

**CCSM Polar Climate Working Group Meeting
REPORT**

17 June 2008

Breckenridge, Colorado

Marika Holland (NCAR) and Elizabeth Hunke (LANL), Co-chairs

The Polar Climate Working Group met in Breckenridge, Colorado, to hear about new climate modeling studies and progress in model development.

Cecilia Bitz, University of Washington

A series of stabilization runs in the 21st Century: What tipping point?

Many scientists and new articles have argued that Arctic sea ice is likely to exhibit threshold-like behavior as it melts back in a greenhouse warming world. Such a tipping point would be an irreversible bifurcation to a new state. 21st century projections with the CCSM3 and many other climate models exhibit very rapid sea ice decline in the end-of-summer ice cover, especially in pessimistic scenarios of future anthropogenic greenhouse gas emissions. The rapid decline is best characterized as a dramatic response to a fairly modest change in climate forcing. Sea ice meltbacks at the end of summer as large as observed in 2007 occur about 1% of the time in the early 21st century of simulations with CCSM3. But meltback events of that magnitude never occur in pre-industrial simulations, which suggests that thinner sea ice in a greenhouse warming world will experience larger meltbacks with increasing frequency. Curiously, the variability about the ensemble average exhibits large positive ice anomalies with about the same frequency as large negative ones. The near symmetry in variations about the long-term trend (or lack of significant negative skew) is evidence that the model does not experience threshold-like behavior when it thins. A series of future stabilization runs where greenhouse gas and aerosol levels are held fixed at 2020 and 2030 levels in an A1B scenarios were run. With fixed level of radiative forcing, the sea ice extent declines very slowly for the remainder of the 21st century, with coverage far greater than ensemble members of the standard A1B scenario. Thus it is clear that without a constant increase in radiative forcing, the sea ice in CCSM3 does not continue to rapidly retreat.

Ed Andreas, NorthWest Research Associates

New algorithms to predict the turbulent coupling between the atmosphere and winter sea ice, summer sea ice, and the marginal ice zone

Ed has been developing a bulk turbulent flux algorithm from data collected during the Surface Heat Budget of the Arctic Ocean experiment, dividing this year-long data set into just two aerodynamic seasons: winter and summer. In winter, the sea ice is compact and snow covered, and the snow is dry enough to drift and blow under wind forcing. In

summer, the snow is wet and eventually disappears entirely, leads open, and the ice surface is pocked with melt ponds.

In winter the roughness length for wind speed is parameterized in a manner that circumvents a fictitious correlation that occurs when measured roughness length is parameterized with measured friction velocity. A blowing snow effect on momentum transfer, usually invoked to explain this spurious relationship, is no longer required.

In summer, form drag associated with the vertical ice edges created by melt ponds and leads enhances momentum transfer. The same effect occurs in marginal ice zones, which are also a mix of water and ice. Ed and his colleagues developed a relationship between the neutral-stability drag coefficient and the ice concentration that unifies drag predictions in marginal ice zones and over summer sea ice.

For both winter and summer, the roughness lengths for temperature and humidity both follow Andreas's (1987, *Bound.-Layer Meteor.*, 38, 159–184) theoretical model, in which the ratio of roughness length for temperature or humidity to the roughness length for wind speed is a function of the roughness Reynolds number. Neither roughness length (temperature or humidity) depends on the atmospheric stratification in either winter or summer.

Marika Holland, National Center for Atmospheric Research
Arctic sea ice mass budgets: We report, you decide

Marika reported on the Arctic sea ice mass budgets for the 20th century and projected changes through the 21st century from 14 coupled global climate models. The inter-model scatter in the climatological budgets and their changes over the 21st century were in turn related to sea ice conditions and the changing surface heat exchange. Results show that the large inter-model scatter in contemporary mass budgets is strongly related to variations in absorbed solar radiation, due in large part to differences in the surface albedo simulation. Over the 21st century, all models simulate a decrease in ice volume resulting from increased net melt (melt minus growth), partially compensated by reduced transport to lower latitudes. Despite this general agreement, the models vary considerably regarding the magnitude of ice volume loss and the relative roles of changing melt and growth in driving it. Changes in sea ice mass budgets depend in part on the initial (mid 20th century) ice conditions; models with thicker initial ice generally exhibit larger volume losses. Pointing to the importance of evolving surface albedo and cloud properties, inter-model scatter in changing net ice melt is significantly related to changes in downwelling longwave and absorbed shortwave radiation. These factors, along with the simulated mean and spatial distribution of ice thickness, contribute to a large inter-model scatter in the timeframe for reaching seasonally ice-free conditions in these model simulations.

Eric DeWeaver, University of Wisconsin - Madison
The threat to polar bears from global warming

After much delay, the Department of the Interior accepted the U.S. Fish and Wildlife Service (USFWS) proposal to list the polar bear as a threatened species under the Endangered Species Act on May 14, 2008. The decision was based in part on research conducted by the U.S. Geological Survey and collaborators including several PCWG members. The overall conclusion of the USGS research is that projected changes in sea ice conditions, if realized, will result in loss of about two thirds of the world's polar bear population by the mid-21st century. Because the observed rate of summer sea ice decline is underestimated by climate models, this assessment is, if anything, conservative. Eric gave an overview of the USGS reports and showed how data from climate models, satellites, radio telemetry, and field studies was combined to assess the future status of the bears.

Richard Grotjahn, University of California - Davis
Sources of CAM Arctic surface climate bias deduced from the vorticity and temperature equations

Richard Grotjahn described a 3-part diagnostic study of the CAM3.0 Arctic bias and its causes. He discussed equations for temperature bias, vorticity bias, and 3 contributors to vertically-integrated diabatic heating bias. Nonlinear (bias-bias) terms were smallest, supporting use of a linear model to understand what forcing causes what bias response. The Atlantic storm track (and across Europe) dominates the forcing where diabatic heating bias and transient heat flux bias are positive. Top-of-atmosphere (TOA) net radiation is also positive, consistent with CAM having deeper clouds that precipitate too much and emit at colder cloud tops. Over the Arctic Ocean, the TOA radiation bias is negative, where diabatic cooling is present (but only at low elevation) consistent with excessive low cloud in CAM. The work suggests that to improve the Arctic bias one should focus on improving 1) the Atlantic storm track properties (and related quantities like precipitation) and 2) lower atmospheric energy balance over the Arctic.

Dave Bailey, National Center for Atmospheric Research
Drowning by numbers: Progress towards CCSM4

David presented his work on incorporating a new, explicit melt pond parameterization and the Delta-Eddington (DE) shortwave radiation scheme into the Community Ice Code version 4.0 (CICE). These are the main two parameterizations to be added to CICE 4.0 for the upcoming September deadline for freezing the science in the next version of the Community Climate System Model, CCSM4. He found that the new parameterization and physics in atmosphere-ice-slab ocean model experiments (present day and doubled CO2) produced results that were relatively similar to results from experiments using the CCSM3

shortwave with implicit melt ponds. In a 2 x CO₂ world, the shift to more rain and less snow along with enhanced surface ice melt appears to mostly compensate the pond accumulation. He also found that there were generally fewer ponds in the future, likely due to ice-fraction dependent runoff. It was found that these parameterizations do not change the climate sensitivity of the model, but provide more generality for adding radiatively active tracers.

Elizabeth Hunke, Los Alamos National Laboratory
CICE and its global community

The Los Alamos sea ice model, CICE, enjoys a large and vibrant user/development community, both in the US and abroad. Elizabeth gave an overview of efforts being made to improve or extend CICE by members of the sea ice modeling community, projects including data assimilation for operational forecasting, multiple scattering radiative transfer, melt ponds, biogeochemistry, snow physics, frazil and grease ice, constitutive behavior, parameter sensitivities, and numerical improvements for flexibility and speed. She also presented Los Alamos's future plans for the model, emphasizing the current undertaking: development of an ice ecosystem model.

Scott Elliott, Los Alamos National Laboratory
Biogeochemistry in the coupled ice-ocean system

A modeling framework for the study of high latitude marine biogeochemistry is being developed at Los Alamos, including the addition of ice algal ecosystems to CICE and the neighboring pelagic biota in Parallel Ocean Program (POP). During the past year, ecodynamic and elemental cycling models for the skeletal layer under landfast sea ice have been adapted for the pack ice and tested over the entire Arctic. The mechanism is nitrogen-based but extends to carbon, silicon, pigments and also organic sulfur. Standard POP ecodynamics for open water have been augmented with the colonial polar specialist *Phaeocystis*. Coupling of the biogeochemistry models in CICE and POP has begun and will be critical since pelagic organisms filter and process the nutrients supplied to ice algae. Upper ice habitats and improved open water geocycling will be the focus of near term modeling efforts, particularly to simulate ice algal roles in the production of dimethyl sulfide. There will also be opportunities to study the effects of algae on internal ice energy distributions and the Arctic food web structure.

Bill Lipscomb, Los Alamos National Laboratory
An ice sheet model for CCSM, Part I: Coupling and surface mass balance

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. We need models with improved dynamics for modeling fast flow, and we also need to model the surface mass balance more accurately. Bill has coupled the GLIMMER ice sheet model to CCSM and developed a new surface mass balance scheme in the land component, CLM. The ice sheet model exchanges fields with the land model via the coupler. The ice surface mass balance is 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, reduces computational cost, and allows albedo feedbacks on the atmosphere to be simulated during runtime. During the next several months these changes will be merged into CCSM4 and the mass balance scheme tested in fully coupled simulations.

Steve Price, Los Alamos National Laboratory

An ice sheet model for CCSM, part II: First-order flow model

Steve discussed the rationale for developing and incorporating a new, dynamic ice sheet model within CCSM. The model, based on a first-order approximation to the shallow ice equations, is sufficiently complex to include both vertical and horizontal stress transfer at relevant length scales. He reviewed the governing equations for the model, presented results from model benchmarking experiments, and discussed preliminary results demonstrating the model's ability to predict the velocity structure of the Greenland Ice Sheet, relative to previous models. He concluded by reviewing plans for future work.

Steve Vavrus, University of Wisconsin - Madison

Arctic clouds and climate change

Under greenhouse forcing the Arctic is expected to become cloudier, especially during autumn and over sea ice, in tandem with cloud decreases in middle latitudes. Projected future cloud changes depend strongly on the simulated modern annual cycle of Arctic cloud amount: GCMs that correctly simulate more clouds during summer than winter at present also tend to simulate more clouds in the future. The simulated Arctic cloud changes display a tripole structure aloft, with largest increases concentrated at low levels (below 700 hPa) and high levels (above 400 hPa) but slight decreases in the middle troposphere. The changes in cloud radiative forcing suggest that the cloud changes are a positive feedback annually but negative during summer. Local evaporation correlates highly with the cloud changes and is likely responsible for the simulated Arctic cloud response. Clouds also appear to shape rapid ice loss events in the Arctic. Consistent with enhancing surface heating under greenhouse warming, clouds during at least one episode of abrupt ice decrease provide a prolonged period of positive radiative forcing before, during, and after the time of maximum ice loss. The long duration of enhanced warming by the cloud variations is due to a combination of cloud decreases (increases) during summer (autumn), allowing extra solar (longwave) radiation to reach the surface.