Synoptic Antarctic Shelf-Slope Interactions (SASSI)

This document has been prepared by the International Antarctic Zone (iAnZone) programme. It is seen as a supplement to "The Role of Antarctica and the Southern Ocean in Past, Present and Future Climate: A Strategy for the International Polar Year" submitted to International Polar Year (IPY) by Steve Rintoul on behalf of the CLIVAR/CliC/SCAR Southern Ocean Panel. iAnZone is a SCOR-Affiliated Organization and anticipates that an additional affiliation with SCAR will be approved before the end of 2004. iAnZone's goal is to advance our understanding of climate-relevant processes within that region of the Southern Ocean poleward of the Antarctic Circumpolar Current.

The iAnZone membership has identified a significant number of issues and aims that are shared with the CLIVAR/CliC/SCAR Southern Ocean Panel within an IPY strategy context. Submitted in the interest of furthering these aims and in helping to develop a coordinated IPY programme for the Southern Ocean, this document is based on input from a broad international group of primarily physical oceanographic investigators with experience of the Southern Ocean. It is the outcome of a three-day iAnZone open workshop held in August 2004 at which input was presented from the US, UK, Germany, Spain, Italy, France, Norway, Japan, Finland, Russia and New Zealand.

In summary, the SASSI project will conduct the first synoptic study of the Antarctic continental shelf and slope. This is a critical and under-observed region for physical processes determining global climate. iAnZone will provide the coordination to ensure that the SASSI survey is undertaken within a three month period, thus making optimum use of the available resources.

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The Science Issues

The Antarctic continent, with its vast ice sheets that sequester much of the world's freshwater, is separated from the ocean by a complex peripheral system of coastal, shelf and slope currents and fronts. This system defines a boundary between the freshwater resources of the polar icecap and the ocean. Freshwater that passes from the continent northward through this boundary influences the global ocean through its impact on formation of sea ice and of the dense water that drives shallow and deep modes of the meridional ocean circulation (MOC). These processes have a strong impact on global climate, both through the ocean (influencing the strength and properties of the MOC) and through the atmosphere (influencing the heat released to the southern hemisphere atmosphere). Quantitative knowledge of the moisture/freshwater budget is one of the greatest uncertainties in climate modelling, particularly in the southern hemisphere.

The few historical sections across the marginal ocean systems that surround Antarctica have shown varying characteristics. Some reveal simply a westward coastal current, others a complex system of coastal current, shelf break currents, and current jets deeper down along the continental slope. The currents and associated fronts, resulting from lateral gradients in temperature, salinity and density, form dynamic barriers that can control cross-shelf flow of properties. They influence turbulent mixing in the ocean over the continental slope and, by so doing, impact the depths to which dense bottom waters can penetrate. Strong tidal currents further interact with these currents and associated turbulent mixing. Through transport of heat beneath ice, these flows influence the rate of ice melting. These systems influence the intensity and distribution of the meridional fluxes of volume, heat and freshwater. In short, the Antarctic continental margins present both physical and dynamical barriers that impact oceanic meridional fluxes related to the Antarctic freshwater budget. Even existing coarse resolution coupled climate models now indicate a significant impact of Antarctic freshwater on global climate on time scales from months to centuries.

Despite considerable scientific interest and a strong conviction that the resident processes play significant roles in global climate, the Antarctic margins are neither quantitatively well documented nor dynamically well understood. Our present understanding is based on highly non-synoptic data obtained from widely different regions from different years under the auspices of projects having different, or even disparate, scientific goals. Obtaining synoptic data would be a polar science breakthrough, avoiding the confusion of spatial and temporal variability. Interannual variability, such as that associated with the El Nino-Southern Oscillation, Southern Annular Mode, or the Antarctic Circumpolar Wave, as well as secular change, means that adjacent years can exhibit completely different ocean, ice and wind fields, forcing different coastal systems and fluxes. The vast majority of the available data have been collected during the austral summer, when withdrawal of the seasonal sea ice cover allows access for non-ice-strengthened research vessels. Although seasonal coverage has been extended through use of moorings and drifting buoys, winter shipboard programmes have been largely restricted to the Weddell Sea. Our documentation of seasonality in the shelf and slope currents and frontal systems is limited. Finally, geographical spacing of samples has frequently been too great to allow adequate assessment of the dynamically important features. IPY therefore offers a unique opportunity to focus our efforts on obtaining a synoptic data set that resolves, for the first time, the critical processes for climate.

This document addresses the Antarctic, but an analogous peripheral system of marginal currents and fronts surrounds the Arctic Ocean and plays similar roles in the global meridional property transport and freshwater budget. Although the Arctic peripheral system surrounds a largely enclosed basin and the Antarctic system surrounds a continent and is openly connected to the global ocean, similar dynamics are expected to control both systems. Both polar systems are impacted, either seasonally or perennially, by a mobile pack ice cover. Study of the Arctic system can be viewed as complementary to that of the Antarctic system. iAnZone anticipates that such a plan for study of the Arctic system will be put forth by other groups, and will pursue collaborations as appropriate.

Objectives

The SASSI objectives will be to:

1. Obtain a circumpolar synoptic view of the oceanography of the Antarctic shelf and slope
2. Assess, as quantitatively as possible, the properties and amount of inflow of warm, saline deep water onto the continental shelf
3. Assess the role of this onshore heat transport in melting sea ice and ice shelves
4. Improve our knowledge as to where, when and how this oceanic inflow is transformed over the shelf domain into dense Shelf Water and its subsequent derivative Antarctic Bottom Water, through the net cooling and freshwater fluxes during the seasonal sea ice melting/freezing cycle
5. Assess the importance of ice shelves in the net freshening process
6. Understand the dynamics of the coastal current and slope front systems, and how they influence the exchanges between sea ice, glacial ice, coastal and deep ocean waters
7. Quantify freshwater transports around Antarctica both through currents and through atmosphere-ocean-ice interaction
8. Assess the degree to which current coupled ocean-ice models represent the shelf system and its variability
9. Design a long-term monitoring system over the Antarctic continental margins that can act as an early indicator of global climate changes
10. Identify the key Antarctic shelf/slope processes that should be included or parameterised in future climate models.

These objectives contribute directly to two of five themes set forth in the CLIVAR/CliC/SCAR Southern Ocean Panel IPY Strategy document. The themes addressed are (1) Antarctica and the Southern Ocean in the global water cycle and (3) Climate processes at the Antarctic continental margin. They will in addition address key unknowns: specifically, a circumpolar snapshot of the Southern Ocean environment, and the sub-ice ocean circulation and water mass properties.

Implementation Plan

Coordination

A project of the magnitude proposed is too large for any single nation to undertake. It requires the leverage and focus of IPY to enable channelling existing resources and seeking additional funding. iAnZone has more than a decade of experience of planning and executing logistically-challenging multi-national campaigns in the Antarctic Zone. We are ideally placed to offer coordination of the IPY work in this area. We anticipate using many of the coordination tools already developed, such as the iAnZone mailing list and website. This document, and the workshop from which it originates, represent an initial step in such a coordination effort. Interest in undertaking the different components has been expressed by a number of different national programmes. The majority of the projects seen as potential contributors are already in their planning phases but require IPY endorsement to secure funding or logistical support at the appropriate time.

Synoptic Circumpolar Sections across the Antarctic shelf and slope

A series of short transects will be undertaken radiating outwards across the Antarctic continental shelf and slope (Figure 1). To be as synoptic as possible, all sections will be undertaken within the target austral summer period of January-March 2008. Summer is chosen to enable optimum access, and to utilize shiptime already scheduled. Winter coverage will be achieved through mooring array deployments (recoveries in early 2009) and remote sensing, where possible. The sections will link on the landward side with any IPY transcontinental transects that may be undertaken for glaciological and meteorological studies. Coordination with these land transects will be appropriate in order to best encompass ice shelf processes. On the seaward side, the SASSI sections will be coordinated with Southern Ocean CLIVAR transects proposed for monitoring the Antarctic Circumpolar Current (ACC). (Indeed it is likely that in some instances the same shiptime and scientists will accomplish both, and we will encourage that). Station spacing will be sufficiently tight – similar to or less than the internal radius of deformation in the shelf-slope region – to

identify, and resolve where feasible, pertinent shelf and slope features. Of special interest will be the possibility to detect and estimate the transport of newly-formed dense bottom waters flowing westward along the continental slope, to better understand the connections between known deep water sources and the locations where deep water leaves the slopes to flow north. These short transects will incorporate the following where possible:

- CTD/ADCP section of closely spaced stations.
- Collection of water samples for tracer and chemical analyses including oxygen isotopes, nutrients and trace gases.
- Deployment of moored instruments along each section to measure temperature, salinity, current velocities and sea level for at least one year.
- Deployment of autonomous water samplers on the shelf to collect weekly water samples for subsequent tracer analyses.
- Deployment of ice-hardened surface ocean drifters across the coastal and slope break current systems, transmitting temperature, salinity, sea level pressure and location via satellite link until the buoys fail in winter.
- Air-sea heat and freshwater flux measurements.
- Swath bathymetric surveys of the complex shelf and slope terrain.
- Turbulent mixing measurements.
- Continuation of appropriate transects poleward beneath ice shelves and/or sea ice using an autonomous vehicle such as Autosub.

It would not be feasible to maintain such an intensive array of sections and moored instruments for longer than the single IPY period. However the information gained should enable the design of a cost effective and logistically achievable long term monitoring system for the oceans surrounding Antarctica. This might consist, for example, of measuring temperature, salinity and bottom pressure on the continental shelf at locations around Antarctica, if it can be shown that this would yield the information needed for the study of climate variability and change.

The following summary rationales justify inclusion of each transect indicated on Figure 1. Details are subject to change, but the overall picture is likely to remain in place. Transects are referred to by location, either name or longitude, and are listed clockwise starting with the west Antarctic Peninsula. Estimates are provided of the number of national programmes that have expressed interest in contributing a transect in each region. These indicate the logistical and scientific support that might be available for an IPY effort given proper coordination. Endorsement by IPY will enable funding to be secured, and for gaps to be plugged.

West Antarctic Peninsula (just west of Bransfield Strait): Unusual area due to ACC impingement on slope. High level of interest due to concentrations of krill and other biota. Past time series exist. (Plans by three or more national programmes.)

Antarctic Peninsula-Filchner-Ronne Ice Shelf: High interest due to rapid warming of peninsular region, loss of Larsen ice shelf, deep water formation in western Weddell Sea and beneath the ice shelves. (Plans by two or more national programmes)

Cross-Weddell Gyre: Continue to track and assess deep water changes in the Weddell Sea, and document the coastal current in the eastern Weddell. (Plans by at least one national programme)

Greenwich Meridian (several possible closely-spaced sections depicted for simplicity as a single one): Track changes associated with Maud Rise, site of the late 1970s Weddell Polynya, assess impact of warm ACC water on subglacial conditions at the Fimbul ice shelf, document shelf-slope conditions as part of peripheral snapshot of conditions. (Plans by 4-5 national programmes)

40°E: Document shelf-slope out to ACC and track and assess along-slope flows of deep water formed further east. (Plans by at least one national programme)

Prydz Bay: Assess ocean-glacier interactions, deep water formation, shelf-slope structures. (Plans by at least three national programmes)

100°E: Document shelf-slope out to ACC with continuation over Princess Elizabeth Trough and possibly to Kerguelen Plateau. Possible assessment of deep water formation, local and remote. (Plans by at least two national programmes)

140°E: Document shelf-slope out to ACC, assess local deep water formation and throughput of bottom water having Ross Sea origins. (Plans by at least one national programme)

Ross Sea (two or more transects possible): Assess and track changes in landward flow of warm water and egress of deep water, focus possible on ocean-shelf interactions. Crucial area in freshwater balance. (Plans by at least 3 national programmes)

Amundsen Sea: Assess shelf-slope conditions off Pine Island Glacier and impacts of warm ACC water on the subglacial waters. (Plans by at least one national programme)

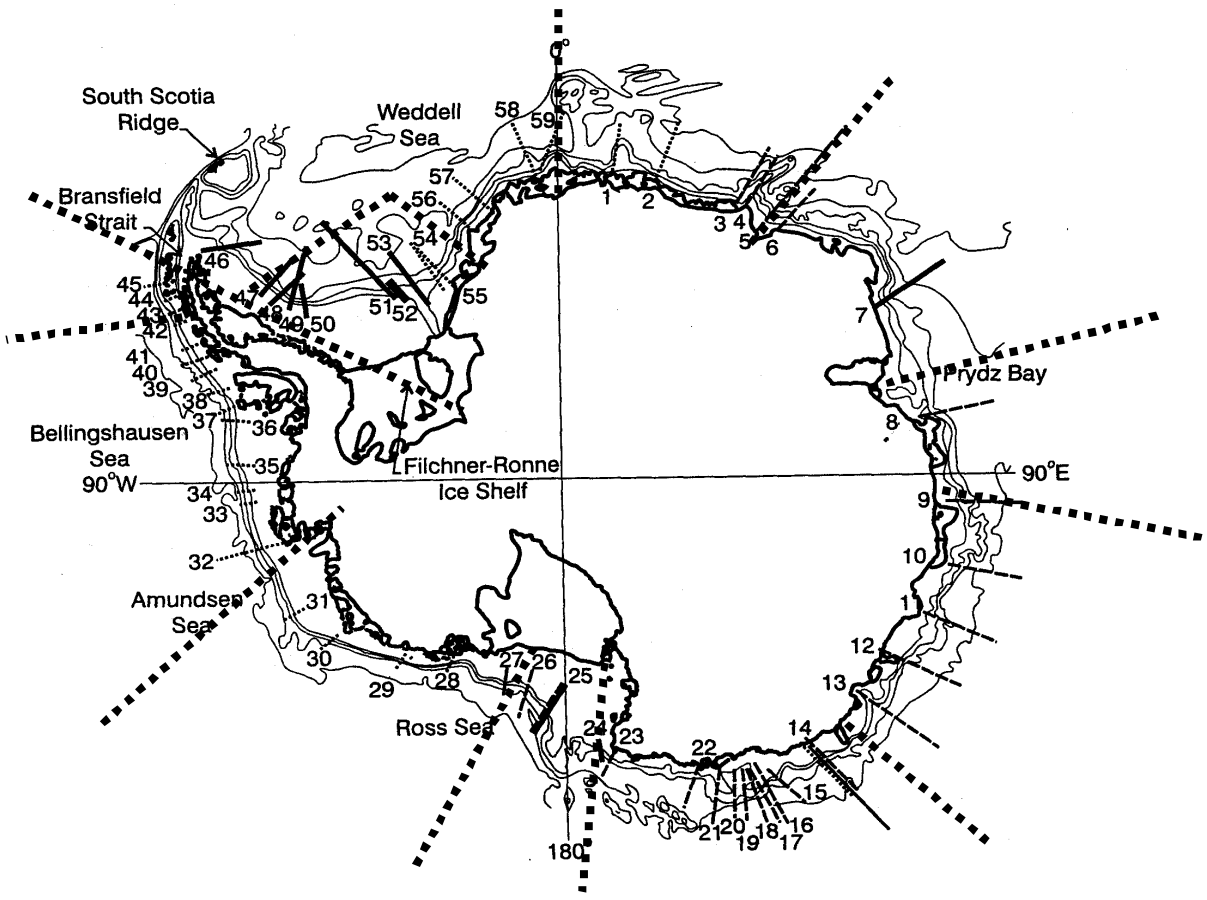

Figure 1. *The heavy dotted lines represent schematic locations for SASSI transects to be occupied during IPY. Many represent more than one interest or programme often in a planning phase. Finer lines summarise all past oceanographic transects made across the Antarctic margins and indicate the geographical coverage of previous research since Antarctic oceanography began [from* Baines and Condie, *1998]. High transect density in some areas, such as the Weddell Sea and Antarctic Peninsula region, represents high interest in processes within those areas, and accessibility.*

Instrument the ice-covered ocean with Lagrangian floats

We will deploy acoustically tracked, subsurface floats, analogous to those used for the highly successful Argo float programme. These will observe, for the first time, the winter properties of the warm deep water that flows onto the shelf and provides a necessary link in the densification process that leads to deep and bottom water formation. These floats are being developed to be tracked

acoustically beneath the seasonal sea ice throughout the winter. They provide profiles of temperature and salinity, along with geographical positions, every 10 days. Plans to deploy the necessary bottom-moored tracking devices are already underway for the Weddell Sea. Extension of this tracking network to other regions surrounding Antarctica will be undertaken as part of the SASSI IPY effort and is essential in providing polar coverage to the global Argo programme.

Synthesis of* in situ *data with models and other data sources

iAnZone recognises the importance of integrating the intensive synoptic *in situ* data with satellite observations, *in situ* atmospheric observations and meteorological reanalyses. The availability of sea ice estimations from microwave sensors, altimetry and SAR will be crucial. High quality surface flux observations in the coastal zone during SASSI sections will be obtained using both ships and instrumented aircraft. iAnZone has always fully involved these aspects of science within projects. We include numerical models as a tool in our armoury to understand dynamical processes. Global ocean-ice models, and models of the coastal region developed during previous iAnZone projects, will be used and assessed, for example by deploying floats and drifters in their output velocity fields to compare with *in situ* floats and drifters. Parameterisations of processes of air-sea and ice-ocean interaction, and processes of cross-frontal exchange on the Antarctic shelf and slope, will be developed for future climate models.

Process Studies

Although our primary thrust for IPY is the synoptic survey, we propose two process studies that will be embedded in the circumpolar coastal ocean science. They will both benefit from, and benefit, the understanding obtained from the network of sections and floats. The first is a study of the Antarctic slope front, including detailed spatial surveys and mooring array deployments. The second is a study of the processes of interaction between the shelf waters and ice shelves, to be conducted using an autonomous vehicle such as Autosub. One likely location is Fimbul ice shelf near the Greenwich meridian, particularly interesting because it overhangs the continental slope.

Legacy

SASSI will leave a legacy of a design for an observing system on the Antarctic margin for future multidisciplinary studies; the first circumpolar synoptic data set on the Antarctic continental margin against which future changes can be assessed; the first simultaneous circumpolar time series including winter; and a network of links between iAnZone and other disciplines to foster future science.

Future planning

Refinement and development of SASSI is anticipated through discussion with the iAnZone mailing list and Steering Committee, and through interactions with other programmes, panels and groups. A further planning and implementation workshop for SASSI will be held in October 2005 at the 9th biennial iAnZone meeting, associated with the Ross Sea Conference in Venice. Particular collaboration is expected with SCAR and SCOR, and with the Southern Ocean Panel. We already have close links with ASPECT, FRISP and with SCAR's proposed programme ACGS. SASSI will implement and coordinate the southernmost parts of the Southern Ocean Panel's strategy for IPY. Although this document is presented primarily from the climate physics perspective, we recognise that the strategy we present here will be equally pertinent to studying the carbon cycle and ecosystems, so will welcome collaboration with those communities.

Reference

Baines, P.G. and S. Condie (1998) Observations and modelling of Antarctic downslope flows: a review, in *Ocean, Ice and Atmosphere: Interactions at the Antarctic Continental Margin*, AGU Antarctic Research Series volume 75, (ed. S.S. Jacobs and R.F. Weiss), 29-49.