

Scientific Final Report

1. IDENTIFICATIONS

Iowa State University Award Number: DE-FG02-07ER64463

Iowa State University Project ID: 401-21-07

Name of Recipient: William J. Gutowski

Project Title: COLLABORATIVE RESEARCH: TOWARDS ADVANCED
UNDERSTANDING AND PREDICTIVE CAPABILITY OF CLIMATE CHANGE IN
THE ARCTIC USING A HIGH-RESOLUTION REGIONAL ARCTIC CLIMATE
SYSTEM MODEL

Principal Investigator: William J. Gutowski, Iowa State University

Principal Collaborators: Wieslaw Maslowski, Naval Postgraduate School

John Cassano, University of Colorado

Dennis Lettenmaier, University of Washington

2. AUTHORIZED DISTRIBUTION LIMITATIONS NOTICES

N.A.

3. EXECUTIVE SUMMARY

The motivation for this project was to advance the science of climate change and prediction in the Arctic region. Its primary goals were to (i) develop a state-of-the-art Regional Arctic Climate system Model (RACM) including high-resolution atmosphere, land, ocean, sea ice and land hydrology components and (ii) to perform extended numerical experiments using high performance computers to minimize uncertainties and fundamentally improve current predictions of climate change in the northern polar regions. These goals were realized first through evaluation studies of climate system components via one-way coupling experiments. Simulations were then used to examine the effects of advancements in climate component systems on their representation of main physics, time-mean fields and to understand variability signals at scales over many years. As such this research directly addressed some of the major science objectives of the BER Climate Change Research Division (CCRD) regarding the advancement of long-term climate prediction.

4. GOALS AND ACCOMPLISHMENTS

	GOAL	ACCOMPLISHMENT
1.	Develop a coupled ocean/ice/atmosphere/land Arctic climate system model (RACM).	Completed. See for example, Higgins, M. E., J. He; J. J. Cassano A. Craig, W. J. Gutowski, J. Jakacki. D. Lettenmaier, W. Maslowski, A. Roberts and C. Zhu. 2012: The Regional Arctic Climate

		<p>Model (RACM): Atmospheric implementation and validation. <i>Journal of Climate</i> (in revision).</p> <p>Gutowski, W.J., W. Maslowski, J. Clement Kinney, A. Roberts, M. Higgins, A. Craig, R. Osinski, J. J. Cassano, D. P. Lettenmaier, W. H. Lipscomb, S. M. Tulaczyk, X. Zeng, 2012: The Regional Arctic System Model: Successes, Challenges and Opportunities. <i>Fall Meeting, American Geophysical Union, San Francisco, CA, December 2012. [invited]</i></p>
2.	Assess model performance with respect to observed Arctic behavior.	<p>Completed. See Fisel, B. J., W. J. Gutowski, Jr., J. M. Hobbs, and J. J. Cassano, 2011: Multiregime states of Arctic atmospheric circulation. <i>Journal of Geophysical Research</i>, 116, D20122, doi:10.1029/2011JD015790.</p> <p>Glisan, J., W. J. Gutowski, J. J. Cassano and M E. Higgins, 2012: Effects of Spectral Nudging in WRF on Arctic Temperature and Precipitation Simulations. <i>Journal of Climate</i> (in press).</p> <p>Also Brandon Fisel, 2011, M.S, Meteorology, Multi-regime States of Arctic Atmospheric Circulation, 42 pp.</p> <p>Justin Glisan, 2012, Ph.D., Meteorology, Arctic daily temperature and precipitation extremes: Observed and simulated physical behavior, 177 pp.</p>
3.	Analyze drivers and physical feedbacks in the fully coupled system, focusing on sensitive physical links of significance to Arctic sea ice states.	<p>Completed. See Fisel, B. J., W. J. Gutowski, Jr., J. M. Hobbs, and J. J. Cassano, 2011: Multiregime states of Arctic atmospheric circulation. <i>Journal of Geophysical Research</i>, 116, D20122, doi:10.1029/2011JD015790.</p> <p>Justin Glisan, 2012, Ph.D., Meteorology, Arctic daily temperature and precipitation extremes: Observed and simulated physical behavior, 177 pp.</p>
4.	Contribute to international coordination of Arctic climate modeling.	<p>Completed.</p> <p>PI Gutowski is a member of the Coordinated Regional Downscaling Experiment (CORDEX) Science Advisory Team (SAT), which is an outgrowth of the WCRP Task Force on Regional Climate Downscaling. The CORDEX SAT also operates under the auspices of the World Climate Research Program.</p> <p>PI Gutowski has also acted as a liaison between the CORDEX SAT and the CORDEX Arctic focus group.</p>

5. SUMMARY OF PROJECT ACTIVITIES

Note: This was a collaborative project involving PIs from four institutions: Naval Postgraduate School (lead institution, PD/PI - Wieslaw Maslowski), University of Colorado in Boulder (co-PI - John Cassano), Iowa State University (co-PI - William J. Gutowski) and the University of Washington (co-PI - Dennis P. Lettenmaier). The following report is a summary of the Iowa State activities.

Activity 1: Regimes of Arctic Atmospheric Circulation

This work was by M.S. student Brandon Fisel. This work started as an examination of differences between simulations that allowed fractional sea-ice cover in a model grid box versus those for which sea ice in each grid box was either 0% or 100% (binary). After extensive analysis, we determined that the forcing effect of different ice treatment was negligible in our simulations. Nonlinear, unforced variability overrode any possible effect. However, we discovered that the ensemble at times contained multiple, simultaneous circulation regimes as the flow evolved that were related to the state of sea ice (Figure 1).

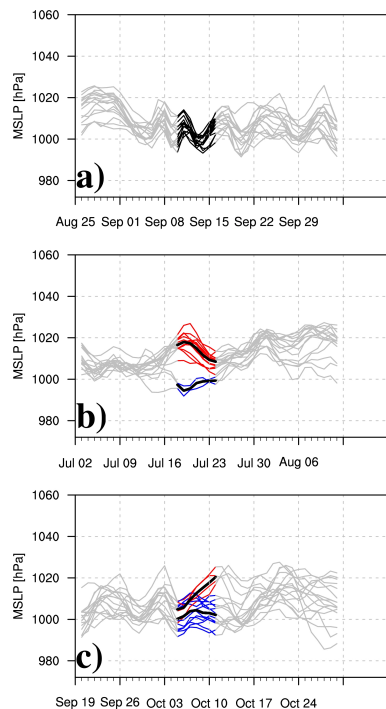


Figure 1 – Examples of different circulation regimes, based on time series of mean sea-level pressure: (a) single regime state, (b) two-regime state produced by statistically significant separation of time series and (c) two-regime state produced by statistically significant differences in trends of time series.

Specifically, ensemble simulations of arctic circulation developed multiple dynamical regimes. We used ensemble simulations of June – December 2007 by the WRF-ARW model to examine regime development. We diagnosed regimes using time series of spatially averaged sea-level pressure for the Beaufort and Chukchi Seas in a model-based clustering method. Multiple regimes were common in our ensemble simulations, although there were differences through the period. There was a slight tendency for two or three regimes to be preferred more in June-July-August than October-November-December. More important, September had the fewest multiple-regime periods. September was also the month of sea-ice minimum, suggesting that open ocean may inhibit the occurrence of multiple regimes in ensemble simulations compared to periods when substantial sea ice is present. Differences in sea-ice treatment had little influence on model results. The regime behavior occurring in this work suggests that as future summer ice cover wanes in the Arctic, the predictability of the atmosphere may increase.

Activity 2: Spectral nudging on the RACM domain

This was work by Ph.D. student Justin Glisan. Substantial bias can appear when using WRF on the RACM domain. Further evaluation has shown that spectral (interior) nudging aids considerably in constraining the model to be more consistent with observed behavior. Spectral nudging is an artificial forcing, which raises a concern over how much it may affect unforced variability and extremes. Strong nudging may reduce or filter out extreme events, since the nudging pushes the model toward a relatively smooth, large-scale state.

The questions then becomes - what is the minimum spectral nudging needed to correct the biases that otherwise occur on the RACM domain while not limiting WRF simulation of extreme events? To determine this, we ran several test cases were devised, each using a six-member WRF ensemble on the RACM grid with a varying spectral nudging strength (2, 1, 1/2, 1/4, 1/8, 1/16, 1/128 and zero times the original nudging strength of 0.000333 s^{-1}).

For each nudging strength, the ensembles simulated a winter month (January 2007) and a summer month (July 2007). Ensemble members were initialized one day apart from days 13-18 of the previous month. We use the first two weeks of the simulations for spin-up and start analyses on the first day of the target months.

The analysis focused on extreme temperature and precipitation and compares model output with observed behavior in four analysis regions: Alaska, eastern Siberia, north-central Pacific and North America. Time average fields were relatively insensitive to the nudging strength, suggesting that one could reduce the nudging strength, so that its contribution to heat, momentum and water budgets is reduced. For extremes, the results were less clear. For both months, the observations always had extremes of greater magnitude than observed, but the effect of varying nudging strength differed between the two months. In January, decreasing the nudging tended to decrease the magnitude of the extremes, so that the strongest nudging yielded extremes closest to observed. In July, decreasing the nudging tended to increase the magnitude of extremes, so that weaker nudging promoted extremes closer to observations. The behavior suggests that January

simulation extremes are an outcome of large-scale dynamics that the model must replicate well in order to produce appropriate extremes. In contrast, the results suggest that July extremes are more local in spatial scale and that constraining local dynamics by nudging inhibits extreme behavior.

Activity 3: Pan-Arctic WRF run on the CORDEX Arctic Domain

This was work by Ph.D. student Justin Glisan. He produced an ensemble of six simulations using WRF on the CORDEX Arctic domain. The ERA-Interim reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) provided initial and lateral boundary conditions. The National Snow and Ice Data Center (NSIDC) provided observed sea ice data.

The ensemble was created by staggering start times for the runs by one day over a six-day period, 1-6 January 1989. Simulations ran continuously through December 2007.

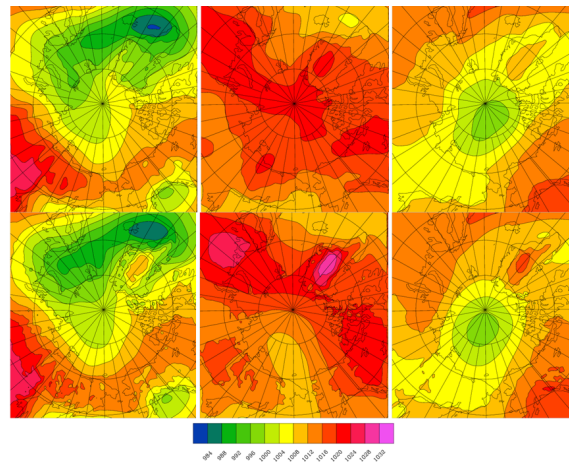


Figure 2 - *top*: Era-Interim MSLP for (left to right) January 1989, April 1989 and July 1989. *bottom*: Same as top, except for WRF monthly ensemble mean MSLP

Initial analysis of multiple fields including MSLP, temperature (surface, 850-hPa, and 500-hPa) and 500-hPa geopotential heights showed good agreement between WRF output and the Era-Interim reanalysis. Bias plots for a winter month (January), a transition month (April) and a summer month (July) showed differences between the reanalysis and model output (e.g., Fig. 2).. These differences are acceptable when considering the unforced variability that occurs in the Arctic region. One measure of the unforced variability appeared in time series of area-averaged bias versus the ERA-Interim for mean sea-level pressure, though the spread among ensemble members. Time series of area-averaged MSLP for a representative year also showed that differences between WRF and the ERA-Interim are relatively small.

Root mean-square difference (RMSD) time series (not shown) for both the reanalysis and WRF simulations provided another measure of internal variability in the

atmosphere. Magnitudes of both RMSD curves corresponded to a high degree, including the seasonal variability. Thus, the model versus reanalysis RMSD may have a considerable dependence on unforced, quasi-random internal variability, and it also simulates the annual cycle of that variability.

Activity 4: Extreme temperature and precipitation events

Justin Glisan analyzed precipitation and temperature extremes in Arctic observations and ensemble simulations on the CORDEX Arctic domain as a first step toward evaluating extremes and their supporting processes as simulated by WRF and by RACM for contemporary and future climates. He performed quality control on Arctic observational data from the National Climatic Data Center for our four focus regions:

- a. Canada A: The Canadian Archipelago – stations within this box are located on islands making up the archipelago. Nearly a quarter of these stations are found north of the Arctic Circle.
- b. Canada B: East of the Canadian Rockies – these stations are found in the interior regions of Canada, spanning the sub-Arctic Canadian plains.
- c. Alaska A: North of the Brooks Range, plus Arctic Sea stations - These stations all reside north of the Arctic Circle and are thus highly influenced by the Arctic Ocean (including sea ice processes).
- d. Alaska B: South of the Brooks Range and west of the Canadian Rockies – influenced by the North Pacific storm track.

He extracted corresponding output from an ensemble of six simulations covering the years 1989 – 2007, with the first three years discarded for spin-up. He compared temperature and precipitation extremes as simulated by the ensemble versus observed extremes. He compared other relevant fields, such as sea-level pressure, atmospheric moisture and geopotential heights to compare the physical processes producing extremes in the observations and the model. For nearly all regions and season, the extreme events involved synoptic (resolved scale) dynamics. The exception was Canada B (East of the Canadian Rockies), where summer extremes were produced by atmospheric convection. His analysis showed that the model tends to replicate fairly well the observed behavior, thus indicating that it replicates the processes leading to the observed extremes.

Related Research Activities

PI Gutowski was a member of the WCRP Task Force on Regional Climate Downscaling (TFRCD), the group that has organized CORDEX. In this role, he served as a bridge between the RACM project and CORDEX. He also gave presentations on CORDEX and performed numerous CORDEX coordinating activities as TFRCD duties, including coordination of WRF simulations for CORDEX and assisting with the set up of Arctic simulations for CORDEX. His position evolved with that of the TFRCD into the CORDEX Science Advisory Team, which continues to operate under the auspices of the World Climate Research Program.

PI Gutowski was a member of the Changes and Attributions Working Group that was formed during a National Science Foundation Freshwater Initiative program. The continuing efforts of this group produced a set of “wiring diagrams” designed to provide

succinct overviews of water reservoirs with their links and feedbacks in the Arctic water cycle. Results of this work were reported in Francis et al. (2009).

PI Gutowski was appointed a Lead Author for Working Group 1 for the IPCC Fifth Assessment Report. His primary responsibility has been Chapter 12 (Long-term Climate Change: Projections, Commitments and Irreversibility). His work on this chapter draws in part upon his work with Arctic climate simulation.

6. PRODUCTS DEVELOPED AND TECHNOLOGY TRANSFER ACTIVITIES UNDER THE AWARD

6.a Technologies/Techniques Product Development Overview

Substantial technologies/techniques were developed in this project for producing the fully coupled Regional Arctic Climate Model. Existing component models for the ocean (POP), sea ice (CICE), land hydrology (VIC) and atmosphere (WRF) were coupled using the Flux Coupler of NCAR's Community Earth System Model. This offered several advantages:

1. It gave us access to the NCAR computational expertise for developing appropriate numerical approaches to the coupling.
2. It used existing coupling software, avoiding code development for this part of the model while also implicitly directing our effort toward appropriate coupling strategies (such as the timing of each component's time steps).
3. It provided a link between the NCAR global model and our regional Arctic model, so that new components developed for one model, such as ice-sheet modeling, could be implemented in the other.
4. It helped standardize the formulation of the fully coupled model, so that we could more easily satisfy a goal of making our regional model available to the broader community.

6b. Publications

i. Journal/Proceedings Publications

Chen, T.-C., J.-D. Tsay and W. J. Gutowski, 2008: A comparison study for three polar grids. *J. Appl. Meteor.Clim.*, 47, 2993-3007 [DOI: 10.1175/2008JAMC1746.1].

Francis, J.A., J. J. Cassano, W. J. Gutowski, Jr., L. D. Hinzman, M. M. Holland, M. A. Steele, D. M. White and C. J. Vörösmarty, 2009: An Arctic hydrologic system in transition: Feedbacks and impacts on terrestrial, marine, and human life. *J. Geophys. Res.*, **114**, G04019 [DOI:10.1029/2008JG000902].

Fisel, B. J., W. J. Gutowski, Jr., J. M. Hobbs, and J. J. Cassano, 2011: Multiregime states of Arctic atmospheric circulation. *Journal of Geophysical Research*, **116**, D20122, doi:10.1029/2011JD015790.

Glisan, J., W. J. Gutowski, J. J. Cassano and M E. Higgins, 2013: Effects of Spectral Nudging in WRF on Arctic Temperature and Precipitation Simulations. *Journal of Climate* (in press).

Higgins, M. E., J. He; J. J. Cassano A. Craig, W. J. Gutowski, J. Jakacki. D. Lettenmaier, W. Maslowski, A. Roberts and C. Zhu. 2012: The Regional Arctic Climate Model (RACM): Atmospheric implementation and validation. *Journal of Climate* (in revision).

Glisan, J., and W. J. Gutowski, 2013: Arctic extremes and their supporting environment in observations and simulations: Summer. *Journal of Climate* (to be submitted).

Glisan, J., and W. J. Gutowski, 2013: Arctic extremes and their supporting environment in observations and simulations: Winter. *Journal of Climate* (to be submitted).

ii. Papers/Posters/Seminars Presented

Gutowski, W.J., 2007: Key Considerations in Linking Permafrost, Ecosystems and Run-off: Readiness of Existing Models for Coupling Land-Atmosphere Water and Energy Cycles. *Arctic System Model Workshop*, Fairbanks, AK, August 2007. [invited]

Gutowski, W.J., 2008: Review of Multi-model RCM Projects: Recommendations for a Coordinated RCM Program in Africa & Beyond. *Fourth ICTP workshop in the Theory and Use of Regional Climate Models*, Trieste, Italy, 3-14 March 2008. [invited]

Gutowski, W.J., 2008: Regional Climate Modeling: Past, Present and Future. *Environment Roundtable*, Institute on the Environment, St. Paul Campus, University of Minnesota, 24 April, 2008. [invited]

Gutowski, W.J., 2008: Coordinated Regional Climate Simulation Programs in North America. Workshop on Future Directions for South African Regional Climate Research, Center for High Performance Computing, Cape Town, South Africa, 4-5 August 2008. [invited].

Cassano, J., W. Maslowski, W. J. Gutowski and D. Lettenmeier, 2009: Development of a Regional Arctic Climate System Model (RACM). Second International Lund RCM Workshop, Lund, Sweden, May 2009.

Maslowski, W., J. Cassano, W. Gutowski, and D. Lettenmaier, 2009: Towards Advanced Understanding and Predictive Capability of Climate Change in the Arctic Using a High-Resolution Regional Arctic Climate System Model (RACM). DOE Climate Change Prediction Program Meeting, Bethesda, MD, April 2009

Gutowski, W.J., 2009: The Arctic Atmosphere's Water Cycle: Scales, Tales and Hail. *Synthesizing International Understanding of Changes in the Arctic Hydrological System*, Stockholm, Sweden, October 2009. [invited keynote]

Gutowski, W.J., 2009: Coordinated Regional Downscaling Experiment (CORDEX). *Arctic System Model Workshop III*, Montreal, Quebec, Canada, July 2009.

Roberts, A., J.E. Walsh, L. Hinzman, R. Doescher, A. Sumi, M. Holland, J. Cassano, W. Maslowski, W. Gutowski, J. Hel, 2009: Towards a community Arctic System Model. *Ice and Climate News*, **10**, 14-15.

Maslowski, W., J. Cassano, W. J. Gutowski and D. Lettenmeier, 2010: Development of a Regional Arctic Climate System Model (RACM). *US. Department of Energy Earth System Modeling Program, PI Meeting*, Gaithersburg, MD, March 2010.

W. J. Gutowski, J. Cassano, M. Higgins, J. Glisan, B. Fisel and M. Seefeldt, 2010: Evolution of the Arctic Climate System as Sea Ice Changes. *State of the Arctic Conference*, Miami, FL, March 2010.

Fisel, B. J., W. J. Gutowski, J. M. Hobbs and J. J. Cassano, 2011: Multi-Regime States of Arctic Atmospheric Circulation. *Eleventh 11th Conference on Polar Meteorology and Oceanography*, Boston, MA, May 2011.

Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland: "Regional Arctic Climate Model: Overview, Selected Results and Future Plans" (W. Maslowski, W. Gutowski and J. Cassano) (May 2011)

Glisan, J., and W. J. Gutowski, 2011: Extreme Daily 2-m Temperature and Precipitation in the CORDEX Arctic domain using Pan-Arctic WRF. *WCRP Open Science Conference*, Denver, CO, October 2011.

Gutowski, W. J., W. Maslowski, J. Cassano, D. Lettenmaier, T. Craig, B. Fisel, J. Glisan, M. Higgins, J. Jakacki, A. Roberts, C. Zhu, 2011: Regional Arctic Climate Model (RACM): Overview and selected results. *WCRP Open Science Conference*, Denver, CO, October 2011.

Maslowski, W., R. Osinski, J. Jakacki, A. Roberts, J. Clement Kinney, J.J. Cassano, M. Higgins, T. Craig, W.J. Gutowski and D.P. Lettenmaier, 2011: Modeling Coupled Feedback Processes in Arctic Climate Using Ice-Ocean and Fully Coupled Regional Climate Models. *Fall Meeting*, American Geophysical Union, San Francisco, CA, December 2011.

Roberts, A., W. Maslowski, J. Jakacki, M. Higgins, T. Craig, J.J. Cassano, W.J. Gutowski and D.P. Lettenmaier, 2011: High frequency and wavenumber ocean-ice-atmosphere coupling in the Regional Arctic Climate Model. *Fall Meeting*, American Geophysical Union, San Francisco, CA, December 2011.

Cassano, J. J., M. Higgins, M.R. Hughes, W.J. Gutowski, D.P. Lettenmaier, W. Maslowski, 2011: Modeling the Arctic Atmosphere with the Regional Arctic Climate

Model (RACM). *Fall Meeting*, American Geophysical Union, San Francisco, CA, December 2011.

Fisel, B. J., W.J. Gutowski, J.M. Hobbs and J.J. Cassano, 2011: Multi-Regime States of Arctic Atmospheric Circulation. *Fall Meeting*, American Geophysical Union, San Francisco, CA, December 2011.

Glisan, J. M., W.J. Gutowski, M. Higgins and J.J. Cassano, 2011: The Effects of Spectral Nudging on Arctic Temperature and Precipitation Extremes as Produced by the Pan-Arctic WRF. *Fall Meeting*, American Geophysical Union, San Francisco, CA, December 2011.

E.N. Cassano, J.J. Cassano, M.E. Higgins, W.J. Gutowski, and J. Glisan, 2012: A model and reanalysis based analysis of the relationship of large-scale weather patterns to temperature extremes in Alaska. *International Polar Year 2012 Conference*, Montreal, Canada, 22-27 April 2012.

Fisel, B. J., W.J. Gutowski, J.M. Hobbs and J.J. Cassano, 2012: Multi-Regime States of Arctic Atmospheric Circulation. *International Polar Year 2012 Conference*, Montreal, Canada, 22-27 April 2012.

Glisan, J. M., and W. J. Gutowski, 2012: Summer Extreme Daily Precipitation over the CORDEX Arctic Domain as Produced in the Pan-Arctic WRF. *International Polar Year 2012 Conference*, Montreal, Canada, 22-27 April 2012. [third prize student winner in the category "Past, present and future changes in the polar regions"]

Gutowski, W.J., 2012: CORDEX and NARCCAP: Foundations in Reanalyses. *4th WCRP International Conference on Reanalyses*, Silver Spring, MD, 7-11 May 2012. [invited]

Gutowski, W.J., W. Maslowski, J. Clement Kinney, A. Roberts, M. Higgins, A. Craig, R. Osinski, J. J. Cassano, D. P. Lettenmaier, W. H. Lipscomb, S. M. Tulaczyk, X. Zeng, 2012: The Regional Arctic System Model: Successes, Challenges and Opportunities. *Fall Meeting*, American Geophysical Union, San Francisco, CA, December 2012. [invited]

6b. Student thesis

Brandon Fisel, 2011, M.S, Meteorology, Multi-regime States of Arctic Atmospheric Circulation, 42 pp.

Justin Glisan, 2012, Ph.D., Meteorology, Arctic daily temperature and precipitation extremes: Observed and simulated physical behavior, 177 pp.

Participant training / professional development

Glisan: International Arctic Research Center (IARC) Summer School on Modeling Arctic Climate, Fairbanks, AK, May-June 2008.

Fisel: International Arctic Research Center (IARC) Summer School on Modeling Arctic Climate, Fairbanks, AK, May-June 2011.

Fisel, Glisan: WRF tutorial, Boulder, CO, July 2008.

6c. Web site

<http://www.oc.nps.edu/NAME/RACM.html>

6d. Collaborative networks fostered

A large number of national and international collaborations have been fostered during the project as indicated by the list of publications. A list of affiliations of collaborators/coauthors other than between the PI over the duration of the grant follows:

- Danish Meteorological Institute
- Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland
- University of Alaska/Fairbanks
- International Center for Theoretical Physics
- University of Cape Town, South Africa
- Rosaby Center, Sweden
- University of Quebec/Montreal, Canada
- University of Iowa

7. COMPUTATIONAL MODEL OVERVIEW

The project developed and applied a fully coupled Regional Arctic Climate Model (RACM) consisting of atmosphere, land-hydrology, ocean and sea ice components. The atmospheric model used in RACM is a version of the National Center for Atmospheric Research (NCAR) Weather Research and Forecasting (WRF) model that has been optimized for the polar regions. The ocean and sea ice models are similar to those currently used in the NCAR Community Climate System Model (CCSM4), although used on a regional domain: the Los Alamos National Laboratory POP ocean model and CICE sea-ice model. Land surface processes and hydrology are represented by the Variable Infiltration Capacity (VIC) model. These four component models are being coupled using the NCAR CCSM coupler CPL7.

The RACM simulation domain covers the entire pan-Arctic region (Fig. 3). It includes all sea-ice-covered regions in the Northern Hemisphere as well as all terrestrial drainage basins that drain into the Arctic Ocean. For the baseline RACM, the ocean and sea ice model uses a horizontal grid spacing of 9 km, while the atmosphere and land component models use a horizontal grid spacing of 50 km. Fully coupled RACM results

are currently being evaluated for physical performance. Multi-decadal integrations and tests with higher-resolution model configurations are planned as part of ongoing work.

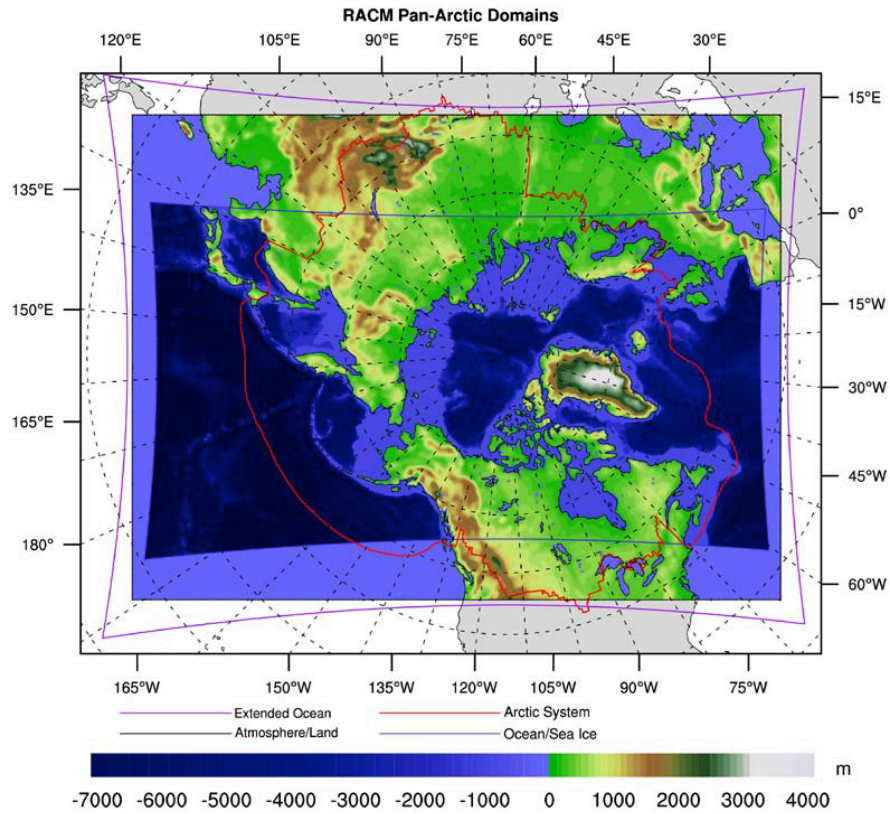


Figure 3. RACM pan-Arctic model domain. WRF and VIC model domains include the entire colored region. POP and CICE domains are bound by the inner blue rectangle. Shading indicates model topobathymetry.