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There are two main uncertainties in determining future climate: the trajectories of future emissions of greenhouse gases and aerosols, and the response of the global climate system to any given set of future emissions [*Meehl et al.,* 2007]. These uncertainties normally are elucidated via application of global climate models, which provide information at relatively coarse spatial resolutions. Greater interest in, and concern about, the details of climate change at regional scales has provided the motivation for the application of regional climate models, which introduces additional uncertainty [*Christensen et al.,* 2007a].

These uncertainties in fine-scale regional climate responses, in contrast to uncertainties of coarser spatial resolution global models in which regional models are nested, now have been documented in numerous contexts [*Christensen et al.,* 2007a] and have been found to extend to uncertainties in climate impacts [*Wood et al.,* 2004; *Oleson et al.,* 2007]. While European research in future climate projections has moved forward systematically to examine combined uncertainties from global and regional models [*Christensen et al.,* 2007b], North American climate programs have lagged behind.

To fill this research gap, scientists developed the North American Regional Climate Change Assessment Program (NARCCAP). The fundamental scientific motivation of this international program is to explore separate and combined uncertainties in regional projections of future climate change resulting from the use of multiple atmosphere-ocean general circulation models (AOGCMs) to drive multiple regional climate models (RCMs). An equally important and related motivation for this program is to provide the climate impacts and adaptation community with high-resolution regional climate change scenarios that can be used for studies of the societal impacts of climate change and possible adaptation strategies.

NARCCAP: Meeting Research Needs

Now is a critical moment, when research dollars need to be invested wisely to best prepare for climate change. Much is made of the putative need for more regional detail about climate change [e.g., *Giorgi et al.,* 2008], particularly for studies aimed at helping society adapt to anticipated changes. However, there are no studies that clearly demonstrate for North America (or any other region) that using climate change scenarios with greater regional detail leads to a superior estimation of impacts or better adaptation plans. NARCCAP could contribute important research on the value of high-resolution information for preparing for climate change.

Through NARCCAP, scientists will produce multiple high-resolution simulations of future climate. Because NARCCAP is using multiple global and regional model simulations, researchers will have the ingredients needed to produce impact assessments that incorporate multiple uncertainties regarding regional climate change. Further, researchers studying climate impact effects and adaptation strategies were consulted regarding their needs in the course of formulating NARCCAP, through online and phone discussions and at the first users' meeting, held in February 2008. Additional NARCCAP goals include further evaluating regional model performance across North America; organizing the regional modeling community; and enhancing collaboration between U.S., Canadian, and European climate modelers.

Program Structure

The spatial domain over which the climate simulations for NARCCAP are performed covers northern Mexico, the lower 48 contiguous United States, most of Canada to 60ºN, and waters of the Atlantic and Pacific oceans adjacent to landmasses in the study area. All simulations are performed at a spatial resolution of 50 kilometers. RCMs used to simulate climate include the Canadian RCM (CRCM), the Met Office Hadley Centre's Hadley Regional Model 3 (HadRM3), the National Center for Atmospheric Research (NCAR)/Pennsylvania State University Mesoscale Model 5 (MM5), the NCAR Weather Research and Forecasting (WRF) model, the Abdus Salam International Center for Theoretical Physics's Regional Climate Model Version 3 (ICTP RegCM3), and the Experimental Climate Prediction Center Regional Spectral Model (RSM).

These models provide a variety of physics and/or have been well tested in climate change experiments across North America. The basic regional modeling technique relies on the larger-scale model (e.g., an AOGCM) providing boundary conditions for large-scale responses to forcing (e.g., increased greenhouse gases) and the regional model simulating finer-scale responses.

NARCCAP involves two phases. The first entails running the regional models using boundary conditions from reanalyses (similar to using observations for boundary conditions), and the second involves nesting the regional models in global climate models for current and future periods. Phase 1 is completed; phase 2 is still under way.

Phase 1: Simulations Using Reanalysis Boundary Conditions

Phase 1 of NARCCAP included the production of 25-year (1980–2004) RCM simulations using the National Center for Environmental Prediction/Department of Energy (NCEP/DOE) Reanalysis 2 for boundary conditions. Using Reanalysis 2 is approximately equivalent to using observations to drive the regional models. Thus, phase 1 provided an assessment of model quality crucial to generating climate scenarios and characterizing their uncertainties.

Phase 2: Simulations of Future Climate

The essential climate change portion of NARCCAP entails using four AOGCMs to provide boundary conditions for the six RCMs to simulate 30 years of current climate (1971–2000). This matrix of AOGCMs and RCMs was also used to simulate 30 years of future climate (2041–2070) using the A2 scenario from the *Special Report on Emissions Scenarios* of the Intergovernmental Panel on Climate Change (IPCC; see *Nakicenovic et al.,* [2000]). A2 is a scenario of relatively high emissions of carbon dioxide (CO_2) and other greenhouse gases.

The following four AOGCMs are used to drive the RCMs: the Canadian Climate Centre CGCM3, the Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1, the Hadley Centre HadCM3, and NCAR's CCSM3. Climate sensitivities (i.e., global temperature response to a doubling of CO_2) of the four AOGCMs are 3.4º, 3.4º, 3.3º, and 2.7ºC, respectively, all relatively close to the center of the likely range assessed by the IPCC [*Meehl et al.*, 2007].

Producing the full suite of 24 simulations (four AOGCMs × six RCMs) was not possible for this project, due to funding limitations. Instead, a statistical design framework is used wherein the full matrix is sampled in a balanced manner with each AOGCM providing boundary conditions for three RCMs and each RCM using boundary conditions from two different AOGCMs.

Time-Slice Simulations

Time-slice simulations with high-resolution (50-kilometer) versions of the NCAR atmospheric model (CAM3) and GFDL atmospheric model (AM2.1) also have been produced for the same time periods as the RCM simulations. These simulations allow for direct comparisons of global climate model outputs with RCM outputs. Such comparisons were produced by nesting RCMs within a corresponding AOGCM that has the same atmospheric model component as the time slice.

Time-slice simulations are driven by boundary conditions at the sea surface. For climate simulations for the period 1971–2000, observed sea surface temperature and sea ice boundaries were used; for simulations of the future, perturbations of these variables derived from AOGCM projections were added to observed values. Climate simulations with higher-resolution atmospheric global models are possible because these models avoid simulating the oceans and the long time scales associated with ocean circulations.

Characterization of Uncertainty

Participants in NARCCAP will jointly apply existing and new evaluation techniques to intercompare and diagnose model errors and differences. These analyses will provide information about the relative credibility of different simulations, which will be used to analyze uncertainty. Geophysical statisticians are producing formal models that characterize uncertainty based on the entire suite of simulations. Hence, users of NARCCAP data will have details available for each climate change scenario as well as probability distributions for all experiments.

Data Archive and Web Site

More than 60 terabytes of data consisting of 52 different variables at 3-hour intervals from all simulations are being produced and archived through NARCCAP. Although data are saved in a widely used format (network Common Data Form (NetCDF), following Climate and Forecast (CF) conventions) fully compatible with geographic information systems (GIS), data also can be extracted as plain text using software available through NARCCAP's Web site (http://www.narccap.ucar.edu). The Web site also provides guidance material for using the data.

Progress to Date

As of August 2009, all phase 1 and time-slice simulations have been completed. The first six RCM simulations using AOGCM boundary conditions have been completed, and output from several of these is available on the Web site. The second set of six simulations will be completed by late fall 2009, and data from the second set will be on the Web site soon thereafter. To become a NARCCAP data user, visit http://www.narccap.ucar.edu.

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