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High Latitude Climate Variability: a Role for CLIVAR

by David M. Legler, Director

The high-latitude regions of the earth are undergoing enormous changes (see http://www.climatescience.gov/Library/sap/sap1-2/final-report/). In the Arctic, this past year marks the third lowest Arctic sea ice extent in the satellite record. The Southern Ocean is another key region where remarkable changes are being noted in (just to name a few) ocean temperature as well as ocean and atmospheric circulation patterns. At the U.S. CLIVAR Summit meeting in July we heard about the changes in the Polar regions as well as relevant climate science questions, research challenges and needs, and where new research communities were addressing some of them. More importantly, we discussed some potential research gaps and opportunities that U.S. CLIVAR could help address with its community of researchers.

In this issue we present two perspectives of the range of climate

Continued on Page Two

IN THIS ISSUE

Seasonal Predictions of Arctic Sea Ice Coverage

Ron Lindsay, University of Washington

The decline in summer sea ice in the Arctic is much in the news and has piqued the interest of many people on both sides of the increasingly vocal debate about global climate change. The dramatic minimum in the sea ice extent of 2007 and the continued very low summer sea ice extents, including the near-record low of September this year, are easily grasped and vivid indicators of rapid changes in the far North. Such drastic changes in sea ice have large influences on natural ecosystems as well as the peoples of the Arctic who face considerable changes in subsistence hunting and fishing practices, commercial fishing, shipping routes, resource extraction, tourist visits, and military presence.

As summer sea ice has declined, the year-to-year variability has increased markedly, leading to increased interest in predicting the state of the summer ice pack on seasonal and longer timescales. Anticipating the future of Arctic sea ice raises a set of interesting questions. What are the prospects for sea ice prediction on seasonal to decadal time scales? What seasons and regions show the most promise for accurate predictions? What are the most promising techniques and how can we know how accurate they are? And if skillful predictions are possible, how should they be expressed and who would find them the most useful?

Sea ice 101

Sea ice coverage changes as a result of both thermodynamic growth or melt of the ice and dynamic stresses from the air and the ocean that push and deform it. Variability in both types of forcing are important in determining the evolution of the ice pack. The thermodynamic forcing determines the surface energy balance and is dominated by the long and short wave radiative fluxes. In the winter, the net loss of heat through longwave radiation dominates, while in the summer the absorbed solar flux does. Changes in either of these large terms in the surface energy balance equation have a direct impact on the ice thickness; they are also the root causes of two important feedbacks, the positive ice-albedo feedback in the summer and the negative thin-ice-growth feedback in the winter. The turbulent heat flux is less important because the air is often in near equilibrium with the surface except over thin ice or open leads where the sensible and latent heat fluxes are substantial, often exceeding 200 W m^{-2} in the winter. Changes in the absorbed solar flux are dominated by changes in the surface albedo as ice melts or as the date of surface melt onset advances.

In addition, dynamic forces such as the winds and the currentsmust also be considered. Ocean tilt is of lesser importance. The ice moves at a mean speed of about 6 km / day, but sometimes it can travel much faster. Changes in the winds can have large impacts on the ice extent as the ice is pushed from one location to another within the Arctic Ocean or as ice export, primarily through Fram Strait, is accelerated or reduced.

Continued from Page One

research challenges tied to the Polar regions. These articles, and some follow-up planning, are helping US CLIVAR discern what it can, and should do, to stimulate and coordinate research addressing knowledge gaps on the variability (e.g. how is it changing) and predictability (e.g. important mechanisms?) of the coupled climate system, especially with regards to ties between the high- and lower-latitudes.

Since our last newsletter, there have been some key leadership changes in CLIVAR. A warm welcome to Dr Bob Molinari, new director of the International CLIVAR Project Office. Bob took over in October from Howard Cattle who ably lead CLIVAR for more than 8 years.

Closer to home, we are excited to introduce Lisa Goddard, the new chair of the US CLIVAR SSC (see related article). Lisa has published extensively on climate predictability and forecast science and has been a member of numerous national and international advisory panels/committees. She is also a member of the International CLIVAR SSG. We are very excited to have Lisa on board!

Variations

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U.S. CLIVAR Office
1717 Pennsylvania Ave., NW
Suite 250, Washington, DC 20006
usco@usclivar.org

Staff: **Dr. David M. Legler**, *Editor*
Cathy Stephens,
Assistant Editor and Staff Writer

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In addition to the thermodynamic and dynamic forcings, the initial thickness of the ice is a key factor for predicting the ice extent. The mean ice thickness at the end of winter is 2–4 m in the interior of the pack and less at the edges. Some locations have much thicker ice, particularly north of the Canadian Archipelago, where it can be 6 m thick or more. But just as important as the mean thickness, the relative amounts of thin and thick ice (the thickness distribution) is important because the thin ice is more easily removed by melt than the thick ice. In recent decades strong trends in the ice area, extent, and volume have been observed. Figure 1 shows how these quantities have changed since 1980 based on retrospective model simulations. The decline in ice volume appears to be much more consistent than for area or extent.

Prediction

Because the ice responds directly to the ocean and atmospheric forcing, accurate short-term predictions of sea ice extent depend on accurate estimates of the initial ice concentration and thickness as well as accurate weather predictions. On monthly to seasonal time scales, accurate weather predictions are challenging, and the initial ice concentration and thickness are most important.

The sea ice thickness provides a source of memory for the system. Figure 2 shows the lagged correlation of the total ice extent in the Arctic Ocean in September with the ice extent, concentration, or thickness in previous months. Much of the lagged correlation is due to the trend in the mean thickness, so for seasonal ice forecasting it is difficult to obtain a better skill score than this trend line. Significant correlations also exist for atmospheric circulation indexes such as the Arctic Oscillation (AO), the North Atlantic Oscillation (NAO), or the Pacific Decadal Oscillation (PDO), but the correlations are much smaller than those based on the ice conditions.

The inherent predictability of Arctic sea ice on seasonal time scales was investigated by Holland et al. (2010). Running a series of ensemble experiments using the Community Climate System Model (CCSM) with identical initial ice conditions they determined that sea ice area exhibits predictability from January for the first summer and for winter conditions in the next year. Comparing experiments initialized with different mean ice conditions indicates that ice area in a thicker sea ice regime

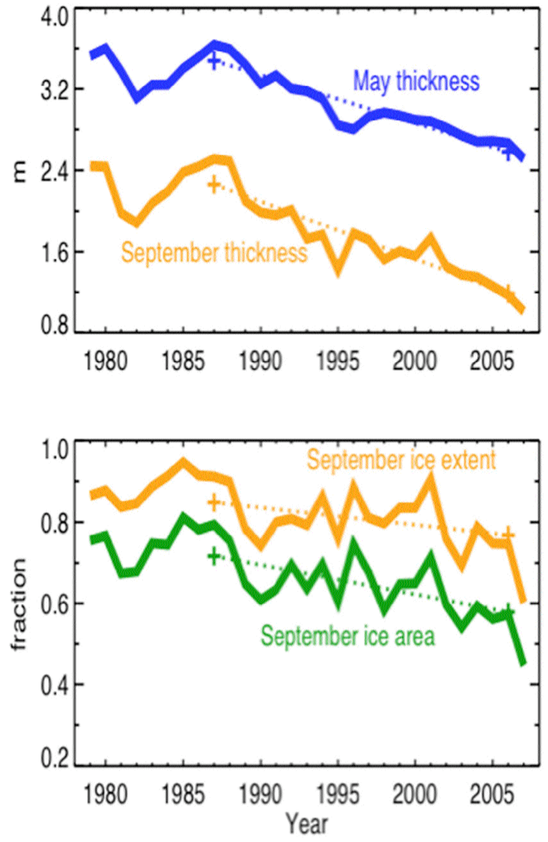

Figure 1. Annual mean ice thickness in the Arctic Ocean in May and September (top) and the September fractional coverage of the Arctic Ocean for the ice area and ice extent (bottom) from retrospective model simulations (Lindsay et al., 2009). The trend lines for the period 1987–2010 are shown as dotted lines. The trend lines account for 90% and 86% respectively of the variance for the May and September mean ice thickness and 66% and 58% respectively of the September ice area and ice extent.

generally exhibits higher predictability for a longer period of time. In a thinner sea ice regime, winter ice conditions provide little ice area predictive capability after approximately 1 year. In all regimes, ice thickness (as opposed to area) has high predictability for at least 2 years.

As in many seasonal prediction problems, there are two basic approaches, one statistical and one based on numerical models of the ice–ocean system. We do not yet know for sure which approach is the best.

Statistical models use the current state of the ice cover or the ocean and use past statistical relationships to project the future state of the ice. The current ice extent or concentration can be measured by satellites, and ice thickness estimates from a model can be used. The age of the ice and the survivability of ice of different ages as well as climate indexes such as the AO or the PDO may also be used. The strength of the statistical method is that it is readily implemented if a sufficiently long and representative sample of the past ice or ocean conditions can be obtained to train the regression model. Neural net models have also been used. These methods, however, rely on a statistically stationary system in which past correlations hold in the present. Because the ice is changing rapidly, this may not be the case and large errors in the forecasts can occur (Lindsay et al., 2008).

Seasonal predictions can also be made with numerical models of the ice–ocean system that are initialized with an accurate hindcast of the system. Because the weather cannot be predicted more than one week or two in advance, an ensemble method is required. Ideally the ensemble method gives a mean expectation and a measure of the uncertainty in the prediction. One approach for estimating future atmospheric forcing (air temperatures, clouds, and winds) is to use data from recent past years to drive the model (Zhang et al., 2008). Figure 3 shows the mean of the ice thickness in September 2010 for a seven-member ensemble using the hindcast ice conditions from the end of June 2010. The predicted ice extent is compared to the observed extent from this year. This method works well if the recent years' weather is similar to what transpires in the current year, but if there are large differences, the fact that there is no interaction between the forcing atmosphere and the ocean or ice surface precludes a large deviation in the ice conditions.

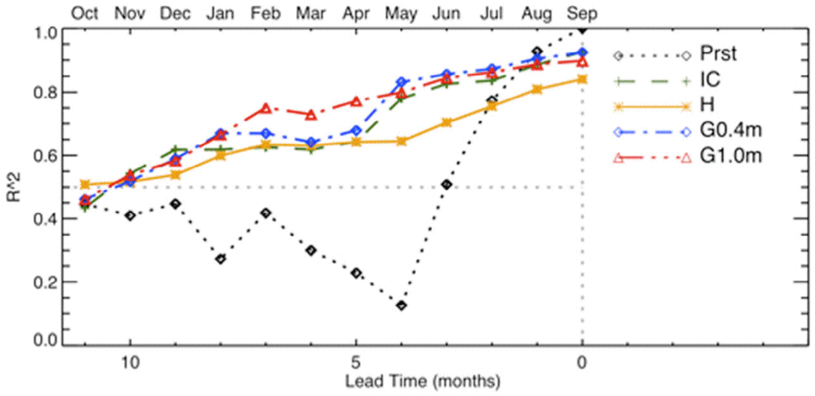

Figure 2. Lagged squared correlations of different quantities with the total September ice extent. Prst is persistence (the total ice extent from the earlier months), IC is the weighted mean of the ice concentration formed from the correlation-weighted-timeseries (CWT; Lindsay et al., 2008), which weights points in the ice concentration field by the degree to which they are correlated with the September total ice extent. H is the CWT mean ice thickness, G0.4m is the CWT area of water and ice less than 0.5 m, and G1.0m the CWT area with water or ice less than 1 m thick. Persistence drops very quickly as a useful predictor. At a lead of six months the area of water and ice less than 1 m, G1.0m, is best, but at shorter lead times the area G0.4m is a little better. At one year lead, about half of the R^2 value is due to the strong trends in all of these quantities.

The weather in the Arctic responds to global conditions, so ultimately the best approach for seasonal predictions may be to use a coupled air–ice–ocean global model that has been initialized with estimates of the current state of the ice and ocean. In this way the memory of the ice thickness can be exploited and the weakness of not including an interactive atmosphere can be avoided. But although the NCEP Climate Forecast System (CFS) is used to make ensemble forecasts of the global climate out nine months or more, it has not been tested and improved for polar conditions and the simulated sea ice is not yet a good representation of the observed ice. CFS predictive skill in the Arctic is not great. More work needs to be done to know how to best initialize a global model with observed ice thickness data or ice thickness data from a high-resolution retrospective ice–ocean model.

All of these methods have been used by different investigators participating in the SEARCH Sea Ice Outlook project in which this year 16 groups offered predictions from the end of June of the September mean total ice extent (from the Sea Ice Index). The project collects and summarizes all of the predictions. An overview of the predictions for this year is found at http://www.arcus.org/search/seaiceoutlook/2010/june. This effort has shown that a single good forecast does not prove the method, nor a single bad forecast disprove it, and that useful forecasts always include an estimate of the uncertainty.

Ice thickness observations suitable for evaluating model performance and eventually to initialize model forecasts are not yet readily available. Some past observations are available since 1975 from submarine transects of the Arctic and from moorings with upward looking sonars tethered just below the ice, for which the ice drift creates a long

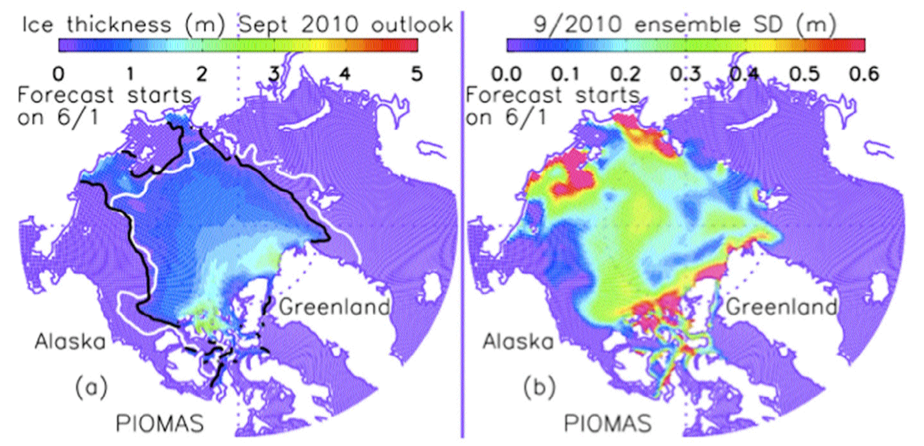

Figure 3. September 2010 sea ice thickness predicted by seven individual ensemble members beginning with the hindcast model thickness from the end of June 2010. The atmospheric forcings come from the summers of 2003–2009. Ensemble median ice thickness shown left and standard deviation (SD) of ice thickness shown right. The black line is the predicted ice extent for September (4.7 x 10^6 km^2) and the white line is the observed ice extent from 2010 (xxxx x 10^6 km^2). The standard deviation shows uncertainty in the predicted ice thickness (Zhang et al. 2008).

sample trajectory under the ice. Aircraft measurements using electromagnetic induction methods are also available. Satellite-based estimates of ice thickness derived from laser altimeter measurements of the freeboard of the ice and snow are available from ICESat from 2003 to 2009. To continue these measurements until the launch of ICESAT-2 in approximately 2015, a NASA program called Operation IceBridge will provide periodic airborne laser altimeter measurements of the ice thickness. A new climate data record of a wide variety of ice thickness estimates can be found at psc.apl.uw.edu/sea_ice_cdr

Because the ice is pushed by unpredictable winds, the prediction of regional ice area, extent, or thickness is much less skillful than for the basin-wide total extent, which is less sensitive to ice moving from one part of the basin to another. Yet for field operations a prediction for a particular place or region is much more useful than one for the entire basin. The prediction uncertainty principle applies here: the smaller the region the greater the uncertainty. It will be an additional challenge to develop skillful regional forecasts.

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Welcome Lisa Goddard, new U.S. CLIVAR Chair

U.S. CLIVAR would like to thank Dr. Martin Hoerling (left) for serving as the U.S. CLIVAR Scientific Steering Committee Chair for the past 3 years. Prior to serving as chair, Marty was a key member of the U.S. CLIVAR Predictability, Predictions, and Applications Interface Panel (PPAI). At the 2010 U.S. CLIVAR Summit, Marty handed over the reins of the U.S. CLIVAR Steering Committee to Dr. Lisa Goddard (right). Lisa is a research scientist at the International Research Institute for Climate and Society. Lisa has previously served as a member and co-chair of the PPAI panel from its inception in 2005, and has been an ardent supporter of CLIVAR for many years. She is also a member of International CLIVAR's Scientific Steering Group. While a membeer of the PPAI panel, Lisa developed and currently oversees a new national post-doctoral program, the Postdocs Applying Climate Expertise (PACE), which explicitly links recent climate PhDs with decision making institutions. Her expertise in improving the quality and content of climate predictions while enhancing society's capability to understand, anticipate and manage the impacts of climate, will be of great value as CLIVAR pursues new themes of research in these directions.

A Vision for Climate Variability Research in the Southern Ocean-Ice-Atmosphere System

Kevin Speer, Matthew England, Kate Stansfield
and the
The Southern Ocean CLIVAR/CliC/SCAR Panel

Southen Ocean Region Changes

The variability of the Southern Ocean at various time scales has been documented from observations of hydrography, sea-surface height, and direct measurements of currents. The Argo network has dramatically increased the total, and importantly, the seasonal hydrographic coverage in the upper 2000m of the water column and has helped to provide evidence for significant warming and freshening (Gille 2008; Böning et al. 2008; Helm et al. 2008). Bottom water variations have been observed as well (Aoki et al. 2005; Rintoul 2007; Jacobs 2004, Jacobs 2006; Johnson et al. 2008; Fahrbach) and point to large-scale warming.

Ocean – ice shelf interaction has been linked to ice shelf collapse and faster-than-expected dynamical response of the ice sheet, with significant implications for sea-level rise (Rignot and Jacobs 2008). Recent results suggest that ocean heat input, from upwelling warmer deep waters, will play a significant role in determining the future of the Antarctic ice sheet and therefore future sea-level rise. Ice sheet models within climate models are rudimentary at present, and as a result, projections of future sea-level rise are very uncertain. In IPCC AR4 a major source of uncertainty in sea-level rise prediction is dynamic change to ice sheets.

Sea-ice is a major factor in the Earth's albedo. While evidence suggests that the sea-ice coverage is retreating near the Antarctic Peninsula, it is marginally increasing in the Amundsen Basin. However, in order to link sea-ice with evolving freshwater fluxes under climate change, it is crucial to determine ice thickness changes. Recently, first estimates of large-scale Antarctic sea ice thickness (Worby et al. 2008) have been made. Cryospheric satellites are making measurements of circumpolar sea-ice properties for the first time, but there is a critical need for further in situ validation. First estimates of sea ice formation rates in the open pack, derived from winter salinity changes measured by elephant seals with CTD sensors (Charrassin et al. 2008) show promise for future observational needs.

New insights into the structure, dynamics and variability of the Antarctic Circumpolar Current(ACC) have been obtained showing the ACC to consist of multiple frontal jets, which can be tracked using altimetric SSH. The fact that the detailed structure of the ACC can be tracked in altimetry allows the variability of the ACC, and its relationship to SSH changes, to be determined (a; Sokolov and Rintoul 2007a; Sokolov and Rintoul 2009b; Sallee et al. 2008).

A much better understanding of the formation, subduction, circulation, and variability of Subantarctic Mode Water and Antarctic Intermediate Water has grown over recent years, and in particular the greater role that eddies play in the evolution of mode water has emerged (Talley et al.,. SAMFLOC experiment; Sallée et al. 2006, 2008, 2009; Herraiz-Borreguero et al. 2009). Analyses of IPCC AR4 models suggest that observed changes in mode and intermediate water properties are broadly consistent with the "fingerprint" of anthropogenic climate change (Meijers et al. 2007; Downes et al. 2009a). IPCC models suggest mode and intermediate water migrate to lighter densities with climate change, but the range between models is very large (Downes et al. 2009b).

Trends in the Southern Annular Mode(SAM) have been associated with ozone depletion (and eventual recovery) at high latitudes and tropical ocean surface warming. In the southeast Pacific these trends interact with ENSO and give rise to the dominant low frequency variability. The impact is different in summer and winter and the resulting seasonal climate signal is important to distinguish. Regional processes control the local impact of atmospheric forcing and determine the nature of the ocean-ice response to changes in forcing, including feedbacks. Significant differences exist in current SAM reconstructions and any conclusions on the significance, or otherwise, of recent trends set in the context of these datasets needs to be treated with caution. Empirical and model efforts should go hand in hand in addressing this question.

The Southern Ocean has been shown to contain large amounts of anthropogenic CO2 and the question of future changes of this carbon sink for the atmosphere are being debated. Air-sea CO2 fluxes may decrease in years to come if the SAM trends continue and more natural carbon upwells. This saturation of the carbon sink (Le Quere et al. 2007) is a topic of current debate (Lovenduski and Ito 2008; Law 2008; Lovenduski et al. 2008). A related matter is the rising acidity levels and the susceptibility of certain regions to species decline resulting from the dissolution of carbonate skeletal material (Orr et al. 2005; McNeil and Matear 2008). Some polar regions, e.g. the Ross Sea, may be the first to suffer from ocean acidification.

The analysis of data and model sim-

Examples of recent progress in Southern Ocean Climate Research

i) OCEANS

- Real-time monitoring of Drake Passage transport by sea level (Woodworth et al. 2006)
- Under-ice Argo measurements in the Weddell Sea (Klatt et al. 2007)
- 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 (Böning et al. 2008). Observations have resolved important new aspects of the regional circulation of the Southern Ocean. The first direct measurements of the Kerguelen deep western boundary current transport (Fukamachi et al. 2009),
- 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.
- Ocean acidification impacts will occur sooner than expected (McNeil and Matear 2008)
- Argo data has been used to resolve the seasonal cycle of mixed layer depth evolution and to examine heat budgets quantitatively (Dong et al. 2008; Sallée et al. 2008), and a larger role of eddy heat fluxes has been found.
- Development of a Southern Ocean State Estimate (SOSE) data synthesis, publicly available, for 2005-2007

ii) ATMOSPHERE

- A better description of the patterns of interannual variability of sea ice cover and a better understanding of the impact of the changes in atmospheric circulation (related to SAM and ENSO in particular) on the ice-ocean system
- SAM relationship with temperature and precipitation across southern high latitudes is not temporally stable: this may reduce the utility of many potential SAM proxies.
- Climate-chemistry models indicate that a future ozone recovery will produce a decline in the SAM (weakened circumpolar westerlies) during austral summer. This is in contradiction to the mean model response of the IPCC AR4 models, several of which do not have ozone and/or ozone recovery.
- Southern Ocean response to a positive SAM trend is complex with opposing trends; natural carbon opposes anthropogenic; heat and freshwater opposes the winds.
- 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

iii) ICE

- Recent satellite derived estimates of the mass balance of both Greenland and Antarctica confirm the IPCC AR4 assessment that they are adding to sea level
- Much of the increased loss from both the Greenland and Antarctic ice sheets is due to accelerated discharge from outlet glaciers and ice shelves – not just enhanced surface melt.
- In-situ measurements for satellite validation of some sea-ice variables – especially snow thickness, that have improved global products – but still require additional calibration, validation, and development

ulations are required to understand the variability of the Southern Ocean System, and the first high-resolution state estimates for Southern Ocean (Mazloff et al., 2009) and first multi-decadal coarse resolution ocean state estimates for global ocean (e.g. ECCO, SODA) have been achieved. 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 overturning, or upwelling circulation are key topics for Southern Ocean climate research. In this framework, a better estimation of heat, moisture fluxes and wind stresses at the ocean surface is of great importance. Model representations of deep-water formation in the ocean, of ocean-ice shelf interactions, and of fast ice streams should be priorities. These goals could in part be achieved through regional reanalyses, eventually using coupled atmosphere-ocean-sea-ice models.

Research Needs

One of the main troubles when addressing the changes in, and behaviors of the Southern Ocean system is the paucity of long time series compared to other oceans. There is an absolute need to maintain the current observations system together with some expansion into under-sampled locations in order to permit the analysis of long-term trends: water masses, sea-ice concentration, sea surface elevation, and the grounding line of ice sheets.

The community should engage a synthesis of observations collected during the 20th century in the Southern Ocean, beginning with physical and biogeochemical parameters, but extending to ecosystems. Surface temperature (ocean and land), deep-water characteristics, carbon content, and sea ice extent are a priority. Innovative methods should be designed to combine observations and model results to be able to estimate the magnitude and variability of the changes over the 20th century and understand their causes.

Ultimately, 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 quality of future SAM predictions made using current AOGCMs without a well modeled stratosphere and chemistry included (e.g. many AR4 models) is questionable, and similar criticisms can be made for the ocean and ice components of climate models. Much work needs to be done to improve the representations of key climate physics, biology, and chemistry, and to link these together into Earth systems models.

The Southern Ocean Panel has defined certain needs or "imperatives" to emphasize the important contribution they make, or would make to progress by the whole community of scientists as opposed to individual researchers. These imperatives include:

- Absolute need to maintain Argo, hydrographic (water sampling), and extend sampling or observational techniques to the under-ice-covered ocean, up to the grounding line
- Better assessment of the role of eddies on transport and mixing
- Better estimates of air-sea fluxes of heat and moisture, CO2, wind stress, and boundary layer parameterizations, especially near the continent
- Broader evaluation of the impact of acidification and the ecosystem response
- More accurate diagnoses of the freshwater and moisture transfers among the coupled ocean-ice-atmosphere system, and associated feedbacks

In addition, as part of our response to CLIVAR, the Panel has identified a few directions for future research that we think would increase our understanding of climate in a fundamental way, and provide a basis for a larger program including:

- What is the future of Antarctic ice?
- Improve model representation for key Southern Ocean processes: upwelling, eddy processes, overturning, convective mixed layers, and interactions with the shelf.
- What is the impact of acidification? How will the Southern Ocean store of CO2 change in the future?
- Carry out reanalyses using coupled models with biochemical representations of the carbon cycle: syntheses of ocean/ice/atmosphere data and models.
- How will the projected trends in greenhouse gases and the SAM impact air-sea heat, moisture, and carbon fluxes
- What is the future of the Antarctic continental margin? Evaluation and improvement of Earth system models in the high latitudes of the Southern Hemisphere, linking the cryosphere to land (e.g. basil melt), the ocean and atmosphere

In conclusion, the Panel supports the establishment of a Southern Ocean Observing System (SOOS) that encompasses not only physical measurements of the climate system components, but also the chemical and biological components amenable to sustained observation. In this way, the progress that has been achieved will translate into an ongoing set of observations, providing benchmarks for evaluating climate variability, assessing key processes, and delivering the best information to policy makers and citizens.

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U.S. CLIVAR

Calendar of CLIVAR and CLIVAR-related meetings

Further details are available on the U.S. CLIVAR and International CLIVAR web sites: www.usclivar.org and www.clivar.org

Evaluation of Reanalyses – Developing an Integrated Earth System Analysis (IESA) Capability

1-3 November 2010
Baltimore, MD
Attendance: Open
http://www.usclivar.org/Reanalysis2010.php

3rd Atmospheric Circulation Reconstructions over the Earth

3-5 November 2010
Baltimore, MD
Attendance: Open
http://www.usclivar.org/Acre2010.php

2010 AGU Fall Meeting

13-17 December 2010
San Francisco, CA
Attendance: Open
http://www.agu.org

AMS Annual Meeting

23-27 January 2011
Seattle, WA
Attendance: Open
http://www.ametsoc.org/MEET/annual/index.html

ASLO 2011 Aquatic Sciences Meeting

13-18 February
San Juan, Puerto Rico
Attendance: Open
http://www.aslo.org/meetings/sanjuan2011/

WCRP Workshop on Drought Predictability and Prediction in a Changing Climate: Assessing Current Knowledge and Capabilities, User Requirements and Research Priorities

2-4 March 2011
Barcelona, Spain
Attendance: Open
http://drought.wcrp-climate.org/workshop/index.html

WCRP Joint Scientific Committee

4-8 April 2011
Paris, France
Attendance: Invited
http://www.clivar.org/calendar/calendar_all.php

34th International Symposium on Remote Sensing of the Environmnet

10-15 April 2011
Sydney, Australia
Attendance: Open
http://isrse34.org/

CLIVAR SSG Meeting

2-6 May 2011
Paris, France
Attendance: Invited
http://www.clivar.org/calendar/calendar_all.php

Past Present and Future Change in the Atlantic Meridional Overturning Circulation

12-15 July 2011
Bristol, UK
Attendance: Open
http://www.noc.soton.ac.uk/rapid/ic2011/

WCRP Open Science Conference

24-28 October 2011
Denver, CO
Attendance: Open
http://www.wcrp-climate.org/conference2011/

U.S. CLIVAR
Climate Variability & Predictability

U.S. CLIVAR OFFICE
1717 Pennsylvania Avenue, NW
Suite 250
Washington, DC 20006

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