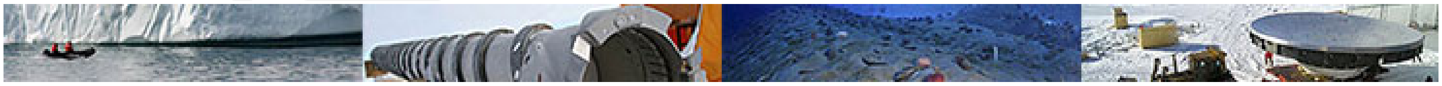

OCEAN AND ATMOSPHERIC SCIENCES

A cable portrudes from the ice wall at Explorer's Cover, New Harbor, McMurdo Sound. The cable is used for the Remotely Operable Micro-Environmental Observatory (ROMEO), an underwater camera. Connected to onshore equipment and linked by radio to the Internet, ROMEO allows scientists to study benthic fauna year-roun. (*NSF/USAP photo by Steve Clabuesch*)

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 Antarctic Ocean and Atmospheric Sciences 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 Meteorological Research Center.

Charles R. Stearns, University of Wisconsin–Madison and David B. Reusch, Pennsylvania State University.

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– science education. (O-202-M/P/S; NSF/OPP 01-26262 and NSF/OPP 05-38064)

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 involve 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 Colm Sweeney, 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 06-11553)

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 also 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 Current 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.

Palmer Station personnel 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)

The Amundsen Continental Shelf and the Antarctic Ice Sheet.

Stanley S. Jacobs

Focusing on the Amundsen Sea and Pine Island Glacier with an experienced team of scientists and engineers aboard the *Nathaniel B. Palmer*, we will use an autonomous underwater vehicle (AUV), sea-floor swath mapping, vertical wate-column profiling, and geochemical sampling to study interactions between the ice shelves and the seawater that floods the deeper parts of the continental shelves in the southeast Pacific sector of Antarctica.

We will also investigate how this water gains access to the continental shelf, transports heat into the ice shelf cavities via deep, glacially scoured troughs, and rises beneath the ice to drive basal melting. This work will be carried out in combination with parallel modeling, remote sensing, and database projects in an effort to narrow uncertainties about the response of the West Antarctic Ice Sheet to climate change.

Our project will be the first use of a sophisticated long-ranging AUV under warm-regime ice shelves and is likely to become the proof of concept for that methodology.

Using state-of-the-art facilities and instruments, our work will enhance knowledge of water mass production and modification, and understanding of the interactions between ocean circulation, sea floor, and ice shelves. Findings will be reported to publicly accessible archives and submitted for publication in the scientific literature. The information obtained should prove invaluable for the development and validation of general circulation models needed to predict the future role of the Antarctic Ice Sheet in sea level change. (O-274; NSF/OPP 04-40775)

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 automatic weather stations as necessary. (O-283-M; NSF/OPP 03-38147)

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 phased-array Doppler sonars, in addition to the existing 150 kilohertz ADCP capability, the maximum profiling range will increase to about 1,000 meters under good sea and scattering conditions while maintaining higher vertical resolution in the upper 300 meters. 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. (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– 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 World Wide Web page. (O-316-M; NSF/OPP 03-38226)

Cape Adare long-term mooring.

Bruce Huber

Antarctic Bottom Water (AABW) is the densest of the major water masses filling the deepest parts of the worlds oceans. Because it obtains many of its characteristics during its contact with the sea and glacial ice and with the atmosphere along the continental margins of Antarctica, it is expected that changes in newly formed AABW may represent an effective indicator for abrupt climate change. The two most important source regions for AABW are within the Weddell and the Ross Seas. The latter arguably the second largest source, yet no systematic efforts have been undertaken to make long-term measurements of its outflow.

An array of moorings will be deployed and maintained east of Cape Adare at the northwestern corner of the Ross Sea to observe the properties of AABW exiting the sea.

This study will significantly improve our knowledge of the long-term variability in the outflow of deep and bottom water from the Ross Sea and will provide the beginnings of a long-term monitoring effort that ultimately will allow global climate changes to be detected in the ocean. When joined with similar efforts ongoing in the Weddell Sea, long-term behavior and possible coupling of these two important sources of the ocean's deepest water mass can be examined in detail.

Several aspects of climate research depend on high quality observations made consistently over a long period of time. This has been recognized, and global programs such as the World Climate Research Program have strongly encouraged such observations. Data from the project will be made available to the community in a timely fashion to foster its widespread use for climate research and operational assessments. (O-399; NSF/OPP 05-38148)