Themes 1 and 2 overview – The heat and freshwater budgets and overturning circulation of the Southern Ocean

October 2013

SOOS Theme 1 leaders: Alberto Naveira Garabato, Mike Meredith, Mauricio Mata, Steve Rintoul

1. Introduction

The SOOS themes 1 (Heat and freshwater budgets of the Southern Ocean) and 2 (Overturning circulation of the Southern Ocean) articulate the large-scale context and climatic impacts of all aspects of the Southern Ocean addressed by SOOS. The Southern Ocean overturning circulation plays a pivotal role in transferring climatically important properties (such as heat and carbon) between the surface and deep layers of the global ocean circulation, and in regulating the atmosphere – ocean partitioning of those properties. There is much discussion at present about the extent and character of the Southern Ocean overturning circulation's sensitivity to climatic perturbations in the exchanges of momentum, heat and freshwater between the atmosphere, cryosphere and ocean, yet a resolution to the debate is hindered by the scarcity of targeted observations. One of the major areas in which adequate measurements are lacking pertains to the heat and freshwater forcings of the Southern Ocean circulation. State-of-the-art estimates of the basic state and climatic evolution of the Southern Ocean heat and freshwater budgets suffer from zeroth-order uncertainties, preventing quantification and understanding of their relationship to the regional circulation, global oceanic heat uptake, changing hydrological cycle and associated climate feedbacks.

Addressing SOOS themes 1 and 2 represents a formidable challenge because of the extreme spatio-temporal sparseness and intermittency of the flows constituting the Southern Ocean overturning circulation, as well as of the heat and freshwater exchanges between the ocean and the overlying atmosphere or ice sheet. The determination of the Southern Ocean heat and freshwater budgets is further complicated by the occurrence of first-order contributions from a wide range of mechanisms; for example, annual-mean freshwater fluxes to the ocean from melting sea ice, sub-ice shelf melting and precipitation are of the same order, and contribute comparably to regional freshwater budgets. These traits of the Southern Ocean are critical in shaping our recommendations on the strategy for SOOS themes 1 and 2.

2. Key variables and elements of an observing strategy

The fundamental variables that need to be observed to measure the evolving overturning circulation and heat and freshwater budgets of the Southern Ocean are temperature and salinity. Other variables (see below) are required to determine the causes of the measured changes. In addition, a major effort is needed to achieve a significant advance in the quantification and understanding of air-sea heat and freshwater fluxes in the Southern Ocean.

It is highly unlikely that the density and accuracy of observations of the physical properties of the Southern Ocean and its interaction with the overlying atmosphere and cryosphere will ever be sufficient to directly compute the climatic evolution in the overturning circulation, heat and freshwater budgets.

Thus, we recommend that a reliable monitoring system must combine a carefully designed, realistic array of sustained (minimum time scale to determine changes of climatic relevance ~ 1 decade) observations with data-assimilative model technology. The remainder of this document will identify the essential elements that the observational array must contain, focusing on those that need to be added to the current state of SOOS.

The framework around which to articulate an observing system that allows closure of the evolving heat and freshwater budgets of the Southern Ocean is defined by the set of repeated (every 1-10 years) WOCE hydrographic sections across the major ACC chokepoints, along 30 S, and along the northern boundary of the subpolar Southern Ocean (nominally 60 S), and by the Argo float / instrumented sea mammal array. It is necessary to sustain these observations with at least the current spatio-temporal resolution, but with the following enhancements:

- extension of meridional sections across the Antarctic continental shelves;
- inclusion of additional short, cross-shelf sections in the vicinity of Antarctic bases (modeled on the SASSI plan - http://sassi.tamu.edu), encouraging ownership of specific sections by individual countries (including new Antarctic nations);
- inclusion of ^{18}O and, where possible, noble gas measurements to quantify glacial water content, particularly in subpolar sections;
- extension of Argo to the seafloor to permit measurement of changes in deep-ocean heat and freshwater budgets;
- addition of oxygen sensors to Argo floats to facilitate the assessment of causes of changes in overturning and heat and freshwater budgets (e.g., changes in ocean ventilation).

While the preceding enhancements to the present state of SOOS are achievable with existing technology, substantial technological innovation is called for to resolve the contributions of the seasonally ice-covered subpolar regions to the Southern Ocean heat and freshwater budgets, which are likely key in at least the freshwater budget. These technological developments were recently identified in a SOOS-sponsored 'Seeing below the ice' workshop held in CSIRO-Hobart, and include:

- development of techniques to extract altimetric observations in ice-covered regions, as has been done in the Arctic;
- development of techniques for satellite measurements of sea ice thickness, validated by underwater vehicle-based observations;
- continuation of satellite measurements of sea ice drift, with a view to estimating sea ice transports when used in conjunction with sea ice thickness observations;
- establishment of an array of targeted low-cost moorings, ice-tethered profilers and under-ice glider transects to measure the properties of shelf and slope waters, focusing on intermediate or deep overflow sites (e.g., the areas off the Larsen and Filchner ice shelves, the Ross Sea and the West Antarctic Peninsula) – note that monitoring temperature, salinity and velocity is the priority, whereas transport is not feasible; this may require the development of telemetry or data capsule technologies;
- continuation of existing time series of coastal ocean / ice properties (e.g., RaTS) and establishment of new ones in the proximity of Antarctic bases.

See Theme 3 document for a discussion of the observational requirements for the sub-ice shelf ocean.

Achieving major progress in the quantification and understanding of air-sea heat and freshwater fluxes calls for (i) the deployment and long-term sustainment of a feasible number of meteorological moorings, coastal automatic weather stations and surface drifters, and the acquisition of near-surface measurements from Argo-floats; and (2) the development and evaluation of regional atmospheric reanalyses. It is recommended that SOOS seeks feedback from the atmospheric reanalysis community on the type of observations that would be most useful in constraining such reanalyses.

It is advised that the primary way to detect changes in the Southern Ocean overturning circulation is by measuring the footprint of such changes in scalar tracer (temperature, salinity, oxygen and transient tracer) distributions. Further theoretical progress is called for to deconvolve the variations in Southern Ocean scalar fields due to passive oceanic advection of anomalies in the surface boundary condition (i.e. air-sea heat and freshwater exchanges) from variations arising from changes in the overturning circulation. The interpretation of such scalar property measurements is to be facilitated by observations of eddy activity from altimetry and of internal wave activity by Argo floats with high vertical resolution (Iridium communication capability). Finally, measuring the deep limb of the Southern Ocean overturning requires the monitoring of key Antarctic Bottom Water outflow sites, such as the Orkney Passage.