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# Antarctic's Role Pursued in Global Climate Change

Paul Andrew Mayewski
*University of Maine*, paul.mayewski@maine.edu

I. Goodwin

likely mediated by instabilities and topographic influences whose horizontal scales are much less than those of the well-studied alongshore flows. Exploring these largely unvisited scales is a new frontier for physical oceanography.

To explore this new frontier, however, physical oceanography requires a continuous supply of graduate students. Similar to many sectors of science today, the recruitment of new students is difficult for a number of reasons. For one, physical oceanography is not visible to undergraduates majoring in mathematics, physics, and engineering. Therefore, physical oceanography does not attract enough graduate applicants from that population.

The interdisciplinary aspects of oceanography should be used to attract new students. Efforts to explore the disciplinary and sometimes physical boundaries of physical oceanography should be encouraged. These include the traditional oceanographic fields of biology, chemistry, and geology and others such as hydrology (nearshore/streams) and meteorology (air-sea interface).

In fact, a strong sense exists that a major thrust in physical oceanography will be along interdisciplinary lines. Yet NSF organization makes it difficult to fund interdisciplinary projects in the ocean sciences. A complicating factor is that, by their nature, interdisciplinary projects require more resources than individual science programs, even though they do not require the vast resources demanded by major programs. Therefore, interdisciplinary projects now seem to fall between the cracks and are perceived to be disfavored.

Despite these problems, a consensus exists that NSF's core program is an invaluable asset for the ocean sciences. The peer review system maintains a balance between scientific rigor and responsiveness and ensures continuing support for innovative and fundamental science. However, increased stresses are being placed on the peer review system as we attempt to maintain scientific infrastructure and increase our responsiveness to societal needs.

Physical oceanographers will be working across boundaries to develop new tools and investigate new problems in the next decades. Advanced sensors from emerging technology will be transmitting data at high rates using improved, inexpensive global communications. This stream of information will be incorporated into data assimilations to be used in new numerical models that will take advantage of modern computing power.

Among the major accomplishments in physical oceanography has been a revolutionary understanding of the coupling of the tropical ocean and atmosphere leading to the development of predictive El Niño models. The collection of data used to feed these models relies on technologies that enable detailed measurement of climate variables. For example, in the last 10 years the errors in surface heat fluxes obtained from ocean moorings have been reduced by a factor of over 40, so that the present uncertainty is 5 watts per square meter.

We also now have a good estimation of the global distribution of mesoscale variability in the world ocean. These observational advances have been in parallel with theories and models of mesoscale instabilities, geostrophic turbulence, and diffusion. Time and space scales that were ignored decades ago are now recognized as very important to physical, biological, chemical, and geological processes. Improved theories and models of this geostrophic turbulence have been developed.

Approaching is the completion of the World Ocean Circulation Experiment that is providing a snapshot of deep ocean hydrography. This and other studies, in an alliance of geochemistry with physical oceanography, have employed tracers such as chlorofluorocarbons and helium/tritium to improve estimates of the pathways and timescales of ocean circulation.

Molecular mixing in the ocean involves turbulent eddies with spatial scales on the order of millimeters or less. It is on these small scales that water-mass conversions of climatological significance ultimately occur. Quantitative measurements have been made of the strength of this small-scale ocean mixing and its dependence on the local internal wave field and other environmental conditions. The main conclusion of these studies is that vertical mixing in the main thermocline is very weak. This inference has been confirmed by direct measurements of vertical mixing via tracer release experiments.

Meetings and workshops assessing research and the future have included Advances and Primary Research Opportunities in Physical Oceanography Studies (APROPOS), Future of Ocean Chemistry in the United States (FOCUS), Future of Marine Geology and Geophysics (FUMAGES), and Ocean Ecology: Understanding and Vision and for Research (OEUVRE). For APROPOS, questions related to physical oceanography's past and future were sent to approximately 550 U.S. scientists working in it and related fields. The questions and responses are posted on the APROPOS Web page (www.joss.ucar.edu/joss_psg/project/oce_workshop/apropos).

## Authors

*Thomas Royer, Department of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, Va, USA, and William Young, Scripps Institution of Oceanography, La Jolla, Calif., USA*

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The impact of Antarctica on global climate change and the impact of global climate change on Antarctica are the focal points of a current series of expeditions there, and an international, interdisciplinary array of researchers met this past spring to go over the expeditions' progress. Advances were reported in describing the impact of the seasonal cycle, semiannual oscillation, and the El Niño-Southern Oscillation (ENSO) cycle on Antarctic accumulation in recent decades.

Difficulties still remain, however, in explaining fully the history and forcing of the Antarctic climate and the links between tropical forcing and high-latitude response. The difficulties arise largely because of the relatively short duration and sparse spatial coverage of Antarctic meteorological data.

The study, the International Trans Antarctic Scientific Expedition (ITASE), has been filling in the gaps in the Antarctic's climate record for the past 200 years or so. This will allow an assessment of natural climate variability there over a number of decades and lead to a better understanding of the global implications.

The expedition is combining available meteorological data from the Antarctic and the Southern Ocean with ice core proxies for a variety of climate parameters, such as moisture balance, atmospheric circulation, and temperature. Available data include reanalysis fields, in situ observations, and operational model fields, providing approximate descriptions of spatial and temporal variability of Antarctic accumulation and associated atmospheric circulation from approximately 1957-1958 (the International Geophysical Year) to the present.

Annual layer dating of ice cores and absolute dating through unique stratigraphic markers were among the topics discussed at the workshop by glaciologists, geophysicists, remote sensing specialists, and meteorologists from 15 countries. Development of annually resolved ice core series is recognized as an essential component of the ITASE program because of the fidelity needed for comparison and calibration with instrumental series.

Several different tools are used in dating ITASE cores. These include annual layer counting of stable isotope, chemistry, and particle series. These annual layering counting tools are calibrated to volcanic and nuclear fallout markers. As an example, sulfate from a variety of well documented volcanic emissions, covering the last ~200 years, is potentially documented in Antarctic ice cores. The cores may contain sulfate from the following eruptions: Lascar, Chile (1993); Pinatubo, Philippines, and Cerro Hudson, Chile (1991); El Chichon,

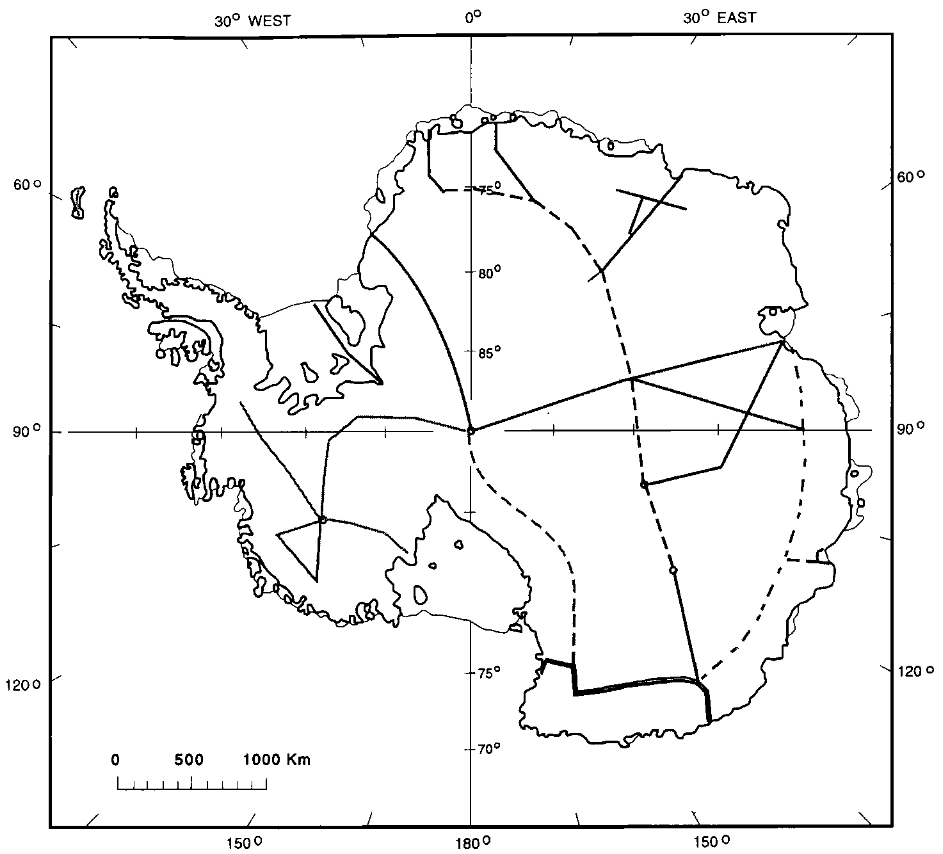


*Fig. 1. Map of planned and proposed national and multinational oversnow traverses that will form the principal fieldwork phase of the International Trans-Antarctic Scientific Expedition (ITASE) in the next decade (2000-2010).*

Mexico (1982); Deception Island, South Shetlands (1972, 1969, 1967); Agung, Indonesia (1963); Cerro Azul, Argentina (1932); Santa Maria, Guatemala (1902); Tarawera, New Zealand (1886); Krakatau, Indonesia (1883); Coseguina, Nicaragua (1835); Babuyan, Philippines (1831); Galunggung, Indonesia (1822); Tambora, Indonesia (1815); and an unknown location (1809).

Ice core proxies for Antarctic moisture flux also were discussed. A selection of 23 ice core derived accumulation rate time series, distributed around the continent, was compared during the workshop. Empirical orthogonal analysis of the series demonstrated that within regions the series share significant common variance. Investigation into associations between regions may provide evidence of the history of moisture-bearing atmospheric circulation systems potentially associated with features in the ENSO system and the Antarctic circumpolar wave.

Ice core proxies for major Antarctic atmospheric circulation patterns were taken up as well. Recent analyses of the instrumental record have shown a dynamic linkage between the tropical ENSO system and the high southern latitudes and have confirmed the existence of an ENSO-Antarctic climatic teleconnection. These investigations reveal that annual temperatures at the South Pole are positively correlated to annual values of the Southern Oscillation Index of the previous year [*Savage et al.*, 1988].

The ENSO signal has been interpreted at the South Pole in an ice core covering the years 1922-1984 and also in a core from Dronning Maud Land. They clearly show increases in methylsulfonic acid (MSA) concentration during El Niño events identified in a historical El Niño chronology by Quinn et al. [1987]. MSA is produced from the oxidation of atmospheric dimethylsulfide, a major emission of marine phytoplankton.

A new record from the South Pole was presented at the meeting. This core extends the South Pole ice core proxy for ENSO back to 1500 A.D. and also identifies a sea ice-MSA association previously observed at a site to the north on the Newall Glacier, southern Victoria Land. Background values of MSA in the South Pole core are associated with sea ice extent anomalies (185°-245°E), and outliers in MSA are associated with warm events (El Niño events), allowing investigation of ENSO-sea ice associations. A sea salt proxy for the strength of the Amundsen Sea low developed from the Siple Dome ice core was also presented.

Another topic of note involved ice core proxies for temperature and borehole temperature. Stable isotope measurements of ice $\delta D$, $\delta^{18}O$, and deuterium excess) have classically been employed as a proxy for temperature in Antarctica, and more recently borehole measurements have been undertaken to provide direct measures of snow surface temperature time series. An overview of results from these studies, combined with instrument observations, reveals an ~1°C warming in the Antarctic peninsula and Dronning Maud Land over the past few decades.

High-resolution ice cores on Law Dome, Wilkes Land, have enabled the discrimination of seasonal stable isotope signals, which are being calibrated to the instrumental meteorological record. This calibration is being used to resolve major precipitation events and temperature fluctuations.

The workshop also took up an examination of the ice sheet record in between ice core sites. Ice cores can provide annually resolved records of environmental change, but they are based on centimeter-scale diameter samples. Snow and ice radar systems on the other hand provide detailed information that can be tuned to investigate snow layering in the upper several tens of meters of the Antarctic ice sheet and down to thousands of meters in depth to detect ice thickness and bedrock configuration. Radar measurements between and around ice core sites add information that is extremely valuable in assessing the representativeness of ice core sites and in the determination of decadally averaged snow layer thicknesses between core sites.

Detailed examination of changes in topography and ice dynamics that exert controls on accumulation rate is being conducted through Global Positioning System surveys along ITASE traverse routes. This is being done to remove the influence of these factors and more clearly assess the influence of climate change on accumulation.

Ground truth for satellite remote sensing of the Antarctic ice sheet also was discussed. Recent advances in remote sensing technology and availability of images have vastly improved traverse route selections, core site selection, and spatial interpolation of ice core time series. As an example, temporal changes in snow surface elevation and velocity can be mapped using laser altimetry and interferometric methods. ITASE traverses provide unique opportunities for developing ground truthing for remote sensing experiments that are geared toward characterizing and interpreting changes in surface topography, surface temperature, surface velocity, and various other surface characteristics of ice sheets, such as roughness, grain size, and albedo.

The workshop also provided a venue for discussing the coordination of sample collection, sample handling, data exchange, data interpretation, and future ITASE oversnow traverse plans for the next decade. ITASE efforts over the next decade are widely dispersed over the continent (Figure 1).

Themes to be investigated in current and future ITASE projects include the relationship between Antarctic precipitation variability with ENSO associated climate, particularly precipitation variability in Southern Australia and perhaps South America; variations in cyclogenesis, storm tracks, moisture flux, and the strength of the low pressure cells that surround Antarctica; interannual and decadal variability in sea ice extent and concentration, persistence, and maintenance of coastal "latent heat" polynyas; and changes in the chemistry of the atmosphere over Antarctica and differentiation of natural versus anthropogenic controls on such change.

ITASE is jointly sponsored by the Group of Specialists on Global Change and the Antarctic of the Scientific Committee on Antarctic Research and the Past Global Changes project of the International Geosphere-Biosphere Programme. Working group reports from the meeting, related references, descriptions of the research presented, and the ITASE Science and Implementation Plan [*Mayewski and Goodwin*, 1997] are available on the Web(www.antcrc.utas.edu.au/scar/itase.html).

The workshop on the International Trans Antarctic Scientific Expedition was held in Durham, New Hampshire, April 19-23, 1999.

### Authors

*P. Mayewski, Climate Change Research Center, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, USA, and I. Goodwin, Scientific Committee on Antarctic Research, Global Change Programme Office and Antarctic Cooperative Research Center, Hobart, Tasmania, Australia*

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# Auroral Spectra as a Tool for Detecting Extraterrestrial Life

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One of the most prominent emissions from the aurora is the greenish-white light from oxygen atoms, while the Jovian aurora contains atomic hydrogen emissions [*Clarke et al.*, 1989]. Most of the processes leading to the production of oxygen atoms are directly or indirectly related to molecular oxygen produced near the ground level. Thus, the oxygen emission, the so-called "green line" (557.7 nm), of the terrestrial aurora, arises mostly from the fact that plants release abundant free oxygen into the atmosphere by the photosynthesis process. Thus, the green line shows that plant life exists on Earth.

It was recently reported that Upsilon Andromedae has three planets [*Lissauer*, 1999; see also *Showstack*, 1999]. This star is a solar-type star [*Fuhrman et al.*, 1998]. This discovery is significant because it shows the planetary system, like the solar system, is not quite unique. It is expected that a number of stars are accompanied by several planets, and it may not be too long before the aurora on such planets can be discovered.

One possible way to detect plant life on such planets is to examine their auroral emissions. If the strong line emission at 557.7 nm can be detected among other emissions in the planetary aurora, the possibility of the presence of plant life is high. Further, if plant life exists, animal life, whether lower or higher, can also exist there.

The Earth-like auroral processes leading to the green light emission require, in addition to plant life, both stellar wind and planetary magnetism. It is highly probable that solar-type stars have stellar wind. If such a planet does not have a strong dipole-like magnetic field, the stellar wind can cause atmospheric glow in which the green line may be present. In any case, if the green emission is detected in the planetary auroral spectra, the possibility of plant life there is high.

There is no doubt that the detection of the green line is technically a very challenging problem, particularly from the ground level. However, the planets expose their full dark sides to Earth once during their revolution around their parent stars. Further, there are a number of prominent atomic oxygen emissions in the FUV range that can be detected by satellites even in the sunlight atmosphere. In any case, this is only a technical problem to be solved.

It is expected that auroral science will evolve in a variety of ways in the future. It is suggested that the subject dealt with here is an example of such a happening. It is hoped that auroral science will contribute to the search for extraterrestrial life, one of the ultimate human endeavors.

### Author

*Syun Akasofu*
Geophysical Institute, University of Alaska, Fairbanks, USA

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