastest in the polar regions. The Adélie penguin is tied to sea ice, a primary factor in rapid polar climate change. Our study will contribute greatly to understanding the effects of climate change on antarctic marine organisms. (Additional information can be found on our Web site: www.penguinscience.com.) (B–031–M; NSF/OPP 0440643)

Investigations on deterioration in the historic huts of Antarctica.

Robert A. Blanchette, University of Minnesota.

During the first two decades of the 20th century, Europeans mounted a handful of expeditions in hopes of reaching (and claiming) the geographic South Pole. Base camps established in the McMurdo Sound region by Scott at Hut Point and Cape Evans and by Shackleton at Cape Royds were abandoned once the expeditions were over, leaving behind thousands of artifacts, as well as the huts the explorers built for shelter and storage. Over the intervening 90 years, the extremes of the polar environment have actually protected some of the artifacts from rapid decay, but conservators have become concerned about the serious degradation of what is an important historical, archaeological site.

Some of the gravest threats are as follows:

- Wood in contact with the ground is being destroyed by a fungus. Also, various molds and cellulose-degrading fungi are attacking artifacts made of leather, textiles, and other organic materials.
- Exterior wood is being degraded by nonbiological processes as well, including salt, ultraviolet radiation, and wind erosion.
- Chemical damage within the huts is apparent, and the soils on the site are contaminated with aromatic hydrocarbons from petroleum products.

We plan to identify the biological and nonbiological agents responsible for the deterioration, study the mechanisms and progressive sequence of the events taking place, test methods to be used to control future deterioration, determine the extent of environmental pollutants in soils at the historic sites, and evaluate chemical spills within the huts. The goal is to provide the scientific data conservators need to help protect these important sites for future generations. But the project should also shed light on these unique deterioration processes, as well as augment scientific understanding of the biology of antarctic microorganisms and the biodiversity of microbes present in this unusual environment. (B–038–M; NSF/OPP 02–29570)

Foraging behavior and demography of *Pygoscelis* penguins.

Wayne Z. Trivelpiece, National Oceanic and Atmospheric Administration.

Seabird research conducted at Admiralty Bay, King George Island, in the Antarctic Peninsula region has documented annual variability in the life history parameters of the population biology of three related penguin species: the Adélie, the gentoo, and the chinstrap (*Pygoscelis adeliae, P. papua,* and *P. antarctica,* respectively). This long-term study has collected more than 25 years of data on these three related species, including survival and recruitment, population size and breeding success, and diets and foraging ecology.

We will extend the research linking penguin demography and foraging ecology to variability in the antarctic marine ecosystem. A major focus will be on the population biology data for the Adélie and gentoo penguins and the distribution and trophic interactions among the three species during the breeding season and the nonbreeding, winter period. Recent studies using satellite tags and time-depth recorders to examine postfledging foraging have provided the first detailed data on the wintering distributions of Adélie and chinstrap penguins in the Antarctic Peninsula.

Specific topics include an examination of the size and sex of krill captured by penguins feeding chicks and krill collected concurrently by net hauls in the adjacent marine environment and the length-frequency distribution of krill collected from penguin diet samples. The winter survival of breeding adults and the recruitment of young (2- to 4-year-old) prebreeding penguins to their natal colony will be compared with the extent of sea ice in the winter before the breeding season. These variables are expected to be positively correlated for the Adélie but negatively correlated for the chinstrap penguin. Detailed studies of adult gentoo penguins, which do not disperse widely from their natal colony, will be conducted using satellite tags.

The data we gather on the impact of environmental variation on the structure of upper-trophic-level predators such as the *Pygoscelis* penguins will improve our understanding of the structure and function of the Antarctic. (B–040–E; NSF/OPP 01–25985)

Evolution of morphology and trophic strategies in antarctic agglutinated foraminifera.

Samuel S. Bowser, New York State Department of Health.

We will study, in an interdisciplinary fashion, the evolution and ecological significance of foraminiferan protists, a major but neglected group of marine organisms. For over a decade, we have studied the cell biology, ecophysiology, and evolution of single-chambered foraminifera (allogromiids), focusing on giant (larger than 1 millimeter) high-latitude species.

Our studies have revealed a high degree of diversity in this group. The molecular phylogenetic framework is based on studies of a single gene (ribosomal small subunit or SSU) that, unfortunately, does not clearly indicate the relationship between major groups. Adding to the confusion is the fact that morphological characters traditionally used for species identification are not distributed in any meaningful way on the SSU tree. Therefore, there is no well-determined phylogeny to evaluate ecological and evolutionary hypotheses. Also, morphological identifications in the field do not always reflect the underlying biological reality. Without a better understanding of morphology, genetic identity, and ecologically relevant behavior, studies of this group are less likely to yield meaningful data.

We will study a taxonomically definitive group of allogromiids to generate a more robust, detailed phylogeny and use this new evolutionary framework as a springboard to test hypotheses in polar marine science. Specifically, we will investigate the biogeography of morphospecies that appear to be distributed in both arctic and antarctic waters. We will also use newly established underwater macroscopy equipment, lipid biomarker analyses, and predator/prey assays to determine the extent of carnivory within the early-evolving lineages. Ultimately, we intend to further develop rapid molecular screening methods for ecological studies and to understand the forces that led to the early diversification of foraminifera, whose origin dates from the Neoproterozoic and spans the dawn of skeletonization in multicellular organisms.

Our interactions with other scientists and international collaborations help transfer state-of-the-art advances in biomedical research to the ocean sciences. We will continue to promote the training of women and underrepresented groups through grass-roots efforts and participation in formal regional and national programs. Moreover, we interface original research with K–12 education and public outreach and will continue to partner with science teacher organizations and educational foundations that emphasize hands-on learning. (B–043–M; NSF/OPP 04–40769)

Interannual variability in the Antarctic–Ross Sea (IVARS): Nutrients and seasonal production.

Walker O. Smith, College of William and Mary, Virginia Institute of Marine Sciences.

During the past few decades, oceanographers and other scientists have found significant variations in Southern Ocean biogeochemical processes from year to year. Some of the more significant of these interannual variations are the extent and concentration of the ice, the composition of herbivore communities, and the distribution and reproductive success of birds and marine mammals.

Even though phytoplankton production is central to the food web, surprisingly little is known about how it varies from year to year or what role these variations may play. The production system in the Ross Sea consists predominantly of two major functional groups: diatoms and *Phaeocystis antarctica,* a colonial haptophyte. We will collect time-series data and assess the interannual variations of phytoplankton in the southern Ross Sea.

The Ross Sea provides a unique setting for such an investigation. We can build on a de facto, already ongoing time-series because so many studies have been conducted there in the past decade. Also, it has been established that there are fewer species there (relative to some other sites) and that seasonal production is as great as anywhere in the Antarctic. Most important, seasonal production of the total phytoplankton community (as well as its two functional groups) can be estimated from late summer nutrient profiles.

Interannual variations in seasonal production (and of the two major taxa of producers) may be an important factor in the growth and survival of higher trophic levels within the Ross Sea food web. They also shed light on the natural variability of the suite of biogeochemical processes in the region. Having a scientific handle on that baseline of change is important because of efforts to model how climate may change in the future. As climate changes, so certainly will biology be profoundly affected, and to model and evaluate such change we need to place it in the context of natural interannual variability. (B–047–M/N; NSF/OPP 00–87401)

Complex molecular-to-global interactions and feedbacks in the marine dimethylsulfide (DMS) cycle.

Patricia Matrai, Bigelow Marine Laboratory.

Ocean ecosystems are part of a complex web that transforms matter and energy and sets the conditions for life on Earth. Communication and feedback among different parts of this web are mediated by the exchange of biogenic trace gases. One feedback involves marine plankton, the volatile sulfur compound dimethylsulfide (DMS), and global climate. DMS produced by marine phytoplankton and the food web enters the troposphere and is oxidized to sulfate particles, which influence cloud albedo and, consequently, climate. Large-scale climate change, in turn, affects the abundance of phytoplankton and food web processes in the oceans and thereby closes the loop.

The strength of this loop is still unknown because of the complex processes that affect DMS emission. No field studies have measured all of the relevant rates and concentrations in the marine DMS cycle simultaneously, nor have complex interactions or measurements been included for important geophysical and chemical parameters, thus hampering the ability of models to accurately map variations in surface DMS concentrations. To address this problem, we will

- measure and model all relevant fluxes of concentrations of DMS and related species in a subtropical gyre and the Southern Ocean,
- develop a global marine DMS model from the field measurements and other existing measurements and models, and
- use this model to evaluate the potential for feedbacks between climate and the DMS cycle.

The DMS system helps explain the complexities in biosphere-geosphere regulation and serves as an excellent model for food-web-dependent biogeochemical processes. Because dimethylsulfoniopropionate (DMSP), the precursor of DMS, is intimately connected to virtually all levels of the food web and because DMSP itself contributes significantly to the carbon flow in the ocean, our investigation will shed light on the critical factors influencing the distribution of organisms in the sea and the cycles of major nutrient elements.

We will include undergraduate and graduate students, as well as a postdoctoral modeler and two K–12 teachers, and create an interactive page on the Bigelow Web site. In addition, each of the investigators will formalize ongoing interactions with regional K–12 schools by creating and using a shared presentation. (B–048–P; NSF/OPP 02–21748)

Free-drifting icebergs: Influence of floating islands on pelagic ecosystems in the Weddell Sea.

Kenneth L. Smith, University of California–San Diego, Scripps Institution of Oceanography.

Over the past decade, atmospheric warming has been associated with retreating glaciers and the increasing prevalence of icebergs in the Southern Ocean. The highest concentration of icebergs occurs in the northwest Weddell Sea, where they drift in a clockwise pattern to the northeast, following the contours of the Antarctic Peninsula through an area called "Iceberg Alley." But little is known about the impact of free-drifting icebergs on the pelagic ecosystem of the Weddell Sea or the Southern Ocean as a whole.

We believe that small to intermediate-size icebergs (less than 10 kilometers) impart unique physical, chemical, and biological characteristics to the surrounding water. Our research will address three questions:

- What are the dynamics of free-drifting icebergs on temporal scales of days to months, based on the correlation of field measurements with imagery from satellite sensors?
- What is the relationship between the size of free-drifting icebergs and the structure of the associated pelagic communities?
- What is the estimated combined impact of free-drifting icebergs in the northwest Weddell Sea on the biological characteristics of the pelagic zone?

We will use oceanographic sampling to determine the sphere of influence for a set of biological factors as a function of iceberg size. Our program is divided into four components:

- remote sensing of icebergs,
- phytoplankton communities,
- zooplankton and micronekton assemblages, and
- iceberg ecosystem synthesis/modeling.

Our research will provide critical data on the effects of atmospheric warming on the Antarctic Peninsula. The recent prevalence of free-drifting icebergs should have a pronounced enrichment effect on the pelagic ecosystem in the Southern Ocean. Enhanced primary production associated with them could influence the global carbon cycle, since the Southern Ocean is considered a major sink for excess carbon dioxide from the atmosphere.

Our results will be incorporated into a collaborative effort called the Ocean Exploration Center, whose focus is to provide researchers and the public with a comprehensive view of the oceans and direct access to databases and Web sites. These data will then be extrapolated to evaluate the impact of icebergs on the ecosystem and archived in a digital library. (B–050–L; NSF/OPP 05–29815)

Former elephant seal colonies in the Antarctic: Implications for Holocene climate change and genetic diversity in the Southern Ocean.

Brenda L. Hall, University of Maine, and Paul Kock, University of California–Santa Cruz.

What drives climate change? Long-term fluctuations may be paced by astronomical cycles, but how these factors and shorter-term variations control climate is poorly understood. The Southern Ocean and Antarctica are crucial for testing hypotheses of global change because their climate may be out of phase with that of the rest of the world. If this is true, it would favor the hypothesis that abrupt climate changes are caused by variations in ocean circulation. We will therefore develop data to address the pattern, timing, and cause of Holocene climate change.

During previous research, we discovered that colonies of southern elephant seals *(Mirounga leonina)* once existed along the Victoria Land coast. Molted sealskin and hair are found along 300 kilometers (km) of coastline, more than 1,000 km from any extant colony. The colony was apparently abandoned about 1600 A.D., possibly because of cooling and the encroachment of land-fast, perennial sea ice that made access to haul-out sites difficult. The record of seal habitation along the Victoria Land coast may therefore be a proxy for climate change.

We will address several questions:

- Why did elephant seals colonize and then abandon the coast?
- What does the record reveal about Holocene climate change and sea-ice conditions?
- What were the seals' foraging strategies and did they change with the climate?
- What is the genetic structure of the Victoria Land seals versus extant populations?
- How did genetic diversity change?
- What can we learn about population dynamics?
- What was the relationship between elephant seals and the Adélie penguins that occupied the sites at different times?

Carbon and nitrogen isotope analyses will provide information on changes in feeding strategies. We will document past sea-ice conditions by beach morphology and sedimentology and determine genetic structure from skin sample analyses. These data will allow us to develop an integrated history of the Victoria Land colonies.

Data from this study will be compared with existing records and used to develop a proxy for Holocene climate. Our research will allow us to test hypotheses of global climate change, modify graduate and undergraduate courses, and train new researchers. (B–068–M; NSF/OPP 04–39979 and NSF/OPP 04–39906)

Long-term data collection at select Antarctic Peninsula visitor sites.

Ron Naveen, Oceanites, Inc.

The Antarctic Site Inventory Project has collected biological data and site-descriptive information in the Antarctic Peninsula since 1994. This research has provided data on sites visited by tourists on shipboard expeditions in the region. Our aim is to obtain data on the population of several key species of antarctic seabirds that might be affected by the cumulative impact of visits to the sites. We will focus on two heavily visited Antarctic Peninsula sites: Paulet Island, in the northwestern Weddell Sea, and Petermann Island, in the Lemaire Channel near Anvers Island. We selected these sites because both rank among the 10 most visited sites in Antarctica each year in terms of numbers of visitors and zodiac landings, both are diverse in species composition, and both are sensitive to potential environmental disruptions from visitors.

We will collect data over 5 years on two important biological parameters for penguins and blue-eyed shags:

- breeding population size (number of occupied nests) and
- breeding success (number of chicks per occupied nest).

Our main focus will be Petermann Island, which we selected for intensive study because of its visitor status and location near Palmer Station. This will allow us to compare data with the Palmer Long-Term Ecological Research Program.

We will collect demographic data in accordance with the standard methods established by the Convention for the Conservation of Antarctic Marine Living Resources Ecosystem Monitoring Program, and the information we gather will thus be comparable to similar data sets being compiled by the research programs of other Antarctic Treaty nations. While separating human-induced change from change resulting from a combination of environmental factors will be difficult, this work will provide a first step toward identifying potential impacts. The long-term data sets we compile will contribute to a better understanding of biological processes in the entire

region and will also contribute valuable information to be used by Antarctic Treaty nations as they address environmental stewardship issues in Antarctica. (B–086–E; NSF/OPP 02–30069)

Distribution and ecology of ammonia-oxidizing bacteria in the Palmer Long-Term Ecological Research study area.

James T. Hollibaugh, University of Georgia.

We propose to investigate the distribution, phylogenetic affinities, and aspects of the ecology of ammonium-oxidizing bacteria in the Palmer Long-Term Ecological Research (LTER) study area. Ammonia oxidation is the first step in the conversion of regenerated nitrogen to dinitrogen gas via denitrification, a three-step pathway mediated by three distinct guilds of bacteria. Although important to the global nitrogen cycle, ammonia oxidation and the overall process of nitrification-denitrification have received little attention in polar oceans where they are significant and where the effects of climate change on biogeochemical rates are likely to be pronounced.

Our goals are to

- obtain more conclusive information on the composition of antarctic ammonia oxidizers,
- begin characterizing their ecophysiology and ecology, and
- obtain cultures of the organism for more detailed studies.

We will characterize water column and sea-ice assemblages of ammonia-oxidizing bacteria phylogenetically and quantify different kinds in various samples. We will also measure nitrification rates across the LTER study area in water column, sea-ice, and sediment samples, determining grazing rates and evaluating the sensitivity of these bacteria to ultraviolet light. In addition, we will assess the significance of urea nitrogen as a source of reduced nitrogen to these bacteria. Finally, we will evaluate the response of nitrification over temperature ranges appropriate to the polar regions.

Our work will provide insights into the ecology of ammonia-oxidizing bacteria and the knowledge needed to model how water-column nitrification will respond to changes in the polar ecosystems accompanying global climate change. (B–114–L; NSF/OPP 02–34249)

Toward an understanding of protein homeostasis in cold-adapted antarctic fish.

Gretchen E. Hofmann, University of California–Santa Barbara.

We will examine protein homeostasis in the cells of antarctic notothenioid fishes. Since previous research has suggested that these proteins may be subject to a great deal of misfolding at the subzero temperatures typical of antarctic coastal waters, we will continue to use a comparative approach highlighting the physiological differences between temperate New Zealand notothenioid fishes and antarctic fishes. Specifically, we will

- use ubiquitin conjugate analysis to measure the levels of damaged proteins tagged and targeted for degradation by the proteasome in the cells of antarctic fishes;
- estimate the efficiency of protein synthesis in cold-adapted antarctic fish cells by using isolated hepatocytes, pulse-chase experiments, and proteasome inhibitors to measure the levels of defective ribosomal products and determine the efficiency of protein biogenesis;
- measure relative 26S proteasome activity in the cells of antarctic fishes by using an established *in vitro* fluorometric assay to provide insight into whether cells are processing high levels of misfolded or otherwise damaged proteins; and
- assess the nature of cold-adapted gene expression in antarctic fishes compared with their temperate New Zealand relatives by examining the patterns of specific genes by means of real-time polymerase chain reactions.

Further, in collaboration with other researchers, we will use DNA microarray analysis to examine genomic-scale gene expression patterns in antarctic fishes compared with the New Zealand species to provide a more global view and to highlight whether deficient expression or alteration in gene expression is found after evolution at subzero temperatures.

In addition to providing undergraduate and graduate students with research experience, we will have an extensive program that includes both K–12 curriculum development and informal outreach. Our team includes an award-winning middle-school science teacher and a writer/journalist who focuses on environmental issues and has written children's books. These efforts will be coordinated through a program called *Oceans Alive!* Sponsored by the Marine Science Institute at the University of California–Santa Barbara, this program has as its primary goal to increase public understanding of earth and ocean science. This collaboration and participants' significant educational expertise will ensure that our efforts will be communicated to a wider audience. (B–134–M; NSF/OPP 04–40799)

Microbial diversity and function in the permanently ice-covered lakes of the McMurdo Dry Valleys, Antarctica.

John C. Priscu, Montana State University–Bozeman; Brian D. Lanoil, University of California–Riverside; Michael T. Madigan, Southern Illinois University–Carbondale; and Steven J. Giovannoni, Oregon State University.

We plan to study prokaryotic organisms in the permanently ice-covered lakes of the McMurdo Dry Valleys in order to identify and characterize novel organisms and elucidate those aspects of their genome and metabolism that are critical to understanding their role in biogeochemical cycles. We will use molecular tools in concert with conventional and high-throughput culturing techniques to define representative prokaryotic groups responsible for the contemporary geochemical gradients existing in these lakes.

The McMurdo Dry Valleys form the driest and coldest ecosystem on Earth and, until relatively recently, have been thought to harbor little life. A primary reason for establishing a microbial observatory for these lakes is to understand not only how the environment controls the diversity of organisms, but also how diversity itself controls the way ecosystems function. The McMurdo Dry Valley lake systems lend themselves to answering this question in a unique way. Given their isolation, the lack of higher life forms, and their

evolutionary history, these lakes offer a unique experimental arena to search for novel microorganisms and to study the interplay of microbial diversity and ecosystem function.

The results we derive will be significant to the growing body of literature in biodiversity, biotechnology, geobiology, polar ecology, and astrobiology. We will work with existing and new programs to archive the phylogenetic and physiological data we collect so that anyone who is interested can access it easily over the Internet. Strong linkages will be made with the highly visible education, outreach, and human diversity programs supported by the National Science Foundation's Office of Polar Programs and the McMurdo Long-Term Ecological Research Program to yield a project that will have a broad impact on society. (B–195–M; NSF/OPP 02–37335, NSF/MCB 02–37576, NSF/MCB 02–37434, and NSF/MCB 02–37689)

Diving physiology and behavior of emperor penguins.

Paul J. Ponganis, University of California–San Diego, Scripps Institution of Oceanography.

The emperor penguin, *Aptenodytes forsteri,* is the premier avian diver and a top predator in the antarctic ecosystem. The routine occurrence of 500-meter dives during foraging trips is a physiological and behavioral enigma. We will attempt to determine how and why emperor penguins dive as deeply and long as they do by examining four major topics: pressure tolerance, management of oxygen stores, end-organ tolerance of diving hypoxemia/ischemia, and deep-dive foraging behavior. These subjects are relevant to the role of the emperor as a top predator and to critical concepts in diving physiology, including decompression sickness, nitrogen narcosis, shallow water blackout, hypoxemic tolerance, and extension of aerobic dive time.

We will test the following hypotheses:

- Prevention of nitrogen narcosis and decompression sickness in emperor penguins is due to inhibition of pulmonary gas exchange at depth.
- Shallow water blackout does not occur because of greater cerebral hypoxemic tolerance and, in deep dives, because of resumption of pulmonary gas exchange during the final ascent.
- The rate of depletion of blood oxygen stores is a function of the depth of the dive and the heart rate.
- The aerobic dive limit reflects the onset of lactate accumulation in locomotory muscle, not total depletion of all oxygen stores.
- Elevation of tissue antioxidant capacity and free-radical scavenging enzyme activities protect against the ischemia and reperfusion that routinely occur during diving.
- During deep dives, the antarctic silverfish, *Pleuoragramma antarcticum,* is the primary prey.

In addition to evaluating these hypotheses, we will cooperate with U.S. and foreign organizations such as the National Institute of Polar Research in Japan, Centro de Investigaciones del Noroeste in Mexico, National Geographic, University of Texas Southwestern Medical Center, and Sea World. Our work will be featured in National Geographic television documentaries that will provide unique educational opportunities for the general public.

Development of state-of-the-art technology (e.g., blood oxygen electrode recorders, blood samplers, and miniaturized digital cameras) will lay the groundwork for future research. Moreover, during our fieldwork at several Ross Sea colonies, we will continue to evaluate the effects of the B–15 iceberg on the breeding success of emperor penguins. (B–197–M; NSF/OPP 02–29638)

Monitoring the effects of tourism and environmental variability on Adélie penguins at Palmer Station, Antarctica.

William R. Fraser, Polar Oceans Research Group.

The potential consequences of antarctic tourism on Adélie penguins *(Pygoscelis adeliae)* have been debated for more than 20 years. However, the rapid proliferation of these activities since 1970, particularly on the Antarctic Peninsula, has not only forced an extension of these questions to wildlife populations in general, but also colored them with a sense of urgency and controversy that has polarized opinions. The key concern is that continued increases in these activities will eventually overcome the ability of research to address critical issues in a timely and biologically meaningful manner. This is a valid concern, since studies to examine human impacts have either not been implemented at critical sites or are limited in scope because of logistic and experimental constraints.

Understanding how tourism might affect Adélie penguins rests on the need to quantify and understand the natural variability manifested by breeding populations over space and time. However, although it is generally recognized that without these data it will be difficult to critically assess any localized changes from tourism, this ecosystem approach is expensive and complex and is not likely to be justified by the need to understand tourist impacts.

We will continue a tourist monitoring program underway at Palmer Station as part of a large ecosystem-scale study. Palmer Station mirrors current patterns in tourism and tourist-wildlife interactions in the western Antarctic Peninsula. It also provides unique opportunities for research on human impacts, including the presence of long-term databases that document environmental variability in both marine and terrestrial habitats, as well as the ability to examine potential tourist impacts as part of controlled experiments.

Our research will expand on two key findings. One is the discovery of a previously unrecognized source of variability in the Adélie penguin population resulting from interactions between landscape geomorphology and changing patterns of snow deposition due to climate warming. The other is the observation that penguins breeding in less desirable landscapes may be more susceptible to cumulative impacts induced by the presence of human activity.

These findings have important implications for understanding interactions between climate change and ecosystem response, and for detecting, mitigating, and managing the consequences of human activities such as tourism. (B–198–P; NSF/OPP 01–30525)

Interactive effects of ultraviolet radiation and vertical mixing on phytoplankton and bacterial productivity of Ross Sea *Phaeocystis* bloom.

Wade H. Jeffrey, University of West Florida; Patrick J. Neale, Smithsonian Institution; and Ann E. Gargett, Old Dominion University.

Ultraviolet (UV) radiation influences plankton in the near-surface waters of most ecosystems. In particular, the Southern Ocean is affected in the austral spring, when UV radiation is enhanced by ozone depletion. While progress has been made in estimating the impact of UV radiation on bacteria and phytoplankton in the Southern Ocean, important issues remain to be resolved. Little is known, for example, about responses by the colonial haptophyte *Phaeocystis antarctica,* which dominates spring blooms in the southern Ross Sea. The presence of open water at a far southerly location, well within the ozone hole in the spring, and of continuous daylight, with implications for DNA repair, make the Ross Sea of intense interest.

A number of studies suggest that vertical mixing can significantly modify the impact of UV radiation. However, the limited measurements that have been done of turbulence intensity in the surface layer have not been integrated with studies of the effects of UV radiation on phytoplankton and bacterioplankton. To address these issues, we will focus on vertical mixing and UV radiation in the Ross Sea and characterize phytoplankton and bacterioplankton responses in laboratory and solar incubations. These studies will lead to biological weighting functions and response models capable of predicting the impact of UV radiation on photosynthesis, bacterial incorporation, and DNA damage in the surface layer.

We will measure depth-dependent profiles of DNA damage, bacterial incorporation, photosynthesis, and fluorescence parameters over a 24-hour cycle. We have optimized measurements for typical springtime conditions in the Ross Sea, where stabilizing influences like solar heating and/or surface freshwater from melting ice mean that there is not enough turbulence to thoroughly mix the upper layer.

We will develop fine-scale vertical density profiles to directly estimate large eddy scales. Estimated turbulent diffusivities and eddy scales will be directly related to surface layer effects and used to generate models of UV radiation responses in the surface mixed layer.

This first in-depth study of UV radiation in the Ross Sea will enhance understanding of vertical mixing processes, trophic interactions, and biogeochemical cycling and will provide a valuable comparison with previous work in the Weddell–Scotia Confluence and Palmer Station regions. (B–200–N, B–203–N, and B–208–N; NSF/OPP 01–27022, NSF/OPP 01–27037, and NSF/OPP 01–25818)

Ultraviolet-radiation-induced changes in the patterns of production and biochemical composition of antarctic marine phytoplankton.

Joaquim I. Goes, Bigelow Marine Laboratory.

There is enough evidence to show that present levels of incident ultraviolet (UV) radiation—280 to 400 nanometers (nm)—are impairing phytoplankton productivity in the Southern Ocean. Yet efforts aimed at extrapolating these findings to allow accurate and unambiguous predictions of the consequences of UV radiation on the antarctic marine food web and biogeochemical cycles in the sea have been confounded by uncertainty. Estimates of the effects of UV radiation on the antarctic marine ecosystem range from insignificant to catastrophic. This disparity has been attributed to lack of information in key areas of photobiology and photochemistry.

Generally, studies have been based on broadband UV radiation and do not take into account competing responses of phytoplankton at different wavelengths across the waveband. Such information is critical if we are to understand the consequences of UV radiation enhancement on carbon assimilation by marine phytoplankton and its consequences for the food web and biogeochemical cycles. This is especially true in regions like the Antarctic, where stratospheric ozone concentrations can decrease by about 50 percent each spring, thereby altering the proportion of UV–B (280 to 320 nm) and UV–A (320 to 400 nm) radiation that phytoplankton receive during their growth season.

We will systematically investigate changes in the production rates and composition of biochemical compounds within antarctic phytoplankton cells under spectrally defined conditions. We will examine both laboratory cultures and natural populations in order to understand

- how the cellular biochemical processes of phytoplankton are affected by the interplay between the different UV wavelengths and visible light,
- how sensitivity to UV radiation varies across taxonomic groups of phytoplankton, and
- whether this difference in sensitivity is responsible for the dominance of one species over the other.

We will also study the effect of UV radiation on nutrient uptake by phytoplankton cells. The information we gain will help ascertain the role of UV radiation in the phytoplankton dynamics of the Southern Ocean. (Additional information can be found on our Web site: http://www.bigelow.org/arctic/goes.html.) (B–206–N; NSF/OPP 01–26150)

Comparative and quantitative studies of protistan molecular ecology and physiology in coastal antarctic waters.

Rebecca J. Gast and Mark R. Dennett, Woods Hole Oceanographic Institution, and David A. Caron, University of Southern California.

Phototrophic and heterotrophic protists (single-cell organisms—e.g., protozoa) are ubiquitous in extreme cold-water environments, where they are central to the production and use of energy and the cycling of elements. The dominance of protists in antarctic food webs indicates major ecological and biogeochemical roles for these unicellular eukaryotes. Understanding the structure and diversity of these communities and the adaptations that allow them to flourish near the lower limit of temperature in the ocean is of fundamental importance to a knowledge of biological oceanography, as well as the activities and evolution of life on our planet.

The diversity of protistan assemblages has traditionally been studied using microscopy and morphological characterization. Such an approach is inadequate for ecological studies of these communities due to its tedious nature and the inherent lack of taxonomic characters associated with most small protists. Molecular methods that use gene sequences to identify and quantify naturally occurring protists offer a better solution to this problem.

We will perform molecular and physiological studies on protistan assemblages in the sea water and ice habitats of the Ross Sea to address community structure, population abundance, and adaptation to life in extreme cold. We will focus primarily on species of

phagotrophic protists (protozoa) that are ecologically important but for which no information exists. Our work is designed to contribute to the understanding of the biodiversity of the protistan assemblages of coastal Antarctica, to provide tools for ecological studies, and to produce benchmark data on the basic physiological processes of protistan species in this extreme cold-water environment. (B–207–N; NSF/OPP 01–25833 and NSF/OPP 01–25437)

National Aeronautics and Space Administration–Astrobiology for Science and Technology for the Exploration of Planets: Subsurface ice and brine sampling—using an ultrasonic gopher for life detection and characterization in the McMurdo Dry Valleys.

Peter T. Doran, University of Illinois–Chicago.

Evidence for ice and fluids near the surface of Mars in both the distant and the recent past is growing with each new mission to the planet. One explanation for fluids forming spring-like features on Mars is the discharge of subsurface brines. These offer potential refugia for extant Martian life, and near-surface ice could preserve a record of past life as well. Proven techniques to get underground to sample these environments and get below the disruptive influence of the surface oxidant and radiation regime will be critical for future astrobiology missions to Mars. We will therefore develop and test a novel lightweight, low-power, ultrasonic corer in the McMurdo Dry Valleys, a Mars analogue environment.

Previous data from Lake Vida, one of the largest lakes in the Dry Valleys, reveal that brine with a salinity seven times greater than that of sea water and a temperature constantly below –10°C lies beneath roughly 20 meters (m) of ice that is at least 2,800 radiocarbon years old. Microbial mats occur throughout the ice column and are viable when thawed. Sediment layers in the ice effectively block incoming solar radiation. Ice below 16 m in depth and the brine body have never been sampled directly.

We will test two general hypotheses:

- Microbial communities within the brine and benthic sediments are viable and active and affect the geochemistry of the lake.
- The ice, brine, and benthos contain geochemical signatures of past microbiological activity.

The combined cold, hypersaline, aphotic, and atmospherically isolated conditions in Lake Vida make it one of the most extreme aquatic environments on Earth. The conditions that exist there were likely to have been present during the last stages of the purported lakes on Mars. The technology we develop and the experience we gain will be directly applicable to future Mars missions. It should also be possible to apply our results to shallow coring on Europa. (B–211–M; NASA/ASTEP 02–000–0036)

Plankton community structure and iron distribution in the Southern Drake Passage and Scotia Sea.

B. Greg Mitchell, University of California–San Diego, Scripps Institution of Oceanography; Christopher Measures, University of Hawaii–Manoa; Meng Zhou, University of Massachusetts–Boston; and Matthew Charette, Woods Hole Oceanographic Institution.

The Shackleton Fracture Zone (SFZ) in the Drake Passage defines a boundary between low- and high-phytoplankton waters. Low-chlorophyll water flowing through the southern Drake Passage emerges as high-chlorophyll water to the east. Previous results indicate that the southern front of the Antarctic Circumpolar Current goes south of the SFZ onto the Antarctic Peninsula shelf, where mixing occurs. The mixed water advects off-shelf with elevated iron and chlorophyll-a. Studying the SFZ can improve understanding of plankton responses to natural iron fertilization and their influence on the export of carbon to the ocean's interior.

We theorize that bathymetry influences mesoscale circulation and iron transport and that the position of the Antarctic Circumpolar Current influences the magnitude of the flow onto the Peninsula shelf, mediating the amount of iron transported into the Scotia Sea.

We will address these issues on a winter cruise in 2006 and a summer cruise in 2007, complementing surface surveys of chemical, plankton, and hydrographic properties with a mesoscale station grid for vertical profiles, water sampling, and bottle experiments. We will determine the distributions of manganese, aluminum, and radium isotopes to trace iron sources and estimate mixing rates. We will study the structure of plankton communities, as well as the relationship between iron concentrations and phytoplankton characteristics, to elucidate the connection between phytoplankton biomass and iron supply and to determine the most important sources of iron for the waters east of the Drake Passage.

Further, we will interpret estimates of organic carbon export from the upper ocean in relation to natural iron fertilization and use satellite photos to relate the current's southern front to seasonal and interannual variations in phytoplankton productivity east of the SFZ. Given indications that the Southern Ocean is warming, understanding the conditions regulating that ecosystem is important to predicting the effects of climate change.

Our project will involve postdoctoral fellows, graduate students, and undergraduates. Further, through a partnership with Literacyworks, we will contribute to the Polar Science Station Web site (http://literacynet.org/polar/), a resource for instructors and students in adult education, home schooling, tribal schools, and family literacy programs, as well as the general public. (B–225–N, B–228–E/N, B–248-N, and B–276–N; NSF/OPP 04–44134, NSF/OPP 04–43403, NSF/OPP 04–44040, and NSF/OPP 04–43869)

Environmental and ecological regulation of differences and interactions between solitary and colonial forms of *Phaeocystis antarctica.*

Kam Wing Tang, College of William and Mary, Virginia Institute of Marine Science.

Phaeocystis antarctica is widely distributed in the Southern Ocean and plays an important role in polar ecology and biogeochemistry. It is a dominant primary producer, a main component of organic matter vertical fluxes, and the principal producer of volatile organic sulfur in the region. Yet *P. antarctica* is also one of the lesser known species, and, moreover, information collected on other *Phaeocystis* species or from different locations may not be applicable to *P. antarctica* in the Ross Sea.

P. antarctica occurs mainly as two morphotypes—solitary cells and mucilaginous colonies; these differ significantly in size, architecture, and chemical composition. Relative dominance between solitary cells and colonies determines not only the size of the population, but also its carbon dynamics, nutrient uptake, and use, and colony formation could effectively alter predator-prey interactions and interspecific competition. However, what regulates the differences between solitary and colonial forms of *P. antarctica* is not certain. We will therefore address the following questions:

- Do solitary cells and colonies differ in growth, composition, and rates of photosynthesis?
- How do nutrients and grazers affect colony development and size distribution?
- How do nutrients and grazers act synergistically to affect long-term population dynamics?

We will conduct laboratory experiments at McMurdo Station to study size-specific growth and rates of photosynthesis in *P. antarctica*, size-specific grazing mortality from microzooplankton and mesozooplankton, the effects of macronutrients on the relative dominance of solitary cells and colonies, and the effects of iron and grazing-related chemical signals on colony development. We will use mesocosm experiments to study the synergistic effects of nutrients and grazing on the long-term dynamics of solitary cells and colonies.

P. antarctica is of critical importance in the Ross Sea and in the entire Southern Ocean, and our research will provide information on factors that regulate its role in food webs and biogeochemical cycles, as well as advance our understanding of many ecological and biogeochemical processes in the waters it dominates. Results will also allow us to compare *P. antarctica* with the better known *P. globosa* and *P. pouchetii* and begin to unveil their ecological and evolutionary similarities and differences. (B–230–M; NSF/OPP 04–40478)

Habitat utilization by Southern Ocean seals: Using novel methods of oceanographic data collection to determine the foraging behavior of crabeater and elephant seals.

Daniel P. Costa, University of California–Santa Cruz.

Marine mammals must be capable of accommodating broad variations in food resources over large spatial and temporal scales. Variation in the physical and biological environment is particularly profound in the Southern Ocean. Our current understanding of this spatial and temporal variation and of how animals respond is limited to population studies that cannot provide insight into the strategies individual animals use or their spatial or temporal course.

The key to understanding the processes that lead to high predator abundance is identifying the specific foraging behaviors associated with different features of the water column. We will examine the southern elephant seal *(Mirounga leonina)* and the crabeater seal *(Lobodon carcinophagus)* in the western Antarctic Peninsula. Although these two species are phylogenetically related, they use different but adjacent habitat types. Southern elephant seals are predominantly pelagic, moving throughout the Southern Ocean and venturing occasionally into the seasonal pack-ice, while crabeater seals range throughout the pack-ice and venture occasionally into open water. We will determine how specific foraging behaviors and animal movement patterns are related to oceanographic and bathymetric features, develop and test models of the importance of these features in defining habitat use, and compare how individual animals respond to environmental variability.

In addition to supporting some of the planet's most abundant marine resources, the Southern Ocean plays an important role in climate. Significant efforts are being directed at developing mathematical models of oceanographic processes with the goal of better understanding the role that the Southern Ocean plays, predicting the responses of ocean and global processes to climate change, and understanding the links between physical and biological processes. These efforts have been limited by the scarcity of oceanographic data, especially at high latitudes during the winter months. This lack impedes understanding of several key features of the Southern Ocean.

In addition to providing new data on temperature and salinity profiles, our efforts are geared toward understanding the dynamics of the upper water column of the continental shelf off the western Antarctic Peninsula, with an eye toward developing a mechanistic understanding of the column's annual and seasonal heat and salt budgets. (B–232–E; NSF/OPP 04–40687)

Physiological and molecular mechanisms of stress tolerance in a polar insect.

Richard Lee, Miami University of Ohio, and David L. Denlinger, Ohio State University.

Polar terrestrial environments are often described as deserts. In addition, prolonged low winter temperatures threaten survival, and summer temperatures produce potentially rapid and difficult transitions from freezing to desiccation. Global warming has had a further impact, especially as a result of glacial retreat along the Antarctic Peninsula.

We will focus on thermal and hydric adaptations in the terrestrial midge, *Belgica antarctica,* the largest and most southerly holometabolous insect living in this challenging environment. Since free water is unavailable, overwintering midge larvae encased in the frozen substrate must endure desert-like conditions for more than 300 days. During the summer, larvae may be immersed in melt water or the outwash from penguin rookeries and seal wallows, in addition to saltwater splash. Alternatively, larvae may be subjected to extended periods of desiccation as their microhabitats dry out.

Our research will focus on three areas:

- **Microclimatic variability:** Our primary objective is to obtain a detailed characterization of microclimatic conditions experienced by *B. antarctica,* especially related to thermal and hydric diversity, both seasonally and among microhabitats near Palmer Station. These data will be critical for establishing the relevant ecological conditions to be used in laboratory experiments.
- **Physiological and molecular responses to extreme fluctuations in water availability:** We will assess the hypothesis that midge larvae use cryoprotective dehydration for winter survival. It is also anticipated that genes encoding heat shock proteins and other genes are up-regulated in larval responses to dehydration and rehydration.
- **Dietary transmission of cryoprotectants:** Our experiments are designed to test the hypothesis that midge larvae acquire

increased resistance to desiccation and temperature stress by getting cryoprotectants from their host plants.

We will also provide outreach to elementary and secondary educators and their students. The field team will include a teacher and will use e-mail and digital pictures to communicate daily progress to elementary school teachers and students. These efforts will be supplemented by presentations at local schools and national teacher meetings and the publication of articles related to cryobiology and polar biology in education journals. Furthermore, our laboratories will continue to train undergraduate, graduate, and postdoctoral students. (B–256–P; NSF/OPP 03–37656)

Controls on Ross Sea Algal Community Structure (CORSACS): Interaction of iron, light, and carbon dioxide on phytoplankton community dynamics in the Ross Sea.

Giacomo R. DiTullio, University of Charleston; Robert Dunbar, Stanford University; Peter Sedwick, Bermuda Biological Station for Research; David Hutchins, University of Delaware; Philippe Tortell, University of British Columbia; and Walker O. Smith, College of William and Mary, Virginia Institute of Marine Science.

The Southern Ocean will play a central role in modulating future climatic changes and will in turn be greatly affected by them. The ability to predict these changes and to assess their impact on marine systems is hindered by a poor understanding of oceanographic processes and their links to global climate. A critical question concerns controls on the large-scale distribution and production of the two major bloom-forming phytoplankton in the Southern Ocean—diatoms and *Phaeocystis antarctica.* Through their involvement in the biogeochemical cycles for carbon, sulfur, and nutrient elements, these two groups may have played important roles in the climate variations of the late Quaternary and are likely to be key players in future environmental change.

One paradigm posits that irradiance (vertical mixing) and iron availability drive phytoplankton dynamics in the Southern Ocean. Recent work, however, suggests that carbon dioxide may also be important in structuring algal assemblages. The Ross Sea is ideal for investigating the factors that regulate the distribution and production of these two algal groups, since it has seasonal blooms that are typically separated by space and time. We will examine the interactive effects of dissolved iron concentration, irradiance, and partial pressure of carbon dioxide on diatom and *Phaeocystis* bloom dynamics in the Ross Sea through

- a field survey and analysis of algal assemblage composition, iron, mixed layer depth, and carbon dioxide levels on two transects in the southern Ross Sea during the spring *Phaeocystis* bloom and the summer postbloom period; and
- shipboard semicontinuous and natural community chemostat culture experiments to examine the response of diatom and *P. antarctica* assemblages to high and low levels of iron, light, and carbon dioxide.

Our project will provide information on the major factors controlling the production and distribution of these phytoplankton and the related biogeochemical cycling of carbon, sulfur, and nutrients. Our results will ultimately enhance the ability to predict how the Southern Ocean will be affected by and could modulate future climatic change. Moreover, we will involve graduate and undergraduate students, postdoctoral fellows, and a student teacher and engage in community outreach and educational activities. (B–258–N, B–267–N, B–272–N, B–279–N, B–282–N, and B–386–N; NSF/OPP 03–38097, NSF/OPP 03–38350, NSF/OPP 03–38164, NSF/OPP 03–38111, and NSF/OPP 03–38157)

Hydrologic controls over biogeochemistry and microbial community structure and function across terrestrial/aquatic interfaces in a polar desert.

Michael N. Gooseff, Colorado School of Mines; Cristina D. Takaes-Vesbach, University of New Mexico; and John E. Barrett, Dartmouth College.

Aquatic-terrestrial transition zones are crucial to understanding the biogeochemistry of landscapes. In temperate watersheds, these areas are generally dominated by riparian zones, which have been identified as biogeochemical hot-spots because of the increased microbial activity and because of their importance in facilitating and buffering hydrologic and biogeochemical exchanges between terrestrial and aquatic ecosystems.

In the antarctic Dry Valleys, terrestrial-aquatic transition zones are intriguing because of the vast importance of water in this polar desert and because the material and energy budgets of Dry Valley ecosystems are linked by hydrology. We will study hydrological margins in Dry Valley aquatic-terrestrial transition zones to answer two questions:

- What are the major controls over hydrologic and biogeochemical exchange across aquatic-terrestrial transition zones?
- To what extent do trends in nutrient cycling across these zones reflect differences in microbial communities or function versus differences in the physical and chemical environment?

The hydrologic gradients that define these interfaces provide the opportunity to assess the relative influence of physical conditions and microbial biodiversity and functioning on biogeochemical cycling. Our coordinated hydrologic, biogeochemical, and molecular microbial studies have the following objectives:

- to determine the role of sediment characteristics, permafrost and active layer dynamics, and topography on subsurface water content and distribution in hydrologic margins;
- to determine the extent to which transformations of nitrogen in hydrologic margins are influenced by physical conditions or by the presence of specific microbial communities; and
- to characterize the microbial community structure and function of saturated zones.

Our research will improve understanding of the interaction of liquid water, soils, microbial communities, and biogeochemistry within the Dry Valleys, whose streams and lakes are unique because higher vegetation does not influence the movement of water. They may therefore provide a model for understanding physical and hydrological influences on microbial ecology and biogeochemistry.

Our findings will contribute to antarctic science, as well as the broader study of riparian zones and hydrologic margins. We will involve

graduate and undergraduate students in our research and will disseminate information through a project Web site. Outreach will include science education in local elementary, middle, and high schools. (B–268–M; NSF/OPP 03–38267, NSF/OPP 03–36970, and NSF/OPP 03–38174)

Genetic sampling and satellite tracking of a fish-eating ecotype of killer whale in the southern Ross Sea.

Robert L. Pitman, National Oceanic and Atmospheric Administration, and Richard LeDuc and Wayne L. Perryman, National Oceanic and Atmospheric Administration, National Marine Fisheries.

We will continue to study the three distinct ecotypes of killer whales (*Orcinus* sp.: Types A, B and C) found in the Ross Sea during the austral summer. These forms have different prey and habitat preferences, different school sizes and geographic distributions, and distinct morphologies, suggesting that they may represent separate species. If true, this hypothesis will reshape our understanding of killer whales in Antarctica. Given their numbers (current estimates, 25,000 to 94,000) and status as top predators, killer whales are undoubtedly a major force in the antarctic ecosystem, but understanding their role and conservation status will depend on identifying their taxonomic relationships, specifying their dietary needs, assessing the impact of commercial fisheries on their feeding, and understanding their seasonal and annual movements.

This season we will focus again on the fish-eating ecotype (Type C) found in the ice leads near McMurdo Station:

- We will use a crossbow to collect projectile biopsy samples. These will be sequenced and analyzed to determine whether there is more than one species. To date, we have collected 59 samples from antarctic killer whales; as a target, we would like 50 of each form.
- We will implant satellite tags into the base of the dorsal fin of up to 20 killer whales. We will be working from the edges of the leads and poking the killer whales that swim by with fiberglass poles equipped with detachable tags. These should allow us to determine short-term movements within the Ross Sea and understand foraging range and habitat during the summer; tags set for longer periods will allow us to look at seasonal movements and migration patterns.

The killer whale is one of the most recognizable and best-studied large animals on Earth. Yet basic questions about how many species there are and what their role in the marine ecosystem remain unanswered. Some 300 to 400 minke whales are killed each year in the Southern Ocean Sanctuary for research purposes: our study will demonstrate the feasibility of using nonlethal techniques to conduct similar research. The possibility that there is a new species of killer whale in Antarctica serves to emphasize that our knowledge of marine biodiversity may be more limited than we realize. (B–289–M; NSF/OPP 03–38428)

Biogeochemistry of dissolved organic material in Pony Lake, Ross Island.

Yu-Ping Chin, Ohio State University; Penney Miller, Rose-Hulman Institute of Technology; Diane M. McKnight, University of Colorado–Boulder; and Christine M. Forman, Montana State University.

Dissolved organic matter is a significant component in aquatic systems because it acts as an important carbon source for microorganisms, absorbs harmful radiation, complexes metals, and participates in important biogeochemical redox reactions. We are studying the biogeochemical cycling of dissolved organic matter in Pony Lake, a small coastal pond on Cape Royds, Ross Island. Because there are no higher plants, all of the organic matter in this lake is microbially derived from photoautotrophic (having the ability to use light to synthesize food from inorganic materials), heterotrophic (dependent on complex organic compounds for nutrition), and mixotrophic organisms, making it an ideal study site.

We will

- examine how natural photolytic processes in the lake and laboratory irradiations of water samples and reconstituted samples of dissolved organic matter alter its composition,
- determine changes in the redox state of this material in the water column and in sediment interstitial water with increased oxygen input,
- examine how the chemical properties of dissolved organic material change with microbial utilization,
- monitor the changes in microbial abundance that result from shifts in dissolved organic material during the transition from ice to open water,
- track the changes in the microbial community as the energy source changes,
- determine whether the extracellular enzyme profiles of the water column vary in relation to the altered material, and
- examine the relationship between microbial diversity and the biogeochemistry of the material.

Last season, we studied the changes as the lake evolved from ice-covered to ice-free conditions. We fractionated samples into classes, as well as monitored composition and reactivity. Finally, we studied the microbial community and monitored changes that occurred during the transition from ice to open water and generated extracellular enzyme profiles, since enzymatic hydrolysis is believed to be the rate-limiting step in carbon remineralization.

This year, we will collect fulvic acid samples. The amount of water needed is significantly smaller than the amount lost to ablation, and all isolates will be thoroughly characterized. In year 3, we plan to perform solar-simulated photolysis and control experiments in the United States.

This project will greatly increase our understanding of carbon cycling and the relationship between microbial diversity and the biogeochemistry of dissolved organic matter. (B–300–M; NSF/OPP 03–38260, NSF/OPP 03–38121, NSF/OPP 03–38299, and NSF/OPP 03–38342)

A graduate training program in Antarctica: Integrative biology and

adaptation of antarctic marine organisms.

Donal T. Manahan, University of Southern California.

Biological impacts of the ozone hole, debates about global warming and temperature adaptations, and the evolution of biological diversity in the cold biosphere are some of the important themes that are central to scientific investigations in Antarctica. Yet because of its remoteness, few students ever have the opportunity to study there. We will therefore offer a series of three graduate training courses for doctoral students and postdoctoral scientists interested in the study of biological adaptations of antarctic marine organisms. The three (austral) summer courses will be offered at McMurdo Station in January 2006, 2008, and 2010, and each will accommodate 20 students. McMurdo Station, the major base for the U.S. Antarctic Program, has well-equipped laboratories suitable for instruction.

The major goal of these courses is to introduce students and new postdoctoral investigators to antarctic science through studies of the diversity of life forms and the mechanisms of biological adaptation in marine organisms. The courses will introduce students to a wide range of vertebrates (fish) and microbes and will be taught by instructors with considerable experience in teaching in Antarctica. A further aim is to train all of the participants in approaches to integrative biology by having them study unique processes that span several different levels of biological organization in the cold biosphere. For instance, long-standing questions on the evolution (cold adaptation) and ecology of antarctic organisms will be examined with physiological experiments on whole organisms, studies of isolated cells and tissues, experiments on protein structure and function, and molecular analysis of genetic systems.

These courses will provide students with hands-on science under realistic conditions. The general format will consist of field collections and laboratory experiments, together with lectures on polar science from course faculty and guest speakers. Some of the specific themes to be covered include biological diversity, biochemical and cold adaptation, energy metabolism, molecular phylogeny, and ultraviolet photobiology. These themes will be interwoven with independent, student-initiated research projects. (B–301–M; NSF/OPP 05–04072)

Salpa thompsoni in the Southern Ocean: Bioenergetics, population dynamics, and biogeochemical impact.

Patricia Kremer, University of Connecticut, and Laurence P. Madin, Woods Hole Oceanographic Institution.

Salps are holoplanktonic grazers that are strikingly different from krill, copepods, or other crustacean zooplankton. Salps sometimes occur in very dense populations that cover large areas and have been shown to have a significant impact from both grazing and the production of fast-sinking fecal pellets. Although salps are commonly acknowledged as a major component of the Southern Ocean zooplankton community, often comparable to krill, they have received relatively little attention. Extensive sampling has documented the seasonal abundance of *S. thompsoni* in the Southern Ocean, but there still is a paucity of data.

In addition to various rate measurements, we will make quantitative surveys of the horizontal and vertical distribution of salps. Results will be used to construct a model of population dynamics. Both experimental and modeling results will be interpreted within the context of the physical and nutritional conditions to which salps are exposed. This integrated approach will provide a good basis for understanding their growth dynamics.

Our tasks are as follows:

- survey the extent of *S. thompsoni* blooms to determine biomass and spatial distribution and to allow a regional assessment of their effects;
- measure the physical characteristics of the water column and the quantity and quality of particulate food;
- measure respiration and excretion rates for solitary and aggregate salps of all sizes;
- measure ingestion rates;
- determine somatic growth rates, fecundity (of solitaries), and fertilization success (for aggregates);
- synthesize rate measurements on salps into complete budgets for both carbon and nitrogen;
- formulate an individually based model of salp population dynamics that includes realistic behavior patterns as well as experimentally determined vital rates;
- identify salp hot-spots and interpret distributions in an appropriate hydrographic context;
- use satellite imagery and information on sea-ice cover to test hypotheses about conditions that result in high densities of salps; and
- evaluate the relationship between specified hydrographic conditions, ice cover, and blooms.

Our work will also involve training graduate and undergraduate students, participating in teacher-researcher workshops, and collaborating with the New England Aquarium on an IMAX movie about research in Antarctica. (B–307–L; NSF/OPP 03–38290)

What limits denitrification and bacterial growth in Lake Bonney, Taylor Valley, Antarctica?

Bess B. Ward, Princeton University.

Denitrification refers to the loss of fixed nitrogen from ecosystems, and its rate and regulation may directly affect primary production and carbon cycling. Previous investigation of the role of metals in regulating denitrification in cultured bacteria and in permanently ice-covered Lake Bonney produced three important findings:

- Cultured denitrifying bacteria could be limited by copper or iron, and nitrogen oxides accumulated because of limitation at the nitrite and nitrous oxide reduction steps, respectively.

- Manipulations of metal availability using chelators, additions of substrates, and cultured bacteria failed to elicit a response from the lake's natural microbial communities. No denitrification or thymidine incorporation was detected in the east lobe, while analogous experiments detected a denitrifying community in the west lobe.
- Silver and iron were the only metals that showed dramatic distribution differences between lobes. Silver concentrations were 150-fold higher in the east than in the west. Cadmium, lead, chromium, nickel, and zinc concentrations were 2- to 5-fold higher in the east than in the west, and iron concentrations were 200 times lower in the east. Low iron concentrations may exacerbate the toxicity of the other metals, so general metal toxicity could inhibit denitrification. Silver can specifically inhibit denitrification because it can interfere with copper binding in nitrite reductase and nitrous oxide reductase. High silver concentrations might prevent the functioning of nitrous oxide reductase in the same way that copper limitation does, causing a buildup of nitrous oxide and a nonfunctional nitrogen cycle.

It is not known whether the east lobe has oxygen concentrations low enough to trigger denitrification. We will use sentinel strains of denitrifying bacteria isolated from the lake, incubated in lake water, and subjected to various treatments to measure these concentrations and will study the effect of silver toxicity and general metal toxicity as well. We will quantify the responses of these strains to changes in metal and oxygen concentrations with single-cell probes.

The relationships between metals and denitrification are expected to shed light not only on Lake Bonney's unusual nitrogen cycle, but also on the role of metals in regulating microbial nitrogen transformations. (B–310–M; NSF/OPP 02–30276)

Improving acoustic estimates of antarctic krill populations.

Joseph Warren, Southampton College.

Antarctic krill are a vital link in the food web of the Southern Ocean. In addition to serving as prey for birds, pinnipeds, and whales, they are also harvested by several nations. To manage this fishery, acoustic surveys are conducted annually. While acoustic methods have several advantages, converting backscatter information to numerical abundance is difficult. In this 3-year program, we seek to improve the accuracy of acoustic surveys by examining three questions:

- Are acoustic surveys underestimating krill by avoiding shallow-water, near-shore areas?
- Is upwelled deep water the cause of the high productivity of the waters around Cape Shirreff, Livingston Island, and, if so, how does this vary?
- Can a new technique improve the conversion of acoustic backscatter data to numerical abundance?

Using a research vessel chartered by the National Oceanographic and Atmospheric Administration's Antarctic Marine Living Resources Program, we will conduct a small-boat survey to collect acoustic, meteorological, hydrographic, and video data. We will sample off- and on-shelf regions, focusing on two submarine canyons flanking Cape Shirreff. We will construct and deploy five spar buoys to collect acoustic backscatter and Acoustic Doppler Current Profiler data. We will use these data, along with the hydrographic information from the small-boat survey, to determine whether Upper Circumpolar Deep Water is traveling up the submarine canyons and increasing productivity. We will determine how this influx varies in order to understand the functions that control the abundance of krill.

We will measure the total target strength of different sizes, ages, and species of live krill during years 1 and 3 and develop algorithms to determine whether broad-bandwidth scattering data can be used to identify types. The results will improve the ability of scientists and fishery managers to use acoustic data to estimate krill abundance and will lead to a better understanding of the importance of near-shore populations and the factors controlling their distribution and abundance.

The instrumentation used in this project will be deployed off Long Island to provide students who will participate in data analysis with access to modern sampling methods. The buoy data and the course materials we develop will be placed on the Internet. (B–320–E: NSF/OPP 03–38196)

Establishing a Polar Remote Interactive Marine Observatory (PRIMO) near Palmer Station on the western Antarctic Peninsula.

Vernon Asper, University of Southern Mississippi, and Scott Gallager, Robert Beardsley, and Keith von der Heydt, Woods Hole Oceanographic Institution.

We will develop a remote underwater observatory that will allow scientists to make Internet-based virtual visits to the sub-ice ocean off Palmer Station. The observatory will consist of an instrument package on the seafloor in 130 meters (m) of water about 3.5 kilometers from Palmer Station. The package will be connected to shore by electro-optical cable, thus providing the capability for Internet-based teleoperation. The observatory will consist of a vertical profiler with conductivity-temperature-depth; a video plankton recorder; a hydrophone; a current meter; sensors for chlorophyll and dissolved organic matter fluorescence, oxygen, and nitrate; a bio-optical package; and an under-ice video observation surveillance system. The profiler will rise to the surface several times a day from a seafloor-mounted platform consisting of a winch, an acoustic Doppler current profiler, and a remote video camera. We will use this near-shore observatory as a proof of concept and test bed for the implementation of a similar observatory to be located on the shelf at a depth of 300 to 400 m. Both observatories will provide infrastructure for projects conducted by many scientists.

Our project will acquire data of interest and immediate application to several ongoing and planned projects. Specifically, the Long-Term Ecological Research project will benefit from year-round observations on the optical and physical properties of the water column, as well as the distribution of organisms living throughout the column. New projects proposed for this area will be invited to plug specific sensors or systems into the node.

In addition to the basic research applications of this project, it will be available for educators and the public to experience the sub-ice environment in Antarctica from anywhere in the world. Through educational programs and collaborations with schools and via mirror sites, virtual visitors will be able to both see and hear the environment around the node. The Web site will include information on the relevance of these and other long-term observations on global change, with specific emphasis on the amplification of this signal observed in the Southern Ocean. (B-390-P/L; NSF/OPP04-21431 and NSF/OPP 04-20757)

Temporal variability in natural and anthropogenic disturbances at

McMurdo Station, Antarctica.

Mahlon Kennicutt, Texas A&M University.

Antarctica represents one of the most carefully tended, strictly monitored habitats on Earth. Protecting the flora, fauna, and atmosphere of this pristine environment is important, but in addition, the extreme southern latitudes provide a virtual barometer of global pollution. A basic precept in understanding human-induced changes in natural systems is that they take place against a backdrop of natural variability that would occur with or without anthropogenic perturbation. The causes of change cannot be unambiguously determined unless natural variability is defined. This requires long-term observations. In this project, we will continue our previous studies at McMurdo Station to establish the extent of temporal variability in terrestrial and marine habitats.

We are collecting observations that should enable scientists to be more aware of any anthropogenic impacts, locating them precisely and tracking them over time. Drawing on our 3-year pilot program, we will create an initial environmental monitoring program that will include point-data sampling grids measuring a series of attributes indicative of change at various spatial scales. Our objectives are to determine

- the spatial and temporal scales of change, as well as its origin;
- how efficiently this system documents relevant changes in important habitat characteristics; and
- the usefulness of various approaches to reference or control locations.

We will collect a series of 163 terrestrial samples of hydrocarbons, trace metals, and carbon analyses at fixed-point and random-sample locations. We will also sample three transects of three offshore points for chemical contaminants, sediment properties, and benthic infaunal assemblages and assay them for toxicity. We will then use geographic information system techniques and geostatistical methods to organize these diverse data sets into a coherent, coordinated framework and multivariate statistics to analyze them.

Continuous observations are a critical component of U.S. environmental stewardship in Antarctica. Our monitoring will provide the objective information needed to make timely and informed management decisions on support and science operations. By providing fundamental knowledge of how antarctic systems operate and how human activities alter them, our study will also help fulfill environmental protection regulations under both domestic law and the Antarctic Treaty. (B–518–M; NSF/OPP 03–54573)

National Science Foundation
WHERE DISCOVERIES BEGIN

LONG-TERM ECOLOGICAL RESEARCH

Scientist Byron Adams takes a soil sample from Lake Hoare as Adler Dillman and Ed Ayres watch. The three are part of the Long Term Ecological Research project in the Dry Valleys, comprised of seven separate science field groups cooperating in their research to understand the area's unique ecosystem. (*NSF photo by Emily Stone*)

In this section:

Overview

Ecology has taken its place among science's vital, strategic disciplines, thanks to an ever-greater awareness of how the web of life and the Earth's other dynamic processes constitute a closed and coherent system. As part of this evolution, the National Science Foundation's Long-Term Ecological Research (LTER) Program, begun in 1980, has grown into a network of 26 research sites, established to acquire long-term data sets from Alaska to Puerto Rico to Antarctica. Such a geographical spread is necessary to collect information on a variety of ecosystem types, such as grassland, desert, forest, tundra, lake, stream, river, and agricultural and coastal systems.

To enhance understanding of ecological phenomena, the program focuses on the role of cyclical/episodic events (ranging from years to decades to centuries) in the structure and function of these distinctive ecosystems. The Antarctic Biology and Medicine Program supports two of these LTER project sites to facilitate research on unique aspects of antarctic ecology: one near Palmer Station in the Antarctic Peninsula and the other in the McMurdo Dry Valleys.

The Palmer Station/Antarctic Peninsula LTER program studies a polar marine biome that focuses on the antarctic pelagic marine ecosystem, including marine sea ice habitats, regional oceanography, and the terrestrial nesting site of seabird predators. It is ideally sited to probe a fundamental issue: As the pack ice varies (seasonally and year by year), what happens to the antarctic marine community? That is, how do ecological processes influence organisms at different trophic levels? The Palmer Station LTER Program was initiated during the 1991–1992 season with the installation of an automatic meteorological station, annual research cruises in the austral summer, and a focused research program at the station facility. During the austral fall and spring seasons, process-study research cruises develop data that can be compared with data collected from other coastal systems in the Antarctic Peninsula.

Due to its unique site, the McMurdo Dry Valleys LTER project is more wide ranging and focuses on the interdisciplinary study of aquatic and terrestrial ecosystems in a cold desert region of Antarctica. The area is one of the most fascinating and contrarian spots on Earth. In fact, it is almost unearthly. National Aeronautics and Space Administration scientists who wondered what conditions might be like on Mars came here, an island of rock in a sea of ice, the largest ice-free area in Antarctica, where winds howl, where what little water there is dessicates or evaporates, and where the only creatures that can survive are microorganisms, mosses, lichens, and relatively few groups of invertebrates. Higher forms of life are virtually nonexistent.

Thus, LTER projects based here take advantage of perhaps the coldest and driest ecosystem on Earth, where life approaches its environmental limits; as such, this may be seen as an "end-member" in the spectrum of environments included in the LTER network. Why is it necessary to conduct long-term ecological research in such a place? All ecosystems depend on liquid water and are shaped to varying degrees by climate and material transport, but nowhere is this more apparent than in the McMurdo Dry Valleys. In very few places on Earth do minor changes in solar radiation and temperature so dramatically affect the capabilities of organisms to grow and reproduce as in the Dry Valleys. Therefore, this site may well be an important natural, regional-scale laboratory for studying the

biological effects of climate changes attributable to human activity. While the antarctic ice sheets respond to climate change on the order of thousands of years, the glaciers, streams, and ice-covered lakes in the McMurdo Dry Valleys often experience nearly immediate (and sometimes profound) change. As such, this area would be one of the first to show the effects of climate change in Antarctica.

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. Though driven by the same basic processes found in all ecosystems (microbial use and remineralization of nutrients, for example), the Dry Valley ecosystems lack many of the confounding variables, such as diverse and fecund biota and many levels of plants and higher animals, inherent in other ecosystem research.

The role of resource legacy on contemporary linkages between biodiversity and ecosystem processes in a cold desert ecosystem: The McMurdo Dry Valley Long-Term Ecological Research Program.

W. Berry Lyons, Ohio State University.

The largest ice-free area in Antarctica is found in the McMurdo Dry Valleys, located on the western shore of McMurdo Sound. Among the most extreme deserts in the world, the McMurdo Dry Valleys are the coldest and driest of all the Long-Term Ecological Research (LTER) sites. Consequently, biological systems are limited to microbial populations, microinvertebrates, mosses, and lichens. Yet complex trophic interactions and biogeochemical nutrient cycles develop in the lakes, streams, and soils of the Dry Valleys. In the austral summer, solar energy produces glacial meltwater, providing vital water and nutrients that have a primary influence on the ecosystems. Such material transport and climatic influences shape all ecosystems, but nowhere is this more apparent than in the McMurdo Dry Valleys.

The McMurdo LTER project focuses on the aquatic and terrestrial ecosystems in the Dry Valley landscape as a context to studying biological processes and to exploring material transport and migration. During this phase of this LTER project, we are extending our research by continuing to investigate the McMurdo Dry Valleys as an end-member system, hoping to better ascertain the role of past climatic legacies in ecosystem structure and function. We will test a series of eight hypotheses in three major focus areas—hydrology, biological activity/diversity, and biogeochemical processes—by continuing our monitoring projects and long-term experiments.

Understanding the structure and function of the McMurdo Dry Valleys ecosystem requires deciphering the hydrological response to climate, both now and in the past. Current patterns of biological activity and diversity reflect past and present distributions of water, nutrients, organic carbon, and biota. Biogeochemical processes responsible for the transport, immobilization, and mineralization of nutrients and other chemicals provide the linkages between the region's biota and the physical environment. The timing, duration, and location of biogeochemical processes in the past and present are controlled by the availability of water. We continue to focus on the integration of the biological processes within and among the lakes, streams, and terrestrial ecosystems that comprise the McMurdo Dry Valley landscape. Our interdisciplinary research team will continue to use modeling and other integrative studies to synthesize data and to examine the McMurdo Dry Valleys ecosystem.

During the 2005–2006 field season, the following studies will be conducted in the McMurdo Dry Valleys as part of the LTER project:

Chemistry of streams, lakes, and glaciers. (B–420–M; NSF/OPP 04–23595)
W. Berry Lyons, Ohio State University.

Flow, sediment transport, and productivity of glacial melt streams. (B–421–M; NSF/OPP 04–23595)
Diane M. McKnight, University of Colorado–Boulder.

Lake pelagic and benthic productivity: Microbial food webs. (B–422–M; NSF/OPP 04–23595)
John C. Priscu, Montana State University–Bozeman.

The influence of environmental conditions on carbon and nitrogen cycling and on soil biota, the effects of environmental change and food supply availability on soil biota, and the effects of climate change on biota. (B–423–M and B–424–M; NSF/OPP 04–23595)
Ross A. Virginia, Dartmouth College, and Diana H. Wall, Colorado State University.

Glacier mass balance, melt, and energy balance: Climate monitoring in Taylor, Wright, Victoria, and Beacon Valleys. (B–425–M; NSF/OPP 04–23595)
Andrew G. Fountain, Portland State University.

Paleoclimatology, paleoecology, and meteorological data collection. (B–426–M; NSF/OPP 04–23595)
Peter T. Doran, University of Illinois–Chicago.

Palmer, Antarctica, Long-Term Ecological Research Project: Climate migration, ecological response, and teleconnections in an ice-dominated environment.

Hugh W. Ducklow, College of William and Mary, Virginia Institute of Marine Science.

The Palmer Long-Term Ecological Research Project (PAL LTER) seeks to understand the structure and function of the antarctic marine and terrestrial ecosystem in the context of physical forcing by seasonal to interannual variability in atmospheric and sea-ice dynamics, as well as long-term climate change. PAL LTER studies marine and terrestrial food webs consisting principally of diatom primary producers; the dominant herbivore the antarctic krill, *Euphausia superba;* the apex predator Adélie penguin, *Pygoscelis adeliae;* and an active microbial food web consisting of planktonic bacteria and *Archaea,* bacterivorous protozoa, and dissolved organic matter. A biogeochemical component studies organic and inorganic carbon fluxes and the sedimentation of particulate matter into the deep sea.

This project monitors western Antarctic Peninsula ecosystems regionally over a grid of oceanographic stations and locally at Palmer Station. The extent and variability of sea ice affect changes at all trophic levels. In recent years, sea ice has diminished in response to general climate warming. A long-term population decline of ice-dependent Adélie penguins provides a clear example of the impact

of this trend in the Palmer region. Adélie populations at the five major rookeries located near Palmer Station and studied for the past 30 years have all shown a gradual decrease in numbers. The western Antarctic Peninsula, the site of PAL LTER research, runs perpendicular to a strong climatic gradient between the cold, dry continental regime to the south and the warm, moist maritime regime to the north. More maritime conditions appear to be replacing the original polar ecosystem in the northern part of the Peninsula as the climatic gradient shifts southward. To date, this shift appears to be matched by an ecosystem shift along the Peninsula, as evidenced by declines in Adélie penguins, which require a longer snow-cover season, and changes in plankton distribution, as reflected in predator diets.

We hypothesize that ecosystem migration is most clearly manifested by changes in upper-level predators (penguins) and certain polar fishes in predator-foraging environments because these longer lived species integrate recent climate trends and because individual species are more sensitive indicators than aggregated functional groups. We hypothesize that in the years ahead, analogous modifications will also become evident at lower trophic levels, although these changes are likely to be seen only through long-term studies of ecosystem boundaries along the peninsula.

By studying extant food webs in both the marine and terrestrial environments, we will continue to investigate ecosystem changes at lower trophic levels; changes in response to continued, dramatic warming; and shifts in the poleward climatic gradient along the western Antarctic Peninsula.

During the 2005–2006 field season, the following studies will be conducted as part of the PAL LTER project:

Seabird (penguins, giant petrels, and skuas) ecology. (B–013–L/P; NSF/OPP 02–17282)
William R. Fraser, Polar Oceans Research Group.

Primary production and phytoplankton ecology. (B–016–L/P; NSF/OPP 02–17282)
Maria Vernet, University of California–San Diego, Scripps Institution of Oceanography.

Physical oceanography and ocean-climate modeling. (B–021–L; NSF/OPP 02–17282)
Douglas G. Martinson, Columbia University.

Zooplankton and nekton stocks, feeding, and growth. (B–028–L/P; NSF/OPP 02–17282)
Langdon B. Quetin, University of California–Santa Barbara, and Robin M. Ross-Quetin, University of California–Santa Barbara.

Remote sensing and bio-optics. (B–032–L/P; NSF/OPP 02–17282)
Raymond C. Smith, University of California–Santa Barbara.

Microbial ecology and biogeochemistry. (B–045–L/P; NSF/OPP 02–17282)
Hugh W. Ducklow, College of William and Mary, Virginia Institute of Marine Science.

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WHERE DISCOVERIES BEGIN

OCEAN AND CLIMATE SYSTEMS

A Long Duration Balloon lifts off near McMurdo Station, Antarctica, carrying a science payload. The balloon will circumnavigate the continent, following a high altitude wind current. Using the balloon to carry instruments to the edge of space is more cost efficient than using a satellite or the space shuttle. The balloon will expand at the edge of space to 11 million cubic meters. Once the balloon returns to the McMurdo area, a signal is sent to the module to release it from the balloon. A parachute activates to slow the payload's descent to the ground. A crew is then sent to retrieve the scientific instruments. (*NSF photo by Brien Barnett*)

On this page:

Overview

Though it borders the world's major oceans, the Southern Ocean system is like no other in the world, with 4 times more water than the Gulf Stream and 400 times more than the Mississippi River. It is a sea where average temperatures do not reach 2°C in the summer, where even the water itself is so distinctive that it can be identified thousands of miles away in currents that originated here. These Antarctic Bottom Waters provide the major source of cooling for the world's oceans. In fact, if the Earth is a heat engine, Antarctica should be viewed as its circulatory cooling component.

The climate in Antarctica is also unique, linked as it is to the extreme conditions of the land, ice, and sea below the troposphere (the inner region of the atmosphere, up to between 11 and 16 kilometers). This ocean/atmosphere environment defines and constrains the marine biosphere and in turn has a dynamic relationship with the global ocean and with weather all over the planet. Few major energy exchanges on Earth can be calculated without factoring in these essential antarctic phenomena. As such, they are both an indicator and a component of climate change.

The Ocean and Climate Systems Program supports research that will improve understanding of the high-latitude ocean environment, including the global exchange of heat, salt, water, and trace elements; there is also an emphasis on sea-ice dynamics, as well as the dynamic behavior and atmospheric chemistry of the troposphere. Major program elements include the following:

- **Physical oceanography:** the dynamics and kinematics of the polar oceans; the interaction of such forces as wind, solar radiation, and heat exchange; water-mass production and modification processes; ocean dynamics at the pack-ice edge; and the effect of polynyas on ventilation.

- **Chemical oceanography:** the chemical composition of sea water and its global differentiation; reactions among chemical elements and compounds in the ocean; fluxes of material, within ocean basins and at their boundaries; and the use of chemical tracers to map oceanic processes across a range of temporal and spatial scales.
- **Sea-ice dynamics:** the material characteristics of sea ice, from the level of the individual crystal to the large-scale patterns of freezing, deformation, and melting.
- **Meteorology:** atmospheric circulation systems and dynamics, including the energy budget; atmospheric chemistry; transport of atmospheric contaminants to the antarctic; and the role of large and mesoscale systems in the global exchange of heat, momentum, and trace constituents.

Antarctic Troposphere Chemistry Investigation (ANTCI).

Fred Eisele, Douglas Davis, Yuhang Wang, David Tan, and L. Greg Huey, Georgia Institute of Technology; Richard Arimoto, New Mexico State University; Detlev Helmig, University of Colorado–Boulder; Manuel Hutterli and Roger Bales, University of Arizona; Jack Dibb, University of New Hampshire; Donald Blake, University of California–Irvine; and Richard Shetter and Roy Mauldin, National Center for Atmospheric Research.

We will study sulfur chemistry in the antarctic atmosphere to enhance our understanding of the processes that control tropospheric levels of reactive hydrogen radicals, reactive nitrogen, sulfur, and other trace species for the further purpose of improving the climatic interpretation of sulfur-based signals in antarctic ice-core records. Specifically, we will be making observations of reactive hydrogen radicals, sulfuric acid and its sulfur precursors, and the flux of ultraviolet radiation. The results we derive will lead to a more comprehensive understanding of antarctic atmospheric chemistry, as well as the factors that influence the levels and distributions of climate proxy species in antarctic ice cores.

Our major science objectives include

- evaluating the processes that control spring and summer levels of reactive radicals in the atmospheric surface layer at the South Pole,
- assessing how representative previously obtained South Pole and coastal measurements are in the larger context of polar plateau processes, and
- investigating the relative importance of the oxidative processes involved in the coast-to-plateau transport of reduced sulfur and determining the principal chemical transition regions.

Secondary objectives include investigating snow/firn chemical species that undergo extensive exchange with the atmosphere and assessing the different chemical forms of the trace elements and their relationships to levels of ozone and other oxidants.

Atmospheric sulfur chemistry is important in climate change because both naturally and anthropogenically emitted sulfur compounds form minute particles in the atmosphere (so-called aerosols) that reflect solar radiation, produce atmospheric haze and acid rain, and affect ozone depletion. These sulfate particles may also act as condensation nuclei for water vapor and enhance global cloudiness. The primary natural sources of sulfur are volcanic emissions and dimethylsulfide production by oceanic phytoplankton.

On the millennial time scale, the variability and background level of atmospheric aerosols can be reconstructed from ice cores. It is, however, necessary to understand how the physical and chemical environment of the process affects the relative concentrations of the oxidation products that become buried in the ice. (O–176–M/S; NSF/OPP 02–30246, NSF/OPP 02–29633, NSF/OPP 02–29605, NSF/OPP 02–30046, NSF/OPP 02–30051, NSF/OPP 02–30117, and NSF/OPP 02–30178)

Antarctic Meteorological Research Center (AMRC).

Charles R. Stearns, University of Wisconsin–Madison.

The Antarctic Meteorological Research Center (AMRC) was created in 1992 to improve access to meteorological data from the Antarctic. The AMRC's mission is to conduct research in observational meteorology and the stewardship of meteorological data, along with providing data and expert assistance to the antarctic community to support research and operations. The AMRC fulfills its mission by

- continuing to maintain and expand, as appropriate, the long-term record of all meteorological data on Antarctica and the adjacent Southern Ocean and make these data available to the scientific community for multidisciplinary use (special attention will be given to obtaining data not normally or readily available by other means);
- continuing to generate satellite products, specifically—but not limited to—antarctic composite imagery, and expand and improve on them as much as possible;
- conducting research in observational meteorology, especially with regard to climatological analyses and case studies; and
- continuing to conduct and expand, as appropriate, educational and public outreach activities associated with antarctic meteorology and related fields.

Using available meteorological interactive processing software and other standard computing tools, we will collect data from all available sources for processing, archiving, and distribution. The mission of the AMRC not only includes the opportunity to advance the knowledge of antarctic meteorology, but with the free availability of its data holdings, the AMRC gives others the opportunity to advance the frontiers of all antarctic science. Continuing educational outreach activities on meteorology and the Antarctic, an important component of this work, have the potential to raise the science literacy of the general public, as well as the level of K–12 science education. (O–202–M/P/S; NSF/OPP 01–26262)

Changes in atmospheric oxygen (O_2), carbon dioxide (CO_2), and argon (Ar) concentrations in relation to the carbon cycle and climate.

Ralph F. Keeling, University of California–San Diego, Scripps Institution of Oceanography.

Oxygen, the most abundant element on Earth, comprises about a fifth of the atmosphere. But much of the Earth's oxygen resides in other chemical species (in water, rocks, and minerals) and, of course, in the flora and fauna that recycle it (both directly and as carbon dioxide) through photosynthesis and respiration. Thus, scientists are interested in measuring the concentration of molecular oxygen and carbon dioxide in air samples; our project includes a subset of collections (flask sampling of air) being made at a series of baseline sites around the world. The two antarctic sites are South Pole and Palmer Stations.

These data should help improve estimates of the processes whereby oxygen is cycled throughout the global ecosystem, specifically through photosynthesis and atmospheric mixing rates, and also improve predictions of the net exchange rates of carbon dioxide with biota, on land and in the oceans. An important part of the measurement program entails developing absolute standards for oxygen-in-air to ensure stable long-term calibration. In addition, we are conducting surveys of the oxidative oxygen/carbon ratios of both terrestrial- and marine-based organic carbon, hoping to improve the quantitative basis for linking the geochemical cycles of oxygen and carbon dioxide. The project will also entail continued measurements of changes in atmospheric argon concentrations, which provide constraints on the magnitude of air-sea heat exchange and on oceanic influences on atmospheric oxygen.

The data we gather will be of great use in modeling studies of ocean circulation and various carbon-related processes. Technology for making climate-relevant observations will be advanced and made available to the scientific community through publications and student training. This project will help enhance our understanding of the processes that regulate the buildup of carbon dioxide in the atmosphere and of the change processes, especially climate change, that regulate ecological functions on land and sea. (O–204–P/S; NSF/ATM 03–30096)

Processes driving spatial and temporal variability of surface pCO_2 in the Drake Passage.

Taro Takahashi, Columbia University, and Jorge Sarmiento, Princeton University.

The Southern Ocean provides an important component of the global carbon budget. Cold surface temperatures, with consequent low vertical stability, ice formation, and high winds, produce a very active environment in which the atmospheric and oceanic reservoirs readily exchange gaseous carbon. The Drake Passage is the narrowest point through which the Antarctic Circumpolar Current and its associated fronts must pass; this so-called chokepoint provides the most efficient site to measure the latitudinal gradients of gas exchange.

Working from the research ship *Laurence M. Gould*, we will use equipment designed to measure dissolved carbon dioxide gas, occasional total carbon dioxide, nutrients, and carbon-13 in the surface waters during transects of the Drake Passage. Two short cruises (4 to 5 days) will also be dedicated to providing a baseline for surface measurements with water column profiles.

This work extends similar measurements made aboard the research ship *Nathaniel B. Palmer* and complements other data collected on surface temperatures and currents. The objective is to test the hypothesis that the mean annual partial pressure of carbon dioxide (pCO_2) in the surface water of the Drake Passage is determined by the degree of winter mixing. This is of special significance in light of two scenarios that may be affecting the ventilation of deep water in the Southern Ocean now and in the future:

- a decrease in water column stratification with observations of higher zonal winds, or
- an increase in stratification due to higher precipitation and warming from climate change.

If winter mixing determines the mean annual pCO_2 in the Drake Passage, the increasing trend in atmospheric pCO_2 will have little effect on sea surface pCO_2.

The data sets we will gather, supplemented by satellite imagery, will enable scientists to estimate the net production and carbon export by the biological community, as well as the basic targets—a quantitative description of the sources of dissolved carbon dioxide variability and a calculation of carbon dioxide fluxes between the ocean and the atmosphere. These data will also help validate biogeochemical modeling efforts and provide a baseline data set for studies throughout the Southern Ocean. (O–214–L/N; NSF/OPP 03–38248 and NSF/OPP 03–38155)

South Pole monitoring for climatic change—U.S. Department of Commerce NOAA Earth System Research Laboratory, Global Monitoring Division.

David Hofmann, National Oceanic and Atmospheric Administration, Earth System Research laboratory, Global Monitoring Division.

For more than 30 years, the National Oceanic and Atmospheric Administration has been conducting studies to determine and assess the long-term buildup of trace atmospheric constituents that influence climate change and the ozone layer. Time-series analyses of long-term data provide insight into several phenomena of particular interest, including

- seasonal and temporal variations in greenhouse gases,
- the depletion of stratospheric ozone,
- transantarctic transport and deposition,
- the interplay of trace gases and aerosols with solar and terrestrial radiation fluxes that occur on the polar plateau, and
- the development of polar stratospheric clouds over Antarctica.

Project scientists measure carbon dioxide, methane, carbon monoxide, stable isotopic ratios of carbon dioxide and methane, aerosols, halocarbons, and other trace constituents. Flask samples are collected and returned for analysis, while concurrent *in situ* measurements of carbon dioxide, nitrous oxide, selected halocarbons, aerosols, solar and terrestrial radiation, water vapor, surface and stratospheric ozone, wind, pressure, air and snow temperatures, and atmospheric moisture are made. Air samples are also collected at Palmer Station.

These measurements allow us to determine the rates at which concentrations of these atmospheric constituents change; they also point to likely sources, sinks, and budgets. We collaborate with climate modelers and diagnosticians to explore how the rates of change for these parameters affect climate. (O–257–S; NSF/NOAA agreement)

The Drake Passage High-Density XBT/XCTD Program.

Janet Sprintall, University of California–San Diego, Scripps Institution of Oceanography.

At the latitude of the Drake Passage, which is off the tip of South America, there are no continental boundaries to impede the flow of the Antarctic Circumpolar Current. The continual circumpolar flow therefore provides an effective mechanism for water-property exchanges and the transfer of climate anomalies throughout the world's oceans. The region experiences the strongest winds in the world, driving the current and enhancing the large heat and momentum exchanges between the ocean and the atmosphere. Recent studies have shown that large fluctuations can occur from weekly to interannual time scales in response to regional and remote forcing.

The dynamics and heat exchange within the Southern Ocean are further complicated by the prevalence of eddy variability: Eddy heat flux probably plays a strong role in heat balance, with a more uncertain role in providing an effective mechanism for dissipating the energy input of the wind. We will attempt to determine the significance of the eddy fluxes to the heat and momentum balance of the current and their relationship to the forcing fields.

During each crossing of the research ship *Laurence M. Gould*, we intend to launch expendable bathythermographs (XBTs), supplemented by expendable conductivity- temperature-depth (XCTD) probes, to obtain high-density sections from which to study the seasonal variability and long-term change in the upper ocean structure of the Drake Passage. Whenever the distance between Antarctica and neighboring land is narrow, as in the Drake Passage, the Antarctic Circumpolar Current, which drives the waters in the Southern Ocean, is extremely strong.

The information we gather will lead to the establishment of a high-quality database that can be used to study the magnitude and depth of penetration of the seasonal signals, the connections to atmospheric forcing, and the effects of interannual variations such as those associated with the Antarctic Circumpolar Wave. The sections obtained during these voyages will supplement the approximately 20 sections that we have been gathering and studying since September 1996. Our data analysis will continue to be carried out in cooperation with the Instituto Antártico Argentino in Buenos Aires. (O–260–L; NSF/OPP 03–37998)

Collection of atmospheric air for the U.S. Department of Commerce NOAA Earth System Research Laboratory, Global Monitoring Division, worldwide flask-sampling network.

David Hofmann, National Oceanic and Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division.

The National Oceanic and Atmospheric Administration has been conducting studies to determine and assess the long-term buildup of trace atmospheric constituents that influence climate change and the ozone layer. Time-series analyses of long-term data provide insight into several phenomena of particular interest, including

- seasonal and temporal variations in greenhouse gases,
- the depletion of stratospheric ozone,
- transantarctic transport and deposition,
- the interplay of trace gases and aerosols with solar and terrestrial radiation fluxes that occur on the polar plateau, and
- the development of polar stratospheric clouds over Antarctica.

Personnel at Palmer Station collect air samples to be analyzed for carbon dioxide, methane, carbon monoxide, and stable isotopic ratios of carbon dioxide and methane. Flasks are also collected for analysis of halocarbons, nitrous oxide, and other trace constituents.

These measurements allow us to determine the rates at which concentrations of these atmospheric constituents change; they also point to likely sources, sinks, and budgets. We collaborate with climate modelers and diagnosticians to explore how the rates of change for these parameters affect climate. (O–264–P; NSF/NOAA agreement)

Operation of an aerosol sampling system at Palmer Station.

Colin G. Sanderson, U.S. Department of Energy, Environmental Measurements Laboratory.

Radionuclides, some of which occur naturally in the surface air, are atoms emitting radioactive energy. It is these, as well as nuclear fallout and any accidental releases of radioactivity, that the Environmental Measurements Laboratory's (EML's) Remote Atmospheric Measurements Program (RAMP) is designed to detect and monitor.

Since 1963, EML, which is part of the U.S. Department of Energy, has run the Global Sampling Network to monitor surface air. The RAMP system provides on-site analysis in 13 different locations around the world, including Palmer Station. Using a high-volume aerosol sampler installed in 1990, a gamma ray spectrometer, and a link to the National Oceanic and Atmospheric Administration's ARGOS satellite system, we will continue to sample the air at Palmer Station for anthropogenic radionuclides. Our data are analyzed and archived at EML and contribute significantly to its database on radionuclides. (O–275–P; NSF/DOE agreement)

Antarctic automatic weather station program: 2004–2007.

Charles R. Stearns and George A. Weidner, University of Wisconsin–Madison.

A network of nearly 50 automatic weather stations (AWS) has been established on the antarctic continent and several surrounding islands. These facilities were built to measure surface wind, pressure, temperature, and humidity. Some of them also track other atmospheric variables, such as snow accumulation and incident solar radiation.

The data they collect are transmitted via satellite to a number of ground stations and put to several uses, including operational weather forecasting, accumulation of climatological records, general research, and specific support of the U.S. Antarctic Program, especially the Long-Term Ecological Research Program at McMurdo and Palmer Stations. The AWS network has grown from a small-scale program in 1980 into a significant, extremely reliable data retrieval system that has proven indispensable for both forecasting and research. This project maintains and augments the AWS as necessary. (O–283–M; NSF/OPP 03–38147)

Solar/wind-powered instrumentation module development for polar environmental research.

Anthony D. Hansen, Magee Scientific Company.

We will develop and test a self-contained, transportable module that will provide a sheltered, temperature-controlled interior environment for standard, rack-mounted equipment. Electric power will be provided by solar panels and a wind generator, backed up by batteries with several days' capacity. The module will offer both alternating and direct current for internal and external use and will include data logging and communications capability for practical application in a polar environment.

At South Pole Station, McMurdo Station, and almost all other inhabited camps in Antarctica, aircraft, helicopters, ground vehicles, diesel generators, and other sources release exhaust, which can affect the environment. The collection of real-time pollution data at downwind locations can be used to assess the amount of pollution and the effectiveness of efforts to improve air quality. At this time, optimal placement of measuring instruments is severely limited by the availability of power and shelter, a limitation that this module is intended to overcome.

Although designed to facilitate measurements at the South Pole, the module will be helpful in a variety of other situations where remotely located equipment is to be used for long-term monitoring of environmental phenomena. The module will have no emissions at all and therefore will not affect the environment that it is designed to study. Also, it can be placed anywhere it is needed. (O–314–S; NSF/DBI 01–19793)

Shipboard acoustic Doppler current profiling on the *Nathaniel B. Palmer* and *Laurence M. Gould*.

Eric Firing, University of Hawaii–Manoa, and Teresa K. Chereskin, University of California–San Diego.

We will build on a successful 5-year collaboration that developed the capability to routinely acquire, process, and archive ocean current measurements from hull-mounted shipboard acoustic Doppler current profilers (ADCPs) on board the research ships *Nathaniel B. Palmer* and *Laurence M. Gould*. We will enhance the technical capabilities of the program through new software developments and hardware acquisition. Also, we will continue the collection and dissemination of a quality-controlled data set of upper-ocean current velocities and acoustic backscatter in the sparsely sampled and remote Southern Ocean, an area that plays an important role in global ocean circulation. In addition, we will perform scientific analyses of upper-ocean current structure in the Drake Passage.

One of our short-term objectives is to develop the ongoing data collection program so it can be maintained with a minimum of personnel and resources and so the observations become publicly available in a timely manner.

Our long-term objectives are to

- measure the seasonal and interannual variability of upper-ocean currents in the Drake Passage,
- combine this information with similar temperature observations to study the variability in the heat exchange, and
- characterize the velocity and acoustic backscatter structure in the Southern Ocean on a variety of time and space scales.

With new dual-frequency ADCP capability gained through the acquisition and installation of 38 kilohertz (kHz) phased-array Doppler sonars, in addition to the existing 150 kHz ADCP capability, the maximum profiling range will increase to about 1,000 meters (m) under good sea and scattering conditions while maintaining higher vertical resolution in the upper 300 m. New software developments will improve the ability to measure currents while the ships are in ice. The collection, quality control, real-time processing, and dissemination of this high-quality data set allow these observations to be used to support ongoing antarctic science programs and make the data easily accessible for conducting retrospective analyses, planning future observations, and validating numerical models.

Finally, after the ship leaves dry dock, we will replace the current logging computer with a newer one and upgrade the acquisition and processing software to accommodate the new system. (O–315–N and O–317–L; NSF/OPP 03–37375 and NSF/OPP 03–38103)

Physics and mechanics of the breakup of warm antarctic sea ice: In-situ experiments and modeling.

John P. Dempsey, Clarkson University.

We will study how the antarctic sea ice cover responds to stresses applied by wind and ocean waves and how the temperature distribution within the sea ice affects these responses. We will investigate the breakup of antarctic sea ice in light of recent findings indicating that the fracture strength of first-year ice is strongly size dependent, that the deformation and fracture on the scale of tens of meters is influenced by microstructural anisotropy, and that the characteristic flaws of sea ice (such as brine drainage features) give rise to length scales relevant to transitions in fracture behavior. Given the importance of warm McMurdo Sound sea ice for research and tourism at McMurdo Station, there is an urgent need to understand its fracture behavior. We will therefore investigate the following topics:

- coupled deformation-diffusion influences (due to fluid transport within the ice matrix),
- the influence of loading rate versus specimen size over a significant size range,
- fractal descriptions of the failure surfaces, and
- a new cyclic loading geometry (independent of the fracture testing).

Our findings will provide insight into the underlying mechanisms of ice breakup and will significantly improve the accuracy and reliability of models.

Each fracture test will have several parts that will allow us to make quantitative comparisons between deformation and fracture energy and the fractal dimension. Few such comparisons are available for any geologic material. We will examine, both theoretically and experimentally, the ability of sea water and brine to be transported within the ice matrix, and we will also make quantitative assessments of permeability. We have timed our work to coincide with significant warming of the sea ice.

Two graduate students will be involved in this project and in the teaching and outreach associated with it, and every effort will be made to recruit them from underrepresented groups. Moreover, a different K–12 teacher will be invited for each of the three trips we will take. To more broadly disseminate our material, we will produce CDs and maintain a Web page. (O–316–M; NSF/OPP 03–38226)

Maud Rise Nonlinear Equation-of-State Study (MaudNESS).

Miles McPhee, McPhee Research Company; David Holland, New York University; Laurence Padman, Earth and Space Research; Eric D'Asaro, University of Washington; and Timothy Stanton, Naval Postgraduate School.

In many parts of the Weddell Sea, modest ice growth and heat loss to the atmosphere could eliminate the density contrast between the cold, relatively fresh surface mixed layer and the underlying Weddell Deep Water, thereby setting the stage for deep convection. However, as soon as warm water mixed from below melts the ice, a strong negative feedback occurs. This process re-verses buoyancy flux at the surface and stabilizes the upper ocean, thus reducing turbulent heat flux from below and preserving the ice-pack. Yet the ice cover has often disap-peared over significant areas during the winter, and the large Weddell polynya (area of open water in sea ice), which persisted for several years, had profound effects on the Weddell Sea and areas farther north. These events seem to be linked to circulation patterns around the Maud Rise seamount.

How can turbulent mixing overcome the stabilizing effect of ice melt long enough to remove the ice cover? The answer may lie in the nonlinear equation-of-state (NES) properties of seawater. When layers of water with similar densities but strong temperature and salinity contrasts interact, a number of possible NES instabilities can convert the potential energy of the unstable temperature stratification to the tur-bulent energy needed to counteract the buoyancy sink from melting. In the Weddell Sea, the cold surface mixed layer is often separated from the underlying warm, more saline water by a thin layer (pycnocline), making the water column particularly susceptible to an instability associated with the pressure dependence of the thermal expansion coefficient.

Our objectives are as follows:

- to use measurements and high-resolution modeling to investi-gate the role of NES instabilities in breaking down stratification, and
- to use longer-term measurements and regional-scale modeling to determine how the circulation around Maud Rise preconditions convection.

The Southern Ocean produces much of the deep water of the global oceans and is a major conduit by which the abyssal ocean communicates with the global climate. Deep-ocean convection in the Antarctic thus represents an important component in the quest for climate simulation and prediction, and our research will contribute to understanding this phenomenon. (O–325–N; NSF/OPP 03–37159, NSF/OPP 03–37073, NSF/OPP 03–37301, NSF/OPP 03–37751, and NSF/OPP 03–38020)

Interactions between cobalt, cadmium, and zinc biogeochemistry and phytoplankton dynamics in the Ross Sea.

Mak A. Saito, Woods Hole Oceanographic Institution.

We will apply voltammetric speciation techniques to water column samples and bottle incubations to investigate the biogeochemistry of cobalt, cadmium, and zinc in the Ross Sea. The CORSACS (Controls on Ross Sea Algal Community Structure) project already planned for the 2006 season (see B–258–N) involves cruises of the research ship *Nathaniel B. Palmer* in the Ross Sea. CORSACS aims to use novel trace metal chemostat culture methods to study the interactions between iron limitation and carbon dioxide use and limitation. Because carbon acquisition by marine phytoplankton depends on the zinc, cadmium, or cobalt metalloenzyme carbonic anhydrase, our adding these trace metal analyses to the CORSACS project should prove highly complementary and yield valuable data.

We will measure total dissolved concentrations and chemical speciation analyses in field samples (to ascertain the ambient geochemical conditions) and in bottle incubation samples (to measure chemical transformations and the drawdown of these micronutrients). We will analyze cobalt by using cathodic stripping voltammetry with dioxime electroactive ligands and cadmium and zinc by using anodic stripping voltammetry.

Ferric reductases have been shown to be involved in the acquisition of ferric iron, including organically chelated forms, but molecular analyses of marine phytoplankton ferric reductases have barely begun. Therefore, we will also collect DNA samples from the Ross Sea and amplify them for genes homologous to these enzymes. We will use polymerase chain reaction and degenerate primers to amplify gene sequences and then screen clone libraries for sequences of interest. This study of ferric reductases will also complement the CORSACS research focusing on iron limitation and is an important first step in the future analysis of ferric reductase gene expression in environmental samples.

This work will contribute to our understanding of how trace metals influence marine primary productivity and carbon biogeochemical cycling in a region of major importance for the marine carbon cycle. (O–398–N; NSF/OPP 04–40840)

National Science Foundation
WHERE DISCOVERIES BEGIN

GEOLOGY AND GEOPHYSICS

Mt. Erebus is the southernmost active volcano in the world. At 3,794 meters in height, it forms the summit of Ross Island at the southwestern corner of Ross Sea. It was named by Captain James Clark Ross in 1841 for his ship, the Erebus. (*NSF photo by Jerrod Clausen*)

In this section:

Overview

Antarctica is not only one of the world's seven continents, it also comprises most of one of a dozen major crustal plates, accounting for about 9 percent of the Earth's continental (lithospheric) crust. Very little of this land is visible, however, covered as it is by the vast East Antarctic Ice Sheet and the smaller West Antarctic Ice Sheet. These ice sheets average some 3 kilometers deep and form a virtual vault; 90 percent of the ice on Earth is here. And it is heavy, depressing the crust beneath it some 600 meters (m). These physical characteristics, while not static, are current. Yet Antarctica is also a time machine, thanks to the sciences of geology and geophysics, powered by modern instruments and informed by the paradigm of plate tectonics/continental drift.

Geologists have found evidence that there was once a forested supercontinent, which they call Gondwanaland, in the Southern Hemisphere. Before the Earth's shifting plate movement began to break the continent up 150 million years ago, Antarctica was a core piece of this assembly; the land adjoining it has since become Africa, Madagascar, India, Australia, and South America. Though the antarctic plate has drifted south only about a centimeter a year, geologic time eventually yields cataclysmic results. The journey moved the antarctic plate into ever-colder, high-latitude climates, at a rate of about 4°C for each million years; eventually conditions changed dramatically, and Antarctica arrived at a near polar position. This astounding story—written in the language of rocks and

fossils—is locked in beneath the ice and the sea, and in the bedrock below them both.

As the ice sheets developed, they assumed, through their interaction with oceanic and atmospheric circulation, what has become a key role in modulating global climate. As a bonus, the South Pole presents a strategic point to monitor the Earth's seismic activity. Antarctica is the highest continent on Earth (about 2,150 m above sea level), with its fair share of mountains and volcanoes; thus, many generic questions of interest to Earth scientists worldwide also apply to this region. Some specific issues of interest to the Antarctic Geology and Geophysics Program include the following:

- exploring new horizons in geology with discoveries that range from new dinosaur fossils to meteorites from Mars;
- determining the tectonic evolution of Antarctica, from its central role in the breakup of the Gondwana supercontinent to the active deformation driving present-day volcanism, rifting, and orogenesis;
- observing unique geologic processes, such as the mysterious formation of subglacial lakes or the aeolian sculpting of the Dry Valleys, in action;
- determining Antarctica's crustal structure;
- determining how the dispersal of antarctic continental fragments may have affected the paleocirculation of the world's oceans, the evolution of life, and the global climate (from prehistoric times to the present);
- reconstructing a more detailed history of the ice sheets, identifying geological controls to ice-sheet behavior, and defining geological responses to the ice sheets on regional and global scales; and
- deciphering paleoenvironmental records, through drilling of the continental margin, to understand Antarctica's role in global climate, ocean circulation, and the evolution of life.

These issues will all become clearer as scientists improve their models of where, when, and how crustal plate movement wrought Antarctica and its surrounding ocean basins. The Antarctic Geology and Geophysics Program funds investigations into the relationships between the geological evolution of the antarctic plate and the life and processes that can be deduced to accompany it—the paleocirculation of the world's oceans, the paleoclimate of the Earth, and the evolution of high-latitude biota. A current emphasis is the West Antarctic Ice Sheet Program, focused on the smaller of the continent's two ice sheets and conducted jointly with the Antarctic Glaciology Program. Several important research support activities are underway as well:

- **Meteorites:** In partnership with the National Aeronautics and Space Administration and the Smithsonian Institution, the program supports meteorite collection through the antarctic search for meteorites (ANSMET) and chairs an interagency committee that is responsible for curating and distributing samples of antarctic meteorites.
- **Mapping and geodesy:** In partnership with the U.S. Geological Survey, the program supports mapping and geodetic activities as an investment in future research in earth sciences. The U.S. Antarctic Resources Center (USARC) constitutes the U.S. Antarctic Program's contribution to the Scientific Committee on Antarctic Research library system for earth sciences; housed here is the largest collection of antarctic aerial photographs in the world, as well as many maps, satellite images, and a storehouse of geodetic information.
- **Marine sediment and geological drill cores:** In partnership with Florida State University's Antarctic Marine Geology Research Facility, the program manages and disseminates marine sediment and geological drill cores mined in Antarctica. The collection includes an array of sediment cores as well as geological drill cores from the Dry Valley Drilling Project, the Cenozoic Investigations of the Ross Sea Drilling Program, and the Cape Roberts Drilling Project. The facility fills requests for samples from researchers worldwide and also accommodates visiting researchers working onsite.

ANDRILL.

David M. Harwood, University of Nebraska–Lincoln; Robert M. DeConte, University of Massachusetts; Thomas R. Janecek, Florida State University; Terry J. Wilson, Ohio State University; and Ross D. Powell, Northern Illinois University.

ANDRILL (Antarctic Drilling), an international program representing over 150 scientists from Germany, Italy, New Zealand, the United Kingdom, and the United States, is designed to investigate Antarctica's role in Cenozoic global environmental change. ANDRILL will obtain a record of important Eocene, Neogene, and Holocene stratigraphic intervals in high southern latitudes and will address four themes:

- the history of the antarctic climate and ice sheets,
- the evolution of polar biota,
- antarctic tectonism, and
- Antarctica's role in the Earth's ocean-climate system.

This research will lead to insights into

- the development of the antarctic cryospheric system (ice sheet, ice shelf, and sea ice);
- the magnitude and frequency of cryospheric changes;
- the influence of ice sheets on Eocene to Holocene climate, the modulation of thermohaline ocean circulation, and eustatic change; and
- the evolution and timing of major tectonic episodes and the development of sedimentary basins.

The successful retrieval of cores and excellent depth of penetration from fast-ice, ice-shelf, and land-based platforms is ensured by the improved drilling system. The program will provide new, seismically linked and well-constrained Cenozoic stratigraphic records from locations proximal to the antarctic cryosphere. Empirical data garnered from these records will calibrate numerical models and will allow new constraints to be placed on estimates of ice volume variability, marine and terrestrial temperatures, the timing and nature of major tectonic episodes, and the development of Antarctica's marine, terrestrial, and sea-ice biota.

This research will contribute to the development of strategies to cope with future climate change, provide insight into relationships between ice-sheet fluctuations and volcanic and seismic hazards, and improve models of glacially influenced sedimentary rift basins.

The project will also contribute to other international science goals, bring together international teams, and provide opportunities to share antarctic earth science with the global community. ANDRILL will foster strong partnerships with established educational programs to develop a broad array of activities designed to educate policymakers, K–12 teachers, students, and the community at large. (G–049–M; NSF/OPP 03–42484, NSF/OPP 03–42407, NSF/OPP 03–42408, NSF/OPP 03–42436, and NSF/OPP 03–42445)

Antarctic mapping, geodesy, geospatial data, and satellite image mapping.

Jerry L. Mullins, U.S. Geological Survey.

The U.S. Geological Survey collects data from several instruments such as the Global Navigation Satellite System to provide mapping, geodesy, geospatial data, and satellite image mapping to the U.S. Antarctic Resource Center (USARC). Year-round data acquisition, cataloging, and data dissemination will continue in the USARC in support of surveying and mapping. Field surveys are planned as part of a continuing program to collect the ground control data required to transform existing geodetic data into an Earth-centered system suitable for future satellite-mapping programs and to reinforce extant control of mapping programs to support future scientific programs. Landsat (Land Remote-Sensing Satellite) data will be collected to support satellite image-mapping projects. These maps will provide a basis for displaying geologic and glaciologic data in a spatially accurate manner for analysis. They will also support future expeditions by providing a basis for planning scientific investigations and data collection. In addition, spatially referenced digital cartographic data will be produced from published maps.

Geodetic projects are planned as part of a continuing program aimed at building the continent-wide GIANT (Geodetic Infrastructure for Antarctica) system, which will support a wide range of U.S. and international scientific research objectives by

- establishing and maintaining a framework of permanent geodetic observatories,
- extending and strengthening the existing network of stations linked to the International Terrestrial Reference Frame,
- establishing geodetic coordinates at identifiable points for georeferencing satellite image-mapping projects,
- maintaining and calibrating tide-gauge instrumentation,
- carrying out absolute gravity measurements,
- applying new high-accuracy remote-sensing measurement technologies such as airborne laser altimetry and digital cameras, and
- expanding the online geodetic database with new and historical data.

The geodetic field program is supported by a cooperative arrangement with Land Information New Zealand. (G–052–M/P/S; NSF/OPP 02–33246)

The antarctic search for meteorites (ANSMET).

Ralph P. Harvey, Case Western Reserve University.

Since 1976, ANSMET (the antarctic search for meteorites program) has recovered more than 14,000 meteorite specimens from locations along the Transantarctic Mountains. Antarctica is the world's premier meteorite hunting ground for two reasons:

- First, although meteorites fall at random all over the globe, the likelihood of finding one is enhanced if the background material is plain and the accumulation rate of terrestrial sediment is low; this makes the East Antarctic Ice Sheet the perfect medium.
- Second, along the margins of the sheet, iceflow is sometimes blocked by mountains, nunataks, and other obstructions; this exposes slow-moving or stagnant ice to the fierce katabatic winds, which can deflate the ice surface and expose a lag deposit of meteorites (a representative portion of those that were sprinkled throughout the volume of ice lost to the wind). When such a process continues for millennia, a spectacular concentration of meteorites can be unveiled.

The continued recovery of antarctic meteorites is of great value because they are the only currently available source of new, nonmicroscopic extraterrestrial material. As such, they provide essential "ground truth" about the composition of asteroids, planets, and other bodies of our solar system. ANSMET recovers samples from the asteroids, the Moon, and Mars for a tiny fraction of the cost of returning samples directly from these bodies.

During the 2004–2005 field season, ANSMET's main field party (eight people) worked at the LaPaz icefields, approximately 250 miles from Amundsen–Scott South Pole Station. More than 1,000 meteorites were recovered from the site during visits in 1991, 2002, and 2003. The field team continued systematic searches of the icefields in an effort to recover a representative sample of the extraterrestrial material falling to Earth.

This year's fieldwork will focus on a full-scale meteorite recovery in the Miller Range icefields. A detailed reconnaissance of these icefields in 2003 yielded 200 specimens, including a Martian meteorite, and demonstrated that a systemic survey would be valuable. (G–057–M and G–058–M; NSF/OPP 99–80452)

The timing of the Holocene climate change in the McMurdo Dry Valleys, Antarctica.

Carolyn B. Dowling, Arkansas State University; Glen T. Snyder, Rice University; W. Berry Lyons, Ohio State University; and Robert J. Poreda, University of Rochester.

The McMurdo Dry Valleys of southern Victoria Land constitute the largest ice-free region in Antarctica. Because most of the perennially ice-covered lakes there have closed basins, small changes in climate can have profound effects on water levels and aqueous

chemistry. The limnology of these lakes has revealed important details about climate change in this region, which is affected by both the West and East Antarctic Ice Sheets and the Ross Ice Shelf. The lakes in the Dry Valleys, despite their geographic proximity, have not experienced the same drawdown and refilling history during the Holocene. In addition, the gain or loss of ice cover on the lakes is important because ice restricts the exchange between lake water and the atmosphere, limits lake circulation, and offers organisms a defense against the harsh winter.

We will provide information about the overall climate history of the McMurdo Dry Valleys, including data about lake levels, the timing of hypolimnia formations, and the presence or absence of ice cover. Data from dissolved gases, helium and other isotopes, and tritium from Lake Joyce (Pearse Valley), Lake Vanda (Wright Valley), and Lake Garwood (Garwood Valley) will impose new constraints on the Holocene climate history of the Dry Valleys. The data we collect, coupled with information from marine sediments, ice cores, and lakes, will provide a more complete picture of the climate history of the McMurdo Dry Valleys through the Holocene.

Our research will also improve understanding of the origin of cryogenic brines in polar regions. Isotope analyses will significantly influence our understanding of how these brines develop and how they migrate over time.

Students working on this research will gain experience both in the laboratory and in the field. In addition, an online limnology module, describing the physical, chemical, and biological aspects of lakes (with special emphasis on Dry Valley lakes), will be created for classes throughout the United States to use. Interpretive material and teaching and study guides will accompany the material. (G–060–M; NSF/OPP 04–40892, NSF/OPP 04–40686, NSF/OPP 04–40709, and NSF/OPP 04–40672)

Deducing the climate in late Neogene Antarctica from fossil-rich lacustrine sediments in the Dry Valleys.

David R. Marchant, Boston University, and Allan C. Ashworth, North Dakota State University.

Ancient lake sediments deposited alongside former outlet and alpine glaciers in the Dry Valleys are sensitive indicators of past climate and ecological change. We will analyze 17 former lake sites above 1,000 meters on the north wall of central Taylor Valley and in north-facing valleys of the Asgard and Olympus Ranges. Chronological control comes from argon isotope analyses of interbedded volcanic ash. Lake sediments over 13 million years old contain layers of well-preserved pleurocarpous mosses, diatoms, woody stems, and insects; younger sediments lack such fossils. The fossil-rich lacustrine sediments of the Dry Valleys contain the only known in-situ tundra-type flora and fauna in the Transantarctic Mountains outside the Beardmore Glacier region.

Our objectives include

- developing a better characterization of the distribution of ancient lakes and their flora and fauna,
- securing a more refined chronology,
- producing a geochemical signature for glass within ice-marginal lakes, and
- providing a comparison for previously mapped terrestrial vegetation in the central Transantarctic Mountains.

Our results will help place the modern Dry Valley lakes in a long-term framework and will facilitate dating among deposits across the Transantarctic Mountains. Moreover, our work will improve dating in nearby marine cores (Cape Roberts).

The key questions we will address are as follows:

- When did the polar desert replace the Neogene tundra?
- Was the climate change that caused the biotic turnover unidirectional and permanent, or did short-lived, warmer climatic conditions, supporting tundra, return to the Dry Valleys after the mid-Miocene?
- Were warmer conditions regional or continental?
- What variation is there in species content and richness among Neogene fossil sites in the Transantarctic Mountains?
- Was the extinction of Gondwanaland biota gradual, or were there dispersal episodes during warmer intervals that replenished the biota from South America, New Zealand, and Tasmania, thus delaying extinction until the Pliocene?

This research will introduce students to a unique synthesis of the Dry Valleys; results will be disseminated in scientific journals and in a special volume of the American Geophysical Union's Antarctic Research Series. (G–063–M; NSF/OPP 04–40711 and NSF/OPP 04–40761)

Collection of marine geophysical data on transits of the *Nathaniel B. Palmer*.

Joann M. Stock, California Institute of Technology, and Steven C. Cande, University of California–San Diego, Scripps Institution of Oceanography.

Well-constrained plate reconstructions of the antarctic region are critical for examining a number of problems of global geophysical importance. During this 3-year project, we are addressing questions about the motion history of the antarctic and other plates and improving plate reconstructions by surveying gravity, magnetics, and swath bathymetry on selected transit cruises by the U.S. research icebreaker *Nathaniel B. Palmer*.

In February 2006, during a transit cruise (NBP 06–02) from McMurdo Base, Antarctica, to Punta Arenas, Chile, we will do geophysical surveys of gravity, magnetics, and swath bathymetry in the Ross Sea and South Pacific Ocean, on the Antarctica plate, to study several major features of the plate that relate to its history of spreading away from other plates (including the easternmost piece of the Australia plate and the Pacific Plate).

These data will be used in combination with previously collected marine geophysical data from the Pitman fracture zone, at the southwestern end of the Pacific-Australia plate boundary, and magnetic anomalies from previous Palmer cruises on the Pacific and Antarctica plates near the Menard Fracture Zone to improve high-precision plate reconstructions and evaluate the limits of possible internal deformation of the Pacific and Antarctica plates in this sector. Our results will contribute to knowledge of plate kinematics and

dynamics, and lithospheric rheology.

The ship schedule has not been finalized for August to October 2006. However, if we are able to sail on another cruise during that time, we will integrate research and education by teaching an on-board marine geophysics class to 30 graduate and undergraduate students (some of them minorities). Classes will consist of daily lectures about the instruments and the data they record. In addition, each student will spend several hours a day standing watch and processing data and will also work on an individual independent research project. (G–071–N; NSF/OPP 03–38317 and NSF/OPP 03–38346)

Stability of landscapes and ice sheets in the Dry Valleys, Antarctica: A systematic study of exposure ages of soils and surface deposits.

Jaakko Putkonen, University of Washington.

The near-perfect preservation of ancient, *in situ* volcanic ash and overlying sediments suggests that hyperarid cold conditions have prevailed in the McMurdo Dry Valleys for over 10 million years. The survival of these sediments also suggests that warm-based ice has not entered the valley system and that ice sheet expansion has been minimal. However, other evidence suggests that the Dry Valleys have experienced considerably more sediment erosion than is generally believed:

- The cosmogenic exposure ages of boulders and bedrock all show generally younger ages than volcanic ash deposits used to determine the minimum ages of moraines and drifts.
- There appears to be a discrepancy between the suggested extreme preservation of unconsolidated slope deposits (more than 10 million years) and adjacent bedrock that has eroded 2.6 to 6 meters during the same interval.

The fact that till and moraine exposure ages generally postdate the overlying volcanic ash deposits (a clear contradiction) could reflect expansion of the continental ice sheet into the Dry Valleys with cold-based ice, thus both preserving the landscape and shielding the surfaces from cosmic radiation. Another plausible explanation of the young cosmogenic exposure ages is erosion of the sediments and gradual exhumation of formerly buried boulders.

We will measure the accumulation of multiple cosmogenic isotopes in rock and sediment profiles to determine the minimum exposure ages, degree of soil stability or mixing, and shielding history of surfaces by cold-based ice to obtain unambiguous minimum ages for deposits. In addition, we should be able to identify areas disturbed by periglacial activity, constrain its timing, and account for the patchy preservation of important stratigraphic markers such as volcanic ash.

In a complex landscape such as the McMurdo Dry Valleys, individual exposure analyses will seldom give unambiguous ages for the surfaces. By contrast, our approach of looking at vertical profiles and multiple isotopes at a few sites will be considerably more informative. The result will be a better understanding of the stability of the East Antarctic Ice Sheet, which could fundamentally change how we view the dynamics of Southern Hemisphere climate on time scales of millions of years. (G–076–M; NSF/OPP 03–38224)

Dry Valley Seismic Project.

Robert C. Kemerait, U.S. Air Force Technical Applications Center.

One recurrent issue in seismography is noise: that is, background phenomena that can interfere with clear and precise readings. The Dry Valley Seismic Project, a cooperative undertaking with the New Zealand Antarctic Program, was established to record broadband, high-dynamic-range, digital seismic data from the remote Wright Valley, a site removed from the environmental and anthropogenic noise that is ubiquitous on Ross Island.

The Wright Valley site provides one of the few locations on the continent with direct access to bedrock. The station there consists of a triaxial broadband borehole seismometer [100 meters (m) deep] and a vertical short-period instrument at 30 m. The seismological data are digitized at the remote location, telemetered by repeaters on Mount Newall and Crater Hill, and received eventually by the recording computer at the Hatherton Laboratory at Scott Base, where a backup archive is created.

From Hatherton, they pass along a point-to-point protocol link to the Internet at McMurdo Station and thence to the Albuquerque Seismological Laboratory for general distribution to the international seismological community. This data set has beautifully complemented the data from other seismic stations operated by the Albuquerque Seismological Laboratory at Amundsen–Scott South Pole Station, Palmer Station, and Casey, an Australian base. (G–078–M; NSF/OPP DoD MOA)

Transantarctic Mountains Deformation Network: Global positioning system (GPS) measurements of neotectonic motion in the antarctic interior.

Terry J. Wilson and Dorota Brzezinska, Ohio State University, and Larry D. Hothem, U.S. Geological Survey–Denver.

We will conduct global positioning system (GPS) measurements of bedrock crustal motions in an extension of the Transantarctic Mountains Deformation Network (TAMDEF) to document neotectonic displacements caused by tectonic deformation within the West Antarctic Rift or mass changes in the antarctic ice sheets. By monitoring the U.S. and Italian networks of bedrock GPS stations along the Transantarctic Mountains and on offshore islands in the Ross Sea, we will tightly constrain horizontal displacements related to active neotectonic rifting, strike-slip translations, and volcanism. We will use GPS-derived crustal motions, together with information from other programs on the ice sheets and from ongoing structural and seismic investigations in Victoria Land, to model glacio-isostatic adjustments due to deglaciation and to modern mass changes in the ice sheets. The integrative and iterative nature of this modeling will yield a holistic interpretation of neotectonics and ice sheet history that will help us discriminate tectonic crustal displacements from viscoelastic/elastic glacio-isostatic motions.

We will do repeat surveys of key sites southward about 250 kilometers along the Transantarctic Mountains. These measurements will cross gradients in predicted vertical motion due to viscoelastic rebound. The southward extension will also allow us to determine the southern limit of the active Terror Rift and provide a better baseline for constraints on any ongoing tectonic displacements across the West Antarctic Rift system as a whole. Further, we will investigate unique aspects of GPS geodesy in Antarctica to determine how the error spectrum compares with that found in mid-latitude regions and to identify optimum measurement and data processing methods.

The geodetic research will improve position accuracies within our network and will also yield general recommendations for other deformation-monitoring networks in polar regions.

An education and outreach program targeted at Ohio State University undergraduates who are not science majors will illuminate the research process for nonscientists. This effort will educate students about science and inform them about Antarctica and how it relates to global science issues. (G–079–M; NSF/OPP 02–30285 and NSF/OPP 02–30356)

Mount Erebus Volcano Observatory and Laboratory (MEVOL).

Philip R. Kyle and Richard C. Aster, New Mexico Institute of Mining and Technology.

Mount Erebus, Antarctica's most active volcano, is a rare example of a persistently active magmatic system. This volcano, which has a history of low-level eruptive activity associated with a highly accessible summit vent complex, also features one of Earth's few long-lived lava lakes. We are developing an interdisciplinary geophysics/geochemistry laboratory on Mount Erebus to pursue basic research on the eruption physics and associated magmatic recharge of active volcanoes. Erebus is especially appropriate because of its persistent open-conduit magmatic system, frequent eruptions, ease of access (by antarctic standards), and established scientific and logistical infrastructure, including real-time data links and relative safety.

The key integrated data-gathering components we will rely on include video surveillance and seismic, infrasound, Doppler radar, infrared, volcanic gas, and geodetic studies. To collect the data, a combination of core Mount Erebus Volcano Observatory and Laboratory (MEVOL)–supported personnel and their students (with specialties in seismology, gas studies, and general volcanology) will collaborate with internationally recognized volcano researchers (with specialties in infrared, Doppler radar, gas studies, and infrasound).

We will then develop quantitative models of the magmatic system of an active volcano, including eruptive energy balance (gravity; explosive gas decompression; and thermal, seismic, acoustic, and kinetic components) and magma recharge (volcanic tremor, convection, residence time, gas emissions, and deformation). We expect this research to contribute substantially to basic knowledge of active volcanoes around the world.

Our work also involves a project to develop and deploy integrated low-power, low-cost, real-time-telemetered volcano monitoring stations at Erebus and other active volcanoes. (Many volcanoes, particularly in the developing world, have little or no modern instrumentation.) The goal is to contribute to the development of low-power, low-cost interdisciplinary geophysical observatories within the larger seismology, geodesy, and geophysical communities.

Our work also includes the education of graduate and undergraduate students in volcanology and geophysics, the dissemination of information to high school audiences, and the provision of year-round monitoring information to the National Science Foundation and to McMurdo Station. Finally, to convey the excitement and relevance of volcanology and other aspects of earth science to society, we expect to continue public outreach through lectures, media interaction, and inquiry response. (G–081–M; NSF/OPP 02–29305)

SHALDRIL, a demonstration drilling cruise to the James Ross Basin.

John B. Anderson, Rice University; Patricia Manley, Middlebury College; and Sherwood W. Wise Jr., Florida State University.

For over three decades, U.S. scientists and their international colleagues exploring the shallow shelves and seas along the margins of Antarctica have been consistently frustrated by their inability to penetrate the overcompacted glacial diamictons encountered at shallow subbottom depths (within the upper 10 meters) over these terrains. This has been particularly frustrating because advanced high-resolution seismic reflection techniques clearly show the presence of older successions of Neogene and even Paleogene sequences lying just beneath this thin veneer of diamictons in many areas. Until the means to recover these sequences are developed, a detailed history of the antarctic ice sheets—an essential prerequisite to understanding Cenozoic paleoclimates and future climate change on a global scale—will remain an elusive and unobtainable goal.

A group of U.S. scientists called the SHALDRIL Committee has identified at least two diamond coring systems deemed suitable for use on existing U.S. Antarctic Research Program ships. We will use one of these systems on the research icebreaker *Nathaniel B. Palmer* to demonstrate the feasibility of both ship-based diamond coring and downhole logging. We will core along a high-resolution seismic reflection dip line off Seymour Island, Antarctic Peninsula, an area of high scientific interest in its own right. Here the well-defined geologic section is estimated to range from Eocene to Quaternary in age, effectively spanning the "greenhouse-icehouse" transition in the evolution of antarctic/global climate. A complete record of this transition has yet to be obtained from anywhere along the antarctic margin.

We will correlate the record we obtain with detailed fluctuations of the ice margin recently recorded at higher latitudes in the eastern Ross Sea. If successful, SHALDRIL will be able to further explore the gap in our technical capability to study the antarctic shelves between the shoreline/fast-ice margin and the continental slope. This technological breakthrough will not only address major outstanding scientific issues of the past three decades, but will also favorably affect many other current antarctic or drilling-related initiatives. (G–083–N; NSF/OPP 01–25922, NSF/OPP 01–25480, and NSF/OPP 01–25526)

Integrated study of East Antarctic Ice Sheet tills (ISET): Tracers of ice flow and proxies of the ice-covered continental shield.

Kathy J. Licht and R. Jeffrey Swope, Indiana University, Purdue University–Indianapolis; John W. Goodge, University of Minnesota; and G. Lang Farmer, University of Colorado–Boulder.

Our interdisciplinary study of glacial deposits in the Ross embayment will help constrain Antarctica's Late Quaternary glacial history (about 18,000 years ago) and improve our knowledge of the rocks underlying the East Antarctic Ice Sheet. While constraining changes to till during transport, we will use till provenance to evaluate models for the last glacial maximum and to characterize rocks eroded from the East Antarctic Craton.

Although progress has been made in constraining the extent and timing of the last glacial maximum in the Ross Sea, reconstructions vary substantially. For example, some studies have concluded that ice streams derived from the west were dominant features of the Ross Ice Sheet during the last glacial maximum, while others show roughly equal inputs from east and west. Glacial sediments from the Ross embayment can be used to test these models.

Despite limited data, our previous work suggests that

- the east-to-west variations in the sand composition of Ross Sea till can be linked to eastern and western sources and that the ice sheets contributed equivalent volumes to the Ross Ice Sheet during the last glacial maximum,
- tills from West and East Antarctica are distinguishable and can be related to Ross Sea tills, and
- detritus from specific glaciers in the Transantarctic Mountains can be isotopically fingerprinted.

We will collect till samples from moraines at the heads and mouths of the Amundsen, Beardmore, Byrd, Liv, Nimrod, Reedy, Scott, and Shackleton Glaciers. We will then characterize particle size distribution, clast lithology, sand petrography, isotopic composition and elemental abundance of the silt/clay fraction, and ages of detrital zircons.

We will build predictions of the ice sheet's response to changing climate and rising sea level from models that accurately predict past configurations. Detailed sampling will allow us to characterize changes to till produced by the processes that modify sediment during transport and to determine constraints on the transport distances of eroded bedrock, as well as provide evidence of unmapped, buried rocks.

Also, we will host curriculum development workshops for 30 Indiana earth science educators, thus allowing us to reach over 600 students from diverse backgrounds. (G–084–M; NSF/OPP 04–40885, NSF/OPP 04-40160, and NSF/OPP 04-40177)

A global positioning system (GPS) network to determine crustal motions in the bedrock of the West Antarctic Ice Sheet: Phase I—Installation.

Ian W. Dalziel, University of Texas–Austin; Robert Smalley, University of Memphis; and Michael Bevis, University of Hawaii.

This project will initiate a global positioning system (GPS) network to measure crustal motions in the bedrock surrounding and underlying the West Antarctic Ice Sheet. Evaluating the role of both tectonic and ice-induced crustal motions in this bedrock is critical to understanding past, present, and future dynamics and the potential role of the ice sheet in future global change scenarios, as well as to improving our understanding of Antarctica's role in global plate motions. The extent of active tectonism around and under the West Antarctic Ice Sheet is largely speculative. Existing GPS projects are located on the fringe of the ice sheet and do not address the regional picture.

In the final season of this project, we will finish installing the GPS network at sites across the interior (approximately the size of the contiguous United States from the Rocky Mountains to the Pacific) and making initial measurements. We designed the network by using a multimodal occupation strategy in which a small number of independent GPS roving receivers make differential measurements against a network of continuous GPS stations for comparatively short periods at each site. This strategy, successfully implemented elsewhere, minimizes logistical requirements.

The GPS network is based on permanent monuments set in solid rock outcrops that have near-zero setup error for roving GPS occupations and that can be directly converted to a continuous GPS site when technology makes autonomous operation and satellite data linkage throughout western Antarctica reliable and economical. The network both depends on and complements existing and planned continuous networks.

Our work complements existing GPS projects by filling a major gap in coverage among the discrete crustal blocks making up western Antarctica. The network will yield increasingly meaningful results over time. We anticipate that these results will initiate an iterative process that will gradually resolve into an understanding of the contributions from plate rotations and viscoelastic and elastic motions arising from deglaciation and changes in ice mass. (G–087–M; NSF/OPP 00–03619; NSF/OPP 00-03834; NSF/OPP 00-03861)

Gneiss dome architecture: Form and process in the Fosdick Mountains, Antarctica.

Christine S. Siddoway, Colorado College, and Christian Teyssier, University of Minnesota–Twin Cities.

Gneiss dome formation involves material and heat transfer from middle or deep crustal levels and therefore represents a fundamental orogenic or mountain-forming process. Recent breakthroughs in understanding the role of migmatitic gneiss domes result from the geophysical exploration of contemporary mountain belts that reveal a thick, midcrustal layer of partially molten crust within the orogenic system. As middle crust exposures, gneiss domes offer the means to study structural and metamorphic processes that cannot be observed directly in contemporary orogens and to undertake a detailed analysis of structures beyond the resolution of seismic imaging.

In the Fosdick Mountains of the Ford Ranges of western Marie Byrd Land are excellent three-dimensional exposures of an elongated migmatite dome derived from sedimentary and plutonic protoliths. Preliminary findings suggest that peak metamorphism occurred about 105 million years ago at depths of about 25 kilometers (km), followed by decompression as the Fosdick dome was emplaced to 16 to 17 km, or possibly 8.5 km, by 99 million years ago. Near-isothermal conditions, favorable for producing substantial volumes of melt, were maintained during ascent. Because mineral assemblages record decompression and because the ages of argon isotopes indicate rapid cooling, the gneiss dome has been interpreted as a product of extensional exhumation. This is a viable interpretation from the regional standpoint, because the dome was emplaced during the mid-Cretaceous with the rapid onset of divergent tectonics along the proto-Pacific margin of Gondwanaland.

However, the complex internal structures in the Fosdick Mountains have not been integrated into the extensional exhumation model, and alternative models have not been explored. Possible alternatives are upward extrusion within a contractional setting or lateral flow within a transcurrent attachment zone. To address this question, we will use detailed structural analysis, paired with geothermobarometry and geochronology, to determine the flow behavior and structural style that produced the Fosdick Dome. Our study will be relevant to research on the role of gneiss domes for material and heat transfer in orogeny and on mechanisms of gneiss dome formation.

In addition to multidisciplinary research, students will be involved in developing curriculum materials. (G–088–M; NSF/OPP 03–38279 and NSF/OPP 03–37488)

Global seismograph station at Palmer Station and the South Pole.

Rhett G. Butler, Incorporated Research Institutions for Seismology.

Seismology, perhaps as much as any other science, is a global enterprise. Seismic waves resulting from earthquakes and other events can be interpreted only through simultaneous measurements at strategic points all over the planet. The measurement and analysis of these seismic waves are not only fundamental to the study of earthquakes, but they also serve as the primary data source for the study of the Earth's interior. To help establish the facilities required for this crucial scientific mission, IRIS (the Incorporated Research Institutions for Seismology) was created in 1985.

IRIS is a consortium of universities with research and educational programs in seismology. Ninety-seven universities are currently members, including nearly all U.S. universities that have seismological research programs. Since 1986, IRIS, through a cooperative agreement with the National Science Foundation (NSF) and in cooperation with the U.S. Geological Survey (USGS), has developed and installed the Global Seismographic Network (GSN), which now has about 137 broadband, digital, high-dynamic-range seismographic stations around the world; most of these have real-time communications.

The GSN seismic equipment at Amundsen–Scott South Pole Station and at Palmer Station was installed jointly by IRIS and USGS, which continue to operate and maintain them. The GSN sites in Antarctica are vital to seismic studies of Antarctica and the Southern Hemisphere, and they contribute to the international monitoring system of the Comprehensive Test Ban Treaty. The state-of-the-art seismic instrumentation is an intrinsic component of the NSF effort to advance seismology and earth science globally.

In 2003, with the completion of the South Pole Remote Earth Science and Seismological Observation (SPRESSO) in the Quiet Sector, the GSN seismic instrumentation was moved to the SPRESSO site, 8 kilometers from the Pole, and deployed into 300-meter deep boreholes in the ice below the firn. The new GSN site, QSPA, achieves the quietest conditions on Earth at frequencies above 1 hertz. (G–090–P/S; NSF/EAR 00–04370)

Reconstructing the high-latitude Permian-Triassic: Life, landscapes, and climate recorded in the Allan Hills, southern Victoria Land, Antarctica.

Molly B. Miller, Vanderbilt University; Derek Briggs, Yale University; Christian A. Sidor, New York Institute of Technology; and John Isbell, University of Wisconsin–Milwaukee.

On the basis of fossil plants and paleosols recorded in the sedimentary rocks of the Transantarctic Mountains, a model of Permian to Triassic climate at high paleolatitudes is emerging: After continental glaciers melted in the early Permian, forests grew in the cold, wet climate. By the early Triassic, warmer, drier conditions inhibited prolific plant growth. A moister, but still warm climate allowed plants to flourish later in the Triassic.

We will test and refine this model and investigate the effects of climate change on Permian to Triassic landscapes and ecosystems. Using exposures in the Allan Hills, we will search for, describe, and interpret fossil forests, vertebrate tracks and burrows, arthropod trackways, and subaqueously produced biogenic structures, and document the end of glaciation and the importance of major episodic sedimentation. In so doing, we will address broader questions that will contribute to understanding

- the evolution of terrestrial and freshwater ecosystems and how they are affected by the end-Permian extinction,
- the abundance and diversity of terrestrial and aquatic arthropods at high latitudes,
- the paleogeographic distribution and evolution of vertebrates and invertebrates as recorded by trace and body fossils, and
- the response of landscapes to changes in climate.

The excellent record preserved by this Permian to Triassic sequence provides a unique opportunity to compare high-latitude forests and freshwater and terrestrial faunas with better-known low-latitude equivalents during an important period of their evolution.

We will also include two activities that we anticipate will have a strong impact on large audiences:

- A professional scientific illustrator has been engaged to paint reconstructions of Permian to Triassic high-latitude landscapes and ecosystems as interpreted by our research. In addition to synthesizing our results, these reconstructions will convey Earth's history to the public.
- A 10- to 15-minute video will chronicle the research. The video, which will be filmed in the field and edited by a professional, will accompany presentations to general audiences by our group and, perhaps more important, by former students and colleagues who have worked with us in Antarctica and have gone on in many cases to become educators. (G–093–M; NSF/OPP 04–40954, NSF/OPP 04–40889, NSF/OPP 04–40910, NSF/OPP 04–40919)

Paleohistory of the Larsen Ice Shelf System: Phase II

Eugene W. Domack, Hamilton College; Laurence Padman, Earth and Space Research; Stephanie Brachfeld, Montclair State University; Amy Leventer, Colgate University; and Scott Ishman, Southern Illinois University–Carbondale.

Building on our previous work, we intend to test the hypothesis that the Larsen B Ice Shelf system has been a stable component of the cryosphere since it formed during rising sea levels 10,000 years ago. This conclusion would be an important step in establishing the uniqueness and consequences of the rapid warming taking place across the Peninsula. Our previous work on the Larsen A and B embayments taught us to recognize the signature and impact of past ice-shelf fluctuations. We have also overcome many of the limitations of radiocarbon-based chronologies in antarctic marine sequences by using geomagnetic-paleomagnetic intensity records for millennial-scale correlation and dating and by refining other dating techniques.

We will pursue these advances and extend our sediment core stratigraphy to areas uncovered by the most recent collapse of the Larsen B Ice Shelf and areas immediately adjacent to the Larsen C Ice Shelf. In addition to the core recovery program, we will use our access to the ice-shelf front to continue our observations of firn/ice stratigraphy, oceanographic character, and ocean floor characterization.

We will also conduct marine process studies across the Vega Drift in the Erebus and Terror Gulf. The Vega Drift—the largest Holocene

deposystem on the antarctic margin—contains an exceptional paleoenvironmental archive for the northwest Weddell Sea. We will install a 1-year instrumented mooring and conduct other process-related observations that will facilitate the optimum interpretation of a drill site to be recovered from the drift in 2005.

This 3-year, multi-institutional, international effort combines expertise in a variety of disciplines and integrates the research plan into undergraduate, graduate, and postdoctoral education. The work will extend over two primary field seasons to accommodate the as yet undetermined schedules for the research ships *Nathaniel B. Palmer* and *Laurence M. Gould*.

The Antarctic Peninsula is undergoing greater warming than almost anywhere on Earth, perhaps because of greenhouse effects. Since these changes will increasingly affect life on Earth, our work will contribute to understanding them where they are occurring first and with the greatest magnitude and impact. (G–096–L; NSF/OPP 03–38142, NSF/OPP 03–38101, NSF/OPP 03–38109, NSF/OPP 03–38163, and NSF/OPP 03–38220)

UNAVCO global positioning system support.

Bjorn Johns, UNAVCO.

UNAVCO is a nonprofit, membership-governed consortium funded through the National Science Foundation and the National Aeronautics and Space Administration (NASA) to support and promote high-precision measurement techniques for the advancement of earth sciences. UNAVCO provides complete support for permanent stations, surveying, mapping, and other applications of the global positioning system (GPS) to U.S. Antarctic Program investigators and maintains a satellite facility with a full range of geodetic GPS equipment and support services at McMurdo Station during the austral summer research season.

A large pool of high-precision GPS receivers and associated equipment is provided for short-term surveys through multiyear data collection in Antarctica. Regular equipment upgrades ensure a steady influx of modern equipment, including

- state-of-the-art dual-frequency GPS receivers,
- power and communication systems for remote locations,
- GPS monument and antenna mount options, and
- accessories for kinematic and real-time kinematic (RTK) surveys.

UNAVCO staff provides year-round support to help ensure the success of field projects and subsequent data management. The level of support is scalable and includes

- survey planning,
- field survey and data processing training,
- custom engineering solutions,
- system integration,
- field assistance,
- GPS station maintenance, and
- data retrieval, flow monitoring, processing, and archiving.

UNAVCO also operates a community RTK GPS base station that covers McMurdo Station and provides maintenance support to the NASA GPS Global Network station MCM4 at Arrival Heights. (G–295–M; NSF/EAR 03–21760)

Controls on sediment yields from tidewater glaciers from Patagonia to Antarctica.

John B. Anderson and Julia S. Wellner, Rice University, and Bernard Hallet, University of Washington.

Glacial erosion is a principal issue in contemporary research on landscape evolution and high-latitude climate change. In the Himalayas, for example, the spatial pattern and rapid rates of tectonic rock uplift correspond closely to patterns and rates of erosion by ice and water. On a global scale, the onset of widespread glacial erosion is often viewed as responsible for the increase in sedimentation that coincided with a change to a cooler, more variable climate at the onset of late Cenozoic glaciation (about 2 to 4 million years ago). At high latitudes, this increase in sedimentation created clastic wedges up to 5 kilometers thick on continental margins; these sediments contain a rich history of climate change recorded in proxy climate data (ice-rafted debris, foraminifera) and sediment accumulation rates that reflect the production of glacial sediment.

Our aim is to define an empirical relationship between glacial erosion rates and ice dynamics. We will use glaciologic and marine geologic techniques to examine the role of glacier dynamics in determining glacial sediment yields. We hypothesize that glacial erosion rates are a function of sliding speed and will therefore diminish sharply as basal temperatures drop below the melting point. To test this hypothesis, we will study six tidewater glaciers ranging from fast-moving temperate glaciers in Patagonia to slow-moving polar glaciers on the Antarctic Peninsula. For each system, we will

- use seismic profiles and core data to assess yields and, by inference, erosion rates by determining sediment accumulation rates in the fjords, and
- measure the dynamic properties and basin characteristics of each of the glaciers, which have different ice fluxes and basal thermal regimes.

We will base our work in Patagonia and the Antarctic Peninsula because

- the large latitudinal range provides for a wide range of precipitation and glacier thermal regimes over relatively homogeneous lithologies and tectonic settings,

- earlier studies have noted a significant decrease in the accumulation of glaciomarine sediment in the fjords along a southward transect, and
- the fjords constitute accessible and nearly perfect natural sediment traps. (G–435–N; NSF/OPP 03–38137 and NSF/OPP 03–38371)

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WHERE DISCOVERIES BEGIN

GLACIOLOGY

Undergraduate researcher Erin Whorton and mountaineer Susan Detweiler approach the top of Taylor Glacier, while a mountaineer monitors their ropes from above. Researchers must climb the glacier to place instruments that will record its temperature, movement and melting. Scientists hope to determine why polar glaciers create shear cliffs unlike glaciers in more temperate regions. (*NSF photo by Kristan Hutchison*)

In this section:

Overview

Ice is indisputably the defining characteristic of Antarctica. The entire continent (with a few exceptions such as the McMurdo Dry Valleys and some lakes and mountains) is covered by ice sheets that have been laid down over eons, if the term "sheets" can be used to describe a dynamic mass that is several thousand meters (m) thick, that is larger than most countries, that rises over 2,000 m above sea level (and peaks in an ice dome nearly twice that high in the east), and that is heavy enough to depress the bedrock beneath it some 600 m. Actually, the continent has two distinctly different sheets: the much larger East Antarctic Ice Sheet, which covers the bedrock core of the continent, and the smaller, marine-based West Antarctic Ice Sheet, which is beyond the Transantarctic Mountains and overlays a group of islands and waters.

The Antarctic Glaciology Program is concerned with the history and dynamics of the antarctic ice sheets; this includes research on near-surface snow and firn, floating glacier ice (ice shelves), glaciers, ice streams, and continental and marine ice sheets. These species of ice facilitate studies on ice dynamics, paleoenvironments (deduced from ice cores), numerical modeling, glacial geology, and remote sensing. Current program objectives include the following:

- correlating antarctic climatic fluctuations (from ice-core analysis) with data from arctic and lower-latitude ice cores;
- integrating the ice record with terrestrial and marine records;
- documenting the geographic extent of climatic events noted in paleoclimatic records and the extension of the ice core time series to provide information on the astronomical forcing of climate;
- establishing more precise dating methodologies for deep ice cores;
- determining the Cenozoic history of antarctic ice sheets and their interaction with global climate and uplift of the Transantarctic Mountains and the response of the antarctic ice sheets to the Pliocene warming;
- investigating the physics of fast glacier flow with emphasis on processes at glacier beds;
- investigating ice-shelf stability; and

- identifying and quantifying the feedback between ice dynamics and climate change.

Ice cores from Antarctica are important for determining whether the rapid climate changes recorded in Northern Hemisphere ice cores, such as those obtained from Summit, Greenland, in the Greenland Ice Sheet Project II (GISP2), are global in extent. Plans are underway to drill a deep ice core at a site that has both thick ice and high annual accumulation and is located on the ice divide in West Antarctica. This is the only antarctic site where scientists can obtain an ice core capable of providing a long, annual resolution history of Southern Hemisphere climate in which compressed snow layers are thick enough to allow absolute dating. This ice core will provide a Southern Hemisphere equivalent to the GISP2, GRIP (the European Greenland Ice Core Project), and North GRIP ice cores and will allow a detailed comparison of environmental conditions between the Northern and Southern Hemispheres. The ice cores will also complement those already under study from Byrd Station and Siple Dome in West Antarctica and Taylor Dome and Vostok Station in East Antarctica. Ice cores are unique in that they contain continuous, or nearly continuous, records of annual precipitation, atmospheric temperature, and components of the atmosphere, including gases as well as soluble and insoluble aerosol particles from a variety of sources (biogenic, terrestrial, solar, marine, volcanic, anthropogenic).

Ice cores collected under the Antarctic Glaciology Program are stored at the National Ice Core Laboratory (NICL), a government-owned facility for storing, curating, and studying cores recovered from the ice-covered regions of the world. NICL is supported through an Interagency Cooperative Agreement with the U.S. Geological Survey (USGS) and provides researchers funded by the National Science Foundation and the USGS with the capability to examine and measure ice cores while preserving the integrity of these cores in a protected environment.

Mechanics of dry-land calving of ice cliffs.

Bernard Hallet, University of Washington, and Andrew G. Fountain, Portland State University.

We will perform a comprehensive study of land-based polar ice cliffs. Through field measurements and modeling, we will identify the physics underlying the formation of ice cliffs at the margin of Taylor Glacier in the McMurdo Dry Valleys.

Preliminary modeling suggests that horizontal velocity peaks one-third the distance up the cliff face and that the highest shear strain rates are at the base. We hypothesize that the displacement field of the glacier is more important than the local ablation pattern in maintaining ice cliffs and that the timing of calving is controlled by rapid temperature fluctuations that cause transient stress fields to develop in the thermal skin of the cliffs.

We will use strain gauges, tilt sensors, thermistors, and a global positioning system surface strain network to measure ice deformation and temperature at three sites near the cliff face. An ablation stake network will augment existing energy balance data, and a small seismic network will monitor local ice quakes associated with cracking and calving. Ultimately, the field data will be used to validate a model that will enable us to explore the sensitivity of ice cliff evolution to basal sliding rate, ice temperature, and angle of incident solar radiation. Finally, we will determine the slope, aspect, and height of ice cliffs using a model derived from a laser altimetry survey conducted by the National Aeronautics and Space Administration.

Our work will provide insight into calving and glacier terminus evolution and will shed light not only on other land- and water-based glacier termini on Earth, but also possibly on the Martian ice caps. Moreover, a better grasp of ice cliff processes will improve predictions of glaciers' response to climate change. A better understanding of moraine formation at polar ice cliffs will contribute to more precise interpretation of paleoglacier margins in the McMurdo Dry Valleys and their correlation with paleoclimatic events derived from the Taylor Dome ice core.

This research will have student involvement and will be incorporated into the curriculum of a wilderness science education program for high school girls, as well as several classroom science workshops for middle and high school girls in the Seattle area. (I–139–M; NSF/OPP 02–30338 and NSF/OPP 02–33823)

Using polarimetric radar methods to detect crystal orientation fabrics near the Ross/Amundsen Sea ice-flow divide and at the Siple Dome ice core site.

Charles F. Raymond and Kenichi Matsuoka, University of Washington.

The alignment of ice crystals, called crystal-orientation fabrics (fabrics), has an important effect on ice deformation. As ice deforms, anisotropic fabrics are produced; these in turn influence further deformation. Consequently, fabric variation measurement can reveal how the ice was deformed and indicate how it will deform in the future. Ice cores can determine a vertical fabric profile, but not horizontal variation. Examining variation over large areas requires remote sensing with ice-penetrating radar. We will therefore use ground-based radar measurements to investigate fabrics near the Ross/Amundsen Sea ice-flow divide, where a deep core will be drilled.

When fabric is not rotationally symmetrical around a vertical axis, vertically propagating radio waves are affected by bulk birefringence related to the fabric's axis. Polarimetric methods can detect the degree of horizontal anisotropy and the orientation of fabrics, even when they are nearly vertical. To understand secondary effects on radar-echo anisotropy, we will make radar measurements at Siple Dome and use fabric information from the ice core to study radio wave propagation.

We will do radar measurements at 10 sites for each of two 300-kilometer lines crossing the divide and at about 5 additional sites. We will use the latter to investigate a ridge-like high elevation that could be transient. In conjunction with polarimetric radar measurements at these 25 sites, we will take ice strain measurements with a global positioning system (GPS) and perform radar profiling to connect all sites. We will use the GPS data, together with depth variation of radar-detected isochrones, to derive modern strain rate configuration and to simulate fabrics for shallow depths (about 1,000 meters). Using the simulated fabrics as a reference, we will examine mismatches between simulated and measured fabric azimuths and strengths, and their horizontal variation, to infer divide migration in the past.

Our work will help evaluate the impact of the West Antarctic Ice Sheet on the rise in global sea level, provide further interpretation of the Siple Dome ice core, and support collaboration between the United States and Japan. Moreover, our measurements may lead to new designs for polarimetric radio-wave sensors for ice on Earth and Mars. (I–163–M; NSF/OPP 04–40847)

Gases in firn air and shallow ice at the proposed West Antarctic Ice

Sheet divide drilling site.

Todd Sowers, Pennsylvania State University; James White, University of Colorado–Boulder; Mark O. Battle, Bowdoin College; Eric Saltzman, University of California–Irvine; Edward Brook, Oregon State University; and Jeffrey Severinghaus, University of California–San Diego, Scripps Institution of Oceanography.

Records of changes in atmospheric composition are essential to understanding how the global biosphere influences, and is influenced by, global climate and environmental change. Moreover, changes in atmospheric composition over the past few centuries provide crucial information on how anthropogenic activities have altered the atmosphere. The best way to reconstruct these changes is from air naturally archived in the polar ice sheets.

We will focus on the composition of firn air and occluded air in shallow boreholes and ice cores from the West Antarctic Ice Sheet divide site, the location of a planned deep ice coring program. We have three primary objectives:

- to establish the nature of firn air movement and trapping at the site to interpret gas data from the deep core,
- to expand atmospheric trace gas species that can be measured in ice and replicate existing records of other species, and
- to intercalibrate all collaborating laboratories to ensure that compositional and isotopic data sets are comparable.

We will initiate the project with a shallow drilling program that will recover two 300-meter cores and firn air samples representing more than 700 years of atmospheric history. These will allow us to address a number of important questions related to atmospheric change over this period.

Having a team drawn from six U.S. laboratories has a number of advantages:

- We will be able to coordinate sample allocation to maximize the resolution and overlap of records of interrelated species.
- Sample registration will be exact, allowing us to compare all records directly.
- We will produce a coherent data set to ensure that we have the best possible understanding of gas records at the site.
- The collaborative structure of the project will encourage laboratories to share techniques, equipment, and ideas.

We will identify the impact of various industrial/agricultural activities and help distinguish them from natural variations. Moreover, we will include species for which there are no long records of anthropogenic impact. Trace records from ice cores provide fundamental data for quantifying anthropogenic perturbations of atmospheric composition, and our work will thus help predict future atmospheric loadings. (I–177–M; NSF/OPP 04–40759, NSF/OPP 04–40498, NSF/OPP 04–40509, NSF/OPP 04–40602, NSF/OPP 04–40615, and NSF/OPP 04–40701)

Investigating iceberg evolution during drift and breakup: A proxy for climate-related changes to antarctic ice shelves.

Theodore A. Scambos, University of Colorado–Boulder.

We will place automated instruments on one of two large icebergs off the east coast of the Antarctic Peninsula. Logistical support will be provided by the Instituto Antártico Argentino, and fieldwork will be conducted by a joint U.S.–Argentine team. Icebergs in this area characteristically drift north toward South Georgia Island and then disintegrate in the subpolar climate. Recent study of a series of large icebergs traversing this track has provided a background of remote-sensing-based information on breakup. The two targets are likely to be the last large icebergs in this position for several years.

To derive our observations, we will install an automated weather station, digital cameras, and an iridium data uplink. Getting the observation station set up as soon as possible will provide baseline measurements before the iceberg's rapid drift northward into warmer conditions.

In contrast to icebergs in other sectors of Antarctica, icebergs in the northwestern Weddell Sea drift northward along a relatively predictable path and reach climate and ocean conditions that lead to breakup within a few years. During this northward drift, rapid changes in surface temperature, surface melt, firn density, and basal melt rate occur. As surface melting increases, firn densification can lead to surface melt ponding, which induces rapid fracturing. It has recently been recognized that the end stages of iceberg breakup can imitate the rapid disintegration observed for the Larsen A and Larsen B Ice Shelves. However, basal melting may also play a significant role in shelf breakup. Resolving these two processes (surface ponding/fracturing versus basal melt) and observing iceberg drift and breakup *in situ* will answer fundamental questions about iceberg evolution and provide other highly relevant data.

Understanding ice-shelf disintegration is an important part of understanding the future climate-related evolution of the Antarctic Peninsula and the antarctic ice sheet in general. Shelf removal has a significant effect on glacier flow and mass balance. Glacier mass balance and the shelf stability of the antarctic ice sheet are critically important to changes in sea level. Our work will further the understanding of ice-sheet dynamics by investigating ice-shelf-related processes. (I–186–E; NSF/OPP 05–40915)

A mobile sensor web for polar ice-sheet measurements.

S. Prasad Gogineni, University of Kansas–Lawrence.

We will use synthetic aperture radar (SAR) carried on ground-level rovers to map polar ice sheets and bedrock. Ground-level radar of this type will provide a two-dimensional picture and more details than have previously been available from satellite imagery and airborne SAR. To produce the detail needed by glaciologists, the radar we will use will be able to operate in either monostatic or bistatic mode.

Much of this project will focus on developing the new technologies needed to carry out the project. These include an intelligent and collaborative radar system—one that can look at the data it is generating in real-time, determine whether these data indicate that an area should be studied in more detail, and then send that information to another radar system that is taking similar measurements only a few kilometers away.

PRISM (Polar Radar for Ice Sheet Measurements) engineers also need to design and build a semi-autonomous ground rover capable of

- withstanding the rigors of the polar environment,
- towing the radar safely and accurately,
- providing power for the radar systems and data analysis systems as well as the rover, and
- keeping track of the exact position of the radar units at all times.

In addition, PRISM scientists will be developing a wireless communication system that operates in harsh polar environments to allow the rover and radars to communicate with one another, as well as transmit near-real-time data back to other researchers and educators in distant locations. (I–188–M; NSF/OPP 01–22520)

Earth's largest icebergs.

Douglas R. MacAyeal, University of Chicago; Emile A. Okal, Northwestern University; and Charles R. Stearns, University of Wisconsin–Madison.

Icebergs released by the antarctic ice sheet represent the largest movements of fresh water within the natural environment. Several of these icebergs, B–15, C–19, and others calved since 2000, represent over 6,000 cubic kilometers of fresh water—an amount roughly equivalent to 100 years of the flow of the Nile River.

We will study the drift and breakup of the Earth's largest icebergs, which were recently released into the Ross Sea as a result of calving from the Ross Ice Shelf. We will attempt to ascertain the physics of iceberg motion within the dynamic context of ocean currents, winds, and sea ice, which determine the forces that drive iceberg motion, and the relationship between the iceberg and the geographically and topographically determined pinning points on which it can ground. In addition, we will study the processes by which icebergs influence the local environment (sea ice near Antarctica, access to penguin rookeries, air-sea heat exchange and upwelling at iceberg margins, nutrient fluxes), as well as the processes by which icebergs generate globally far-reaching ocean acoustic signals that are detected by seismic-sensing networks.

In addition, we will attempt to deploy automatic weather stations, seismometer arrays, and global positioning system tracking stations on several of the largest icebergs presently adrift, or about to be adrift, in the Ross Sea. Data generated and relayed via satellite to our home institutions will lead to theoretical analysis and computer simulation and will be archived on a Web site (http://amrc.ssec.wisc.edu/iceberg.html) that scientists and the general public can access.

A better understanding of the impact of iceberg drift on the environment, and particularly the impact on ocean stratification and mixing, is essential to understanding the abrupt global climate changes witnessed by proxy during the Ice Age and future greenhouse warming. More specifically, the study will generate a knowledge base useful for the better management of antarctic logistical resources that can occasionally be influenced by the adverse effects icebergs have on sea ice (the shipping lanes to McMurdo Station, for example). (I–190–M; NSF/OPP 02–29546, NSF/OPP 02–29492, and NSF/OPP 02–30028)

Dry Valleys Late Holocene climate variability.

Karl J. Kreutz and Paul A. Mayewski, University of Maine.

We will collect and develop high-resolution ice-core records from the Dry Valleys in southern Victoria Land and provide interpretations of interannual to decadal climate variability during the past 2,000 years (late Holocene). We will test hypotheses related to ocean/atmosphere teleconnections (e.g., El Niño Southern Oscillation, Antarctic Oscillation) that may be responsible for major late Holocene climate events such as the Little Ice Age in the Southern Hemisphere.

Conceptual and quantitative models of these processes in the Dry Valleys during the late Holocene are critical for understanding recent climate changes. We plan to collect intermediate-length ice cores (100 to 200 meters) at four sites along transects in Taylor and Wright Valleys and analyze each core at high resolution for stable isotopes, major ions, and trace elements. A suite of statistical techniques will be applied to the multivariate glaciochemical data set to identify chemical associations and to calibrate the time-series records with available instrument data.

Broader impacts of the project include

- contributions to several ongoing interdisciplinary antarctic research programs;
- graduate and undergraduate student involvement in field, laboratory, and data interpretation activities;
- use of project data and ideas in several University of Maine courses and outreach activities; and
- data dissemination through peer-reviewed publications, University of Maine and other paleoclimate data archive Web sites, and presentations at national and international meetings. (I–191–M; NSF/OPP 02–28052)

Tidal modulation of ice stream flow.

Sridhar Anandakrishnan, Richard B. Alley, and Donald Voigt, Pennsylvania State University; Robert Bindschadler, National Aeronautics and Space Administration, Goddard Space Flight Center; and Ian Joughlin, National Aeronautics and Space Administration, Jet Propulsion Laboratory.

We will investigate the newfound, startling sensitivity of major west antarctic ice streams to tidal oscillations to learn the extent and character of the effect and its ramifications. Ice streams D, C, and Whillans (B) all show strong but distinct tidal signals. The ice plain of Whillans is usually stopped outright, forward motion being limited to two brief periods a day, at high tide and on the falling tide. Motion propagates across the ice plain at seismic wave velocities. Near the mouth of D, tides cause a diurnal variation of about 50 percent in ice-stream speed that propagates upglacier more slowly than on Whillans, and seismic data show that C experiences even slower upglacier signal propagation. Tidal influences are observed more than 100 kilometers (km) upglacier on C and more than 40 km upglacier on D and may be responsible for fluctuations in basal water pressure reported 400 km upstream on Whillans.

During the first year, five coordinated seismic and global positioning system (GPS) instrument packages placed 100 km apart on each stream measured Whillans and ice stream D. These packages were deployed at sites selected by satellite imagery and operated autonomously for two lunar cycles to study the sensitivity of the streams to spring and neap tides. Also, we examined existing data

sets for clues to the mechanisms involved and developed preliminary models.

During the second and third seasons, we will examine in greater detail the tidal behavior of Whillans and D. We will focus especially on at least one source area for Whillans, assuming that areas inferred from preliminary data remain active. Vertical motions have not yet been detected, but differential GPS will increase sensitivity. Seismic instrumentation will greatly increase temporal resolution and the ability to measure the propagation speed and any spatial heterogeneity.

Improved knowledge of ice-stream behavior will contribute to assessing the potential for rapid ice-sheet change affecting global sea levels. Results will be disseminated through scientific publications and talks at professional meetings, as well as contacts with the press, university classes, visits to schools and community groups, and other activities. (I–205–M; NSF/OPP 02–29629 and NSF/OPP 02–29659)

Monitoring an active rift system at the front of Amery Ice Shelf, East Antarctica.

Helen A. Fricker, University of California–San Diego, Scripps Institution of Oceanography.

Iceberg calving from the front of fringing ice shelves is the primary mechanism by which the antarctic ice sheets lose mass. A single large iceberg can remove a large fraction of the mass gained through years of accumulation and thus can be a significant component in the overall mass balance. This mass contributes to the freshwater flux of the Southern Ocean but does not lead to a change in sea level, since the ice was already floating. However, the presence of ice shelves can influence the discharge of inland ice via the ice streams that feed the shelves; in particular, a reduction in the extent of the ice shelf could increase the rate of discharge. Further, any changes in mass caused by calving could be an indicator of the regional effects of climate change and could modify freshwater mass production rates, which could have global consequences. Therefore, it is important not only to monitor the frequency of iceberg calving, but also to understand the mechanisms that govern it.

Icebergs calve when "rifts," crevasses that penetrate from the surface of the ice shelf to its base, propagate far enough that part of the ice shelf becomes detached. The mechanics are not well understood. We will therefore examine an active rift system—a combination of two longitudinal-to-flow rifts and two transverse-to-flow rifts—that formed at the tip of the western longitudinal rift on the Amery Ice Shelf about 7 years ago. We will use instruments to study the latter two rifts. Their propagation is not independent, and the longer of them is propagating at around 8 meters per day. When this rift meets the eastern longitudinal rift, an iceberg (roughly 30 kilometers by 30 kilometers) will calve. Once calving has occurred, we will examine its effects on the dynamics of the ice shelf and previously inactive rifts.

Calving sparks a great deal of media and public interest. We will report our results widely at conferences and in the scientific literature, and we will use the Visualization Center at the Scripps Institution of Oceanography to display our results. (I–277–E; NSF/OPP 03–37838)

Is Kamb Ice Stream Restarting? Glaciological investigations of the Bulge-Trunk transition on Kamb Ice Stream, West Antarctica.

Slawek M. Tulaczyk, University of California–Santa Cruz; Ian Joughlin, National Aeronautics and Space Administration, Jet Propulsion Laboratory; and Robert W. Jacobel, St. Olaf College.

The West Antarctic Ice Sheet contains enough ice to raise the global sea level by several meters, and concerns have been raised about its possible retreat or collapse. However, measurements have shown that the Ross Sea sector of this ice sheet is in a positive mass balance. This is surprising, because geologic and glaciologic data indicate that the ice sheet has been retreating for about 10,000 years. It is possible that the observed positive mass balance is a result of a short-term (decadal- or century-scale) oscillation in ice discharge, rather than an indication of a long-term shift in ice-sheet behavior. In particular, the Ross Sea sector of the West Antarctic Ice Sheet could return to neutral or negative mass balance if the Kamb Ice Stream (formerly called "Ice Stream C"), which has stopped, restarts and begins flowing at ice-stream–like velocities. Because the tributaries of this stream are still active, a massive ice bulge is building up where they run into the locked-up trunk of the Kamb Ice Stream, near the site of the former Upstream C Camp. On mountain glaciers, buildup of ice bulges is associated with a sharp increase in ice velocity in a relatively short time.

We will test to see whether the Kamb Ice Stream may already be in the process of restarting. If so, we will establish what the rate of reactivation is and what mechanisms are controlling it. If not, we will determine what physical controls are preventing surging and what the alternative scenarios for the evolution of the stream are. One scenario is an increase in ice diversion toward neighboring Whillans Ice Stream; this could prevent a complete stoppage of the stream, which has been slowing down for almost 25 years.

Our work will have two components:

- field observations of bed properties, geometry of internal radar reflectors, surface strain rates, and velocity/topography changes using ice-penetrating radar and differential global positioning systems, and
- numerical modeling of the evolution of the Kamb Ice Stream over the next 100 to 1,000 years.

This project is a collaboration of scientists from three different types of U.S. institutions—a liberal arts college (St. Olaf College), a public research university (University of California–Santa Cruz), and a National Aeronautics and Space Administration research laboratory (the Jet Propulsion Laboratory). We will make project results available to the public and educators through downloadable graphics and animations posted on the research Web site. Field data resulting from the project will be shared with other investigators through the Antarctic Glaciological Data Center. (I–345–M; NSF/OPP 03–38295 and NSF/OPP 03–37567)

High-resolution ice thickness and plane wave mapping of near-surface layers.

Pannirselvam Kanagaratnam, University of Kansas–Lawrence.

We will build and operate two compact, low-power radar systems along the planned traverse route of the U.S. International Trans Antarctic Scientific Expedition (ITASE). The first is a step-frequency depth sounder operating over a wide frequency range of 50 to 200 megahertz for measuring ice thickness, deep internal layers with high resolution, and basal conditions. The second is a wide-band

radar operating over a frequency range of 12 to 18 gigahertz for detecting near-surface internal firn layers to a depth of approximately 7 meters with better than 10-centimeter resolution. These measurements will allow us to determine the spatially continuous snow accumulation rate along the route, which is of critical importance to the validation of satellite missions aimed at assessing the current mass balance of the polar ice sheets. The antenna systems are relatively compact and will be located on the sledge carrying the radar systems.

Our broad scientific focus will be to investigate processes relevant to glacier dynamics and ice-sheet mass balance. Our objectives are to

- obtain high-resolution characterization of internal layering in deep ice to provide a history of past glacier deformation,
- obtain ice-thickness measurements to assess the driving stress of the major ice streams traversed,
- use measurements to validate theoretical models,
- determine basal conditions, whether the bed is wet or frozen, and relate them to glacier flow fields, and
- characterize with high depth resolution the spatial variability of the snow accumulation rate along the traverse route to use in validating satellite mission data.

As part of this project, we will institute a strong outreach program involving K–12 education and a minority institution of higher learning (Haskell Indian Nations University, with which we have an existing collaboration). We also work closely with the Advanced Learning Technology Program at the University of Kansas to develop online, interactive, resource-based lessons for use by students at all grade levels, and we will develop new lessons related to this project. (I–346–M; NSF/OPP 02–30378)

A hyperinsulated instrumentation system to support year-round research in polar regions.

Anthony D. Hansen, Magee Scientific Company.

Year-round scientific research is seriously challenged by the ambient environment in polar regions. Extremely low temperatures, 6 months of darkness, high winds, and icing create substantial problems for the unattended operation of remote instrumentation stations for a year or more. Further, the risks and logistical costs of accessing a remote site even once a year can be considerable. Consequently, many research projects experience loss of data or the inability to acquire data over extended areas or periods of time, leading to temporal and geographical gaps in our knowledge. The ability to deploy an instrumentation package that could survive these conditions and gather data unattended for a year or more would help fill these gaps. This type of system could also support year-round research at locations that have well-developed summer camps but are unoccupied and inaccessible during the winter.

The system we will create synthesizes in an innovative manner many recent developments in other areas. When buried in a shallow snow pit at –60°C, the system will provide a warm, powered environment for an instrumentation payload with a passive design endurance of 10,000 hours. Insulation will be provided by a large-capacity metal Dewar flask like the ones used to preserve samples in liquid nitrogen. Thermal storage will be provided by the latent heat of fusion from 150 liters of specially formulated paraffin oil; electrical energy will come from lithium-ion batteries recently developed for military applications. Solar panels will provide multiyear operation by recharging the system electrically and thermally during the summer. An iridium modem will allow reporting on system status and transmit summaries of scientific data stored on solid-state memory.

The system is designed to be transported to remote field sites by helicopter or Twin-Otter aircraft and to be set up by no more than two people. We will develop and test the system during two year-long deployments at existing camps on the Antarctic Plateau. For testing purposes, we will equip it with an array of temperature probes like the ones used for glaciology research, but the system will be explicitly designed to accommodate almost any payload of data-gathering equipment. (I–414–S; NSF/OPP 03–37737)

Using a deep ice core from the West Antarctic Ice Sheet ice divide to investigate climate, ice dynamics, and biology.

Kendrick C. Taylor, Desert Research Institute.

The U.S. ice core research community will collect a deep (3,400 meters) ice core from the West Antarctic Ice Sheet ice-flow divide and integrate approximately 15 separate projects to develop, analyze, and interpret a series of interrelated climate, ice dynamics, and biological records in order to understand the interactions among global systems.

The most significant characteristic of this program will be the development of climate records with an absolute annual-layer-counted chronology for the past 40,000 years (approximately). Lower temporal resolution records will extend to roughly 100,000 years ago. These records will enable us to compare environmental conditions in the Northern and Southern Hemispheres and to study greenhouse gas concentrations in the paleoatmosphere in more detail. The themes of the program are as follows:

- **Climate forcing by greenhouse gases:** This research will provide a record of greenhouse gases with unprecedented time resolution during the rapid climate changes that occurred at the end of the last glacial period. The relative timing of changes in greenhouse gases and other environmental parameters will be determined.
- **The role of Antarctica in abrupt climate change:** We will develop high-time-resolution records that can be used to infer the interaction of the southern oceans and atmosphere with each other and with their northern counterparts. This will allow a precise investigation into the role of the Antarctic in abrupt climate changes.
- **The relationship among northern, tropical, and southern climates:** Small differences in the age of the ice versus the age of the gas in the ice will allow us to investigate the relative timing of Northern Hemisphere Dansgaard-Oeschger events and corresponding Southern Hemisphere climate excursions.
- **The stability of the West Antarctic Ice Sheet:** We will determine how the West Antarctic Ice Sheet responded to previous climate changes, thereby improving predictions of how the ice sheet and sea level will respond now and in the future.
- **Biological signals in deep ice cores:** This research will yield information about biogeochemical processes that control and are controlled by climate, as well as lead to new insights about life on Earth. (I–477–M; NSF/OPP 04–40817)

National Science Foundation
WHERE DISCOVERIES BEGIN

ARTISTS AND WRITERS

At the Penguin Ranch near McMurdo Station, an underwater observation tube allows researchers to watch penguins dive. (*NSF photo by Kris Kuenning*)

In this section:

Overview

The National Science Foundation's (NSF's) Antarctic Artists and Writers Program makes it possible for the humanities (painting, photography, writing, and history) to be part of the U.S. Antarctic Program. Artists and writers work at U.S. stations and camps, often with science groups but sometimes on their own, to create works that portray the region or the activities that take place there.

The Antarctic Artists and Writers Program contributes to NSF's goal of advancing discovery while disseminating results broadly to enhance scientific and technological understanding. The program helps record the Nation's antarctic heritage, responding to White House direction that the U.S. Antarctic Program support the range of U.S. interests in the region. Application procedures are available on the NSF Web site at http://www.nsf.gov/pubsys/ods/getpub.cfm?ods_key=nsf04558, and a list of past participants can be found at http://www.nsf.gov/od/opp/aawr.jsp.

The selection process for the Antarctic Artists and Writers Program is comparable to the one for science projects in that a peer-review panel meets at NSF annually to evaluate the applications; this panel's advice heavily influences the selections. The applicants who are chosen receive field support (including air travel from the United States), but no direct NSF funding. The program, while intended mainly for U.S. citizens, considers requests from artists and writers who live in other Antarctic Treaty nations but whose applications demonstrate that their works will reach a significant U.S. audience. The application deadline for participation in the 2007–2008 austral summer season will be 13 June 2006.

Examination of crevasses and other ice forms as artistic sources.

Gabriel P. Warren.

In 1999, Gabriel Warren became the first sculptor ever to be sent to Antarctica. This deployment represents a continuation of and builds on his previous visit. Ice is the primary source in the natural world for Warren's sculpture, which is always positioned at the interdisciplinary border between art and science. The pivotal role of the polar regions in global climate regulation, the threats posed to them from human activities, and the stunning beauty of ice forms provide ample justification for their use not only as a visual source, but in a metaphorical role to a impart larger meaning to his work.

A main focus of this deployment is crevasses and other internal spaces of ice forms. Mr. Warren will fly to the South Pole to observe the crevasse fields and chaos zones in and around the Transantarctic Mountains, fly over other areas at lower altitudes in helicopters that will take off from McMurdo Station, and descend into crevasses on Hut Point and other Ross Island sites. In the field, he will sketch, draw, paint if possible, keep a journal, photograph, converse, and be open to the unexpected. Upon his return, he will draw on these resources to create both indoor sculptures and large outdoor interpretive ice sculptures using stainless steel, aluminum, weathering steel, and bronze.

Mr. Warren exhibits his sculptures regularly. Moreover, his photographs from this deployment will become part of exhibitions and

articles and will also be used as research material and in lectures and slide talks. He lectures extensively on his work and its implications in venues such as galleries, museums, and schools and maintains a comprehensive Web site to show and explicate his work (http://www.art-farm.net/). (W–217–M; NSF/OPP 04–41979)

In Cold Pursuit.

Sarah Andrews.

Sarah Andrews has been a geologist, teacher, and writer for some 30 years and has written 11 previous science-based mystery novels. During this deployment, she will be assisting geologists at a field camp in Antarctica to gather background and information for a book tentatively titled *In Cold Pursuit.* In this book, her protagonist, geologist-sleuth Em Hansen, travels to Antarctica with a forensic team to investigate the fate of a fictional explorer and finds herself on the trail of murder in the coldest place on Earth.

By drawing on her collaborative work with her geologist colleagues as she researches her novels, Ms. Andrews is able to present not only current scientific knowledge, but also the benefits that earth science professionals provide to society and culture. *In Cold Pursuit* will highlight U.S. antarctic research and communicate its value to the public in an easily understood, appealing, and compelling form appropriate for adult and young adult (ages 12 and up) readers. Her inquiring mind and scientific bent will give readers a scientist's view of life and research on the ice continent. She increases the impact, outreach, and integration of her work with a Web site (http://www.sarahandrews.net/), and, by talking both to her colleagues and to the lay public, she helps build a bridge between science and its beneficiaries. (W–218–M; NSF/OPP 04–40665)

Images from a frozen continent.

J. Alan Campbell.

Mr. Campbell is no stranger to Antarctica. He made his first trip there in 1987–1988. The following year, he went to Palmer Station, and in 1994, he sailed on the research ship *Nathaniel B. Palmer*. During their 2-month deployment, he, together with his son and colleague Mr. Colin Campbell, will paint and take photographs. Mr. Colin Campbell will be working as a field assistant and associate researcher/artist producing his own body of work for joint exhibitions. Their artwork will include images of the landscape, wildlife, and light of Antarctica and portraits of support personnel and scientists.

Before flight operations begin, they will seek to accompany flagging and reconnaissance parties, search and rescue teams, field camp construction teams, and other nonscience teams out of McMurdo Station. In collaboration with photographer Ann Hawthorne (W_224–M), they also plan a 4- to 6-week field camp on the fast ice at Erebus Bay, Backdoor Bay, or North Bay. When flight operations begin in early October, they plan short trips to the rim of Mount Erebus and to a number of locations on Ross Island, including the Emperor penguin rookery at Cape Crozier.

Following these trips, they plan one or more field camps for the Taylor, Beacon, or Wright Valleys. In late October, a 2-day camp at Cape Royds will be followed by a 2-day camp at Cape Evans for extensive photography, drawing, and painting of the exteriors and interiors of the historic huts left by early explorers, as well as the surrounding terrain.

This deployment will produce drawings, watercolors, and oil paintings that tell the story of a full austral summer season in Antarctica. This collaboration between art and science will help expand public understanding of the region and the research and will be central to the exhibitions, publications, and publicity flowing from the project. Exhibitions in New Zealand and the United States, as well as two books, are planned. (W–219–M; NSF/OPP 04–40702)

Antarctica: The frozen desert.

George Steinmetz.

Most people do not realize that Antarctica is a desert. By photographing the most unusual aspects of this dry landscape, Mr. Steinmetz hopes to convey to the public a new perspective of the arid beauty of Antarctica and the significance of its changing climate. To illustrate Antarctica's similarity to other deserts, he will pay particular attention to the great variety of arid features in the Dry Valleys (dunes, wind-eroded rock formations, patterned ground, nunataks, salt lakes) and some unique sites on Ross Island.

To take advantage of the low angle of early-season light, he plans to start with aerial photographs of the Dry Valleys and the summit of Mount Erebus. He is also interested in photographing the historic huts left by early explorers, to show how cold, arid conditions preserve the past, and the mega-dunes of the East Antarctic Ice Sheet.

He plans to accompany scientists to their camps and research sites to document their work, to draw on their expertise in understanding desert processes, and to give a human scale to remote areas.

Mr. Steinmetz has spent the past 7 years photographing hyperarid deserts for *National Geographic* and *GEO* magazine. His work in Antarctica will be published next year by *GEO* magazine in Germany and France, *Smithsonian* magazine, and *WashingtonPost.com*. (W–222–M)

Field guide to antarctic features: McMurdo Sound region.

Lawrence J. Conrad and Ann Hawthorne.

This project involves taking ground-view photographs of named geographic features close to McMurdo Station. The photographs will be used to illustrate a geographically arranged, historical gazetteer that will be published in print and online versions. During the 2003–2004 field season, Mr. Conrad and photographer Ann Hawthorne worked from McMurdo Station during August, September, and October. In November and December, they traveled with and photographed mountaineers—most notably, Louis Sass—during a traverse ranging from McMurdo, north of Granite Harbor to Cape Ross via the Miller and Debenham Glaciers, and then south to the Koettlitz Glacier and up the Ferrar and Taylor Glaciers to Turnabout Glacier.

Weather and terrain precluded complete photographic coverage of several areas during the earlier deployment. In the 2005-6 season, Ms. Hawthorne will finish taking pictures of Ross Island and the Dry Valleys and of sites along the coastal area between the Ferrar Glacier and Mount Morning. (W–224–M)

The Scientific Method: Poems of Antarctic Inquiry.

Kathleen M. Heideman.

Ms. Heideman's objective is to move the public's understanding of Antarctica beyond the historic photographs of polar explorers to the particulars of modern antarctic science. Her project will result in a rich body of poems that ponder, celebrate, and explicate the questions posed by current research. Using McMurdo Station as a base, she will travel to scientific sites and camps (Long-Term Ecological Research sites, the Mount Erebus Volcano Observatory and Laboratory, the Dry Valleys, South Pole Station) to conduct poetic field research by observing science in the field, conversing with scientists working in various disciplines, and engaging in private reflection. Additional poems, inspired by the landscape itself, will be written in the voice of the antarctic terrain: That is, they will be conversations between the landscape and all who would approach it. She proposes to use her poetry as a sort of information filer to discern meaningful connections.

Her poetry draws on formal hypotheses, informal notes, factoids, concept maps, scientific texts, and the modern aesthetics of fragmentation, collaboration, specialization, and human curiosity. Ms. Heideman is keenly interested in the metaphors of Antarctica-as-database and database-as-poetic-form, as well as in the use of data visualization tools. She will log all geographic coordinates gathered throughout her project in order to later map them with their source texts/media to form an interactive, database-driven poetic map of Antarctica. (W–227–M; NSF/OPP 04–40619)

Extra 4 days in McMurdo to Shoot Video to Supplement W0–220–0 (2001).

Henry J. Kaiser.

Henry J. Kaiser, composer and guitarist, is creating original music inspired by being in Antarctica in 2001 under the auspices of the Antarctic Artists and Writers Program. His photography and videography will help establish the context of the music, which is intended to reach audiences that might not otherwise pay attention to antarctic research.

He was obliged to curtail his 2001 visit because of an injury. He did separate work in Antarctica in 2004 with a research group headed by Samuel S. Bowser, of the New York State Department of Health (B–015–M). Mr. Kaiser needed an extra 4 days in McMurdo Station to complete the videography for the work begun in 2001.

A Season at Palmer.

Joseph Montaigne.

Mr. Montaigne, a Pulitzer Prize nominee with a strong background in writing about science, will write a book that tells the story of ecologist William Fraser's life and work by chronicling a season in the field with him at Palmer Station, Antarctica. Dr. Fraser has spent a lifetime studying the population changes resulting from the effects of global warming on the Adélie penguin. Mr. Montaigne will follow the birding team from the moment the penguins show up to nest in October until the last fledged chicks head out to sea in late February. He hopes to paint a portrait of a dedicated field biologist, the breathtaking place at the heart of this scientist's work, and the changes affecting the lives of creatures there as a result of rapid warming. The intent is to put a human, and animal, face on climate change—a situation that has left many people perplexed and resigned.

The book is intended for a lay audience, and the story serves as a narrative line on which important issues relating to science, philosophy, and the environment are suspended. The book should have a broad impact and is likely to draw in readers who previously have had little or no interest in Antarctica or climate change.