DRAFT Version 1.1

The Role of Antarctica and the Southern Ocean in Past, Present and Future Climate: A Strategy for the International Polar Year

The strategy has been prepared by Steve Rintoul on behalf of the CLIVAR/CliC/SCAR Southern Ocean Implementation Panel. The panel recognised a number of common threads and opportunities for synergy in the submissions to the ICSU IPY Planning Group. The panel volunteered to draft a strategy for integration of individual IPY proposals in order to stimulate development of a coherent and coordinated IPY program in the southern hemisphere. The strategy is based on input from a wide cross-section of the community who submitted ideas to the IPY planning group and provided direct input to the panel (contributors are listed in the appendix).

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Executive Summary

The purpose of this document is to outline a strategy for an integrated and interdisciplinary approach to understand the role of Antarctica and the Southern Ocean in past, present and future climate during the International Polar Year (IPY) 2007-2008.

Climate research proposed for the IPY can be organized into five themes:

1. Antarctica and the Southern Ocean in the global water cycle
2. Southern hemisphere teleconnections
3. Climate processes at the Antarctic continental margin
4. Climate – ecosystem – biogeochemistry interactions in the Southern Ocean
5. Records of past Antarctic climate variability and change

To address these themes, an integrated IPY Southern Ocean observing system is needed that includes synoptic, multidisciplinary transects; time series measurements; enhanced atmospheric measurements; and new paleoclimate data sets. Extensive use of new technologies such as autonomous floats, gliders and aircraft will be required to sample regions, seasons and variables that have eluded us in the past.

The IPY observing system will tackle a number of key unknowns. The IPY will:

- Obtain the first circumpolar snapshot of the Southern Ocean environment, including physical, ecological and biogeochemical properties.
- Measure the circumpolar volume (extent and thickness) of Antarctic sea ice through an annual cycle for the first time.
- Observe the sub-ice ocean circulation, water mass properties and biological distributions

The strategy directly addresses four of the science themes identified by the ICSU IPY 2007-2008 Planning Group: to determine the present environmental status of the polar regions; to understand past and present change in the polar regions; to advance our understanding of polar-global teleconnections; and to investigate the unknowns at the frontiers of science in the polar regions.

The Southern Ocean strategy and the AOSB/CliC initiative "The Northern Seas at a time of Global Change" together form the integrated bi-polar program required to address the goals of the IPY.

The Southern Ocean IPY will leave a legacy of a targeted, affordable, sustained observing system; a circumpolar snap-shot to serve as a benchmark for the assessment of past and future change; models capable of simulating interactions between climate, ecosystems and biogeochemical cycles, providing vastly improved projections of future change; a well-integrated interdisciplinary polar research community; and inspire a new generation of polar researchers.

Background and Rationale

Polar regions are experiencing the most rapid rates of environmental change in the world. However, the pattern of change is not symmetric between the two hemispheres. While summer and autumn Arctic sea ice has thinned by 40% in recent decades (Wadhams 1997; Laxon, 2003) and sea ice extent in the summers of 2002 and 2003 reached minima unprecedented in the observational or historical record (Serreze et al. 2003, Fetterer and Knowles, 2004), Antarctic sea ice has apparently not changed or has slightly increased during the satellite era. At the same time, the Antarctic Peninsula has been warming at a rate of nearly 0.5°C per decade over the last four or five decades. The increase in summer melt as a result of higher air temperatures has been identified as the likely cause of the catastrophic collapse of the Larsen B ice shelf in 2002 (Figure 1).

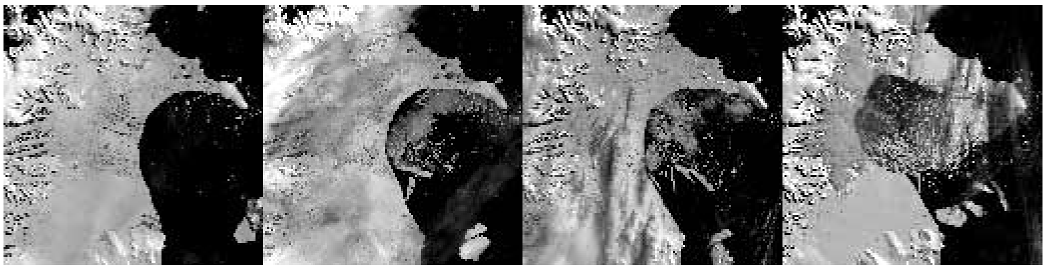

Figure 1: Collapse of the Larsen B ice shelf in March 2002. Images from MODIS on (from left to right) January 31, February 17, February 23 and March 5, 2002. The dark spots on the left-most image correspond to pools of melt water on the surface of the ice shelf. The melt water is believed to enhance the propagation of crevasses, destabilizing the ice shelf (Scambos, et al., 2000). (Figures downloaded from http://www.nsidc.org/iceshelves/larsenb2002/index.html).

The cause of the warming of the Antarctic Peninsula remains a topic of debate. While the peninsula has warmed, many stations in the rest of Antarctica have cooled in recent decades. The Southern Annular Mode (SAM), the dominant pattern of variability in the southern hemisphere atmosphere, has trended toward its positive index state over the same time period (in part reflecting a change in the seasonality of the mode). The positive phase coincides with a strengthening and poleward contraction of the circumpolar vortex. These changes in the SAM have been attributed to depletion of ozone in the stratosphere (Thompson and Solomon, 2002; Gillett and Thompson, 2003) and the enhanced greenhouse effect (Fyfe et al., 1999; Cai et al., 2003). Much of the recent trend in surface winds and air temperatures can be explained by a strengthening of the polar vortex associated with a positive SAM index (Figure 2). The implications of the SAM trend for ocean circulation, sea ice distributions, and Antarctic ecosystems are only starting to be considered (e.g. Hall and Visbeck, 200X; Oke and England, 2004).

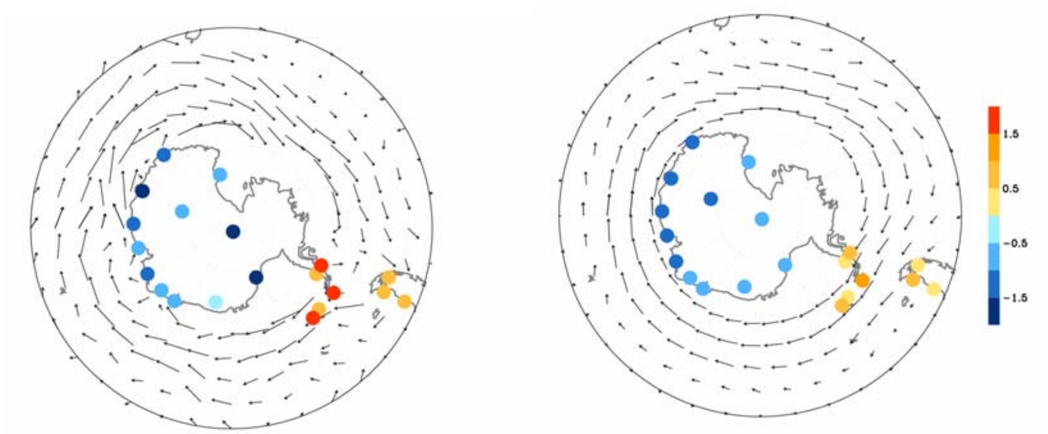

Figure 2: Left plot: recent trends in surface air temperature and surface wind (December to May, 1969 – 2000). Right plot: the part of the trend that is congruent with the Southern Annular Mode. (Thompson and Solomon, 2002).

The polar regions both drive and respond to climate change. The Southern Ocean plays several key roles in the global climate system. Changes in sea ice extent will change the Earth's albedo, providing a positive feedback to climate change. About 40% of the total ocean uptake of anthropogenic carbon dioxide is found on the northern flank of the Southern Ocean, between 30°S and the Antarctic Circumpolar Current (ACC) (Figure 3, Sabine et al., 2004). Climate models suggest the Southern Ocean uptake of carbon dioxide will decrease as a result of changes in circulation and stratification caused by enhanced greenhouse warming, providing another potential positive feedback for climate change (Sarmiento et al., 1998). At higher latitudes, the ocean is a net source of carbon dioxide to the atmosphere, as the result of upwelling of carbon-rich deep water. However, in spite of being a net carbon dioxide source it can play a significant role as a sink of anthropogenic carbon dioxide. Changes in the rate of upwelling, stratification and the extent to which sea ice limits air-sea exchange may also impact the future atmospheric concentration of carbon dioxide, as is believed to have occurred in the past (eg Francois et al., 1997; Sigman et al., 2004).

Anthropogenic CO_2 Column Inventory (mol m-2)

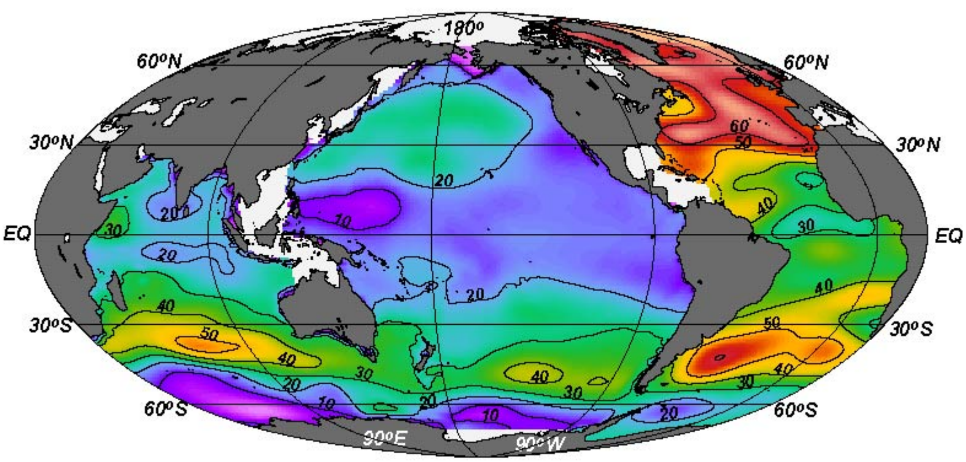

Figure 3: The water column inventory of anthropogenic carbon dioxide. Approximately 40% of the total inventory is found south of 30°S. (Sabine et al., 2004).

Carbon dioxide is carried from the sea surface into the interior of the ocean by the upper limb of the Southern Ocean overturning circulation, as well as by biogeochemical processes. Divergent wind stress drives upwelling of deep water south of the maximum of the surface westerlies (Figure 4). Deep water that upwells near the coast of Antarctica spreads poleward and is converted to denser Antarctic Bottom Water through intense atmosphere – ocean – ice interactions over the continental shelf. Water that upwells beneath the westerly wind regime is driven north in the surface Ekman layer and transformed to lighter density by the addition of heat, precipitation and ice melt. Recent research has shown that the water mass transformations taking place in the Southern Ocean form a crucial link in the global overturning circulation by connecting the deep and intermediate layers of the ocean (Speer et al., 2000; Rintoul et al., 2001).

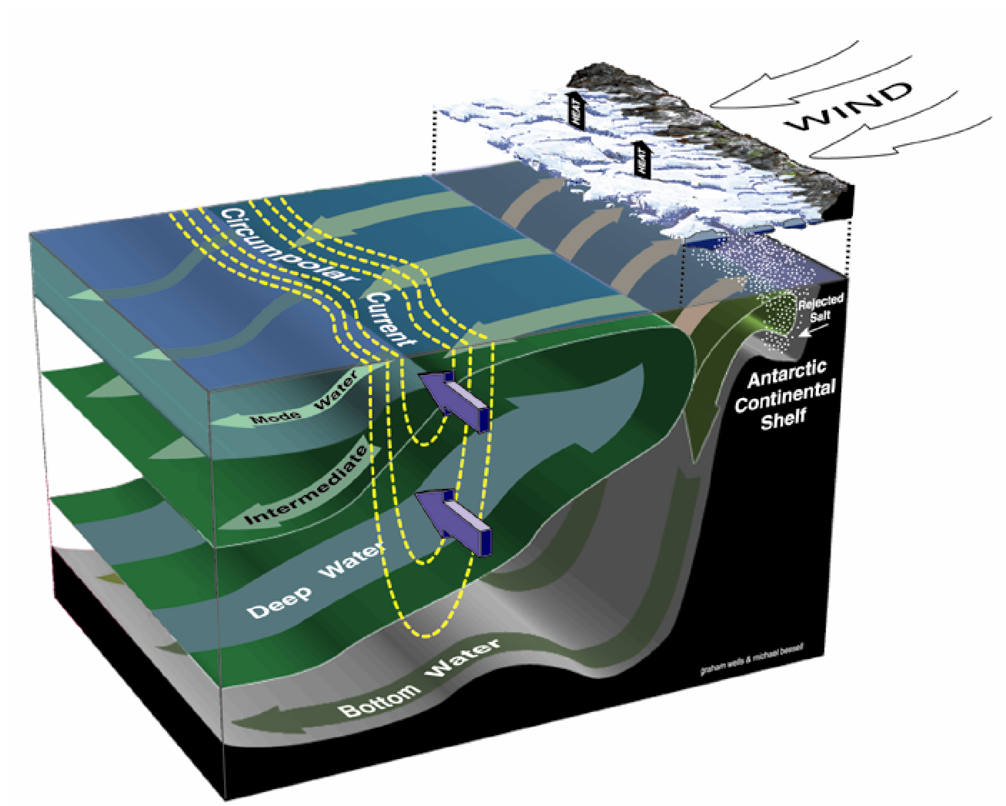

Figure 4: A schematic cross-section of the Southern Ocean, illustrating the two overturning cells. (Rintoul, 2001).

The formation and export of Subantarctic Mode Water and Antarctic Intermediate Water are also critical to the heat, freshwater and nutrient balance of the southern hemisphere. Heat sequestered by the upper branch of the overturning circulation determines the rate and pattern of southern hemisphere sea-level rise due to thermal expansion. The equatorward flow of relatively fresh intermediate waters from the Southern Ocean is the primary return path for moisture carried poleward in the atmospheric branch of the hydrological cycle (Sloyan and Rintoul, 2001). Nutrients exported from the Southern Ocean in Subantarctic Mode Water have been shown to support 75% of global export production (Sarmiento et al,. 2004). The response of both the upper and lower branches of the Southern Ocean overturning to future change will have a significant impact on the climate of Antarctica and the globe.

Climate models in fact suggest the overturning circulation in both hemispheres is sensitive to climate change (e.g. IPCC, 2001). Enhanced greenhouse warming is expected to drive a more vigorous hydrological cycle, with increased precipitation at high latitudes and increased evaporation at low latitudes. The increased precipitation lowers the surface salinity and reduces the formation of dense water at high northern and southern latitudes. Paleoclimate records demonstrate that changes in the overturning circulation have been associated with large and abrupt climate changes in the past. While our ability to understand and simulate the polar processes involved in the global water cycle remains primitive, sparse ocean observations suggest ocean salinity is already changing, in a manner broadly consistent with a more vigorous hydrological cycle (e.g. Wong et al., 2001; Curry et al., 2003). The IPY provides an opportunity to make the observations and model improvements required to assess the likelihood and consequences of a slow-down of the overturning circulation in response to a more vigorous hydrological cycle.

Antarctic sea ice has a significant influence on the climate system and Antarctic ecosystems. The sea ice covers an area of 20 million km^2 at maximum extent, an area larger than that of the Arctic ice cover or the Antarctic continent. The presence or absence of sea ice influences climate through the ice-albedo feedback. The release of brine during the formation of sea ice increases the density of Antarctic shelf waters and drives the formation of Antarctic Bottom Water. The seasonal formation and melting of sea ice is the dominant term in the freshwater budget of the high latitude ocean and controls the stratification of the upper ocean. Sea ice cover inhibits the air-sea exchange of heat and gases such as carbon dioxide. The sea ice pack also plays important roles in the ecology of the Southern Ocean and variability in ice extent has been linked to variability in krill and penguin numbers and distributions. Despite the importance of Antarctic sea ice, our knowledge of the processes controlling sea ice extent, thickness and variability remains primitive. The IPY represents a significant opportunity to fill this hole in our understanding of the southern polar regions.

The short instrumental record in the Southern Ocean is also starting to provide evidence of low-frequency variability and trends in temperatures. Comparison of floats and historical data suggest the circumpolar Southern Ocean has warmed at a depth of 900m in recent decades (Figure 5, Gille, 2002). The deep and bottom waters of the Weddell Sea warmed throughout most of the 1990s, before cooling again in recent years (Fahrbach et al. 2004). We do not yet understand the mechanisms driving variability of the Southern Ocean on time-scales from years to decades and longer.

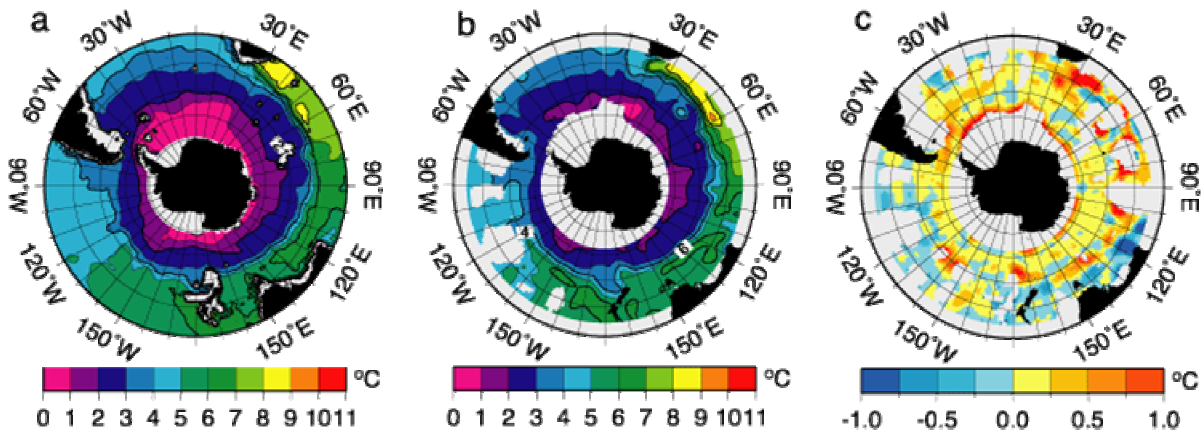

Figure 5: Temperature at 900 m depth from climatology (left), from WOCE floats (centre) and the temperature change between recent float data and historical ocean profile data. (Gille, 2002).

Recent research has also sparked interest in teleconnections linking the high southern latitudes to lower latitudes. El Nino – Southern Oscillation (ENSO) signals are evident in a number of Antarctic and Southern Ocean variables, but the strength of the connection appears to vary in time and the mechanisms are poorly understood (Turner, 2004). The Rossby wave train emanating from the tropical Pacific, the Pacific - South America (PSA) pattern, transmits climate signals to the southeast Pacific, where the strongest interannual variability is located. The Southern Ocean response to the PSA consists of a dipole pattern, with anomalies of opposite sign in the southeast Pacific and southwest Atlantic, known as the Antarctic Dipole (Yuan and Martinson, 2001). Once established, the Antarctic Dipole is maintained by anomalous heat flux by the mean meridional circulation in the atmosphere (Figure 6). The propagating pattern of anomalies known as the Antarctic Circumpolar Wave (White and Peterson, 1996) may also be connected to tropical forcing by the PSA. Other dominant modes of variability in southern hemisphere climate include the semi-annual oscillation (SAO) and Southern Annular Mode (SAM). Both patterns experience high- and low-frequency variability for reasons that are not yet fully understood. A major challenge for the IPY is to understand the physical mechanisms behind teleconnections and modes of variability linking the high and low latitudes of the southern hemisphere, their low-frequency behavior, and the impact of these modes on Antarctic climate and ecosystems. Paleoclimate records will be of great benefit by extending observations of natural variability back beyond the start of the instrumental record.

The Southern Ocean is also the location of the greatest oceanic teleconnection. The Antarctic Circumpolar Current (ACC) carries 137±9 x 10^6 m^3 s^{-1} from west to east through Drake Passage (Cunningham et al., 2002), increasing to 147±9 x 10^6 m^3 s^{-1} south of Australia (Rintoul and Sokolov, 2001). The interbasin exchange accomplished by the ACC allows a global scale overturning circulation to exist and permits anomalies formed in one basin to propagate between basins to influence regional climate downstream. Efforts to understand the Southern Ocean role in the global heat and water cycle will need to take into the account the transport and variability of the ACC. In addition, recent work has shown that the southern hemisphere wind field and the limited southern extension of the African and Australian continents allow the subtropical gyres of the three southern hemisphere basins to connect to form a "supergyre" (Speich et al., 2004). Measurements of interbasin exchange during the IPY need to extend northward to each of the southern hemisphere continents to sample these interbasin connections.

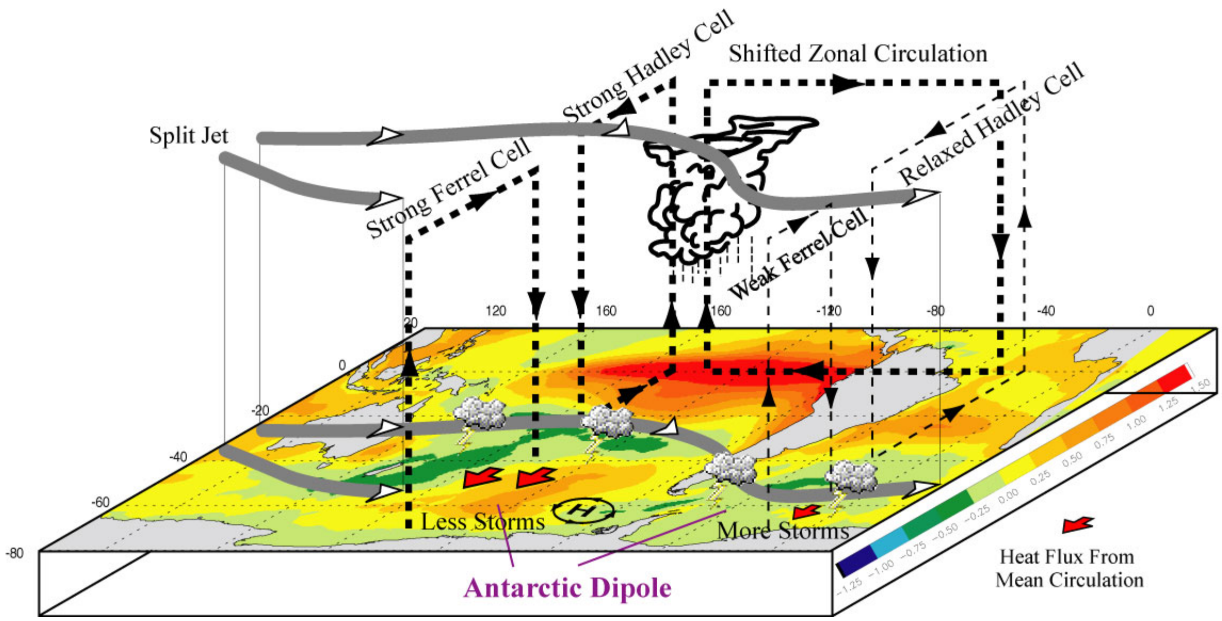

Figure 6: A schematic illustration of a possible mechanism for the initiation and maintenance of the Antarctic Dipole, corresponding to the warm phase of ENSO (Yuan).

The Southern Ocean harbors a series of unique and distinct ecosystems in biogeographic zones defined by the fronts of the ACC and the subpolar gyres and coastal currents to the south of the ACC. Phytoplankton biomass is generally low, despite the high supply of macronutrients by upwelling of nutrient-rich deep water. A series of recent experiments have demonstrated that addition of iron can fuel a dramatic increase in phytoplankton biomass, supporting the hypothesis that an increase in aeolian deposition of iron-rich dust during glacial periods caused phytoplankton blooms and a reduction in atmospheric carbon dioxide. Southern Ocean primary production supports a vast population of krill, which in turn supports a large population of higher predators. The geographical isolation and extreme environment of the Southern Ocean has resulted in a high degree of endemism and unique community and foodweb structures. Climate variability and change are likely to have significant but poorly understood impacts on Southern Ocean ecosystems and biogeochemical cycles. A primary goal of the IPY should be to obtain sufficient understanding of the links between climate, ecosystems, biogeochemical processes and biodiversity to determine the response of the Southern Ocean system to climate variability and change.

A number of modelling studies and paleoclimate proxy records have suggested that changes in northern and southern hemisphere climate are linked on glacial – interglacial time-scales. Cooling in Greenland is generally associated with warming in Antarctica, giving rise to the concept of a "bipolar seesaw." Recently the seesaw concept has been extended to account for the response of ocean heat transport to a freshwater anomaly introduced in the North Atlantic (Knutti et al., 2004). The model does an impressive job of explaining many of the climate variations in both hemispheres during the last glacial period (Figure 7) and emphasizes the strong coupling between the hemispheres.

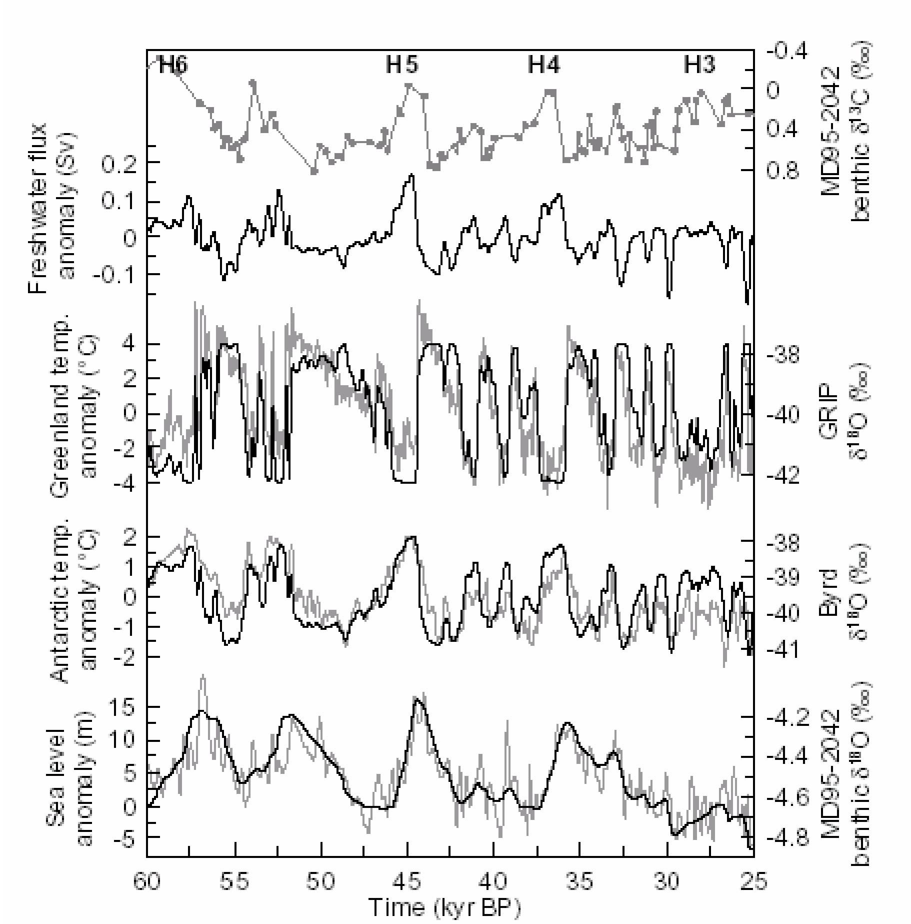

Figure 7: Variability of Greenland and Antarctic temperature and sea level proxy data (grey, right axes) explained by a conceptual model (black, left axes). The conceptual model is based on an extended and quantitative "thermal – freshwater" bipolar seesaw mechanism that includes both changes in the thermohaline circulation and a direct response of ocean circulation and heat transport to an input of freshwater in the North Atlantic. The model illustrates the strong coupling between the northern and southern hemispheres.

A Strategy for the Southern Ocean IPY

We propose to organise IPY activity in Antarctica and Southern Ocean climate around five themes:

1. **Antarctica and the Southern Ocean in the global water cycle**
2. **Southern hemisphere teleconnections**
3. **Climate processes at the Antarctic continental margin**
4. **Climate – ecosystem – biogeochemistry interactions in the Southern Ocean**
5. **Records of past Antarctic climate variability and change**

1. Antarctica and the Southern Ocean in the global water cycle

The goal of Theme 1 is to quantify the high-latitude contributions to the global water cycle, to determine the sensitivity of the water cycle to climate change and variability, and to identify the impact of changes in the high latitude water cycle on the rest of the globe. Here we consider the water balance to include the atmosphere (eg precipitation, evaporation and circulation), the cryosphere (eg sea ice and glacial ice), and the hydrosphere (eg ocean circulation and stratification, run-off). The Arctic Ocean Science Board has proposed a similar initiative in the northern polar regions.

Due to the nonlinear dependence of water vapour pressure on temperature, an increase in vigour of the hydrological cycle is one of the most robust projections of future climate change. Limited observations suggest changes in the global water cycle may already be apparent in changes in ocean stratification. The polar regions may indeed provide the earliest indicators of climate change. Changes in the polar water cycle will have global impacts due to the sensitivity of the overturning circulation and heat transport to changes freshwater input. The stratification of the Southern Ocean, in particular, is delicately poised and sensitive to changes in the freshwater balance. The largest uncertainties in the high latitude water balance (e.g. sea ice thickness) are of such a scale that a coordinated multi-disciplinary, multi-national effort is required to address them, and so a major initiative like the IPY is essential.

Recent developments in technology, simulation and understanding make it now feasible to quantify the key processes, to determine the response of the ocean to changes in freshwater forcing, and to forecast the response of the global system to changes in the water cycle at both poles. Innovative technologies are required to observe key components of the polar water balance (e.g. under-ice profiling and cost-effective ice thickness measurements; biogeochemical sensors on AUVs and time series moorings), fueling development of an observing system that will provide a foundation for future decades of polar studies. Many of the required tools are now under development; the IPY will provide the impetus to ensure they are brought from prototype to operational status in a timely manner.

The program will require an enhanced observation period over a full annual cycle in both polar regions. Observations of the atmosphere, ocean and cryosphere are needed. The observing system must observe variables such as the atmospheric circulation (winds, storms, evaporation, precipitation, moisture flux); the horizontal and vertical circulation of the ocean, including exchange between high and low latitude and the circulation beneath the sea ice, through the annual cycle; sea ice extent, thickness and distribution; and the contribution of glacial ice (ice shelf melt and iceberg production) to the high latitude water balance. Models will play a central role in integrating sparse observations, testing hypotheses, aiding the interpretation of observed changes and projecting future change. New satellites promise to observe aspects of the freshwater balance that are unobservable by conventional means, including snow and ice thickness, but are in critical need of validation data sets.

Relevant IPY submissions (see appendix for submissions):

129	Southern Ocean activities in the International Polar Year
081	Southern Ocean Freshwater Interactions (SOFI)
013	Polar Climate Transects
096	An enhanced network of Antarctic sea ice zone data buoys
057	Antarctic Sea Ice Thickness in the IPY
036	An International Fleet of Polar Rovers to Demonstrate Long-Range Robotic Exploration and Address Climate Science During IPY
038	The New Polar Explorers of the 21st Century: Autonomous Vehicles
016	WMO activities in the 3rd International Polar Year
155	Studies of freshwater input to the ocean (and extraction as sea ice); the influence of the changing hydrological cycle and impact on climate
156	Commence long-term observations of evolving high-latitude water mass properties and fluxes, of relevance to large-scale thermohaline circulation and climate
026	A study of the role of the High Latitude Oceans in the Global Water Cycle
334	JCOMM input to the IPY
335	SCAR input to the IPY
342	Russian investigations in the IPY 2007-8
003	WCRP input to the IPY
Various	Arctic submissions to develop technology for under-ice observations
new	Role of chokepoint sections in the IPY
new	SCAR programme on the Role of Antarctica in the Global Climate System (AGCS)
new	iAnzone initiative Synoptic Antarctic Shelf-Slope Interactions Study (SASSI)

2. Southern hemisphere teleconnections

The objectives of Theme 2 are to understand the climate connections between low and high latitudes, including both atmospheric and oceanic pathways; to determine the role of air-ice-ocean interactions in southern hemisphere variability and change; and to assess the sensitivity of the modes of variability to future change.

Recent research has highlighted a number of modes of variability in the southern hemisphere atmosphere-ocean-cryosphere system. Examples include the Southern Annular Mode (SAM), the Pacific South American (PSA) pattern, the Antarctic Dipole, and the Antarctic Circumpolar Wave. Many of these modes involve teleconnections in the atmosphere and ocean that transmit climate signals over great distances. The dynamics of the teleconnections remain poorly understood. In particular, we do not yet understand how and why the atmosphere shifts between its preferred modes, nor the implications of such shifts for the underlying ocean, sea ice and ecosystems. The extent to which upper ocean dynamics play an active or passive role in patterns like the Antarctic Dipole remains unclear. The unique circumpolar connection provided by the ACC and the Antarctic Coastal Current means that oceanic teleconnections can play a significant role in southern hemisphere climate variability. The overturning circulation is another example of an oceanic teleconnection with significant impacts on regional and global climate.

Climate reconstructions suggest the climate of the northern and southern hemispheres are strongly coupled on millennial time-scales (e.g. Knutti et al., 2004). The two hemispheres are linked by the overturning circulation. Freshwater flux anomalies in either hemisphere can cause anomalies in the overturning circulation and ocean heat transport, with significant impact on regional and global climate. An assessment of the sensitivity of the overturning circulation to future climate change requires attention to high latitude regions in both hemispheres.

Key scientific questions for Theme 2 include:

- How does variability in tropical and mid-latitude atmospheric and oceanic conditions modulate the Antarctic climate? Does variability in Antarctic climate modulate tropical and mid-latitude atmospheric and oceanic conditions?
- How and why have the teleconnections and dominant modes of climate variability in the southern hemisphere changed with time?
- What role does coupling between the atmosphere, cryosphere and ocean play in southern hemisphere climate variability and change?
- How will Antarctic climate change over the next century? How sensitive is the Southern Ocean overturning circulation to climate change?

Progress on Theme 2 requires the observations described in Theme 1 (e.g. ocean stratification and circulation; sea ice extent and volume). In addition, the IPY should be used to obtain the first synoptic picture of the ACC system from hydrographic sections at the chokepoints and several other longitudes. The meridional transects should cross the ACC and extend poleward across the continental shelf, to link the offshore and continental margin environments (see theme 3). Bottom pressure recorders and tide gauges across key passages are needed to provide time series of transport variability (Aoki, 2002; Hughes et al., 2003). Inverted echo sounders can be used to monitor changes in baroclinic variability of the ACC.

Observations of the atmosphere must also be enhanced. During the enhanced observation period of the IPY, an expanded array of sea-level pressure buoys on ice and water should be deployed. The additional pressure observations will improve the numerical weather predictions during the IPY and ultimately the reanalysis products derived from such models. An expanded network of automatic weather stations (AWS) and remote profilers is needed to cover regions that remain data-sparse. Robotic aircraft have an important role to play in profiling the atmospheric boundary layer over sea ice, ocean, and the Antarctic continent.

Paleoceanographic records from high accumulation rate sites can make a significant contribution to studies of southern hemisphere teleconnections, by providing a time history of natural climate variability (see theme 5).

Relevant IPY submissions (see http://www.ipy.org/concept/ideas ***for submissions):***

129	Southern Ocean activities in the International Polar Year
013	Polar Climate Transects
016	WMO activities in the 3rd International Polar Year
017	Sea level and bottom pressure measurements
177	South Atlantic Box proposal
178	Polar ocean gateways: the key for long-term global change
154	Use of data from gravity satellites in better determining the characteristics and dynamics of high-latitude oceanographic circulation
155	Studies of freshwater input to the ocean (and extraction as sea ice); the influence of the changing hydrological cycle and impact on climate
156	Commence long-term observations of evolving high-latitude water mass properties and fluxes, of relevance to large-scale thermohaline circulation and climate
186	Variability of the Southern Ocean
056	The Polar Atmospheric Initiative
XXX	SCAR programme on the Role of Antarctica in the Global Climate System (AGCS)

3. Climate processes at the Antarctic continental margin

The objectives of Theme 3 are: to improve our understanding and models of ocean-ice-atmosphere interactions at high southern latitudes; to obtain a snapshot of the circumpolar distribution of the complex system of coastal, shelf and slope currents along the periphery of Antarctica; to quantify the production rate of Antarctic Bottom Water over an annual cycle and implement an observing system for long-term monitoring of AABW export; to measure the circumpolar volume of sea ice for the first time; and to investigate the impact of warmer ocean temperatures on ice shelf stability.

The Antarctic continental margin is a region of particular importance for the Earth's climate system. Intense air-sea-ice interactions occur where cold, dry air blows off the continent. Rapid formation and export of sea-ice from coastal polynyas results in a net input of brine over the continental shelf, forming dense high salinity shelf water. The dense shelf water escapes from the continental shelf and sinks to the deep sea to form Antarctic Bottom Water (AABW), but the details of the exchange across the shelf and slope and the subsequent entrainment remain poorly understood. The onshore flow of modified circumpolar deep water and offshore flow of new Antarctic Bottom Water form the deep cell of the Southern Ocean overturning circulation. Climate models suggest the formation of AABW may be sensitive to climate change, but the present generation of models cannot capture the complex processes taking place at the Antarctic continental margin.

Studies of Antarctic sea ice did not really commence until the advent of passive microwave satellite coverage in 1973. The level of activity devoted to studies of Antarctic sea ice remains substantially less than that in the Arctic. Only one short term ice drift station (Ice Station Weddell in 1992) has been carried out to date, in contrast to multiple drift stations with year-long coverage in the Arctic. Submarine observations have provided evidence of long-term changes in the thickness of Arctic sea ice, but no submarine measurements exist in the Arctic. Measurements of ice thickness in the Antarctic are limited to ice observations from ships and a few upward-looking sonar measurements. New technologies provide an opportunity to make significant progress during the IPY in understanding Antarctic sea ice and its role in the global system.

The volume of the circumpolar sea ice pack is a key climate variable that has remained unobservable. While extent can be measured remotely, sea ice thickness to date has required in situ observations which remain sparse. The IPY should set the goal of measuring the volume of Antarctic sea ice over an annual cycle for the first time. A combination of ice profiling sonars on floats, gliders, autonomous vehicles and moorings; ship-board observations, including drifting ice stations; and remote sensing from the new cryospheric satellites and other airborne sensors is required. An intense observational effort in one or more regions will be used to ground-truth the remote sensing products and numerical models that will be used for circumpolar integration.

The IPY should include a focused effort to improve our ability to observe, understand and simulate the ocean-ice-atmosphere processes occurring near the margin of Antarctica. Enhanced observations of the atmosphere and ocean boundary layer over an evolving sea ice distribution are required. An expansion of the sea ice drifter array to obtain circumpolar coverage of ice drift and surface pressure is needed during the IPY.

The continental margin is also the region where the ocean interacts directly with glacial ice. Recent events such as the rapid collapse of the Larsen B ice shelf have focused attention on the sensitivity of ice shelves to future change. Observations from Larsen B suggest that the collapse of the ice shelf has greatly accelerated the flow rate of the outlet glacier that fed the ice shelf, with profound effects on the local mass balance of grounded ice. Two hypotheses have been proposed to explain ice shelf collapse, both related to climate change: fracturing due to increased surface meltwater and enhanced basal melting due to warmer ocean temperatures. Long-term projections of sea-level rise and the impact of enhanced freshwater supply from melting of continental ice require improvements in our ability to understand the response of ice shelves to climate change.

The Synoptic Antarctic Shelf-Slope Interactions (SASSI) program being developed by iAnZone is particularly relevant to this theme.

Relevant IPY submissions (see* http://www.ipy.org/concept/ideas *for submissions):

129	Southern Ocean activities in the International Polar Year
081	Southern Ocean Freshwater Interactions (SOFI)
013	Polar Climate Transects
020	Exchanges across Antarctic and Arctic Circumpolar Shelf Break Fronts: Similarities, Differences and Impacts

254	Larsen Ice Shelf Retreat and Glacier Acceleration on the Antarctic Peninsula
016	WMO activities in the 3rd International Polar Year
096	An enhanced network of Antarctic sea ice zone data buoys
057	Antarctic Sea Ice Thickness in the IPY
036	An International Fleet of Polar Rovers to Demonstrate Long-Range Robotic Exploration and Address Climate Science During IPY
038	The New Polar Explorers of the 21st Century: Autonomous Vehicles
154	Use of data from gravity satellites in better determining the characteristics and dynamics of high-latitude oceanographic circulation
155	Studies of freshwater input to the ocean (and extraction as sea ice); the influence of the changing hydrological cycle and impact on climate
156	Commence long-term observations of evolving high-latitude water mass properties and fluxes, of relevance to large-scale thermohaline circulation and climate
183	Proposal to monitor deep water fluxes in the Southern Ocean
186	Variability of the Southern Ocean
185	The process of the Amery Ice Shelf and its interaction with the ocean
056	The Polar Atmospheric Initiative
new	SCAR programme on the Role of Antarctica in the Global Climate System (AGCS)
new	iAnzone initiative Synoptic Antarctic Shelf-Slope Interactions Study (SASSI)

4. Climate – ecosystem – biogeochemistry interactions in the Southern Ocean

The objective of Theme 4 is to understand the impact of climate variability and change on Southern Ocean ecosystems biogeochemical cycles.

The Southern Ocean is a major player in the Earth's carbon cycle. Approximately 40% of the anthropogenic carbon dioxide that has accumulated in the global ocean is found south of 30S (Sabine et al., 2004). Climate models suggest the Southern Ocean uptake of carbon dioxide is sensitive to climate change, representing a potential positive feedback in the global climate system (Sarmiento et al., 1998). However, model projections remain highly uncertain in the Southern Ocean, due to inadequate representation of both physical and biogeochemical processes (Orr et al., 2001).

The Southern Ocean circulation plays a key role in biological productivity, both in the Southern Ocean itself and in the rest of the globe. Sarmiento et al. (2004) concluded that 75% of global ocean export production is supported by nutrients supplied by Subantarctic Mode Water exported from the Southern Ocean. The upwelling of deep water brings macronutrients to the surface of the Southern Ocean, supporting the largest marine ecosystem on Earth (by area), including fisheries and higher predators. Changes in Southern Ocean circulation, stratification and sea ice could have global impacts on biological productivity and biogeochemical cycles.

The unique ecosystems and biodiversity of the Southern Ocean remain poorly sampled. The transects and process studies needed to address the themes outlined in this strategy would provide an excellent platform for circumpolar sampling of Southern Ocean biodiversity. In addition, by making such sampling an integral part of multi-disciplinary experiments aimed at understanding interactions between climate and biology, there is an opportunity to investigate how patterns of biodiversity are likely to change with changing climate.

A variety of approaches are needed to investigate the linkages between climate, ecosystems, and biogeochemical cycles:

- An array of quasi-synoptic transects that cross the ACC and extend to the Antarctic.
- Finescale ocean surveys in regions of special interest, including use of AUVs under the sea ice and towed vehicles in open water.
- Remote sensing of sea surface height, sea surface temperature, ice coverage and characteristics, and ocean colour will be employed for interpolation in space and time between sparse observations.
- Sustained time series are needed to place the synoptic observations of the IPY into the context of seasonal to interannual to decadal variability.
- Modelling will play an important part in experimental design, in the integration and analysis of IPY observations, for testing of hypotheses (e.g. concerning links between physics and biology), and for projecting future change.

Relevant IPY submissions (see* http://www.ipy.org/concept/ideas *for submissions):

114	Integrated Analyses of Circumpolar Climate Interactions and Ecosystem Dynamics in the Southern Ocean (ICCED)
080	Synoptic Circum-Antarctic Climate-processes and Ecosystem study (SCACE)
115	Southern Ocean CIRCLE
004	Circum-Antarctic Census of Marine Life (CircAntCML)
343B	Effects of climate change and anthropogenic perturbation in polar regions on ecosystem processes and risks from invasive species
343E	Biogeochemistry of the Southern Oceans
129	Southern Ocean activities in the International Polar Year
013	Polar Climate Transects
339	NIPR: Global Environment Dynamics through Bi-polar Observation
new	GEOTRACES: Biogeochemical cycles of trace elements in the Southern Ocean

5. Records of past Antarctic climate variability and change

The objectives of theme 5 are to use high resolution proxy records to determine the natural modes of climate variability on time-scales from years to millennia and to improve our understanding of the mechanisms of abrupt climate change in the past, including the role of northern versus southern hemisphere.

Our ability to understand the natural modes of variability of the southern hemisphere is limited by the short duration of the instrumental record. Ice and sediment cores hold the key to extending the record of climate variability in the past.

The IPY can stimulate rapid progress in understanding the climate history of the southern hemisphere by:

- Identification of sites where ice cores will provide the longest possible climatic record, extending back to the time when glacial cycles waxed and waned in 41,000 year cycles rather than the current 100,000 years (eg Augustin et al., 2004).
- Collection of a circumpolar array of shallow and intermediate depth cores from high-accumulation rate coastal sites. These cores will be used to document the natural variability of the climate system, atmospheric circulation, and chemistry over the last few millennia.
- Obtaining new sediment cores from high to medium sedimentation rate sites in Antarctic and subantarctic regions to identify changes in Southern Ocean circulation and structure over the last 500,000 years, and the relationship between changes in the northern and southern hemispheres.
- Extracting new information from paleoclimate data sets by refining the interpretation of proxy records (eg Noone and Simmonds, 2002, 2004) and improving the transfer functions used to link proxy records to climate processes.

Relevant IPY submissions (see* http://www.ipy.org/concept/ideas *for submissions):

178	Polar ocean gateways: The key for long-term global change
236	Ice Coring Science and the IPY: Perspectives of the US Ice Core Working Group
289	International Partnerships in Ice Core Sciences (IPICS)
197	Rapid and abrupt oceanic changes during the last climatic cycles in Antarctic and Subantarctic regions
260	Climatic inferences on development of the sedimentary record
013	Polar Climate Transects

Key Elements of an Integrated IPY Southern Ocean Observing System:

The observations needed to address the themes described above are best obtained as part of an integrated, multidisciplinary observing network. Such a network should include the following elements.

Synoptic multi-disciplinary transects: During IPY a set of meridional transects should be occupied in one season to provide the first synoptic snapshot of the circulation, stratification and biogeochemical status of the Southern Ocean. At a minimum, each of the "chokepoint" sections between Antarctic and the southern hemisphere continents should be occupied, plus one or more additional lines in each basin. The transects will include physical (e.g. CTD/O, LADCP, tracers), biogeochemical (e.g. nutrients, trace elements and micronutrients, carbon, isotopic measurements of export flux, DMS), and biological (e.g. primary production, pigments, bio-optics, fast repetition rate fluoromoter, molecular/genetic techniques, biomarkers, targeted trawls, acoustic) measurements. The sections should extend from north of the ACC and to the Antarctic coast, including the sea ice zone and the continental slope and shelf. The synoptic transects will provide a platform for a variety of biodiversity studies (e.g. material for genomic studies, whale observations, etc.) and an opportunity for deployment of autonomous vehicles, floats and drifters. The full hydrographic sections at the chokepoints will be complemented by repeat high density XBT lines, with ADCP, thermosalinograph, fluorometer and state-of-the-art meteorological sensors.

Sea ice volume: A primary focus of the IPY should be to make the first measurement of the volume of Antarctic sea ice throughout the annual cycle. A variety of tools will need to be used to meet this challenge: AUV's and fixed-point moorings with ice-profiling sonars, acoustically-tracked floats, ship-board observations, remote sensing and data-assimilating models all have a role to play. Two ships using an AUV to obtain "ice-edge to coast" transects could complete sixteen to twenty transects over the four-month winter period, consistent with the spatial sampling required to account for regional variability as assessed by ASPeCt. The AUV program would collect a variety of physical and biological data as well as ice thickness (e.g. salinity, temperature, currents, sonar for biology), and support on-ice process studies to help validate remote sensing products. Time series of ice thickness from fixed-point moorings are needed to complement the spatial sampling from the AUV program. Even with an enhanced effort during the IPY, in situ observations will remain sparse in space and time. Remote sensing from new satellites and airborne sensors and data-assimilating models will play an important role in integrating the in situ observations.

Enhanced sea ice drifter array: Our understanding of the intense and highly variable ocean – ice – atmosphere interactions taking place in the Antarctic sea ice zone is poor due to the lack of observations. Numerical weather predictions south of 60S suffer from a lack of surface pressure observations from the SIZ; as a consequence, flux products derived from reanalyses of the NWP models are also uncertain. An enhancement of the circumpolar array of sea ice buoys during the IPY will provide a one year snapshot of sea ice drift around the whole of Antarctica, will complement efforts to measure sea ice thickness, and will greatly improve southern hemisphere meteorological analyses. A basic array of 50 to 100 buoys will measure surface pressure and position. A smaller number of "mass balance buoys" will be used to measure ice and snow thickness, providing crucial ground-truth for new satellite sensors. Dense clusters of platforms will be deployed in some locations for detailed studies of ice dynamics and deformation.

Ocean circulation under sea ice: The ocean circulation and structure beneath the Antarctic sea ice remains largely unknown. New technologies will allow ocean currents and stratification beneath the sea ice to be observed for the first time during the IPY. The strategy for sub-ice observations in the Antarctic will rely heavily on technology being developed for the Arctic: acoustic tracking of floats and gliders; acoustic communication links; ice-tethered profilers and listening/telemetry/sound source stations; ice thickness measurements from floats; ULS and current meter moorings.

However, the challenges are significantly greater in the Antarctic. The area of the Antarctic sea ice pack is much greater than that of the Arctic; many areas are more remote; and the divergence and strong seasonality of the sea ice pack makes ice-tethered stations more difficult to maintain. Therefore, in the Antarctic the IPY should focus on one or more "well-measured" regions or basins. For example, the entire Weddell Gyre is sufficiently small that it is feasible to deploy an array of acoustic floats, gliders, sound sources and moorings to measure the three-dimensional circulation, stratification, and ice thickness and drift for the duration of the IPY. The Ross Gyre would be another good candidate for an enhanced observation network.

Enhanced Southern Ocean Argo: A primary tool for obtaining a snapshot of ocean conditions during the IPY period will be the Argo array of profiling floats. The IPY should set the goal of achieving at least the 3° X 3° sampling of the global array throughout the southern hemisphere oceans south of 30S, for the full duration of the IPY (March 2007 to March 2009). Acoustically tracked floats will provide profiles and current velocities from key ice-covered seas (see above). In other areas of Antarctica, floats will be programmed to continue to profile and store data beneath ice, but not to surface. Once the floats detect open water, the stored profiles will be transmitted. While the position of the sub-ice profiles is not known without acoustic navigation, the floats can survive the winter and the stored profiles provide a statistical description of winter stratification.

Monitoring of key passages: Key passages and boundary currents should be instrumented to obtain transport estimates. Examples include Drake Passage and the locations of deep outflows (eg the western Weddell Sea). Tide gauges and bottom pressure recorders have been shown to provide a cost-effective means of monitoring the transport of the Antarctic Circumpolar Current (eg Hughes et al, 2003). Efforts to benchmark the Antarctic tide gauges and understand the causes of long-period variability (eg land movements and sea-level rise) during the IPY would help increase the utility of these measurements as part of a sustained observing system.

Environmental sensors on marine mammals: Recent experiments have demonstrated the viability of using temperature and conductivity sensors mounted on large marine mammals for oceanographic monitoring. Elephant seals, for example, dive repeatedly to depths of up to 1500 m and spend the autumn and winter in the marginal ice zone, where few previous measurements have been made. The seals also provide high resolution transects across the Antarctic Circumpolar Current during trips between subantarctic islands and the sea ice zone. The tags also provide valuable information on the relationship between seal distributions and oceanographic features. The technology is likely to develop further before the IPY. A deployment of 50 to 70 tags during the IPY would provide a unique data set to complement the more traditional oceanographic sensors. Similar deployments are anticipated on Arctic seals during the IPY.

Enhanced meteorological observations: The IPY should serve as a test of the impact of an enhanced atmospheric observing system on Antarctic and southern hemisphere weather forecasts. The enhanced observations should include additional automatic weather stations and remote profilers, sea level pressure observations from ice and ocean drifters (see above), and aircraft (manned and un-manned). One of the benefits of improved weather forecasts for climate research is the increased accuracy of the flux products derived from NWP model reanalyses. The air-sea fluxes of heat and moisture are poorly known at high southern latitudes, making it difficult to diagnose the interactions between atmosphere, ocean and sea ice that lie at the heart of climate variability and change. During the IPY, state-of-the-art meteorological sensors (e.g. IMET systems) should be installed on as many Antarctic research, supply and tourist ships as possible to provide validation data for the next generation of flux products from reanalyses and satellites.

Ice cores from high accumulation rate coastal regions: The short duration of the instrumental record poses a huge challenge when attempting to understand southern hemisphere climate variability and change. Ice cores from high accumulation rate coastal sites will be of immense value in reconstructing a record of past change on time-scales from years to millennia (eg Curran et al., 2003; Goodwin et al., 2004). The IPY should be used to kick-start the collection of shallow and intermediate cores from a circumpolar distribution of coastal sites.

Sediment cores: New sediment cores from medium to high accumulation rate regions will help to identify changes in Southern Ocean circulation and structure during the course of past glacial cycles. These cores will provide estimates of past changes in sea ice extent and shifts in ocean fronts, and help to clarify the relationship between changes in the northern and southern hemispheres.

Remote sensing: Satellite measurements will play a critical role in the IPY. Key instruments include satellite altimeter and scatterometer, infrared and microwave radiometers for sea surface temperature, gravity missions, ocean colour, and cryosphere satellites to measure ice extent, ice thickness, and snow thickness (eg ICESat, CryoSat, EOS Aqua). A major hurdle for use of the new crysophere sensors is the need for ground-truth. A major goal of the IPY should be to obtain the field measurements needed to validate the new generation of cryosphere satellites.

Process studies: Some of the key unknowns regarding the role of Antarctica and the Southern Ocean in the global climate system require focused process studies to be resolved. Exchange of water masses across the Antarctic Slope Front is an important, but poorly understood, process in the formation of dense water on the continental shelf. The complex interactions between the ocean and ice shelves, including melting near the grounding line and formation of marine ice beneath the ice shelf, remain largely unobserved. These interactions are important to the freshwater balance, to water mass transformation, and to the stability of the ice sheets that feed the ice shelves. New technology to explore the ice shelf cavities is now available and expected to provide a significant step forwards. The distribution of diapycnal mixing remains a central issue in oceanography. Recent studies suggest the Southern Ocean may be a hot-spot for diapycnal mixing (e.g. Naveira – Garabato et al., 2004). Microstructure measurements should be conducted during the IPY to test this hypothesis. Progress in understanding what physical and biogeochemical processes control the rate of carbon export in the

Southern Ocean will require focused field experiments and biogeochemical time series measurements from moorings.

Status of the pilot Southern Ocean observing system

The many contributors to CLIVAR, CliC, Argo and other programs have worked hard in recent years to develop and implement a pilot observing system for the Southern Ocean. The existing observing system is incomplete, but provides a starting point on which the IPY observational plan can build. The IPY should target those additions to the existing observing system that require a coordinated international approach and that will enable a significant jump in our understanding of the Southern Ocean system. The sustained observations will provide a time history to aid in the interpretation of the intensive but limited duration measurements to be made during the IPY.

Key elements of the existing sustained Southern Ocean observing system include:

- Repeat hydrographic sections at the chokepoints (annual at Drake Passage, every 3-5 years along the GOODHOPE line south of Africa, every 5-7 years south of Australia).
- High density repeat XBT lines (30 per year at Drake Passage, with ADCP; twice per year south of Africa; six times per year south of Australia; additional lines with less frequent repeats)
- Biannual repeats of a transect between Reunion, Crozet, Kerguelen, and Amsterdam Islands in the Indian Ocean.
- Argo profiling floats.
- Bottom pressure recorders on either side of Drake Passage.
- Tide gauges at a number of coastal and island sites.
- Surface drifters (ice drifters and ocean drifters).
- Moored monitoring arrays in the Weddell Sea (e.g. WECCON, NW Weddell).

In addition to the sustained observations, a number of process studies are planned that will contribute directly to the goals of the IPY. A complete list will be developed during the Implementation Plan stage.

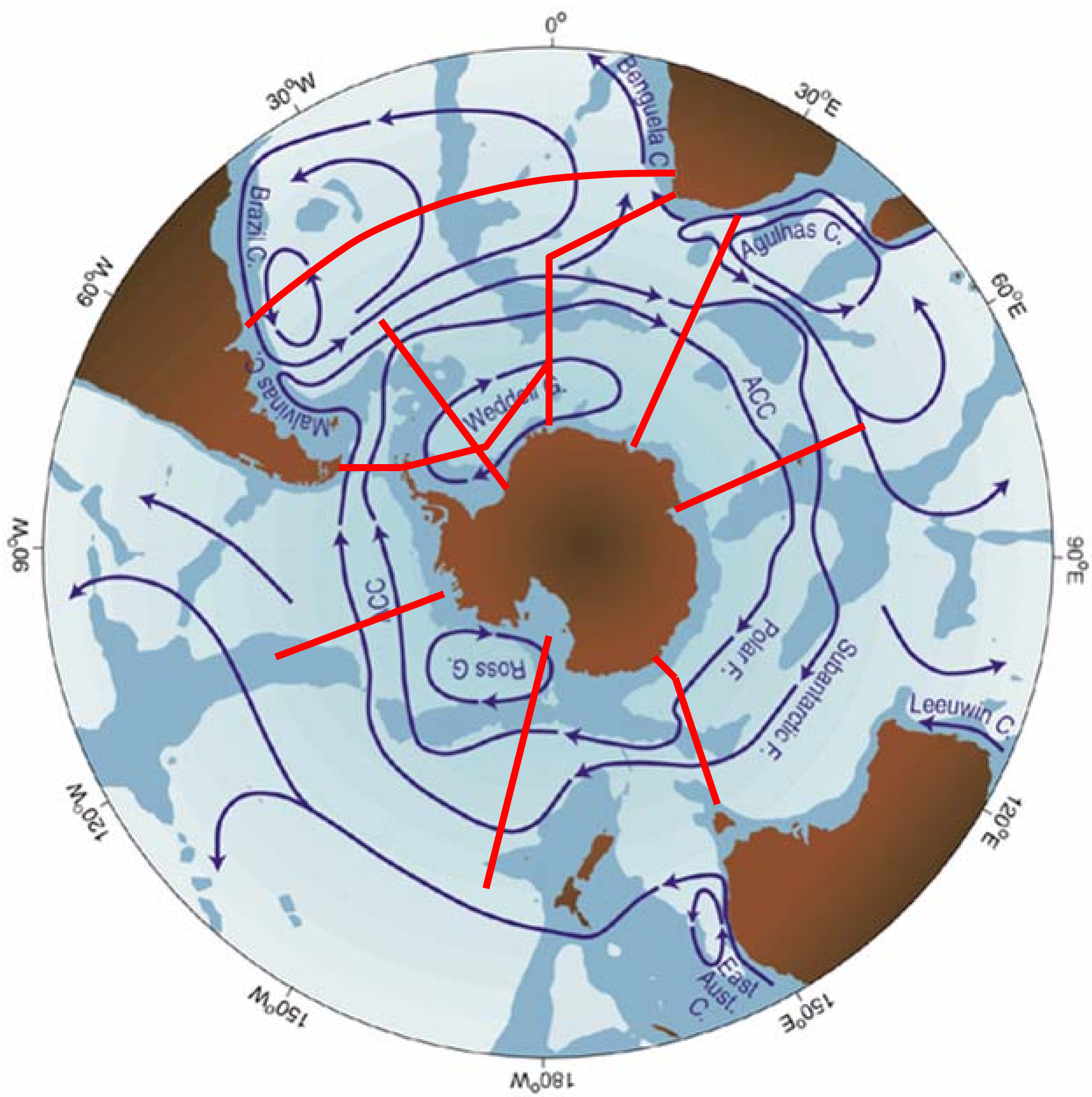

Figure 8: Synoptic transects proposed for the IPY (see e.g. IPY proposals 129, 177, 080, 081, 013, 020). Sections have been chosen because they continue an established time series (e.g. chokepoint sections occupied during WOCE and CLIVAR; 170W section occupied by the AESOPS program; southern end of OISO section at 70E) or cross major features (Weddell and Ross gyres; a center of the Antarctic dipole at 110W). On each section a wide range of physical, biogeochemical and biological measurements will be carried out. Sections should run from the continental shelf, across the sea ice zone and across the ACC. Re-occupations of zonal lines across each subtropical basin should be encouraged during the IPY, to constrain estimates of exchange between the Southern Ocean and low latitudes.

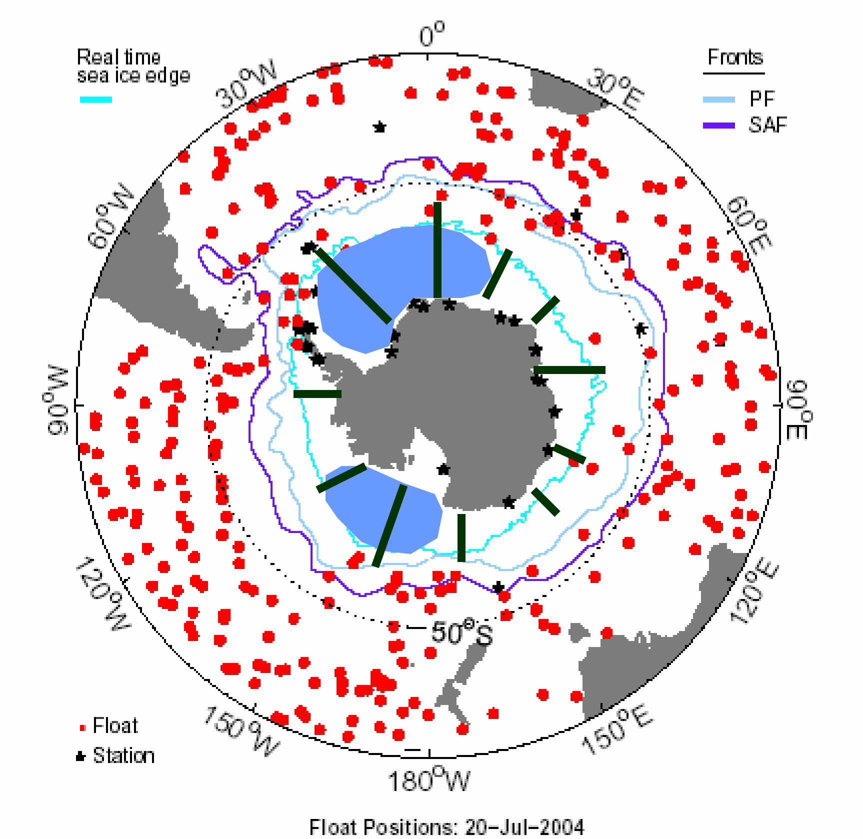

Figure 9: Present status of Southern Ocean Argo (red dots), as of 20-July-2004. Note that significant gaps remain, particularly south of 50S (float map courtesy of Kevin Speer, FSU, http://www.argo.fsu.edu). The IPY should set a goal of achieving at least the nominal global Argo coverage of one float per 3 degree square for the duration of the IPY, including both the open ocean and ice-covered seas. The blue regions in the Weddell and Ross gyres indicate the location of intensive observation systems, including acoustic tracking of floats and gliders, ice-tethered stations and moored instruments. A schematic of such an array is shown below. The dark green transects indicate possible winter ice thickness transects conducted with an Autosub or other autonomous underwater or airborne vehicle. It might be used along the transects or from ships on the transect on a perpendicular course. To achieve the goals of the IPY in both hemispheres in the same time frame will mean that autonomous systems are likely to play a significant role in obtaining year-round observations.

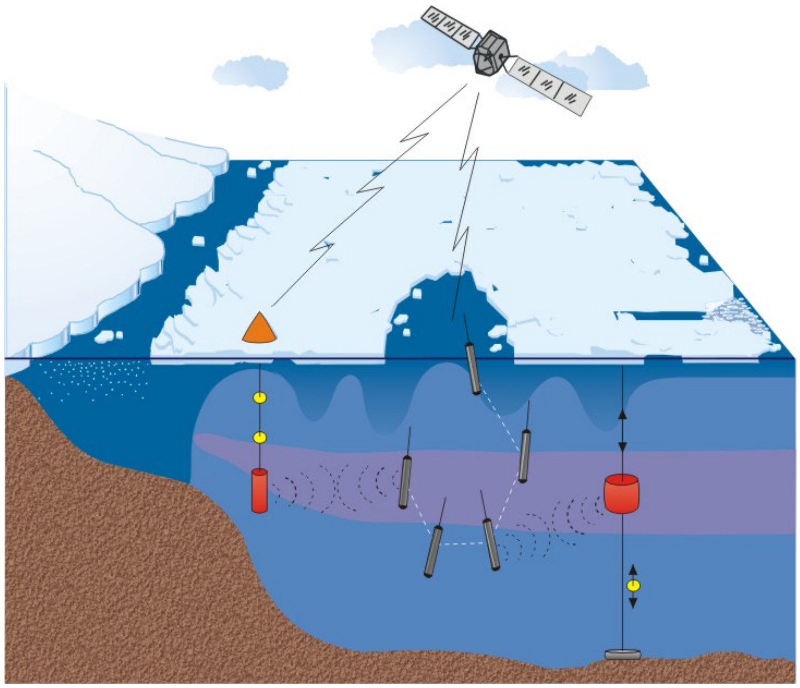

Fig. 10: Envisaged hybrid Antarctic observation system (HAFOS) combining sea-ice drifters, profiling floats and moored instruments to achieve long term measurements in the ocean under the sea ice with spatial coverage comparable to the global Argo system. (Courtesy Eberhard Fahrbach, AWI).

Relevance to IPY goals

The program outlined here is targeted directly at themes identified in the Initial Outline Science Plan (20th April 2004) prepared by the ICSU IPY Planning Group. Together with activities planned for the Arctic, in particular the "Northern Seas at a time of Global Change" plan prepared by AOSB/CliC, a bi-polar perspective will be brought to each of these themes.

Theme 1: To determine the present environmental status of the polar regions by quantifying their spatial and temporal variability.

The strategy outlines an integrated, interdisciplinary plan for synoptic observations of the Southern Ocean environment during the IPY. The program will document temporal and spatial variability of Southern Ocean climate, ecosystems, and their interactions. Key variables and processes to be targeted include sea ice thickness and extent, snow cover, ocean circulation and stratification, water mass formation, ocean-atmosphere-ice interaction, ice shelf – ocean interaction, carbon storage and export, ecosystem response to physical and chemical forcing, and biodiversity.

Theme 2: To quantify, and understand, past and present environmental and human change in the polar regions in order to improve predictions.

A primary focus of the climate research strategy for the IPY is to understand, interpret and predict climate variability and change in the southern polar regions and its impact on Antarctic and global processes. The activities undertaken to provide the synoptic snapshot will also deliver the understanding of climate processes needed to improve our ability to predict future change. The enhanced effort to observe the Southern Ocean during the IPY will leave a legacy of a long-term observing system capable of documenting change in the southern polar regions. A well-integrated modelling effort will be necessary. Paleoclimate records are required to document natural variability in the past.

Theme 3: To advance our understanding of polar – global teleconnections on all scales, and of the processes controlling these interactions.

Teleconnections between polar and lower latitudes, between the ocean basins, and between the upper and lower atmosphere, are the focus of theme 3 of the climate research strategy outlined here. Key phenomena to be addressed include the Southern Annular Mode and its impact on the underlying ocean and sea ice; the Antarctic Dipole; the impact of ENSO on Antarctica and the Southern Ocean; the potential for feedback from the polar regions on lower latitude climate; the influence of ACC variability on regional and global climate; and the response of marine ecosystems and carbon fluxes to changes in the physical and chemical environment driven by low-latitude forcing.

Theme 4: To investigate the unknowns at the frontiers of science in the polar regions.

The observational program described here is targeting several new frontiers. During the IPY we will for the first time measure the volume of Antarctic sea ice through an annual cycle and observe the sub-ice ocean circulation and ecosystems. New technologies such as autonomous underwater vehicles, acoustically-tracked floats and gliders, and ice-tethered platforms make it possible to tackle these challenges during the IPY.

By demonstrating the crucial role of high southern latitudes in the global climate system, the IPY will make clear to the public and policy-makers the value of polar research and monitoring. The ambitious science program will inspire a new generation of polar researchers, who will become the first to design an under-ice observing system for the Southern Ocean, the first to measure the volume of Antarctic pack ice, or the first to synthesise diverse physical and ecological data sets and models to infer the impacts of climate change on Antarctic ecosystems.

Legacy of the IPY 2007-2008

The legacy of the IGY included a number of manned stations in coastal and inland Antarctica. Most of what we know about Antarctica and its connections to the rest of the globe has depended on the fifty years of observations collected at these stations. However, the number of stations is limited and hence our understanding of many aspects of the links between global climate and Antarctica and the Southern Ocean remains primitive.

The legacy of the IPY 2007-2008 will be a sustained, cost-effective observing network for Antarctica and the Southern Ocean. The system will rely heavily on autonomous instruments to provide long time-series from remote and inaccessible locations. During the IPY we will test a variety of new observational approaches for their suitability as part of a sustained system. Examples include acoustically tracked floats and gliders under sea ice, measuring ice thickness, ocean circulation and stratification; mass balance buoys deployed on sea ice; airborne instrumentation suitable for use on planes and helicopters used for intracontinental and intercontinental transport; biogeochemical sensors suitable for deployment on new generation autonomous vehicles; robust, long-lived automatic weather stations. Through a combination of these techniques, the IPY will deliver an observing system capable of providing year-round sampling with spatial and temporal sampling at least an order of magnitude greater than presently available.

The Southern Ocean IPY will leave a number of other legacies on which the future of Antarctic and Southern Ocean research will be built: a first synoptic snap-shot of the Southern Ocean physical, biological and biogeochemical environment, which will provide a benchmark for assessments of past and future change; models capable of simulating the physical climate system and its interactions with ecosystems and biogeochemical cycles, providing vastly improved projections of future change; and a better integrated, interdisciplinary polar research community.

Next Steps

The strategy outlined here is one approach to integrate IPY activity relevant to the role of Antarctica and the Southern Ocean in the global climate system. The document was prepared by the CLIVAR/CliC/SCAR Southern Ocean Implementation Panel, with assistance from many others.

An earlier draft was circulated widely for comment. The present version has been submitted to the ICSU IPY Planning Group for consideration at their meeting in September.

If supported by the ICSU planning group and the broader community, the next important step is to develop an implementation plan. Given the breadth of activities described in the strategy, it is the view of the CLIVAR/CliC/SCAR panel that the details of implementation are best handled by individuals directly involved in the science programs. The panel can play a facilitation and coordination role and help pull together the international teams required to address the major science challenges being tackled by the IPY.

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Appendix: IPY submissions referred to in the proposal

The complete text of the following submissions can be found at:
http://www.ipy.org/concept/ideas

003	WCRP input to the IPY
004	Circum-Antarctic Census of Marine Life (CircAntCML)
013	Polar Climate Transects
016	WMO activities in the 3rd International Polar Year
017	Sea level and bottom pressure measurements
020	Exchanges across Antarctic and Arctic Circumpolar Shelf Break Fronts: Similarities, Differences and Impacts
026	A study of the role of the High Latitude Oceans in the Global Water Cycle
036	An International Fleet of Polar Rovers to Demonstrate Long-Range Robotic Exploration and Address Climate Science During IPY
038	The New Polar Explorers of the 21st Century: Autonomous Vehicles
056	The Polar Atmospheric Initiative
057	Antarctic Sea Ice Thickness in the IPY
080	Synoptic Circum-Antarctic Climate-processes and Ecosystem study (SCACE)
081	Southern Ocean Freshwater Interactions (SOFI)
096	An enhanced network of Antarctic sea ice zone data buoys
114	Integrated Analyses of Circumpolar Climate Interactions and Ecosystem Dynamics in the Southern Ocean (ICCED)
115	Southern Ocean CIRCLE
129	Southern Ocean activities in the International Polar Year
154	Use of data from gravity satellites in better determining the characteristics and dynamics of high-latitude oceanographic circulation
155	Studies of freshwater input to the ocean (and extraction as sea ice); the influence of the changing hydrological cycle and impact on climate
156	Commence long-term observations of evolving high-latitude water mass properties and fluxes, of relevance to large-scale thermohaline circulation and climate
177	South Atlantic Box proposal
178	Polar ocean gateways: the key for long-term global change
183	Proposal to monitor deep water fluxes in the Southern Ocean
185	The process of the Amery Ice Shelf and its interaction with the ocean
186	Variability of the Southern Ocean
197	Rapid and abrupt oceanic changes during the last climatic cycles in Antarctic and Subantarctic regions
236	Ice Coring Science and the IPY: Perspectives of the US Ice Core Working Group
254	Larsen Ice Shelf Retreat and Glacier Acceleration on the Antarctic Peninsula
260	Climatic inferences on development of the sedimentary record
289	International Partnerships in Ice Core Sciences (IPICS)
334	JCOMM input to the IPY
335	SCAR input to the IPY
339	NIPR: Global Environment Dynamics through Bi-polar Observation
342	Russian investigations in the IPY 2007-8
343	Themes proposed by the United Kingdom IPY National Committee
new	SCAR Role of Antarctica in the Global Climate System (AG CS)
new	Chokepoint sections in the IPY
new	GEOTRACES: Biogeochemical cycles of trace elements in the Southern Ocean
new	SASSI: Synoptic Antarctic Shelf-Slope Interactions, iAnZone
various	Arctic proposals for new technologies to measure ice thickness and sub-ice ocean circulation

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