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WCRP
World Climate Research Programme

The Southern Ocean Observing System

SOOS

SOUTHERN OCEAN OBSERVING SYSTEM

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The Southern Ocean

Due to its position as the principal connector of the major ocean basins, the Southern Ocean strongly impacts climate, sea level, biogeochemical cycles and biological productivity on a global scale. The Southern Ocean influences the global distribution and movement of heat and carbon (e.g. Rintoul et al., 2001), and it features a vigorous overturning circulation that drives deep-water carbon and nutrients to the surface and draws down anthropogenic carbon from the atmosphere, with implications for global climate change and large-scale productivity (Sarmiento et al., 2004; le Quere et al., 2007; Meredith et al., 2012). The Southern Ocean exerts a strong influence on sea levels via melting of glacial ice (Rignot and Jacobs, 2002; Rignot et al., 2011), and it encompasses a sea-ice system that provides an important habitat for marine organisms, and which influences surface albedo and air-sea gas and heat exchange (Thomas and Dieckmann, 2002). The Southern Ocean also includes some of the most productive and vulnerable marine ecosystems on Earth, many of which support economically important species.

Given the significance of the Southern Ocean to the Earth system, any change in the region will have global ramifications. Recent scientific advances suggest that change is indeed already underway. The Southern Ocean is warming and freshening throughout most of the ocean depth (Böning et al., 2008; Gille, 2008), and major currents are postulated to be shifting south in some regions, causing regional changes in sea level (Sokolov and Rintoul, 2009a,b) and shifts in the distribution of organisms (Cubillos et al., 2007). These changes, and enhanced upwelling due to strengthening winds, have resulted in the supply of additional heat to the rim of Antarctica in some sectors, increasing melt rates of glacial ice (Jacobs, 2006; Jacobs et al., 2011) and impacting strongly on marine ecosystems (Schofield et al., 2010). Further, the future of the Southern Ocean carbon sink is a topic of vigorous debate (le Queré et al., 2007; Böning et al., 2008; Meredith et al., 2012), with the Southern Ocean taking up a large percentage of anthropogenic carbon, resulting in an increase in acidity of 30% (Rintoul et al., 2012). Complex feedbacks in the Southern Ocean will impact on the future trajectory of the climate system and ecosystems, but these are currently poorly understood, hindering our predictive skill.

Progress in understanding Southern Ocean processes has been slowed by a lack of observational data. The Southern Ocean is remote from population centres and shipping lanes, and the hostile environment has hampered data collection efforts. Over the last few decades, several international initiatives have focussed on monitoring aspects of the Southern Ocean (e.g., ISOS, POLEX-South, WOCE, JGOFS, BIOMASS, GLOBEC); however these initiatives had discrete foci, were generally based on observational programmes that were widely separated in space and time, and were often heavily biased to the summer months. More recently, growing recognition of the importance of the Southern Ocean has resulted in an increasing focus on the region, and new technologies have improved our ability to observe this region. Against this background, the International Polar Year (IPY; 2007-2008) was well timed to harness the human and logistic resources of the international community, and exploit technological developments to deliver an unprecedented view of the status of the Southern Ocean.

During IPY, most of the WOCE/CLIVAR repeat hydrographic sections were re-occupied, providing a near-synoptic snapshot of the physical and biogeochemical state of the Southern Ocean through the full water depth. Argo floats collected more than 60,000 temperature and salinity profiles during the 24-month IPY period, providing broad-scale, quasi-synoptic, year-round sampling of the upper 2 km of the Southern Ocean. Oceanographic sensors on marine mammals provided a similar number of profiles, including measurements from

regions where traditional oceanographic instruments have difficulty sampling, such as the sea-ice zone in winter. Moorings provided continuous time-series measurements of dense water overflows and boundary currents, major currents like the Antarctic Circumpolar Current and the Antarctic Slope Front, and coastal sea level. DNA barcoding and environmental genomics provided a completely new way of investigating evolution and biodiversity, ecosystem function and biological processes. New cryospheric satellites increased our ability to measure variables such as sea-ice volume.
Perhaps most importantly, IPY activities spanned all disciplines of Southern Ocean science and demonstrated that an integrated, multi-disciplinary, sustained observing system is feasible and urgently needed to address issues of high scientific and societal relevance. In recognition of this, the scientific community, under the guidance of the Scientific Committee on Antarctic Research (SCAR), the Scientific Committee on Oceanic Research (SCOR), the World Climate Research Programme (WCRP, specifically the CLIVAR/CliC/SCAR Southern Ocean Panel) and others, developed a strategy for sustained observations of the Southern Ocean, the Southern Ocean Observing System Initial Science and Implementation Strategy (available for download from www.soos.aq).

The Southern Ocean Observing System

SOOS will address six fundamental challenges of scientific and societal importance:

1) The role of the Southern Ocean in the planet's heat and freshwater balance,
2) The stability of the Southern Ocean overturning circulation,
3) The role of the ocean in the stability of the Antarctic ice sheet and its contribution to sea-level rise,
4) The future and consequences of Southern Ocean carbon uptake
5) The future of Antarctic sea ice, and
6) The impacts of global change on Southern Ocean ecosystems.

The following elements have been identified as being critical to the success of the SOOS in delivering the data required to address these challenges.

Repeat hydrography: Hydrographic sections from research vessels are the only means of sampling the full ocean depth for many variables. Repeat hydrography provides water samples for analysis of those properties for which in situ sensors do not exist, the highest precision measurements for analysis of change and for calibration of other sensors, accurate transport estimates, and a platform for a wide range of ancillary measurements.

Underway sampling from ships: The hydrographic sections need to be complemented by more frequent underway sampling transects, to reduce aliasing of signals with time-scales shorter than the 5-7 year repeat cycle of the repeat hydrography. Such underway sampling can be undertaken by supply vessels and tourist ships, as well as dedicated research vessels.

Enhanced Southern Ocean Argo: Year-round, broad-scale measurements of the ocean are needed to address many of the key science challenges in the Southern Ocean. These measurements can only be obtained using autonomous platforms like profiling floats. A sustained commitment to maintain and enhance a profiling float array in the Southern Ocean is critical, including a sub-sea ice component.

Time-series stations and monitoring of key passages: Several key passages and boundary currents in the Southern Ocean are high priorities for sustained observations because of their role in the global-scale ocean circulation and because they offer the best opportunities to measure water mass transport. High priority sites include Drake Passage and other chokepoint sections across the Antarctic Circumpolar Current and the dense water overflows and boundary currents carrying Antarctic Bottom Water to lower latitudes as part of the lower limb of the global overturning circulation.

Phytoplankton and primary production: Sustained observations of phytoplankton biomass, species distributions and primary production are needed to relate biological variability to environmental change. Ocean colour satellites are critical because they provide the only circumpolar view of biological activity in the Southern Ocean. In situ measurements are needed to refine algorithms used to interpret the satellite data, to relate surface chlorophyll to column-integrated production, for analysis of additional pigments and phytoplankton community composition, and to relate biological variables to simultaneous measurements of the physical and chemical environment.

Zooplankton and micro-nekton: Antarctic plankton may be particularly sensitive and vulnerable to climate change. Global warming will affect sea ice patterns and, therefore, plankton distributions (e.g., a decrease in the geographical extent of sea ice has been linked to a decline in krill numbers). Increased UV levels, ocean acidification, invasive plankton species, pollution and harvesting impacts are also potential threats. Underway sampling by continuous plankton recorders is required, as are targeted net tows and acoustic sampling.

Ecological monitoring: Observations of the distribution and abundance of top predators (fish, penguins, sea birds, seals and whales) can provide indications of changes in the ecosystem as a whole. The SOOS will provide the integrated multi-disciplinary observations needed to understand the interactions between physics, chemistry and biology in the Southern Ocean. Continued long-term and large-scale observations of functional and structural changes in ecosystems are essential to assess the sensitivity of ecologically key species, document biological responses and trends, and to ground-truth predictive models. In addition there is a need to develop new sensors to rapidly measure biological and chemical variables.

Animal-borne sensors: Oceanographic sensors deployed on birds and mammals can make a significant contribution to SOOS in two ways: by relating predator movements, behaviour and body condition to fine-scale ocean structure, and by providing profiles of temperature and salinity from regions of the Southern Ocean that are difficult to sample by other means (e.g., beneath the winter sea ice). The SOOS requires continuation and enhancement of the program of seal tag

deployments established during IPY, and development of a multi-species tagging approach along the lines of the Global Tagging of Pelagic Predators (GTOPP) and Tagging of Pacific Predators (TOPP) programmes.

Sea-ice observations: Measurements of both the extent and thickness of sea ice are needed to monitor changes in sea-ice production and related impacts on the climate and Southern Ocean ecosystem processes. A variety of satellite instruments provide continuous, circumpolar observations of sea-ice extent, with varying spatial resolution. Measuring sea-ice volume, however, remains a significant challenge and requires in situ sampling to provide ground-truth data for the satellite sensors. These measurements need to include a combination of sampling from ice stations, helicopters, autonomous vehicles, moorings and underway observations.

Observations of floating ice shelves and glacier tongues: Basal melting and freezing on the undersides of floating ice shelves exert significant influences on the ocean close to the Antarctic margin. These processes impact strongly on shelf water characteristics and the dense precursors of Antarctic Bottom Water. Ocean circulation and properties under shelf ice have been measured in only a few locations (Figure 1), and sustained measurements are needed to track the impacts of ocean climate changes on the ice shelves, and the subsequent feedbacks.

Enhanced meteorological and surface flux observations: The air-sea fluxes of heat, moisture, momentum and other climatically important properties are poorly known at high southern latitudes. Improvements are needed to accurately diagnose the interactions between atmosphere, ocean and sea ice that lie at the heart of climate variability and change, and the ecosystem responses to these. SOOS implementation requires improvements in surface flux measurements that parallel the improvements in the oceanic observational network.

Remote sensing: Access to high-quality remote sensing data is particularly critical in the Southern Ocean, where in situ data are difficult to obtain. High-priority satellite measurements include radar and laser satellite altimetry, ocean colour, scatterometer, infrared and microwave sea surface temperature, passive microwave, and synthetic aperture radar. Recommendations for satellite observations of the cryosphere, including sea ice, are given in the Cryosphere Theme document produced for the Integrated Global Observing Strategy (IGOS) Partnership (http://www.eohandbook.com/igosp/cryosphere.htm).

Towards Implementation

Commitments have already been made to complete many of the key elements of the SOOS. For example, most of the repeat hydrographic lines will be re-occupied within the next five years through the GO-SHIP programme (Figure 2; Hood et al., 2010). Several countries have long-standing commitments to monitor Drake Passage with annual full-depth hydrography, more frequent sampling of the upper ocean, and moored instruments including continuations of the long-term bottom pressure recorder deployments and tide gauge observations (Meredith et al., 2011). A well-established network of underway observations has been in place for more than a decade and is expected to continue. Several moored arrays in the Weddell Sea have been maintained for a decade and are planned to continue. Similar programmes are being established in other locations around Antarctica (Figure 3), for example in the eastern South Pacific sector (www.oceanobservatories.org/infrastructure/ooi-station-map/southern-ocean/). Plans are being developed for a comprehensive system to monitor circulation in the South Atlantic Ocean through the South Atlantic Meridional Overturning Circulation (SAMOC) programme. With regard to biological sampling, the Palmer LTER on the western Antarctic Peninsula has been in operation for 30 years, and the long-term monitoring conducted by the CEMP and Rothera Time Series (RaTS) programmes also have long-standing commitments. Several nations have committed to ongoing CPR transects across the Southern Ocean. The number and breadth of biological measurements being made from ships of opportunity is slowly growing.

While the list of existing commitments provides some grounds for optimism and a firm foundation on which to build, there is substantial work to be done to secure the resources for a truly sustained and comprehensive observing system in the Southern Ocean. Programmes like the Argo profiling float array and the Marine Mammals Exploring the Oceans Pole to Pole (MEOP) network of tagged seals have helped to revolutionise our ability to observe the Southern Ocean. However, there is as yet no firm commitment to long-term sustained funding of these systems. Challenges facing the SOOS are common to the global ocean observing system as a whole (e.g., sustained funding; biological and biogeochemical sampling in winter and at large scales; lack of time-series data, particularly for biology and biogeochemistry; inadequate integration of physical, biological and biogeochemical observations; sparse sampling of the deep ocean; and adequate access to research vessels). Almost all elements of the observing system require enhancement to reach the sampling required to address the key scientific challenges.

A first step in the implementation of SOOS is to design optimal sampling plans for each element, and an overall integrated sampling scheme. This will provide the quantitative targets for the number and frequency of observations that are required, so that progress towards implementation of SOOS can be assessed. For some elements of the SOOS, these requirements have been defined (e.g., repeat hydrography, Argo, surface drifters, and ice drifters). For others, including many of the biological parameters, the further work that is required will be conducted in the early stages of SOOS implementation.

The provision of high-quality, easily accessible and, where possible, real-time data is a key objective of the SOOS. For the SOOS to succeed, it is critical that a data system be established that ensures that both past and future data sets are accessible and of known quality. A SOOS Data Management Sub-Committee is currently being developed to ensure the data strategy objectives are met. The sub-committee will establish a SOOS data policy (based on IPY, ICSU and IOC policies) and will help to drive the development of a SOOS Data Portal, which will provide a central locale for access to all SOOS-relevant data.

The sub-committee will also be integral in developing other data products as needed by the community.

A programme of the scale and complexity of the SOOS requires an International Programme Office (IPO). The SOOS IPO will serve as a central contact point for SOOS, monitor progress towards SOOS goals, facilitate coordination of field work, assist in the organisation of workshops and synthesis activities, and coordinate a Web site and other activities to advertise the aims and achievements of the SOOS. The SOOS International Project Office has recently been established in Hobart, Australia, hosted by the Institute for Marine and Antarctic Studies (University of Tasmania), with additional support from the Australian Antarctic Division. Dr. Louise Newman has been appointed as SOOS Executive Officer.

Using the recently published science strategy as a solid foundation, SOOS will now identify and take clear steps to achieve the SOOS mission. Towards this, the SOOS Scientific Steering Committee (SSC) has been selected from an international pool of nominees, and will be chaired by Dr. Mike Meredith (BAS, UK) and Dr. Oscar Schofield (Rutgers University, USA). This committee recently held its inaugural meeting in Salt Lake City (Utah, USA) alongside the Ocean Sciences Meeting, to progress the implementation of SOOS. SCAR and SCOR sponsor the SSC and oversee the SOOS as a whole. Committee and meeting details will be announced on the SOOS website (www.soos.aq), which is currently being developed and will be fully functional in early 2012.

The success of SOOS will depend on effective integration and coordination of national and international research efforts. The Southern Ocean is a vast and remote domain and the logistical resources available for its study are relatively limited. This places a further imperative on effective coordination of research among nations and across disciplines.

For more information on the SOOS, or to receive a copy of the SOOS Initial Science and Implementation Strategy, please contact Louise Newman (Louise.Newman@utas.edu.au).

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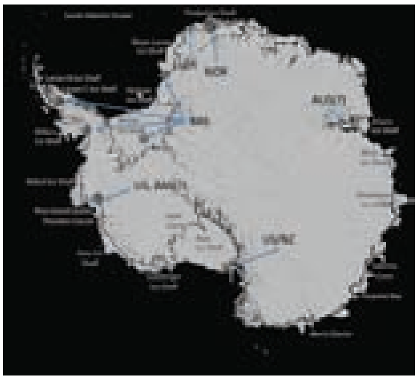

Fig 1: Location of existing or planned drill holes through ice shelves (circles), allowing sampling of underlying ocean waters.

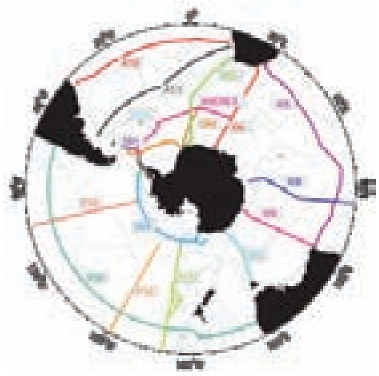

Fig 2: Repeat hydrographic sections that will contribute to the SOOS. Labels indicate the WOCE/CLIVAR designations for each line.

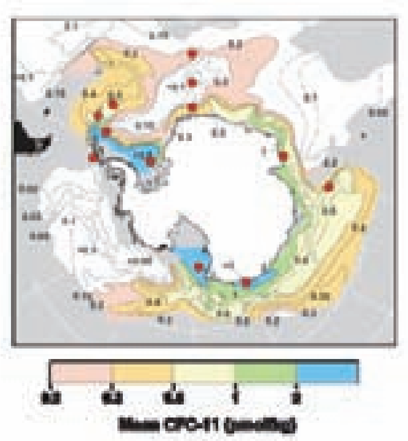

Fig 3: Map of proposed moored arrays (red circles) to sample the primary Antarctic Bottom Water (AABW) formation and export sites, as part of a coordinated global array to measure the deep limb of the global overturning circulation. Each of these sites has been occupied in recent years. The map shows the inventory of chlorofluorocarbon 11 (CFC-11) in the density layer corresponding to AABW. Modified by A. Orsi from figure in Orsi, A.H., G.C., Johnson, and J.L. Bullister. 1999: Circulation, mixing and production of Antarctic Bottom Water, Progress in Oceanography, 43: 55-109. Reprinted with permission from Elsevier.

Forthcoming International workshop on interdecadal variability of the global monsoons

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Understanding interdecadal variability of the climate system is a prerequisite for attribution of present and future changes under anthropogenic forcing. The Global Monsoon represents the dominant mode of annual variation of the tropical precipitation (1) and circulation (2) and is thus a defining feature of seasonality and a major mode of variability of the Earth's climate system. The components of the global monsoon (Asian-Australian; West African; American Monsoons) all feature seasonal reversals of surface winds and contrasting rainy summers and dry winters; domains as shown in Figure 1. While the regional monsoons show some cohesive variations on interannual timescales, there may also be important decadal variations with potential large socio-economic impacts. However there is little consensus on the character of this variability. Studies (e.g., 3-5) have highlighted interdecadal variability in:

- The various regional monsoons;
- Features embedded in the monsoon, such as tropical cyclones and monsoon depressions;
- The strength of monsoon teleconnections, impacting the prospect for seasonal prediction.

We therefore announce a major international workshop to: (a) review evidence of monsoon interdecadal variability collectively and regionally; (b) discuss how these variations are linked to each other and other major modes of interdecadal variability in the global oceans such as the PDO, IPO, or AMO, and to climate change as in Figure 1; (c) examine possible mechanisms underlying these interdecadal variations, including in simulations and numerical experiments that address driving physical processes with the goal of assessing the predictability of monsoon interdecadal variations.

Sessions will last around half a day each, consisting of invited speaker(s) and a period of discussion. The majority of scientific presentations will be made via interactive poster sessions:

- Session 1: Monsoon decadal variability in the modern observational era (19th/20th centuries).
- Session 2: What do palaeo-modelling and proxy data tell us about monsoon interdecadal variability?
- Session 3: Interconnections between the regional monsoons and other modes of climate variability.
- Session 4: Mechanisms for decadal modulation of the monsoon.
- Session 5: Using our knowledge of decadal variability to further monsoon prediction and projection.

The workshop will provide an overview of the state of knowledge and emerging issues in monsoon interdecadal variability and promote coordinated experimental designs to test possible causes and explore predictability. The workshop