# Final Report

**Grant:** DE-FG02-07ER64434

**Principal Investigator:** Eric T. DeWeaver

**Institution:** University of Wisconsin - Madison

**Title:** "Dynamics of Arctic and Sub-Arctic Climate and Atmospheric Circulation: Diagnosis of Mechanisms and Biases Using Data Assimilation"

**Start Date:** 08/01/2007

**End Date:** 03/31/2009

**SC Division:** SC-23.1

**Program Manager:** Anjuli S. Bamzai 301-903-0294

**Objectives:**

The overall goal of work performed under this grant is to enhance understanding of simulations of present-day climate and greenhouse gas-induced climate change. Enhanced understanding is desirable 1) as a prerequisite for improving simulations; 2) for assessing the credibility of model simulations and their usefulness as tools for decision support; and 3) as a means to identify robust behaviors which commonly occur over a wide range of models, and may yield insights regarding the dominant physical mechanisms which determine mean climate and produce climate change. A further objective is to investigate the use of data assimilation as a means for examining and correcting model biases. Our primary focus is on the Arctic, but the scope of the work was expanded to include the global climate system to the extent that research targets of opportunity present themselves.

**Activities and Results:**

Research activities fall into six main areas:

1) Data assimilation research:

Research on data assimilation and its usefulness as a tool for understanding climate model behavior was conducted using the ensemble filter provided by the Data Assimilation Research Testbed (DART), applied to the Community Atmosphere Model (CAM, version 3), both available from the National Centers for Atmospheric Research (NCAR). Experiments were performed in which the DART/CAM data assimilation system was used to assimilate both conventional observations

(temperature, moisture, and winds from radiosondes, plus observations from aircraft) and radio occultation (RO) observations from GPS satellites taken by the six satellites of the Constellation Observing System for Meteorology, the Ionosphere, and Climate (COSMIC). COSMIC satellites observe the refraction of radio waves from GPS satellites during the rising and setting of the GPS satellites relative to each COSMIC satellite. This work resulted in a master's thesis for Justin Bagley, a student supported on the grant. His thesis considers the ability of the RO observations to constrain the atmospheric state given that the refractivity of the atmosphere is determined by both temperature and moisture, with moisture playing the dominant role in the tropics but not elsewhere. Moisture is difficult to assimilate, and the time-mean analysis increments of moisture suggest that 1) the model does not assimilate moisture well; and 2) the large-scale structure of the increment suggests that the model atmosphere is too dry at low levels in regions of deep tropical convection, but too moist in the subsidence regions. The analysis is of interest because 1) moisture is not well constrained in reanalysis products, so the assimilation process yields a novel comparison, and 2) the moisture biases are consistent with a lack of stratiform-convective precipitation in the model.

2) Projections of optimal polar bear habitat under climate change mitigation scenarios:

In an earlier funding cycle we participated in a research team led by the U.S. Geological Survey which provided decision support to the U.S. Department of the Interior, as they considered the petition to list the polar bear as a threatened species under the Endangered Species Act. The USGS-led research made projections of polar bear habitat and demographics over the 21st century using sea ice concentration from the SRES A1B "business as usual" global warming simulations prepared for the IPCC fourth assessment report. One conclusion of that research was that the availability of the sea ice which constitutes optimal polar bear habitat in late summer would decline dramatically over the 21$^{st}$ century, with very little left by the end of the century. Work under this grant complements the previous effort by considering the extent to which habitat can be conserved if concentrations of greenhouse gases (GHGs) are controlled through emission mitigation efforts. Our research uses ensembles of CCSM3 integrations forced by GHG concentrations from several GHG forcing scenarios, including SRES A1B, SRES B1, the Climate Change Science Program's 450ppm scenario, and a comparable mitigation scenario from the Goddard Institute for Space Studies. Preliminary results suggest that substantial late summer optimal polar bear habitat will remain on the Arctic coasts of Canada and Greenland under the mitigation scenarios, although a near-total loss of optimal late summer habitat appears unavoidable in the remainder of the Arctic basin.

3) An assessment of the credibility of Arctic sea ice thickness simulations by state-of-the-art climate models:

Present-day sea ice simulations from climate models show large differences in the mean thickness of perennial Arctic sea ice, which are clearly undesirable from a

basic science perspective and lead to large uncertainty in model projections of future sea ice decline. To understand the large thickness spread, we assessed the sensitivity of sea ice thickness to the ensemble spread of the on-ice surface energy budget. Inter-model thickness and energy flux variations were related through a diagnostic calculation of thickness from surface temperature and energy fluxes. The calculation was intended to determine whether the range of mean sea ice thickness values is consistent with the thickness spread expected from a highly idealized representation of the dependence of sea ice thickness on the surface energy balance. The diagnosis was motivated by earlier claims that sea ice thickness is extremely sensitive to errors in longwave flux resulting from errors in the simulation of Arctic clouds, which are artificially compensated through nonphysical adjustments of ice and snow albedo. In our diagnostic calculation, the ensemble range of 60 watts per square meter in energy fluxes results in an approximate range of 1 to 5 meters in mean annual ice thickness, close to the actual thickness range. Differences in longwave forcing appear to play a relatively small role, suggesting that 1) the thickness spread arises naturally from, and is consistent with, the surface energy budget; and 2) artificial compensation for longwave cloud forcing errors is not necessary and is not occurring.

4) An examination of the persistence and reemergence of Northern Hemisphere sea ice area (SIA) anomalies in simulations and observations:

We performed research considering the performance of climate models in simulating the persistence of Northern Hemisphere sea ice area (SIA) anomalies which occur as part of the natural climate variability. This topic is relevant to recent efforts at NCAR and elsewhere to make intraseasonal to interannual forecasts of NH SIA, and because persistence in natural variability is linked to sensitivity under climate change and hence the question of how abruptly sea ice will disappear due to global warming. The key finding of the research is that SIA anomalies in simulations demonstration a "reemergence" behavior in which SIA anomalies in one month can decorrelate in the following month but reappear in the following year. The reemergence can be understood in terms of the "memory" implied by the thermal inertia due to sea ice thickness and mixed layer heat content anomalies. However, comparable reemergence does not occur in SIA anomalies found in the observational record. Reasons for the discrepancy between simulations and observations are not clear at present.

5) An examination of the roles played by changes in net radiation and surface relative humidity in determine the evaporation response to global warming:

Changes in the hydrological cycle under global warming are a topic of great current interest, and there have been several recent studies linking changes in precipitation to the tropospheric energy budget. In this work, we considered the somewhat better constrained relationship between evaporation (which, in the global mean, must balance precipitation) and the surface energy budget. We identified an adjustment mechanism through which the surface latent and sensible heat fluxes act

in opposition to balance an increase in net radiation due to increases in GHG concentration. We also identified an increase in surface relative humidity over most of the global ocean which occurs robustly over the IPCC AR4 model ensemble. The relative humidity is small, but large enough to have a substantial impact on surface evaporation and hence the global hydrological cycle.

**Deliverables:**

**Papers prepared/published**


Lorenz, D. J., E. T. DeWeaver, and D. J. Vimont, 2008: Evaporation change and global warming -- the role of net radiation and relative humidity. J. Climate, in review.

Amstrup, S. C., H. Caswell, E. T. DeWeaver, I. Stirling, D. C. Douglas, B. G. Marcot, and C. M. Hunter, 2009: Rebuttal of "Polar bear population forecasts: A public-policy audit". Interfaces, (journal of the Institute for Operations Research and the Management Sciences), DOI: 10.1287/inte.1090.0444.

Bagley, J. E. S., 2008: Data assimilation in the NCAR Community Atmosphere Model. Master's thesis, Atmospheric and Oceanic Sciences Department, University of Wisconsin-Madison.

DeWeaver, E. T., 2008: Introduction. In DeWeaver, E. T., C. M. Bitz, and L.-B. Tremblay, eds., 2008: Arctic sea ice decline: observations, projections, mechanisms, and implications. Geophysical Monograph Series, American Geophysical Union, Washington, DC, 180pp (ISBN 978-0-87590-445-0).

DeWeaver, E. T., E. C. Hunke, and M. M. Holland, 2008: Sensitivity of Arctic sea ice thickness to intermodal variations in the surface energy budget. In DeWeaver, E. T., C. M. Bitz, and L.-B. Tremblay, eds., 2008: Arctic sea ice decline: observations, projections, mechanisms, and implications. Geophysical Monograph Series, American Geophysical Union, Washington, DC, 180pp.

Durner, G. M., D. C. Douglas, R. M. Neilson, S. C. Amstrup, T. L. McDonald, I. Stirling, M. Mauritzen, E. W. Born, O. Wiig, E. DeWeaver, M. C. Serreze, S. E. Belikov, M. M. Holland, J. Maslanik, J. Aars, D. A. Bailey, and A. E. Derocher, 2008: Predicting the 21st century distribution of polar bear habitat from general circulation model projections of sea ice. Ecological Monographs, 79, 25-58.

DeWeaver, E. T., E. C. Hunke, and M. M. Holland, 2008: Comment on Eisenman et al., “On the reliability of simulated Arctic sea ice in global climate models”. Geophysical Reseach Letters, 35, L04501, doi:10.1029/2007GL031325.

DeWeaver, E. T., 2007: Uncertainty in climate model projections of Arctic sea ice decline: an evaluation relevant to polar bears. USGS Alaska Science Center, Anchorage, Administrative Report, online at http://www.usgs.gov/newsroom/special/polar_bears.


**Presentations**


DeWeaver, E. T., 2009: Reemergence of sea ice cover anomalies and the role of the sea ice-albedo feedback in CCSM simulations. Presentation at the Polar Climate Working Group Meeting, 2/20/2009, Santa Fe, NM.

Lorenz, D. J., DeWeaver, E. T., and D. J. Vimont, 2008: Evaporation change and global warming – the role of net radiation and relative humidity. EOS, Trans. AGU, 89 (53), Fall Meet. Suppl. Abstract GC42A-07.

Bitz, C. M., Holland, M. M., Bailey, D. A., and DeWeaver, E. T., 2008: A series of stabilization runs in the 21st Century: Is there a tipping point? EOS, Trans. AGU, 89 (53), Fall Meet. Suppl., Abstract U13C-0069.

DeWeaver, E. T., 2008: Reemergence of sea ice cover anomalies and the role of the sea ice-albedo feedback in CCSM simulations. EOS, Trans. AGU, 89 (53), Fall Meet. Suppl., Abstract U13C-0068.

DeWeaver, E. T., and S. C. Amstrup, 2008: How does global warming threaten the polar bear? Oral presentation at the 13th Annual CCSM Workshop, 6/17/08, Breckenridge, CO.

DeWeaver, E. T., 2008: Climate variability patterns and their role in climate change. Invited presentation at the Education Forum on Climate Change (organized by Phil Mote, UW Seattle), 88th AMS Annual Meeting, New Orleans, LA, January 19th 2008.

Amstrup, S. C., and E. T. DeWeaver: Summary of Results: USGS science to inform U.S. Fish and wildlife decision-making on polar bears. Briefing presented to the White House Office of Science and Technology Policy, Old Executive Office Building, January 16, 2008.

DeWeaver, E. T., 2007: Does global warming threaten the polar bear? Seminar presented at the Goddard Institute for Space Studies, New York City, NY, December 7, 2007.

DeWeaver, E. T., 2007: Assessing threats to wildlife from global warming: the polar bear test case. Invited presentation at the annual meeting of the Midwest Natural Resources Group, organized by the Region 3 office of the U. S. Fish and Wildlife Service. Minneapolis, MN, November 28, 2007.

Amstrup, S. C., H. Caswell, C. Hunter, I. Stirling, E. Regehr, D. Douglas, B. Marcot, G. Durner, 2007, and E. T. DeWeaver, 2007: Briefing on Results: USGS science strategy to support U. S. Fish and Wildlife Service polar bear listing decision. Briefing presented at the U. S. Department of the Interior, September 7, 2007.

**Media Outreach**

Brown, S., 2008: Last days for US polar bear dithering? Nature News, March 7, doi:10.1038/news.2008.655.

Gilleland, N., and Auerbach, E., 2008: Polar bears and global climate change. University of the Air, Wisconsin Public Radio, June 8, online at wpr.org/webcasting/audioarchives_display.cfm?Code=uoa

Seeley, R., 2008: Polar bear predictions. Wisconsin State Journal, March 23, online at www.madison.com/archives/read.php?ref=/wsj/2008/03/23/0803220246.php.

**Collaborators:**

David Lorenz, Center for Climatic Research, University of Wisconsin – Madison, Madison, Wisconsin.
Cecilia M. Bitz, Atmospheric Science Department, University of Washington, Seattle, Washington.
Elizabeth Hunke, Los Alamos National Laboratory, Los Alamos, New Mexico.
Marika Holland, National Center for Atmospheric Research, Boulder, Colorado.
Daniel J. Vimont, University of Wisconsin – Madison, Madison, Wisconsin.

**Graduate Students Supported:**

Justin Bagley (MS 2008), Erica Bickford (MS 2008)

**Reason for Early Termination:**

The expected funding period for this grant was from 8/1/2007 to 7/31/2010. Instead, the grant was terminated on 3/31/2009, due to the departure of the PI from the University of Wisconsin. It is expected that the research begun under this grant will continue under a new grant to the PI at the University of Maryland.