WCRP REPORT

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Project Report

Report of the Fifth Meeting of the CLIVAR/CliC/SCAR Southern Ocean Region Panel

16 - 18th February 2009, University of New South Wales, Sydney, Australia

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1 Summary of Action Items

ACTION: update of the SOOS figures (Stansfield with input from panel members) – status completed since the panel meeting.

ACTION: The SOOS community should write to funding agencies advocating sustaining the marine mammal as ocean observers tagging activities.

ACTION: Feedback from panel members to finalize/rationalise the SO indices. (England/Speer/All Panel)

ACTION: Nominate SO panel members to analyze the chosen indices in the various Ocean Data Analysis products (All panel)

ACTION: Summary of the key gaps identified to be compiled to send to CLIVAR WGOMD (Co-chairs/ICPO/All panel)

ACTION: Co-chairs to liase with Tony Worby and CliC on producing an estimate of the SO freshwater balance.

ACTION: Seek SSG approval for Dr. G. Marshall to join the panel (Speer/England/ICPO)

2 Introduction

2.1 Terms of Reference

In 2004 the Scientific Committee on Antarctic Research became the third co-sponsor of the Southern Ocean region panel. Thus the Southern Ocean - Climate Variability and predictability / Climate and Cryosphere / Scientific Committee on Antarctic Research (SO - CLIVAR/CliC/SCAR) panel is charged with refining and implementing the science plans of CLIVAR, CliC and SCAR in the SO Sector.

The terms of reference (TOR) of the panel are:

1. To design a strategy to assess climate variability and predictability of the coupled ocean-atmosphere-ice system in the Southern Ocean region.
2. To develop and refine an implementation plan for the Southern Ocean region that defines the process studies, sustained observations, and model experiments needed to meet the objectives of CLIVAR, CliC and SCAR.
3. To work in concert with relevant CLIVAR panels (e.g. regional panels, numerical experimentation groups), ACSYS/CliC Panels (DMIP, OPP, NEG) and other groups (e.g. Ocean Observation Panel for Climate, Argo Science Team) to integrate SO observations with those in neighbouring regions to ensure the objectives of CLIVAR/CliC/SCAR are met and resources are used efficiently.
4. To enhance interaction between the meteorology, oceanography, cryosphere, biogeochemistry and paleoclimate communities with an interest in the climate variability of the SO region.
5. To serve as a forum for the discussion and communication of scientific advances in the understanding of climate variability and change in the SO region.
6. To work with the CLIVAR, CliC and SCAR data systems on issues related to distribution and archiving of SO observations.
7. To advise the CLIVAR, SCAR and ACSYS/CliC SSGs on progress achieved towards implementation.

For further details see: http://www.clivar.org/organization/southern.php

2.2 Main Aims

The main aims of the CLIVAR/CliC/SCAR Southern Ocean region panel are:

i. To design a strategy to assess climate variability and predictability of the coupled ocean-atmosphere-ice system in the Southern Ocean region.
ii. To oversee and coordinate Southern Ocean region process studies, sustained observations, and model experiments needed to meet the objectives of CLIVAR, CliC and SCAR.

Further details can be found at: http://www.clivar.org/organization/southern/southern.php

2.3 Fifth Panel meeting

The 5th meeting of the CLIVAR/CliC/SCAR Southern Ocean region panel (SOP) was held from the 16th to 18th of February 2009 at the Climate Change Research Centre of the University of New South Wales, Sydney, Australia.

The meeting started with a welcome and introduction from the local host and panel co-chair Matthew England. Kevin Speer (also co-chair of the panel) then gave a brief overview and reminder of the remit of CLIVAR and the Panel.

Day one focused on a reminder of the meeting goals, an update on the state of the system, reports from and key research directions

The main actions and outcomes from the meeting are summarized here. Where appropriate, relevant updates that have occurred since the meeting have been highlighted.

We take this opportunity to thank Matthew England and Sophie Kober for organizing the local logistics so well, and also Matthew England and Andy Pitman, co-directors of the Climate Change Research Centre, for providing us with the venue for the meeting and lunches and refreshments.

3 Meeting Outcomes and Agreed Actions

3.1 Southern Ocean Observing system evaluation

Plans for the Southern Ocean Observing system (SOOS) continue to develop and since the panel meeting a community white paper, lead by Steve Rintoul and co-authored by several other members of the Southern Ocean panel, has been submitted to the Ocean Obs'09 meeting.

The need for a sustained SOOS arises from its unique geography. By connecting all of the ocean basins, the upper and lower limbs of the ocean overturning circulation, and by supporting the planet's largest current, the Antarctic Circumpolar Current (ACC), the Southern Ocean (SO) plays a critical role in the global ocean circulation, biogeochemical cycles and climate.

The SOOS is designed to address six key challenges:

- Role of Southern Ocean in global freshwater balance
- Stability of Southern Ocean overturning
- Stability of Antarctic ice sheet and future contribution to sea-level rise
- Future of Southern Ocean carbon uptake
- Future of Antarctic sea ice
- Impacts of climate change on Antarctic ecosystems

As it currently stands the strawman SOOS consists of a combination of:

- Repeat full-depth hydrographic/tracer sections along World Ocean Circulation Experiment (WOCE) lines
- Profiling floats, open ocean and under sea ice
- Sensors on marine mammals
- Sea ice observations
- Ocean-ice shelf interaction
- Surface meteorology observations

- Surface and sea-ice drifters
- Ecological monitoring

The SOOS vision for the next 5-10 years and beyond to 2030 includes but is not limited to:

- Enhanced profiling floats with additional sensors, depth range and longevity.
- Cost-effective time series stations, using data capsule technology and expendable moorings.
- Supply/research ships doing routine surveys/sections on way into Antarctic bases
- Network of integrated fast ice "mass balance" stations
- A network of ice-capable gliders

It is hoped that the SOOS will help to resolve some or all of the following challenges:

- The role of the SO in the global freshwater balance
- The stability (and variability) of the meridional overturning circulation in the SO
- The stability of the Antarctic ice sheets and their contribution to sea level rise
- The future of CO_2 uptake in the SO
- The future of Antarctic sea ice
- The impacts of climate change on Antarctic ecosystems

Activities that are already taking place:

A number of ARGO floats have already been deployed in the SO however the coverage is sparse in the Pacific Sector and the SouthWest Indian sector. Overall only about one quarter of the drifters that are needed are active in the SO. Sound sources have been deployed on some moorings in the southern Wedell to track modified ARGO floats under the ice. By tagging marine mammals with a small CTD instrument many more water column profiles have been achieved under sea-ice. Using this method as many as 30 times more profiles under sea ice have been retrieved from seals than from any other method. Also south 60 ^{o}S seals have produced more profiles than all other sources combined. Regionally, the seals deliver fewer profiles in the South Pacific as there are few islands for seal breeding. The marine mammal tagging program is only due to last until 2011 and through SOOS the community should advocate for an extension to the program.

Continuous plankton recorder tows have been carried out during the period 1991 to 2008. These surveys cover over 70 % of the Southern Ocean from October to April with 40-50 tows each year.
The surveys provide information about zooplankton populations on a large scale. In addition, there is information from satellites and a few isolated deployments of moored arrays of current meters, and sediment traps. There is also a tide gauge network in place.

The main gaps identified include observations from the ice covered regions, data below the maximum profiling depth of the ARGO floats (i.e. below 2000 m), information from within ice shelf cavities, observations close to the seabed and non-physical measurements. In addition there is a paucity of time series data for most variables.

A revised version of the SOOS planning document will be available in mid 2009 for comment by the community.

ACTION: update of the SOOS figures (Stansfield with input from panel members) – status completed since the panel meeting.

ACTION: The SOOS community should write to funding agencies advocating sustaining the marine mammal as ocean observers tagging activities.

3.2 Carbon science observing system within SOOS

The panel were reminded of the upcoming workshop in Princeton, New Jersey which will focus on carbon cycling and marine ecosystems in the context of climate variability in the Southern Ocean.

The Southern Ocean plays a critical role in the global climate system owing to its unique physical, biogeochemical, and ecological features. The region is undergoing substantial changes in response to climate trends and variability, and future changes are expected to exert substantial impacts on biogeochemical cycles and ecosystem processes of the Antarctic. Despite increased efforts to understand these processes, significant discrepancies still exist between models and observations, and a number of key processes remain poorly quantified. There is a clear and increasing need to develop a coordinated approach that advances our understanding of climate variability in the Southern Ocean and its implications for ecosystem dynamics and biogeochemical cycling. The Southern Ocean will be impacted by greenhouse gas warming by both the direct effect of rising CO_2 and indirect effect of ocean warming and circulation changes. Monitoring how these changes feedback on greenhouse warming and on the functioning of the carbon cycle and marine ecosystems is important.

Recent work has shown that_ocean acidification impacts will occur sooner than expected (McNeil and Matear 2008) hence the need to develop a SOOS which will monitor these changes (e.g. the Ross Sea focused PULSE biogeochemical time series).

The panel are not clear as to the SOOS plans for biogeochemical observations nor as to what the community has planned for longer term carbon monitoring or carbon process studies. There is a strong need for ground-truthing of biological data. Possible future plans could include adding dissolved oxygen sensors to ARGO floats which would provide a way to quantify the strength of biological pump in the SO, repeat hydrographic sections which provide a valuable tool to monitor CO_2 changes in the oceans, and improved links and support for atmospheric CO_2 and O_2 observations to monitor the SO changes in carbon cycling.

3.3 Climate/Carbon process study development

There is a high negative correlation between SO changes in natural and anthropogenic carbon uptake. For recent the past and for the next several decades the natural response will dominate the SO response. The SO carbon response to climate change is not clear because the response to the different forcing fields is complex. It is not known how the SO will respond to a more positive SAM which may drive a net change in Ekman transport and mode and intermediate water subduction. Inversion of historical atmospheric oxygen data should answer this question. In addition acidification of the SO is occurring with under-saturated aragonite conditions in the winter when atmospheric CO_2 reaches 450 ppm

In the SO, the response to the different forcing fields is complex. In the models the response is dominated by changes in ocean ventilation so it is not clear that the SO carbon uptake is declining. New work with both the ocean models and the atmospheric inversions suggest that the conclusion of Le-Quéré *et al*., (2007) that the SO CO_2 uptake is declining may be premature. The response of reduction in uptake may also be a transient because eventually atmospheric CO_2 levels could rise enough for the natural carbon cycle to dominate.

Recent advances from observations show considerable seasonal amplification of the carbonate ion concentrations in the Southern Ocean. The Ross Sea was found to have a huge seasonal cycle, and the rapid decline in the Aragonite saturation state (Ω) between summer and autumn can not be ruled out in causing the Pteropod die-off collected in sediment traps. Very low winter-time values coupled with future anthropogenic CO_2 levels will induce 'corrosive' seawater conditions decades before previously though (~2030 in the open Southern Ocean). The very low winter Ω brings forward the onset of aragonite saturation to the year 2015 in the Ross Sea. These results imply that atmospheric CO_2 concentrations of 450 ppm may be the tipping point for these corrosive conditions. However coincident biological and geochemical time-series studies are needed to understand the implications of these 'corrosive' conditions for Southern Ocean calcifiers (such as Pteropods).

3.4 Report of state of southern climate system variations and key modes

There is some consensus that the ACC is driven primarily by wind stress for example using linear theory (e.g. Marshall and Radko 2003) the transport depends linearly upon the wind stress (τ) and eddies in the ACC interact with the buoyancy forcing to control stratification. This is consistent with most GCM simulations but is dependent on how the eddies are parameterized. In the eddy saturation case (e.g. Hallberg and Gnanadesikan 2006) the transport is independent of τ as it is the eddies which take up the additional wind stress energy via baroclinic instability. In this case it is the stratification which controls transport implying that high viscosity seems to enhance the mean flow. This occurs because when viscosity is low, eddies are strong. But what happens if the wind stress changes (for example through an intensification of the Southern Annular Mode - SAM)?

In the Southern Ocean, eddies transfer momentum vertically. This means the link between momentum input at the surface and pressure torque at the bottom acts faster, so that total zonal flow has less momentum. Also, bottom topography acts to steer the flow, forming fast-flowing jets.

Results using a Quasi-Geostrophic (QG) model in an "eddy saturated" parameter regime show that increases in wind stress do not increase the ACC transport; instead, the wind stress amplifies the potential energy, which decays to eddy kinetic energy (EKE) through baroclinic instability, with a lag of several years. The observed lag between wind stress forcing and EKE can be explained if the ocean is also in an eddy saturated state – but this is not predicted by coarse resolution (IPCC) models.
But if IPCC models can't simulate the interannual response to wind stress, can we have confidence that they represent the processes important to interdecadal changes?

Observations reported by Böning *et al.*, (2008) and primitive equation models (e.g. Screen *et al.* 2000) also support the eddy saturation hypothesis.

Uncertainties that remain include:

- The role of diabatic processes in offsetting the eddy saturation hypothesis
- Is upwelling of CDW sensitive to eddy processes?
- Is there a long term feedback on stratification in the SO region?
- What is the vertical structure of the eddies and the eddy heat flux?
- How to jets/fronts respond to the meridional position of the wind stress maximum?
- What are the interactions of the overturning circulation, the buoyancy forcing and the ACC?

It is proposed that future work should encompass a hierarchy of QG and Primitive equation process models to evaluate above the uncertainties, and to assist progress towards eddy-resolving GCMs.
There is certainly a need for improved eddy parameterizations but also for continued observations and analysis to delineate between the conflicting theoretical predictions.

Questions remain as to how much and where surface water is exported into Subantarctic Mode Water (AAIW) and Antarctic Intermediate Water (AAIW) layers and what are the export mechanisms? In order to calculate the subduction we need to know the divergence of the Ekman flow, the mean geostrophic flow and the eddy flow. To estimate the last term some estimate of the effective lateral diffusivity has to be made.

Surface mixing is large in the Southern Ocean and has strong diabatic and adiabatic impacts. Surface mixing plays an important role on the local formation of water surface and eddies have a large contribution to the subduction of water through the eddy-induced transport. Computations using ten years of surface drifter data show a strong regional variability of the surface mixing with peaks in the western boundary currents and where the ACC interacts with the bathymetry. This leads to a strong regional variability of the subduction process where the bathymetry is a constraint on the position of the subduction hotspots. The eddy-induced contribution is a first order term but questions remain as to the correct method to use when calculating this component especially in the near-surface layers.
Small scale eddies are neglected but the new generation of very high resolution models suggest that they could have a very large impact on mixed-layer vertical velocities and contribute to the subduction/ventilation process. Finally, the circumpolar average picture hides the occurrence of regions of strong subduction which is strongly linked to the bathymetry.

3.5 Identification of the key gaps in SO climate modeling (to be sent to CLIVAR WGOMD)

SO indices proposed by the SO Panel in Nov. 2005
(see CLIVAR/GODAE Global Synthesis Evaluation Framework, Lee and Stammer, 2006)

1. Drake Passage transport index, bottom pressure, etc.

2. Drake Passage, Hobart to Antarctica, Greenwich meridian Expendable-Bathythermograph (XBT) repeat temperature time series
3. Antarctic Dipole ocean-sea-ice index
4. Greenwich meridian current meter based transport of Weddell Gyre
5. Comparison with ARGO direct current estimates (versus assimilated dynamic height)
6. Sea-ice advection, area (and possibly thickness?) from drifters and remote sensing
7. Snow thickness (from remote sensing) on sea-ice for freshwater fluxes

At this meeting the panel produced a revised set of possible data-based metrics for model evaluation:

<u>For all models (IPCC-class through to eddy-resolving models):-</u>

- 1) Drake Passage transport index, bottom pressure, etc., both mean and variability
- 2) Drake Passage, Hobart to Antarctica, Greenwich meridian XBT repeat temperature time series
- 3) Distribution of the Mixed Layer Depth, especially in relation to deep winter mixed layers over mode water formation sites and stratified waters over Circumpolar Deep Water (CDW) upwelling sites
- 4) Weddell and Ross Gyres: e.g. Greenwich meridian current meter based estimates of transport in the Weddell gyre
- 5) Temperature-Salinity (T-S) and tracer sections, especially Chlorofluorocarbons (CFCs), along WOCE lines
- 6) Sea-ice advection, sea-ice area (and possibly thickness?) from drifters and remote sensing
- 7) Snow thickness (from remote sensing) on sea-ice for freshwater fluxes
- 8) Antarctic Dipole ocean-sea-ice index

<u>For eddy-resolving models:-</u>

- 9) Distribution of eddy kinetic energy over the ACC and adjacent oceans
- 10) Location, variability and intensity of Southern Ocean fronts
- 11) Velocity fields in comparison with ARGO direct current estimates (and/or against assimilated dynamic height for ocean reanalysis products)

We need to limit these to a few indices and provide them to our representative on the Global Synthesis and Observations Panel and the Ocean Observations Panel for Climate. In addition, we should make the metrics available on their and our websites. In prioritizing the metrics thought should be given to those which are relevant to processes that matter for IPCC models, that take into account model limitations and which will inform on model skill.

Southern Ocean Modelling issues identified by the Panel at this meeting included:

- Response of the ACC to poleward intensifying winds: how to resolve the increase in transport in the AR4 runs (IPCC OGCMs) which does not occur in the eddy saturation runs (QG models)?
- Response of the SO stratification to poleward intensifying winds: coarse models show decreasing stratification whereas eddying models show less change in stratification (this is important for changes in temperature, ocean CO_2 change etc.)
- In the SO why does the Gent-McWilliam eddy parameterization used in the IPCC class models not capture the relevant eddy effects with respect to poleward wind shift experiments? Is this still a problem if the model resolution is increased to 1^o or 0.5^o resolution?
- Response of SO water-masses to climate change e.g. changes in glacial melt water and Antarctic Bottom Water (AABW) freshening and warming
- Frontal locations in the ACC in IPCC AR4 models tend to be in the wrong places. Does this matter? What sets the front locations? Topography? Buoyancy fluxes? Wind stress curl?
- Mixing rates – diapycnal and isopycnal – how do we set these?
- Convection schemes and bottom boundary flows are absent or poor in the IPCC models
- The Gent-McWilliam eddy diffusivity must be set to physically based values
- Chronic T-S errors in water masses: What is needed is for ocean-ice only models to separate ocean GCM errors from air-sea flux errors (but problematic as the air-sea fluxes poorly constrained)
- CDW interaction with the ice-shelves is poorly constrained
- Air-sea flux climatologies for ocean-ice only models are missing

- Consistent air-sea exchange physics for intercomparisons

Issues with other model components include:
Atmosphere
- The resolution of low-level clouds at the mid-latitudes
- Accurate simulations of the Southern Hemisphere jet stream and its response to CO_2/O_3 changes (presently baseline models all have the peak of the jet stream equatorward of the observations)
- Ozone hole recovery / persistence, and mechanisms of storm track response

Sea-ice
- Resolution of Polynyas
- Interaction with ice shelves
- Iceberg calving
- Ice shelf cavities

Coupled model issues
- Wind stress dependence on Atmospheric wind speed as opposed to models that have wind stress dependent on (Atmospheric wind speed – Ocean surface velocity)

ACTION: Feedback from panel members to finalize/rationalise the SO indices. (England/Speer/All Panel)

ACTION: Nominate SO panel members to analyze the chosen indices in the various Ocean Data Analysis products (All panel)

ACTION: Summary of the key gaps identified to be compiled to send to CLIVAR WGOMD (Co-chairs/ICPO/All panel)

3.6 Atmosphere and Ocean Reanalysis and fluxes in Southern Ocean/Ice system

Sea-Ice
With new satellite sensors comes the urgent need for validation data sets including measurements of Antarctic sea-ice thickness that are reliable enough to measure change.

The panel recommends the development of a regional capability for sea ice and snow thickness mapping (airborne and Autonomous Underwater Vehicle) and the implementation of a sustained observing network, this would provide data sets suitable for the validation of satellite products. Establishing these networks will require the development of radar and laser altimetry for global ice and snow thickness products. There is also the need to improve treatment of the ice thickness distribution in climate models; in particular the movement of ice between thickness classes and response of ice thickness distribution to basal melting. ice). The Antarctic Sea Ice Thickness Workshop (2006) announced the establishment of the Antarctic sea ice data base:
(http://data.aad.gov.au/aadc/seaice).

CliC is keen to work with the SO panel on a SO freshwater balance. CliC would contribute the cryospheric elements with the aim of jointly producing an assessment document (with +/- error bars).

Fast-Ice / Ice sheets
Recent satellite derived estimates of the mass balance of both the Greenland and Antarctic ice sheets confirm the IPCC AR4 assessment that they are adding to sea level rise. For Greenland there is evidence of increased discharge from the ice streams over the last decade. Much of the increased loss from ice sheets in both hemispheres is due to accelerated discharge from outlet glaciers and ice shelves – not just enhanced surface melt. Errors in the mass budget estimates are still very large however they should improve with time if the satellite (gravity altimeter) systems are maintained.
Of concern is that from 1993 to 2006 the observed global sea level rise was already close to the upper limit of the IPCC assessment prediction. With only slight further warming, the Greenland Ice Sheet surface melt will increase more rapidly than precipitation and lead to irrevocable decay of the ice sheet over a few thousands of years. Processes of enhanced discharge are not well understood. As a result, projections of future sea level rise are very uncertain. In the IPPC AR4 report a major source of the uncertainty is the

dynamic response of the ice sheets to climate change. Major improvements to ice sheet models are therefore required (see Community Ice Sheet Model report; *Lipscomb et al.*, 2009). In addition it is vital that satellite (gravity altimeter) measurements of ice sheet mass budget are sustained.

Air-Sea fluxes

In terms of the atmospheric fluxes we know that there is a balance between the large-scale ocean heat gain (shortwave) and the wind-driven heat loss (latent) components of the heat budget. Also that there is a strong seasonal variation resulting from the changing balance between the latent / sensible / longwave heat loss and the shortwave gain. What is uncertain is the sign of annual mean heat exchange over much of the region. In addition there are few observations of air temperature and humidity fields, particularly in Pacific sector and very little is known about the freshwater budget in the SO, with consequent errors for calculating the buoyancy exchange.

Surface meteorology is critical for understanding the basic features of air-sea interaction which are currently unknown. In particular: the sign of the sea-air temperature/humidity difference, whether the ocean is gaining or losing heat and the magnitude of solar radiation input to ocean. These variables are poorly known/unknown over much of the SO with the Pacific sector being particularly bad in summer and all regions in winter.

ACTION: Co-chairs to liase with Tony Worby and CliC on producing an estimate of the SO freshwater balance.

3.7 Membership

Ian Renfrew has rotated off the panel. The panel will approach the SSG for approval of Gareth Marshall to join.

ACTION: Seek SSG approval for Dr. G. Marshall to join the panel (Speer/England/ICPO)

References

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Appendix A. Agenda

Day 1. Monday 16th   Introduction to meeting goals, state of the system; key research directions

09:00-09:30 Welcome and CLIVAR/SCAR/CliC Business (Matthew England and Kate Stansfield on behalf of CLIVAR)

09:30-10:00 Aims and purpose of meeting (Kevin Speer and Matthew England)

10:00-10:30 Status of the SOOS (Steve Rintoul)

10:30-11:00 Coffee break

11:00-11:30 GSOP report (Fukamachi)

11:30-12:00 Sea-ice and CliC update (Tony Worby)

12:00-14:00 Lunch

14:00-14:30 Agulhas and SO reanalyses (Sabrina Speich, TBC)

14:30-15:00 SOSE / IPY synthesis (Matt Mazloff and Kevin Speer)

15:00-15:30 SO air-sea flux climatologies and uncertainties (Simon Josey)

15:30-16:00 SO - Atmosphere and climate change (Dave Thompson)

16:00-16:30 Coffee break

16:30-17:00 SAM reconstructions and dynamics (Gareth Marshall)

17:00-17:30 SAO (Harry Van Loon)

17:30-18:00 Regional climate aspects of SAM variability (Harry Hendon)

Day 2. Tuesday 17th   Climate modeling, climate dynamics and gaps, process studies

09:00 -09:30 Day's aims (Matthew England and Kevin Speer)

09:30-10:00 SO in IPCC class models (Joellen Russell)

10:00-10:30 SO circulation / change in IPCC models (Alex Sen Gupta)

10:30-11:00 Coffee break

11:00-11:30 SOPHOCLES update (Siobhan O'Farrell)

11:30-12:00 Modeling: status, coarse vs. high res; summary of modeling gaps and needs (Matthew England)

12:00-14:00 Lunch

14:00-15:00 DIMES (Kevin Speer)

15:00-15:30 Lateral mixing and subduction (Jean-Baptiste Sallee)

15:30-16:00 Coffee break

16:00-16:30 Annual Cycle (Harry Van Loon)

16:30-17:00 Discussion: Key SO climate problems; a priority list for the SSG (Matthew England and Dave Thompson)

Day 3. Wednesday 18th Carbon, SOOS Evaluation, Workshop synthesis and outputs

09:00-09:15 Day's Aims (Kevin Speer)

09:15-09:30 Panel Review Article (Matthew England)

09:30-10:00 Carbon and climate system observables, physical and biological? (Richard Matear)

10:00-10:30 Direct effects of CO_2 uptake on SO ecosystems (Ben McNeil)

10:30-11:00 Coffee break

11:00-11:30 Carbon observations within SOOS? (Richard Matear and attendees)

11:30-12:00 Discussion of SOOS elements (Kevin Speer and Dave Thompson)

12:00-14:00 Lunch

14:00-14:30 Ice observations within SOOS (Tony Worby)

14:30-15:00 Ice sheet modeling/observations: status and needs (Ian Allison)

15:00-15:30 SOOS, OceanObs09 continued (Steve Rintoul and Gareth Marshall)

15:30-16:00 Review Article – writing tasks and timeframe (Kevin Speer and Matthew England)

16:00-16:30 Coffee break

16:30-17:00 Wrap up (Kevin Speer and Matthew England)

Appendix B: Pre-meeting Vision documents for the SO Panel

B.1 Summary of the meeting goals and proposed outcomes:
The goal for this meeting is a concise assessment of what has been accomplished so far and what specific tasks need to be undertaken in order achieve predictions of climate on seasonal, inter-annual and decadal timescales in the context of the Southern Ocean region. Beyond improving modeling skill, these tasks include evaluating the current status of various assimilation products and filling gaps in the Southern Ocean Observing System. ***We urge the various presentations to focus on the specific questions each program has (or will have) answered – and what questions will remain.***

We would like to see our efforts lead to some form of paper or article/review. We are considering Reviews of Geophysics. This might take the form of a report on the status and role of the Southern Ocean system in climate, with contributions from each of us. We would also like to help define the research needs for SOOS (Southern Ocean Observing System - note that ice, biology, are also part of this) and evaluating the SOOS plan for adequate sampling of the climate system. This effort will feed into the OceanObs09 effort.

We should also address SO reanalyses: to continue to lobby for and support a SO component of an "IPY data synthesis", and to provide input to GSOP, to begin to evaluate reanalysis products, etc.

<u>Outcomes:</u>
1. SOOS evaluation
2. Carbon science observing system within SOOS
3. Climate/Carbon process study development
4. Report of state of southern climate system variations and key modes
5. Identification of the key gaps in SO climate modeling – to be sent to CLIVAR WGOMD
6. Atmosphere and Ocean Reanalysis and fluxes in Southern Ocean/Ice system
7. Report and Reviews of Geophysics submission

Kevin Speer and Matthew England
December 17, 2008

B.2 Vision points for the Southern Ocean panel meeting
We seek coverage of:
1/ the most significant progress achieved over the past few yrs, and
2/ the most pressing research issues for the next 3-5 yrs.
The main outcome from the meeting will be a report/review paper.

<u>B2.1 Summary</u>
One of the main troubles when addressing the behavior of the Southern Ocean system is the absence of long time series. At the very least we absolutely need to maintain the current observations system in order to have homogenous series that permit the analysis of long-term trends: sea ice concentration, sea surface elevation, elevation of the ice sheets, etc.

We should make a synthesis of observations collected during the 20th century in the Southern Ocean. An inter-calibration is then required in order to compare those observations with the modern ones. Surface temperature (ocean and land), deep-water characteristics, carbon content, and sea ice extent are a priority. Innovative methods should be designed in order to combine observations and model results in order to estimate the magnitude of the changes over the 20th century and understand them.

Combined analysis of new and existing data as well as model simulations are required to understand the recent variability of the Southern Ocean System, in particular the dynamics of atmospheric modes and their impact on the ocean-ice system, the influence of the ocean and ice on these modes, the dynamics of the ACC, and the stability of the Southern Ocean circulation. In this framework, a better estimation of heat, moisture fluxes and wind stresses at the ocean surface is of great importance. This could be in part achieved through regional reanalysis, eventually using a coupled atmosphere-ocean-sea-ice model.
We should evaluate the quality of Earth system models in the high latitudes of the Southern Hemisphere and propose improvements in order to provide better projections of future Southern Ocean carbon uptake, water-

mass trends, changes in Antarctic sea ice, the stability of the Antarctic ice sheet, and the response of the ecosystem to acidification. The model representation of deep-water formation in the ocean, of ocean-ice shelf interactions, and of fast ice streams should be a priority.

Trends in the SAM and the SAO

Trends in SAM have been associated with ozone depletion at high latitudes and tropical ocean surface warming. In the Southeast Pacific these trends interact with ENSO and give rise to strong low frequency variability. The impact is different in summer and winter and the resulting seasonal climate signal projects onto the SAO as well. Regional processes, temperature trends, tropical SST, and ozone are all components of the change. We must try to understand why such changes happen. Empirical and model work should go hand in hand in addressing these questions.

B2.2 Imperatives

- New syntheses of data and model simulations
- Absolute need to maintain (at least) the current observations system in order to have homogenous series that allow the analysis of long term trends: sea ice concentration, water-masses, sea surface elevation, elevation of the ice sheets, etc.
- Better estimates of air-sea fluxes of heat and moisture, and wind stress
- Dynamics of atmospheric modes and their impact on the ocean-ice system.
- Dynamics of the ACC and response of the ACC system to a changing climate. The quantification of eddy impact and dynamics (meso and submesoscale).
- Evaluation and improvement of Earth system models in the high latitudes of the Southern Hemisphere
- Analysis of meridional shifts in rainfall and winds associated with modulations in the Southern Annular Mode - effects of GHG's, ozone and other large-scale trends.
- Improve the model representation of deep water formation in the ocean (especially convection, downslope flows, and eddy interactions); improve the model representation of ocean-ice shelf interactions, and of fast ice streams.
- Analysis of the stability of the Southern Ocean overturning, including stability of mode, intermediate and bottom water overturn (wind, eddy saturation; buoyancy; basic T-S feedback, carbon uptake impacts).
- Stability of the Antarctic ice sheet and future contribution to sea-level rise.
- Ecosystem response to acidification (CO_2 feedback?)
- Impact of atmospheric modes on ocean-ice system and subsequent feedback of ocean-ice onto these atmospheric modes

B2.3 Frontiers

- We should make a synthesis of observations collected during the 20th century in the Southern Ocean. An inter-calibration is then required in order to compare those observations with the modern data. Surface temperature (ocean and land), deep water characteristics and sea ice extent are a priority. Innovative methods should be designed in order to combine observations and model results in order to estimate the magnitude of the changes over the 20th century and understand them.
- Reanalysis using coupled models, including the use of such methods to provide a better estimation of heat, moisture fluxes and wind stresses at the ocean surface.
- What is the role of the Southern Ocean in the global heat and freshwater balance? (e.g. moisture feedback)
- What is the future of Southern Ocean carbon uptake (CO2 feedback), and its impact on ecosystems (e.g. acidification).
- Future of Antarctic sea ice (albedo and surface heat flux feedbacks), ice shelves, and land-ice.

1. Significant progress achieved over the past few years

- Real-time monitoring of Drake Passage transport by sea level
- Under-ice Argo measurements in the Weddell Sea
- Adelie Land Bottom Water transport estimated by a mooring experiment
- Kerguelen DWBC transport estimated by a mooring experiment
- The confirmation that the Southern Ocean is warming and that this warming is consistent with the response of the climate system to the anthropogenic forcing.
- The better description of the patterns of interannual variability of sea ice cover and the better understanding of the impact of the changes in atmospheric circulation (related to SAM and ENSO in particular) on the ice-ocean system

• The importance of the interaction of isopycnal and diapycnal mixing in the ACC and overturning
• Progress on the interaction of the oceanic mesoscale with bottom topography (and subsequent loss of geostrophic balance) and the implication for a significant physical coupling between the upper and lower cells of the Southern Ocean overturning.
• Realization that the 'eddy saturation limit' may apply
• Diagnosis of the impacts of the SAM on the coupled ocean-ice-atmosphere system, including the role of air-sea fluxes, ocean dynamics, and eddy fluxes
• Recognition of the importance of the Southern Ocean as a sink for CO2 and heat from the atmosphere and recognition that this sink may change as a result of a changing wind field and altered stratification
• Several studies have noted that the available flux products differ substantially (e.g. by 100s of W/m^2 for heat flux), and the data fields appear to show small eddy-scale variability that is not reflected in the NWP flux products
• Argo data has been used to resolve the seasonal cycle of mixed layer depth evolution and to examine heat budgets quantitatively and a larger role of eddy heat fluxes has been found.
• SOSE model output has been used to show that water mass transformation is strongly influenced by salinity, and that the major transformation occurs at different densities in each ocean basin.

B2.4. The most pressing research issues/questions for the next 3-5 yrs
• Expansion of under-ice Argo measurements
• Direct measurement of deep currents (where?).
• Direct measurements of AABW transport through the Princess Elizabeth Trough.
• Simultaneous direct measurements of AABW transport and sea-ice production.
• Model and process studies of the interaction of isopycnal and diapycnal mixing in the ACC and overturning.
• Assessment of the subtle physics shaping isopycnal and diapycnal mixing in the ACC and ultimately the Southern Ocean overturning.
• Investigating the robustness of the eddy saturation limit (is it truly intrinsic to any conceivable state of the ACC, and if not, under what forcing conditions does it kick in?) and its implications for stability of Southern Ocean overturning.
• A well-validated parameterization of melting and refreezing beneath ice shelves
• An accurate, semi-empirical law for iceberg calving, and its implementation in coupled models
• An accurate, numerically robust treatment of grounding-line migration on a fixed grid
• A challenge for the next decade remains to better understand eddies.
• Why has there been no trend in Antarctic sea-ice extent over the last 30 years? Has the sea-ice extent decreased during the last 50-100 years and will it decrease during the next few decades as projected by the present generation of global climate models?
• How have deep water formation and deep water masses properties changed over the last few decades and how will they change in the future? How will these changes affect climate in the Southern Ocean and at global scales?
• What will happen to the SAM? - i.e. fundamental discrepancy between the IPCC models and the models with more sophisticated treatment of ozone recovery.
• What is the long term response of the SO to changes in the SAM? Does the absence of explicit eddies fundamentally change this response? How do we handle this in the next round of IPCC models?

Appendix C: Attendees

Panel members	
Matthew England (co-chair)	University of New South Wales, Sydney, Australia
Kevin Speer (co-chair)	Florida State University, Talahassee, USA
Yasushi Fukumachi	Hokkaido University, Sapporo, Japan.
Steve Rintoul	Commonwealth Scientific and Industrial Research Organisation, Hobart, Australia
Dave Thompson	Colorado State University, Fort Collins, USA
Invited guests	
Ian Allison	Australian Antarctic Division, Kingston, Australia
Harry Hendon	Bureau of Meteorology, Melbourne, Australia
Andy Hogg	Australia National University, Canberra, Australia
Simon Josey	National Oceanography Centre, Southampton, UK
Ben McNeil	University of New South Wales, Sydney, Australia
Gareth Marshall	British Antarctic Survey, Cambridge, UK
Richard Matear	Commonwealth Scientific and Industrial Research Organisation, Hobart, Australia
Matt Mazloff	Scripps Institution of Oceanography, La Jolla, USA
Joellen Russell	University of Arizona, Tucson, USA
Siobhan O'Farrell	Commonwealth Scientific and Industrial Research Organisation, Aspendale, Australia
Jean-Baptiste Sallee	Commonwealth Scientific and Industrial Research Organisation, Hobart, Australia
Alex Sen Gupta	University of New South Wales, Sydney, Australia
Harry Van Loon	NorthWest Research Associates, Inc., Boulder, USA
Tony Worby	Australian Antarctic Division, Kingston, Australia
ICPO	
Kate Stansfield	National Oceanography Centre, Southampton, UK

(Note that the list of attendees in the science sessions was much higher as it included other local and visiting scientists and students)

Appendix D: Panel Members

The members of the SO panel at the time of the meeting were:

Matthew England (co-chair)	University of New South Wales, Sydney, Australia
Kevin Speer (co-chair)	Florida State University, Talahassee, USA
Yasushi Fukumachi	Hokkaido University, Sapporo, Japan
Hugues Goosse	Université Catholique de Louvain, Louvain-la-Neuve, Belgium
Gareth Marshall	British Antarctic Survey, Cambridge, UK
Doug Martinson	Lamont Doherty Earth Observatory, Palisades, USA
Alberto Naveira Garabato	National Oceanography Centre, Southampton, UK
Steve Rintoul	CSIRO, Hobart, Australia
Sabrina Speich	University of Bretagne Occidentale, Brest, France
Dave Thompson	Colorado State University, Fort Collins, USA

Ex-Officio members:
Eberhard Fahrbach Alfred-Wegener Institute, Bremerhaven, Germany
(representing the SCAR/SCOR Oceanography Expert group)
Alex Orsi (representing iAnZone) Texas A&M University, College Station, USA

Appendix E: National representatives

There are also several national representatives who keep the panel – and SO community as a whole – up to date with their country's work in the SO region and act as a contact point in their country.

Argentina - Alejandro Bianchi
Australia - Steve Rintoul
Belgium - Hugues Goosse
Brazil - Mauricio Mata
Chile - Dante Figueroa
China - Zhaoqian Dong
Finland - Aike Beckmann
France - Sabrina Speich
Germany - Eberhard Fahrbach
Italy - Enrico Zambianchi
Japan - Yasushi Fukumachi
Netherlands - Michiel van den Broeke
New Zealand - Mike Williams
Norway - Svein Osterhus
Russia - Alexander Klepikov
South Africa - Chris Reason
Spain - Damià Gomis
United Kingdom - Alberto Naveira Garabato
USA - Kevin Speer