Eos, Vol. 93, No. 26, 26 June 2012

Implementing a Southern Ocean Observing System

PAGES 241–243

The Southern Ocean is fundamental to the operation of the Earth system. It is the central connection among the major ocean basins and between the upper and lower layers of the global ocean circulation. It influences global climate and planetary-scale biogeochemical cycles, because the Southern Ocean accounts for half of the annual ocean uptake of anthropogenic carbon from the atmosphere [*Rintoul et al.,* 2001; *Le Quéré et al.,* 2007; *Meredith et al.,* 2012]. The Southern Ocean also supplies nutrients that fertilize the majority of global ocean biological productivity north of 30°S [*Sarmiento et al.,* 2004].

The Southern Ocean is changing rapidly. These changes, which have been observed over the past several decades, include a large-scale warming that exceeds the global average, including hot spots of extreme regional warming [*Böning et al.,* 2008; *Gille,* 2008] (Figure 1). Both upper and lower limbs of the Southern Ocean overturning have freshened due to changes in the hydrological cycle and ice melt [*Böning et al.,* 2008]. The rate at which the Southern Ocean can draw down anthropogenic carbon from the atmosphere has weakened [*Meredith et al.,* 2012]. In addition, ocean acidification will result in the Southern Ocean's becoming undersaturated in aragonite calcium carbonate in the coming decades, with strong ramifications for the marine food web [*Rintoul et al.,* 2012].

Need for an Observing System for the Southern Ocean

The critical need to observe and understand the Southern Ocean is well established; however, harsh conditions and its remote location have led to its being the most undersampled region of the world. Sustained observations are required to detect, interpret, and respond to the physical, chemical, and biological changes in the ocean.

In response, the Southern Ocean research community produced an integrated plan for developing the Southern Ocean Observing System (SOOS), which would integrate the global assets of the international community to enhance data collection; provide access to data sets; and guide the development of strategic, sustained, and multidisciplinary science in the Southern Ocean. The development of SOOS has been led by the Scientific Committee on Antarctic Research (SCAR) and the Scientific Committee on Oceanic Research (SCOR), both of which are committees of the International Council for Science (ICSU). The community developed the vision for SOOS with the support of the international World Climate Research Programme, the Partnership for Observation of the Global Oceans, the Census of Antarctic Marine Life, the Global Ocean Observing System, and the U.S. National Oceanic and Atmospheric Administration.

Through these programs, the scientific community identified the science priorities for SOOS as understanding

- the role of the Southern Ocean in the planet's heat and freshwater balance,
- the stability of the Southern Ocean overturning circulation,
- the role of the ocean in the stability of the Antarctic Ice Sheet and its contribution to sea level rise,
- the future and consequences of Southern Ocean carbon uptake,
- the future of Antarctic sea ice, and
- the impacts of global change on Southern Ocean ecosystems.

To address these issues, sustained observations of physical, biological, and chemical properties of the Southern Ocean are required, especially observations of the interface between the ocean, atmosphere, and ice. The goal of SOOS is to guide the design and implementation of a sustained, feasible, and cost-effective observing system. The diverse, integrated array of data will be critical to understanding the interactions and feedbacks in the Southern Ocean. Community efforts have highlighted key variables and the range of observational platforms required, but some disciplines, such as biology, still struggle with the lack of synoptic measurements over ecologically relevant space and time scales.

Moving Forward

SCAR and SCOR have convened an SOOS Scientific Steering Committee, charged with steering the strategies for implementation, and the Institute for Marine and Atmospheric Science (University of Tasmania) has funded the SOOS International Project Office in Hobart, Australia. SOOS will build on existing sampling programs and then focus on expanding observing efforts to provide a comprehensive view of the system. A key element will be repeat hydrography transects every 30°–60° of longitude to provide estimates of ocean transport and allow water mass changes to be detected. In addition, water samples can be collected, allowing researchers to link the observed physical changes to the biogeochemistry of the Southern Ocean. To improve spatial and temporal coverage in measurements of the physics and biogeochemistry, underway surface water sampling needs to be expanded to all vessels (tourist, fisheries, and resupply) and complemented with year-round measurements of physical, chemical, and biological properties from all Antarctic research bases. These in-water measurements will be combined with an expanding suite of remote sensing measurements of the ocean, atmosphere, and sea ice.

Even with the enhanced sampling described above, SOOS will not be adequate to address the key science challenges, which will require year-round, full-depth, multidisciplinary monitoring of the Southern Ocean. Therefore, new technologies are needed, many of which are under development. For example, there is a need to expand the number of profiling floats with additional

Fig. 1. An ice bridge with a convoy of polar Adélie penguins. Rapid warming (5 times the global average) in the northern West Antarctic Peninsula is leading to declining sea ice and modifications in the food web including decreasing populations of Adélie penguins. Photo by Zena Cardman.

biogeochemical sensors and depth ranges to resolve low- and high-frequency changes of the circumpolar current. Augmenting the floats, autonomous underwater vehicles and gliders are required to provide higher-resolution adaptive sampling to resolve water mass formation and dynamics in marginal ice zones and underneath ice sheets. Megafauna need to be instrumented to provide insight into their ecology and interaction with hot spots of biological activity, which often reflect physical transitions in the system that have structured ecological and evolutionary patterns. Spatial mapping needs to be complemented by cost-effective high-frequency time series located where there are major water overflows, outflows, and transformations to resolve episodic events. Ocean dynamics will be coupled to measurements of sea ice and snow thickness (collected by satellite sensors calibrated against in situ studies) to understand their coupling and feedbacks.

As the number of platforms in the ocean increases, there is a need for the development of affordable biological and chemical sensors. For example, developing cost-effective fluorometers is a priority, to assess not only the biomass but also the physiological state of phytoplankton. Other trophic levels, including zooplankton, require monitoring in critical areas, and new techniques to enable observations over broad areas in a sustainable manner require development. Information on the technology developments required, and the scientific drivers for them, can be found in the publication *The Southern Ocean Observing System: Initial Science and Implementation Strategy* (http://www.soos.aq/pdf/SOOS_Strategy-lowres.pdf).

The design and implementation of SOOS is beginning, and key strategies have been recommended. SOOS needs to enable quantitative modeling and state estimation of the Southern Ocean. In turn, quantitative studies of the balances to be struck within the observing network should be assessed using a variety of approaches, including observing system simulation experiments, to define the target number and frequency of observations required. This process will benefit from the historical data that have been collected in the Southern Ocean; however, improving data access remains a challenge. Consequently, a key component of SOOS will be the creation and maintenance of a Southern Ocean data portal. The scale of this effort will require strong leveraging of existing data centers; new cyberinfrastructure development efforts; and defined data collection, quality control, and archiving procedures across the international community.

Many challenges lie ahead, but the rapid pace of change of the Southern Ocean means that action is required to enable scientists to observe and understand this most remote of regions. SOOS will transform researchers' ability to collect information and collaborate in the Southern Ocean for the benefit of science and society and to maximize their capacity to use this information across disciplines and between nations.

References

Böning, C. W., A. Dispert, M. Visbeck, S. Rintoul, and F. U. Schwarzkopf (2008), The response of the Antarctic Circumpolar Current to recent climate change, *Nat. Geosci., 1,* 864–869, doi:10.1038/ngeo362.

Gille, S. T. (2008), Decadal-scale temperature trends in the Southern Hemisphere ocean, *J. Clim., 16*(18), 4749–4765, doi:10.1175/2008JCLI2131.1.

Le Quéré, C. L., et al. (2007), Saturation of the Southern Ocean CO_2 sink due to recent climate change, *Science, 316*(5832), 1735–1738, doi:10.1126/science.11361880.

Meredith, M. P., A. C. Naveira Garabato, A. M. Hogg, and R. Farneti (2012), Sensitivity of the overturning circulation in the Southern Ocean to decadal changes in wind forcing, *J. Clim., 25,* 99–110, doi:10.1175/2011JCLI4204.1.

Rintoul, S. R., C. W. Hughes, and D. Olbers (2001), The Antarctic Circumpolar Current system, in *Ocean Circulation and Climate: Observing and Modeling the Global Ocean, Int. Geophys. Ser.,* vol. 77, edited by G. Siedler, J. Church, and J. Gould, pp. 271–302, Academic, San Diego, Calif.

Rintoul, S. R., M. Sparrow, M. P. Meredith, V. Wadley, K. Speer, E. Hofmann, C. Summerhayes, E. Urban, and R. Bellerby (Eds.) (2012), *The Southern Ocean Observing System: Initial Science and Implementation Strategy,* Sci. Comm. on Antarct. Res., Paris.

Sarmiento, J. L., N. Gruber, M. A. Brzezinski, and J. P. Dunne (2004), High latitude controls of the global nutricline and low latitude biological productivity, *Nature, 427,* 56–60.

—Oscar Schofield, Coastal Ocean Observation Laboratory, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, N. J.; E-mail: oscar@marine.rutgers.edu; Michael Meredith, Polar Oceans Research Programme, British Antarctic Survey, Cambridge, UK; Louise Newman, Southern Ocean Observing System International Project Office, Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia; Michael Sparrow, Scientific Committee on Antarctic Research Secretariat, Scott Polar Research Institute, Cambridge, UK; and Ed Urban, Scientific Committee on Oceanic Research, University of Delaware, Newark