CCSM Polar Climate Working Group Meeting
REPORT
16–17 January 2008
NCAR Mesa Lab
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The Polar Climate Working Group met in Boulder, Colorado, to hear about and discuss new climate modeling studies and progress in model development. Participants the first day presented an interesting array of topics, including seasonal forecasting, uncertainties in sea ice/climate modeling, atmospheric and ocean circulations, permafrost, atmospheric chemistry, biology in ocean and sea ice, and snowfall modeling and observations. The second day was spent discussing modeling issues, including CCSM plans, ice sheets, and sea ice model physics. A final discussion focussed on Earth System Modeling.

Wednesday, 16 January:

Todd Arbetter *Seasonal Arctic ice forecasting: Can we still use the past to predict the future?*

The National/Naval Ice Center, part of the North American Ice Service, produces weekly operational sea ice charts based on combinations of a variety of satellite imagery (SSM/I, AMSR, MODIS, RadarSAT, etc). Each year, it produces a Seasonal Outlook, an early prediction of that summer's Arctic sea ice conditions. The NIC and its predecessors have monitored the opening and closing dates for the shipping route between Point Barrow and Prudhoe Bay, Alaska, and produced a seasonal summer outlook each spring since 1977. These forecasts are determined using statistical relationships of an array of monthly mean geopotential heights, sea level pressures, and surface temperatures calculated during the previous winter. These values are then compared with records of previous summers to determine an empirical forecast for the oncoming summer, using the opening and closing of the coastal shipping route between Barrow and Prudhoe Bay as the metric. Over the course of the summer, ice analysts determine the actual opening and closing dates. These records indicate a trend towards longer shipping seasons, although much variability is seen from year to year. Since 1953, there has been an increase of 24 days of navigable conditions along the route, with 20 more of those days being ice free. Since 1977, the coastal shipping route opens 12 days earlier and stays open 12 days later. This work is in collaboration with Sheldon Drobot, Ignatius Rigor, LT John Woods, and Pablo Clemente-Colon.

Cecilia Bitz *Sea ice retreat: Sensitivity to the mean state*

Arctic sea ice extent in summer has declined at an alarming pace over the past few decades. The September retreat has been about 8% per decade. September 2007 set a new

record low for the satellites era—an additional 20% below the level expected from extrapolating the linear trend. Cecilia applies systems analysis along with simple and complex models to construct a framework for discussing important feedbacks that affect sea ice within the climate system. Not only are substantial positive feedbacks involved, but at least two of the major feedbacks are strongly nonlinear. The implications of these unique properties were discussed within the context of sea changes in the past and those expected in the future.

Alexandra Jahn *Effect of the large-scale atmospheric circulation on the Arctic Ocean freshwater and heat exchange*

Fresh water (FW) is leaving the Arctic Ocean through sea-ice export and the outflow of low-salinity upper ocean water. Whereas the variability of the sea-ice export is mainly driven by local winds, the mechanisms which regulate the variability of the liquid FW export are still unclear. Alex presented an analysis of the variability of the liquid FW export from the Arctic Ocean, using simulations from a coupled global ocean-atmosphere model forced with specified daily winds, focussing in particular on a large positive signal in the Fram Strait liquid FW export during the 1990s. Her results show that the simulated variability of the Fram Strait liquid FW export lags changes in the low-frequency variability of the large-scale atmospheric circulation over the Arctic by about five years. Changes in the cyclonicity of the atmospheric forcing are found to cause a FW redistribution in the Arctic through changes in Ekman pumping in the Beaufort Gyre. This in turn causes changes in the sea surface height and salinity upstream of Fram Strait, which affect the velocity and salinity of the outflow and explain a large part (70%) of the variance of the liquid FW export. The local wind forcing explains a much smaller fraction (21%) of the variance. Finally, we find that the variability of the liquid FW export is strongly coupled with the ocean heat transport into the Arctic Ocean. This coupling is important because it potentially provides a strong positive feedback for the Arctic sea-ice decline associated with global warming. Bruno Tremblay, Lawrence A. Mysak, and Robert Newton collaborated in this study.

Wieslaw Maslowski *On modeling the oceanic heat fluxes from the North Pacific / Atlantic into the Arctic Ocean*

Wieslaw and his colleagues J.L. Clement Kinney and J. Jakacki use output from the Naval Postgraduate School (NPS) coupled ice-ocean model of the pan-Arctic region and validate it against several data sets. While many previous studies have analyzed changes in ice extent and concentration, this research focuses on ice thickness and volume as it gives a better indication of the total sea ice cover variability and rates of change. Analyses of combined sea ice and ocean model results suggests that the oceanic heat, in addition to atmospheric radiative and sensible heat input, contributes to sea ice melt, especially in re-

gions directly downstream of oceanic heat advection from the Pacific and Atlantic oceans. Recent reduction of the Arctic ice pack has been primarily associated with anomalies of surface air temperature and circulation over the Arctic and those in turn have been linked to the Arctic Oscillation (AO). Such studies typically assume the dominant role of external atmospheric forcing and neglect effects of processes internal to the Arctic Ocean, especially the oceanic thermodynamic control of sea ice through under-ice ablation and lateral melt along marginal ice zones. However, those ice-ocean interactions may act to de-correlate AO forcing, which could help explain some of the recent timing issues between AO/atmospheric forcing and sea ice variability. The NPS model indicates an accelerated thinning trend in Arctic ice during the last decade. This trend is robust and independent of timescales for surface temperature and salinity relaxation in the ocean model. Validation of model output with submarine and satellite data supports this result, lending credence to the postulation that the Arctic not only might, but is likely to be ice-free during the summer in the near future. In addition, the analysis shows that oceanic heat fluxes into the western Arctic Ocean and the west Greenland Sea correlate well with regional sea ice melt and can regionally explain over 60% of the sea ice variance. Oceanic advection of summer Pacific Water is an important and overlooked source of heat to the upper western Arctic Ocean. These ocean-ice interactions help explain the lack of correlation between Arctic warming / melting sea ice cover and the AO/NAO index. The beginning of the decline of ice cover in the late 1990s coincides with the preceding anomalous export of sea ice through Fram Strait in the mid-1990s. Model results correlate well with observations of sea ice export. Comparison of selected ensemble runs from the NCAR CCSM3 model (b30.030b and b30.040f) with NPS model output and available data suggests that CCSM3 under-estimates northward oceanic heat fluxes through Bering Strait and Fram Strait and over-estimates fluxes through the Barents Sea into the eastern Arctic Ocean. Such limitations help explain the CCSM3 discrepancies in the sea ice distribution and time rate of melt in comparison with observations.

David Lawrence *Accelerated warming during abrupt sea ice loss events and implications for permafrost degradation*

Coupled climate models and recent observational evidence suggest that Arctic sea ice may undergo abrupt periods of loss within fifty years. For the western Arctic, the Community Climate System Model exhibits land warming trends during rapid sea ice loss that are 3.5 times greater than secular climate-change trends outside these periods. The accelerated warming signal extends up to 1500km inland and is apparent throughout most of the year, peaking in autumn. Idealized experiments using the Community Land Model, with improved permafrost dynamics, indicate that an accelerated warming period substantially increases ground heat accumulation—the earlier the event, the greater the long-term impact. For warm permafrost, enhanced heat accumulation can lead to rapid degradation. For colder ground, heat accumulation preconditions permafrost for earlier and/or more rapid degradation under continued warming.

Jean-Francois Lamarque *Arctic tropospheric chemistry and sea ice changes: Possible links and feedbacks*

Little is known about interactions and feedbacks between tropospheric chemistry and ice and snow. Jean-Francois highlighted a few examples. Regional abrupt depletions of ozone in the Arctic surface atmospheric boundary layer have been observed in spring that are correlated with increases in BrO. Reactions to provide the necessary bloom of BrO are thought to occur on the snow surface or aerosols, although the mechanism is not clear. In the Antarctic, iodine also is a catalyst for ozone depletion and could be a source of aerosols. A possible mechanism for the origin of high iodine levels is through algae located directly under sea ice which concentrate iodine; it then percolates upward to the atmosphere. Finally, black carbon can be transported from Asia and other polluting sources into the Arctic, where its depostion will strongly affect the ice and snow albedo.

Scott Elliott *High latitude biogeochemistry in Los Alamos COSIM*

Since it serves as a central component of marine systems models, the biogeochemical Parallel Ocean Program (POP) has recently been augmented with dynamic global geocycling for several climate-active trace gases. Emphasis during this effort has been placed on volatile reduced sulfur compounds and aqueous photochemistry. Although most results are encouraging, high latitude processes remain deficient in key areas. Polar improvements thus constitute a new set of code development challenges. Based on a blend of available regional models, major element processing by the epontic algae has been implemented within the Los Alamos sea ice model (CICE), which runs interactively with POP. Pan-Arctic results are in rough agreement with sparse data for peripheral, land-fast ecosystems. Simultaneously, more direct representation of pelagic biota within POP is being prepared by segregating specialized high latitude phytoplankton classes including Phaeocystis. The new organisms are treated as explicit variables competing with diatoms and microbes. Progress is reported for Arctic simulations conducted in a decoupled cryobiological CICE, the northern polar domain of the POP ocean model, and basin scale, interactive ice-ocean biogeochemical computations. Near-term plans include sensitivity testing on the incorporation of biotic absorption of radiation within the skeletal layer using multiple scattering radiative transfer. In the medium term the new polar biogeochemical systems will be extended to Antarctica and the Southern Ocean.

David H. Bromwich *20th century Antarctic air temperature and snowfall simulations by IPCC climate models*

David and his colleagues employ new observationally-based datasets of Antarctic near-surface air temperature and snowfall accumulation to evaluate 20th century simulations

from five representative global climate models (GCMs, including the NCAR CCSM) that support the Intergovernmental Panel on Climate Change Fourth Assessment Report. Annual Antarctic snowfall accumulation trends in the GCMs agree with observations during 1960-1999, and the sensitivity of snowfall accumulation to near-surface air temperature fluctuations is approximately the same as observed, about 5% K^{-1}, suggesting that if Antarctic temperatures rise as projected, snowfall increases may partially offset ice sheet mass loss by mitigating an additional 1 mm y^{-1} of global sea level rise by 2100. However, 20th century annual Antarctic near-surface air temperature trends in the GCMs are about 2.5-to-5 times larger than observed, raising questions about the robustness of the 21st century projections. Resolving the relative contributions of dynamic and radiative forcing on Antarctic temperature variability will be an important step toward improving GCM projections. Andrew Monaghan and David Schneider contributed to this study.

Thursday, 17 January:

Marika Holland *Update on progress towards CCSM4*

Marika gave an update on the progress being made in the development of the CCSM4. A number of improvements are present in the CCSM3.5 sea ice and polar climate simulations as compared to CCSM3, including an improved Arctic ice distribution, better ice concentration in both hemispheres, and improved Arctic clouds and radiative fluxes. Test simulations are ongoing to diagnose the influence of a multiple-level snow model over sea ice, the sea ice Delta-Eddington radiative transfer scheme, and melt pond parameterizations on climate simulations.

Bill Lipscomb *Ice sheets in CCSM*

As the Greenland and Antarctic ice sheets lose mass at an increasing rate, there is more urgency than ever to develop realistic ice sheet models and couple them to global climate models. Bill has been working to add the GLIMMER ice sheet model to the Community Climate System Model (CCSM). The GLIMMER model, with wrapping routines denoted as GLC, now runs as a fifth physical component of CCSM, along with the atmosphere, ocean, sea ice, and land components. The ice sheet model exchanges fields with the land model via the coupler. The ice surface mass balance will be computed on the coarse (100 km) land grid in 10 elevation classes and downscaled to the finer (10 km) ice sheet grid. This innovative approach improves energy consistency, avoids code duplication, and reduces computational cost. In response to theory and observations suggesting that the West Antarctic ice sheet could retreat abruptly, a proposal to model ice shelf-ocean interactions has been submitted. Much more work is needed to make credible predictions of ice sheet and sea level changes. Fortunately, the resources devoted to ice sheet modeling are increasing at LANL and elsewhere.

Masami Nakagawa *Polar sea ice ridging modeling*

Masami presented basin-scale simulations from Mark Hopkins' granular material model for sea ice dynamics, along with his thoughts about social modeling of communities like Reykjavik, where a broad approach to addressing their energy issues could aid efforts to slow anthropogenic climate change. He writes, "It was a great meeting for me to learn what this group does... I will keep searching the ways that our detailed modeling will be helpful to you. At the same time, I would be interested in putting a group of people who might be interested in planning how to address social and other political issues... These issues will be more and more important as your hard core science part makes more progress so it is important to start thinking about them now."

Bruno Tremblay *Convergence of sea ice models*

Bruno and his colleagues have developed a high resolution (10 km) sea ice model of the Arctic to study energy dissipation associated with sea-ice deformations. This new platform can be used with various yield curves and flow rules defining many viscous-plastic formulations. To solve the non-linear momentum equation, the equation is first linearized and solved using the preconditioned Generalized Minimum RESidual method (GMRES). These two steps are repeated multiple times (outer loop) until a convergence criterion is met. The GMRES method has low storage requirements, is computationally efficient and parallelizable. Convergence properties of the GMRES method are investigated using point and line Successive Over-Relaxation (SOR) preconditioners, and computational efficiency of the preconditioned GMRES is compared with that of a stand-alone point SOR. It is observed that GMRES preconditioned by line SOR is about five times faster than the stand-alone point SOR. GMRES allows for the solution of a non-symmetric system. The Coriolis term and off-diagonal part of the water drag term can then be treated implicitly. It was observed that the implicit treatment eliminates a residual oscillation in the total kinetic energy of the ice pack that is present when these terms are handled explicitly. Finally, Bruno discussed the convergence criteria employed for sea-ice dynamic models. In ongoing work, they are currently implementing Newton's method to replace the outer loop and plan to parallelize the model.

Elizabeth Hunke *CICE update and future plans*

A poster highlighting CICE development over the past decade and several recent studies using CICE was available for browsing at the breaks. Plans for the model include further implementation of biogeochemical cycling, improving the snow physics, adding or improving processes that weaken or contribute to accelerated melting of the ice, adding alternative dynamics schemes, fully implementing the geodesic model infrastructure, and

implementing ice hydrology (prognostic salinity, percolation, flushing, flooding, and so on). CICE users request, and sometimes supply, further developments that currently include fast ice, alternative rheologies, air and ocean drag modified by ice ridges, new parameterizations for frazil, pancake and other new ice formation, and a regional configuration for the model. Already available from users are space-filling curves (from NCAR) and EVP on the C-grid (from MIT).

Discussion

Marika led a final discussion about Earth System Modeling. Workshop participants highlighted two physical parameterizations that would be desirable in an Earth System Model, tides and blowing snow. Tides are currently included in the CCSM ocean model via a mixing coefficient, but their effects are not included in the ice model. Tides could be important in the Barents Sea, where they may affect Atlantic Water flowing into the Arctic. Surges of warm water are also important under ice shelves. Land modelers are considering adding blowing snow to CCSM, but a difficulty is lack of data, especially for snowfall density.

Biogeochemistry will also be an important component of an Earth System Model. Currently, dust bypasses sea ice in CCSM, but there are computing resources available to incorporate dust deposition in the ice model. Plans at Los Alamos included coupling the BGC parameterizations in CICE and POP, adding new high-latitude, open-ocean organisms in POP, and utilizing the multiple scattering radiative transfer apparatus in CICE. DMS is also being pursued in POP for coupling with the CCSM ecosystem component. Methane clathrates could be a huge problem in the Arctic, although that is still under debate. In the land model component, dynamic vegetation needs improvement, specifically competition and transitions in forests. For instance, pine beetles are not included in the model, nor are fire and forestry policies.

Initially, societal and human impacts studies would likely take output from climate models and feed it into economic models. The two types of models could be coupled, but they are not ready yet. Such models will eventually need to include interactive changes in agriculture and land use, fisheries, pollution, etc.

John Walsh announced the IARC Arctic Regional Model Workshop planned for the end of May at Center Green in Boulder. Wieslaw Maslowski and colleagues have secured DOE funding to develop a regional Arctic climate model, which may be considered by IARC, using off-the-shelf components: POP, CICE, WRF, and the CCSM coupler. A land hydrological model will also be included. Other researchers are working on 2-way nesting of WRF in CAM and ROM in POP, for up- and down-scaling studies with CCSM.