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Project Title: Comparative Regional Climate Simulations

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D. Description of Calculations

D.1. Appropriateness for CSL

The proposed research adheres to the "Criteria for Use of the CSL." It is part of a collaborative effort with impacts-assessment scientists, and builds upon the recommendations of a workshop, "Interfacing Mesoscale Climate Models with Impact Assessment," that we hosted on 5–6 December 1996 at NCAR. Our work will lead ultimately to regional climate change impacts assessments in support of the IPCC Third Assessment Report (TAR). The long-term runs to be performed here require intensive, dedicated supercomputing resources such as the CSL.

In terms of the specific criteria for use of the CSL:

1. The research is being conducted by U.S. researchers at a U.S. institution.
2. The calculations require dedicated supercomputing. Regional climate models are to be run for multiple simulations of ten years or more, a task that is feasible with CSL resources but would not be practicable without dedicated high-performance computing.
3. The project will produce regional climate projections to be used in the IPCC Third Assessment Report. As indicated above, the project is being conducted in close collaboration with climate impacts scientists.
4. The proposed research is a critical part of our EPRI peer-reviewed research project.

D.2. Discussion of the Science

D.2.1. Introduction

The goal of this project is to evaluate regional implications of global climate change by a suite of comparative simulations using mesoscale models. In the first stage we will run several regional climate models for an extended period (at least 10 years) on a common domain driven by NCEP/NCAR reanalysis boundary conditions for comparison with observed climate conditions. We will then use these same models to perform simulations driven by GCM simulations for current climate and future climate perturbed by enhanced CO2 and aerosol effects.

Atmospheric mesoscale models have been used to study and forecast the behavior of the atmosphere over periods usually of one to several days. In recent years, scientists have begun applying these models to regional climate (continental scale or smaller) in simulations lasting several weeks to several years (e.g., Giorgi et al. 1993; Jones et al. 1995; Hiriakuchi and Giorgi 1995; Copeland et al. 1996; Christensen et al. 1996). These models can be desirable tools for providing output for climate impact assessment because natural and human impacts of climate change are typically felt on the regional scales.

Climate simulation with mesoscale models is a relatively new approach and its range of validity must be documented. Biases that are of little consequence for the usual time scales of mesoscale simulations may become important when much longer integrations are performed. The adequacy of GCM-supplied boundary conditions for the regional model may also be a significant source of error (Pielke et al. 1997). We will address these and other scientific and technical issues in evaluating the suitability of mesoscale models for climate impacts assessment.

D.2.2. Research plan

D.2.2.1. Long-Term Regional Climate Simulations

We will deploy a small group of mesoscale models to perform a set of extended regional climate simulations for a domain that covers most of the continental U.S. It is desirable to use long runs (here 10 years; 1979-1988 which overlaps the AMIP period) in order to include a broader range of climate regimes and to give a more representative sampling with more degrees of freedom. We consider 10 years to be achievable and will attempt 20-year simulations given sufficient computing resources through the NCAR CSL. A second important point is that the longer simulations provide more information on the slow parts of the hydrological cycle. Here, the longer period is important because it is not just the number of hydrological extremes that is important, but their *sequencing* is crucial as well (for example, the 1993 floods were worsened because the soil already was anomalously wet from the previous year’s rainfall).

A central question for mesoscale climate modeling is: What added value can it give to global climate-change simulation? The improved resolution should enable more detailed representations both of physical processes (such as the central U.S. nocturnal low-level jet and its effect on the generation of precipitation) and of geographic features (such as land use and topography). Our preliminary results indicate that the regional models give improved representation of the low-level jet compared with the NCEP/NCAR reanalysis, and that the diurnal variability of warm-season precipitation is better predicted.

The simulations will be done using three distinct regional models to give a preliminary indication of the robustness of regional climate projections. The regional models we will run at the NCAR CSL are the NCAR Regional Climate Model (RegCM2; Giorgi et al. 1993) and the Colorado State University Regional Atmospheric Modeling System (RAMS; Pielke et al. 1992). The third model, HIRHAM4, is being run by Jens Hesselbjerg Christensen at the Danish Meteorological Institute and will not require NCAR resources. Dr. Filippo Giorgi of NCAR, the lead developer of RegCM2, advises us on the use of RegCM2.

D.2.2.2. Simulation design and computational strategy

The simulation domain covers the continental U.S. and most of Mexico with a forced outer frame surrounding a free inner region. The horizontal grid uses a nominal resolution of 60 km. The simulations will begin with a "spinup" period that will not be considered as part of the results to be supplied to impacts assessors.

The simulations are being run with three sets of initial and lateral boundary conditions:

- First, climate of the recent past (1979-1988, included within the AMIP period) is being simulated using analyses of observed data to provide the same initial and boundary conditions for all three of the regional models. Driving data are given by the atmospheric reanalyses produced by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR), using a T62 resolution spectral forecast model and a variational objective analysis (see Kalnay et al. 1996 for a description of the reanalysis methodology). Within caveats regarding analysis accuracy the reanalysis can be viewed as the limiting case of a "perfect" GCM in which to nest the regional model. The regional model results can be compared directly to observed data in order to establish the models' skill at replicating regional climate and its variability.

- Second, the same three regional models will perform 10-year simulations of regional climate for the same location but with initial and boundary conditions supplied from Hadley Centre GCM simulations of present climate. The second-generation Hadley Centre model is a coupled atmosphere-ocean GCM run on a 2.5^{o} by 3.75^{o} latitude-longitude Arakawa-B grid, which is slightly coarser than the T62 transform grid used in the NCEP/NCAR reanalysis. By comparing these results with the reanalysis driven simulations and with observations we can identify biases that are attributable to driving the regional models with large-scale information from this GCM rather than from observations.

- The third set of simulations will be identical to the second except that initial and boundary data will be taken from Hadley Centre output for future climate perturbed by increased greenhouse gases and by aerosol effects (Johns et al. 1997). Comparison of these results with the preceding two sets allows us to interpret the projected regional climate change in light of the errors induced both by the regional models and by the use of the GCM-supplied initial and boundary conditions.

Codes to develop the regional model boundary conditions from the NCEP/NCAR reanalysis data and the Hadley Centre GCM output have been developed. The NCEP reanalysis output is available at NCAR. We have received and processed 10 years of the Hadley Centre results for both the control climate and CO2/aerosol scenario, and soon will receive another 10 years. Additional datasets describing topography, land use, ocean and lake surface temperature have been assembled.

We will use standard statistical measures such as threat scores and pattern correlations in addition to means and higher-order statistics (e.g., Takle and Mearns 1995) to evaluate simulation accuracy for mean behavior, spatial and temporal variability, and extreme events. Additional diagnostics will be computed in order to evaluate whether the regional climate model is appropriately coupled to the observed or GCM-supplied climate (as in Jones et al. 1995). The results will provide an ensemble estimate of simulation accuracy through comparison with observations. This information will help place bounds on types of impacts assessments that can be reasonably attempted using current models. Output analysis may also indicate immediately fruitful avenues for model improvement. Close consultation will be maintained with model developers to correct any anomalous behavior that should arise during the extended simulations.

D.2.3. Interactions with impacts assessments

The physical climate simulated by a mesoscale model provides input into impact assessment models such as agricultural, water resources or human-health models. This is the most direct and immediate use of mesoscale climate simulation. Numerous examples exist of such assessments using global models, which can guide mesoscale-model applications. Output archives for the simulations will be created in ongoing consultation with impacts assessors to ensure that we are archiving the most appropriate data. We will make output available in a timely manner so that impacts assessments for the IPCC Third Assessment Report can start as soon as possible.

The Principal Investigators conducted a workshop, “Interfacing Mesoscale Climate Models with Impact Assessment,” held 5–6 December 1996 at NCAR (supported by the Electric Power Research Institute, EPRI). The workshop provided important guidance for developing regional climate simulations and output archives that support impacts assessment. Among the specific recommendations made by the impacts assessors was a consensus that increased computational resources would be better devoted to longer simulations than to improved spatial resolution, so long as the horizontal resolution is not much coarser than about 50 km. Interactions with the impacts community are continuing in part through collaboration with a parallel statistical downscaling project led by T. Wigley and R. Wilby at NCAR. PIRCS will work with WGNE and other oversight groups to establish standards, procedures, and templates for intercomparison experiments and collaborative research programs.

D.2.4. Interactions with PIRCS and other modeling programs

The project proposed here is a part of a larger effort, the “Project for Intercomparison of Regional Climate Simulations” (PIRCS). The mission of PIRCS, as established by the First PIRCS Workshop (Takle 1995), is to advance the status of regional climate modeling by evaluating the strengths and weaknesses of limited-area models and their component procedures through systematic comparative simulations. PIRCS consists of an on-going series of intercomparison experiments using different regions of the world and different time periods. The first PIRCS experiment is an intercomparison using the same domain as in the present proposal but for shorter periods, specifically 60-day simulations during the 1988 drought and 1993 flood over the central U.S. Preliminary results for the first experiment have been obtained by nine modeling groups from North America, Europe and Australia. The PIRCS web site is located at http://www.pircs.iastate.edu.

PIRCS is a project of the International Institute of Theoretical and Applied Physics (IITAP), which is sponsored jointly by UNESCO and Iowa State University. Additional support for PIRCS (and the primary support for the mesoscale climate simulations) is provided under a contract from the Electric Power Research Institute (EPRI). PIRCS is also coordinating its activities with other international programs such as the Comparison of Mesoscale Prediction and Research Experiments (COMPARE), GEWEX (specifically GCIP), AMIP and the Working Group on Numerical Experimentation (WGNE) of the World Climate Research Program. The WGNE has appointed Dr. Andrew Staniforth to serve as liaison between the WGNE and PIRCS and to promote interaction between PIRCS and COMPARE (WGNE 1996). We also are maintaining close contact with related efforts in regional climate modeling and downscaling of climate projections, such as the European Community MERCURE project.

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E. Computing Requirements

E.1. Computing resources needed:

Estimated computing resources are approximately 100 C90 hours per year of simulation for the RegCM2 runs on the domain we intend to use. The 20-year runs would thus require 2,000 C90 hours for a single scenario. The RAMS runs would require computing resources about 50% larger than RegCM2. Combining both models for all three scenarios, plus some allowance for test runs we request 18,000 C90 CPU hours.

E.2. Machine preference

We request the C90 for this project. The RegCM2 and RAMS models are not parallelized (although experimental parallel versions of RAMS exist). Therefore each of the models will be run on a single C90 processor and will not be run in a parallel-processing configuration. In order to reduce wall-clock time, the models (RegCM2 and RAMS) and scenarios can be run simultaneously on independent processors.

E.3. Memory, output and analysis

Each simulation requires about 8 MW of memory. Output is about 18 GB per year. Most of the quantitative analysis will be performed at NCAR. The output also will be written on magnetic tapes and transferred to Iowa State University where data can be visualized using tools such as Vis5D.

E.4. Utilization of request

Utilization will begin immediately upon allocation of the request, as the RegCM2 model has already been implemented on Cray systems and the boundary-condition (reanalysis) data are in hand. RAMS will require setup on the Cray and those runs are projected to begin in June 1998.

E.5. Expected completion date:

31 December 1998

E.6. Milestones:

Contractual obligations from the research sponsor (EPRI) require us to have the simulations completed by the end of the contract (December 1998). There is some flexibility in our schedule in that both models have restart capabilities; thus, the use of the C90 allocation need not be continuous, and we can work around other projects that may require all processors on the machine.

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