

**CCSM Polar Climate Working Group Meeting Report**  
**The Village at Breckenridge, Breckenridge, Colorado**  
**Wednesday, 21 June 2006**

The Polar Climate Working Group (PCWG) met jointly with the Paleoclimate Working Group (PaleoWG) for two talks that focussed on Abrupt Climate Change, first a modeling study followed by results from observations. Later the PCWG heard results from model intercomparison studies. Abstracts from the presentations follow. At the end of the PCWG meeting, poster presenters gave short overviews of their results.

Joint meeting of the Polar Climate and Paleoclimate Working Groups: Focus: Abrupt Climate Change

Cecilia Bitz, University of Washington

"Freshwater Perturbation of the Thermohaline Circulation: Regional and Teleconnected Climate Impacts and Mechanisms of Recovery in Ensemble Simulations"

Shutdown of the thermohaline circulation (THC) by fresh water hosing is usually only temporary in sophisticated climate models. Once hosing ends, the circulation recovers in a few decades. Hosing in these experiments begins under roughly modern climate conditions. However, when hosing is initiated from a Last Glacial Maximum (LGM) climate with the CCSM, the THC is nearly shutdown and stays drastically reduced for over a century after the hosing ends. The corresponding reduction in ocean heat transport causes wintertime sea ice to advance as much as 20 deg latitude in the North Atlantic with profound surface air cooling. The surface air temperature over Greenland is more than 5°C colder annually 100 years after hosing in the LGM climate, while the temperature is essentially normal after 50 years in a comparable modern hosing experiment with the same model. The THC shutdown in the LGM climate persists because the fresh water anomaly at the surface dissipates more slowly than in the modern hosing experiment. The fresh water anomaly is dispersed horizontally in either case, but surprisingly it is also dispersed vertically in the modern hosing experiment. Therefore, the initial stable stratification from the hosing is eroded in a matter of decades and the THC recovers rather quickly in the modern case.

It is instructive to compare the nonlocal response of our hosing experiments, which have a dynamical full-depth ocean, to runs with an artificially enhanced Arctic sea ice cover with a surface slab ocean. In either case, anomalously cold and dry air spreads equatorward and reaches the northern subtropics by the second year after hosing. Although the atmospheric cooling above the northern latitudes is larger in the hosed experiments, the surface cooling in the tropics is not as great. The dynamic ocean in the hosing runs adjusts quickly to reduce the northward heat transport exported by the ocean out of the tropics. This competes with the wind-evaporative-sea surface temperature (WES) feedback, which on its own acts to amplify the cooling by cold air imported from the north. As a result the meridional temperature gradient and shift in the intertropical convergence zone is much weaker in the experiments with a dynamic ocean than with a slab ocean.

Jean Lynch-Stieglitz, Georgia Institute of Technology  
"Abrupt Climate Change and the Atlantic MOC"

Abrupt climate changes are clearly seen in the North Atlantic and elsewhere in the Northern Hemisphere on the deglaciation (Younger Dryas/ Bolling Allerod oscillation) and during the time of intermediate ice volume preceding the Last Glacial Maximum (LGM), Marine Isotopic Stage 3 (Dansgaard-Oeschger events). The prevailing paradigm is that these abrupt climate changes result from changes in the northward heat transport by the meridional overturning circulation (MOC) in the Atlantic Ocean. In this talk I reviewed the evidence for changes in the Atlantic MOC during the Holocene, the LGM, and during the abrupt climate change events. During the Holocene, variation in the Atlantic MOC appears to have been small. During the LGM, the Atlantic was dominated by a shallow, nutrient poor water mass above 2 km and more nutrient rich waters below. There are several lines of evidence pointing to a weaker MOC consistent with a reduced transport of heat by the ocean into the far North Atlantic. There is also good evidence that the Younger Dryas cold episode during the deglaciation was associated with weaker overturning, and the Bolling Allerod warm event with stronger overturning. There is also data supporting the idea that the presumably large input of melt water to the North Atlantic associated with the most recent Heinrich event dramatically increased the residence time of deep waters, consistent with a shut-down of deepwater production in the North Atlantic. Direct evidence for changes in the Atlantic MOC during the Stage 3 Dansgaard-Oeschger events remains elusive.

Polar Climate Working Group Meeting: Focus: Model Intercomparison Studies

Alex Hall, University of California, Los Angeles  
"What Controls the Strength of Snow Albedo Feedback?"

The strength of snow albedo feedback in any one of the current generation of transient climate change simulations is determined almost exclusively by the surface albedo decrease associated with snow cover loss. Meanwhile, the reduction in snow albedo due to metamorphosis of the snowpack in a warming climate barely contributes to the overall strength of the feedback in any particular model. The three-fold intermodel spread in snow albedo feedback strength is likewise attributable almost exclusively to the snow cover component. Thus, the choice of how to parameterize snowpack metamorphosis effects is largely irrelevant relative to snow albedo feedback. The spread in the snow cover component is mostly attributable to a more than two-fold spread in the albedo of snow-covered surfaces (effective snow albedo). Models with large (small) effective snow albedos have a large (small) surface albedo contrast between snow-covered and snow-free regions, and exhibit a correspondingly large (small) surface albedo decrease when snow cover decreases. Models without explicit treatment of the vegetation canopy in their surface albedo calculations typically have high effective snow albedos and strong snow albedo feedback, often stronger than observed. In models with explicit canopy treatment, completely snow-covered surfaces typically have lower albedos, and the simulations have weaker snow albedo feedback. Snow albedo feedback in this model is generally weaker than observed. We speculate that in these models either snow albedos or canopy albedos when snow is present are too low or vegetation shields snow-covered surfaces excessively. Detailed observations of surface albedo in a representative sampling of snow-covered surfaces would

therefore be extremely useful in constraining these parameterizations and reducing snow albedo feedback spread in the next generation of models.

Eric DeWeaver  
University of Wisconsin-Madison  
"Climate Change and the Stability of the Sea Ice Edge"

A simple "toy" model is devised to study the stability and climate sensitivity of oceanic regions that are sea ice covered in winter but ice free in summer. The premise of the model is that the rates of ice freezing and melting and ice-free mixed layer warming and cooling are determined by external climate forcing, independently of the lengths of the seasons. The system adjusts to changes in external climate forcing through changes in the lengths of the freezing, melting, cooling, and warming seasons. We first examine the stability of the seasonal ice states with respect to perturbations in the start dates of the seasons. Stability can be assessed by considering the ratio of the freezing rate to the melting rate or the ratio of the mixed layer warming and cooling rates. More simply, stability can be assessed by comparing the durations of the freezing and melting seasons or the durations of the warming and cooling seasons. Roughly speaking, the seasonal ice climate is stable if the ice "wants" to melt but the mixed layer "wants" to freeze.

To examine the sensitivity of the seasonal ice climate to changes in external climate forcing, we construct a 4-by-4 matrix that can be solved for the lengths of the four seasons. The matrix then is reduced to two equations for the lengths of the ice freezing and mixed layer cooling seasons. The lengths of the freezing and cooling seasons can be represented by the intersection of the lines representing the two equations. When the system is stable with respect to initial conditions, a shift to warmer climate forcing causes the intersection of the two lines to move upward and to the left, signifying a transition to a longer ice-free cooling season and a shorter ice-covered freezing season.

Finally, we compare the climate sensitivity of two versions of the toy model, one in which the rates are determined entirely by external climate forcing and one in which the lengths of the seasons can influence the rates (a nonlinear calculation). The linear stability criterion is satisfied by the nonlinear calculation, and there is qualitative similarity between the linear and nonlinear calculations. However, the nonlinear calculation is less sensitive near the ice-covered limit. The reduced sensitivity can be understood in terms of the ice thickness-ice growth feedback. As climate warms, the growth rate of ice is reduced. However, the length of the freezing season also shortens, which reduced the thickness of the ice, thereby increasing the freezing rate, since thin ice grows faster than thick ice. The increase in freezing rate due to the shortened season thus partially offsets the decrease in freezing rate due to the change in climate forcing.

Richard Cullather, Columbia University  
"Climate Model Simulations of Arctic Sea Ice: A Comparison of GFDL CM2.1 and NCAR CCSM3"

Richard presented a comparison of Arctic sea ice distributions in 20th Century simulations of the NCAR CCSM3 and the GFDL CM2.1. These two models have similar spatial resolutions and ice rheologies, yet produce strikingly different sea ice characteristics. The mean ice area of the

CM2.1 was found to have a significantly larger amplitude in the annual cycle as compared to the CCSM3 and to observation; however, the main differences between the models were found to be associated with the total ice volume. With some exceptions, the mean wintertime ice thickness distribution simulated by the CCSM3 was found to be similar to observation in showing values greater than 3m in the central Arctic and greater than 5m along the Canadian Archipelago. In contrast, sea ice simulated by the CM2.1 was found to be overly thin. Throughout the Arctic, simulated mean wintertime ice thicknesses in CM2.1 were found to be less than 2m. These differences were further investigated through comparisons of the simulated sea ice export, atmospheric general circulation, surface energy balance, and energy transports from lower latitudes. In comparison to SHEBA observations, the CM2.1 was found to significantly overestimate the net SW surface flux during the melt season in May and June. The differences for these two months are equivalent to melting about 0.5m of ice. While the CCSM3 surface energy balance compares more favorably to SHEBA observations, considerable discrepancies with observation exist in the simulated mean atmospheric circulation and with sea ice drift patterns.

Andrey Proshutinsky, WHOI

"The Arctic Ocean Model Intercomparison Project (AOMIP): Do We Use Correct Forcing?"

The overarching project goal of AOMIP is to determine major directions for Arctic Ocean model improvements based on coordinated numerical experiments and intercomparisons across an international suite of participating models. In parallel, the second project goal is to investigate major mechanisms of the Arctic Ocean circulation and its variability. During last 5 years, AOMIP scientists investigated these topics with the following results:

- (1) Atlantic water circulation within the Arctic Ocean. Models have a wide variety of behaviors. Many models produce a cyclonic circulation in the Eurasian Basin, but differences are larger in the Canadian Basin. Fundamental questions controlling this circulation are still unanswered.
- (2) Fresh water content variability. Models generally agree that the Eurasian Basin is salty, but differ on the fresh water content and circulation on the shelves and in the Beaufort Gyre. There seems to be a salty drift in the gyre, the cause of which is still unknown.
- (3) Sea level variability and causes for its change. Fully 3D models can reproduce the general seasonal cycle and even interannual variability although they frequently miss high/low events.
- (4) Sea ice distribution. The mean-weighted ice thickness variability among models is relatively low in much of the Arctic Ocean, but increases near the MIZ. This may be a function of ocean heat fluxes.

AOMIP studies also concluded that:

- Tidal forcing is important for Arctic Ocean modeling;
- Tidal and inertial dynamics must be included in sea ice models;
- The inverted barometer effect is an important component for simulations of synoptic variability;
- Variable river runoff and Bering Strait inflow are important parameters influencing Arctic climate and must be taken into account;
- Land-fast ice is an important regulator of dynamics and thermodynamics because it influences upwelling and downwelling, sea ice production and brine rejection, and shelf water properties.

- Careful analysis of model forcing is needed. Correct forcing can significantly improve simulation results.

To solve the latter task, the scientists involved in the AOMIP model validation activity compared observational data from 32 drifting stations for the period 1948-present with the results of NCAR/NCEP reanalysis (2m air temperature, 2-meter air humidity, 10-m wind speed and direction, and total cloudiness). It was found that NCAR/NCEP wind and humidity data can be used for model forcing without corrections; the air temperature data need significant corrections before forcing, and that the total cloudiness from NCAR/NCEP data cannot be used at all.

Poster Overviews (first author shown):

- Vladimir Alexeev, "Polar Amplification and Atmospheric Heat Transport"
- David Bailey, "Investigation of a Melt Pond Parameterization for CCSM"
- Govindasamy Bala, "CCSM3 FV 1x1.25 Simulations for the Detection and Attribution of Regional Climate Change in the Western USA"
- G. I. Belchansky, "Study of Uncertainty of Sea Ice Albedo in the Arctic in Observations and Modeling"
- Uma Bhatt, "Arctic-Atlantic Multi-Decadal Variability in the CCSM3"
- Richard Cullather, "Arctic Sea Ice Cover 'Events' in CCSM3 Control Simulations"
- Mark Flanner, "Present Day Climate Forcing and Response from Black Carbon in Snow"
- Richard Grotjahn, "Diagnosing Arctic Winter CAM3 Bias with a Stationary Wave Model"
- Elizabeth Hunke, "Highlights from AOMIP"
- Bill Lipscomb, "Ridging, Strength and Stability in Sea Ice Models"
- Julie McClean, "Fine Resolution Ocean and Ice Modeling"
- D. Nikolsky, "Modeling Permafrost Dynamics in Alaska by CLM3 and Comparing with Observations"
- H. S. Park, "Development of High Resolution CSIM"
- Ed Schneider, "Tracking Down the Causes(s) of Temperature Sensitivity Differences between CCM3 and ECHAM4"
- Steve Vavrus, "The Role of Terrestrial Snow Cover in the Climate System"

**Attendees:**

Elizabeth Hunke, Los Alamos National Lab

Marika Holland, NCAR

Aixue Hu, NCAR

Alex Hall, UCLA

Andrey Proshutinsky, WHOI

Justin Bagley, University of Wisconsin, Madison

Uma Bhatt, University of Alaska, Fairbanks

Cecilia Bitz, University of Washington

Baris Onol, North Carolina State University

Clark Kirkman, IV, University of Washington

Richard Cullather, Columbia University

David Bailey, NCAR

David None, CU

Detelina Ivanova, Scripps Institution of Oceanography  
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Michael Alexander, NOAA  
Megan Linkin, University of Maryland  
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Mingfang Ting, Columbia University  
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Vladimir Alexeev, University of Alaska, Fairbanks  
Victor Paulis, University of Central Florida  
Wanli Wu, NCAR  
Wei Cheng, University of Washington  
Scott Weese, NCAR  
Bill Large, NCAR  
Xiaohua Pan, George Mason University  
Steve Yeager, NCAR  
Young-Oh Kwon, NCAR  
Yongxin Zhang, Los Alamos National Lab  
Tianjun Zhou, Chinese Academy of Sciences  
Trey White, Oak Ridge National Lab