# OCEAN AND CLIMATE STUDIES

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 Racer Rock weather station is located on a small outcrop of land approximately 150 miles from Palmer Station near the northern tip of Two Hummock Island on the Antarctic Peninsula. It is one of five remote weather stations on the peninsula that monitor wind, temperature, pressure, humidity and sea temperature. The data is sent to U.S. researchers via satellite. Due to the station's isolated location, it is not often that conditions are conducive to landings by zodiac boat. Sea ice can block a route into the station making it difficult to maintain. In late September 2002, a new solar panel, batteries and a field repair to the antenna brought the station on line and weather data was again being sent to the U.S. for analysis.

*NSF photo by Jeff Kietzmann*

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 sponsors 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 far 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)

## Solar radiation processes on the east antarctic plateau.

*Stephen G. Warren and Thomas Grenfell, University of Washington.*

This project is an experimental study of solar radiation processes near the surface at Dome C, the French-Italian station in East Antarctica. It will be carried out in cooperation with the Laboratoire de Glaciologie et Geophysique de l'Environment in Grenoble, France. The emphasis is on the reflection of sunlight by snow and the transmission of sunlight through clouds. The observations we gather will be relevant to climate, remote sensing, and the physics of ice and snow.

Observations of the angular pattern of solar radiation reflected from the snow surface will allow us to validate information from satellite-derived radiances. Using radiative transfer modeling through the atmosphere, we will reconcile measured surface-reflection functions with the empirical functions obtained from the Advanced Very-High-Resoution Radiometer on the polar orbiting satellites of the National Oceanic and Atmospheric Administration. (O–201–M; NSF/OPP 00–03826)

## Antarctic Meteorological Research Center (2002–2005).

*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 and NSF/OPP 01–26263)

### A study of atmospheric oxygen variability in relation to annual-to-decadal variations in terrestrial and marine ecosystems.

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

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 sample collections being made at a series of baseline sites around the world.

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.

These results should 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 in the sea. (O–204-P; NSF/ATM 00–00923)

### Validation of the Atmospheric Infrared Sounder (AIRS) over the Antarctic Plateau.

*Von P. Walden, University of Idaho.*

The Antarctic Plateau is ideal for calibrating and validating infrared satellite instruments. The large continental ice sheet is one of the most homogeneous surfaces on Earth in terms of surface temperature and emissivity. Ground-based measurements of upwelling infrared radiation from the surface between 8 and 12 micrometers are very nearly equal to those measured by satellite instruments because of minimal atmospheric emission and absorption. Therefore, accurate measurements of spectral infrared radiance can provide valuable validation data for the National Aeronautics and Space Administration’s Atmospheric Infrared Sounder (AIRS).

We will measure upwelling and downwelling spectral infrared radiance with the Polar Atmospheric Emitted Radiance Inferometer. Its viewing angle will be adjustable in both nadir and azimuth to match the AIRS viewing angle of the surface and atmosphere. Also, we will use the AIRS Mobile Observing System to map changes in surface radiation at spatial scales similar to the AIRS field of view. Then, in conjunction with the University of Nice and the University of New South Wales, we will use a Vaisala atmospheric sounding system to obtain temperature and humidity profiles. Finally, using a ground-based global positioning system unit, we will attempt to measure the extremely low values of total precipitable water (about 1 millimeter in the summer).

The data we gather will be extremely helpful in validating the measurements obtained from AIRS. (O–213–M; NASA award)

### Measurements and improved parameterizations of the thermal conductivity and heat flow through first-year sea ice.

*Hajo Eicken, University of Alaska–Fairbanks, and Martin Jeffries, University of Alaska Geophysical Institute.*

The sea-ice cover in the polar oceans strongly modifies ocean-atmosphere heat transfer. Most important, the ice cover thermally insulates the ocean, with sea-ice thermal conductivity determining the magnitude of the heat flow for a given ice temperature gradient. Despite the importance of sea ice (second only to ice albedo), our knowledge of sea-ice thermal conductivity is limited to highly idealized models developed several decades ago. General circulation models (GCMs) and large-scale sea-ice models include overly simplistic parameterizations of ice thermal conductivity that are likely to contribute significantly to errors in estimating ice production rates.

We will carry out a set of field measurements from which the thermal conductivity of first-year sea ice will be derived as a function of ice microstructure, temperature, salinity, and other parameters. Measurements will be carried out by letting thermistor arrays freeze into the fast ice of McMurdo Sound, which represents an ideal natural laboratory for this type of measurement. To minimize errors and identify the most robust technique, we will collaborate with colleagues from New Zealand and compare different methodologies for measurement and analysis. We will also assess the impact of ice microstructure (spatial distribution of brine, crystal sizes) and convective processes on the effective rate of heat transfer.

Antarctic data will be compared with arctic thermal conductivity data sets to assess regional contrasts and the impact of different physical processes on heat flow and to arrive at a comprehensive, improved parameterization of ice thermal conductivity for large-scale simulations and GCMs. This component of the work will involve ice-growth modeling and collaboration with the Sea-Ice Model Intercomparison Project Team established under the auspices of the World Climate Research Program. This research will advance and improve

- our understanding of the processes and parameters controlling heat transfer and the thermal conductivity of first-year sea ice,
- techniques for deriving thermal conductivity and heat flow data from thermistor arrays,
- our understanding of sea-ice processes and heat flow through the ice cover in McMurdo Sound,
- parameterizations of thermal conductivity for use in large-scale and high-resolution one-dimensional simulations, and
- the representation of first-year ice thermal properties (both antarctic and arctic) in GCMs. (O–253–M; NSF/OPP 01–26007)

### South Pole monitoring for climatic change—U.S. Department of Commerce NOAA Climate Monitoring and Diagnostic Laboratory.

*David Hofmann, Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, South Pole Station.*

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)

### Collection of atmospheric air for the NOAA/CMDL worldwide flask-sampling network.

*David Hofmann, Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, Palmer Station.*

The National Oceanic and Atmospheric Administration has been conducting studies to 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

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- 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)

### Antarctic automatic weather station program: 2001–2004.

*Charles Stearns and George 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.

Their data 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/S; NSF/OPP 00–88058)

### Advanced Microwave Scanning Radiometer (AMSR) sea-ice validation during the *Laurence M. Gould* traverse to Antarctica.

*Konrad Steffen, University of Colorado–Boulder.*

We intend to make passive microwave measurements onboard the *Laurence M. Gould* while enroute from Puente Arenas, Chile, to Antarctica in August and September 2003. We will use passive microwave radiometers to monitor the sea-ice surface at four frequencies [11.4 gigahertz (GHz), 21 GHz, 35 GHz, and 94 GHz] at horizontal vertical polarizations. The brightness temperatures can then be related to aircraft overflight measurements and to AMSR-E [Advanced Microwave Scanning Radiometer EOS (Earth Observing System)] satellite measurements.

We will also

- make meteorological measurements of temperature, wind speed and direction, humidity, and pressure;
- make latent and sensible heat flux measurements with eddy-correlation instruments to derive the heat fluxes over various types of ice;

- examine short- and long-wave radiation components of incoming and outgoing fluxes;
- gather cloud statistics with an all-sky camera with hemispheric coverage;
- make optical path-length measurements;
- make sea and ice-surface temperature profile measurements along the ship's transect;
- make *in situ* ice thickness and salinity profile measurements of various ice types characteristic of regions along the ship's transect;
- analyze snow layers over sea ice with ground-penetrating radar;
- make spectral reflectance measurements of different snow and ice types for the 300- to 2,500-nanometer (nm) range with 1- to 3-nm spectral resolution.

We also plan to launch about 50 radiosonde balloons to measure the temperature, wind speed and direction, and humidity profile from the surface of the water to about 10 kilometers above it. (O–309–L; NASA award)

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

*Anthony 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 could be placed anywhere it is needed. (O–314–M; NSF/DBI 01–19793)