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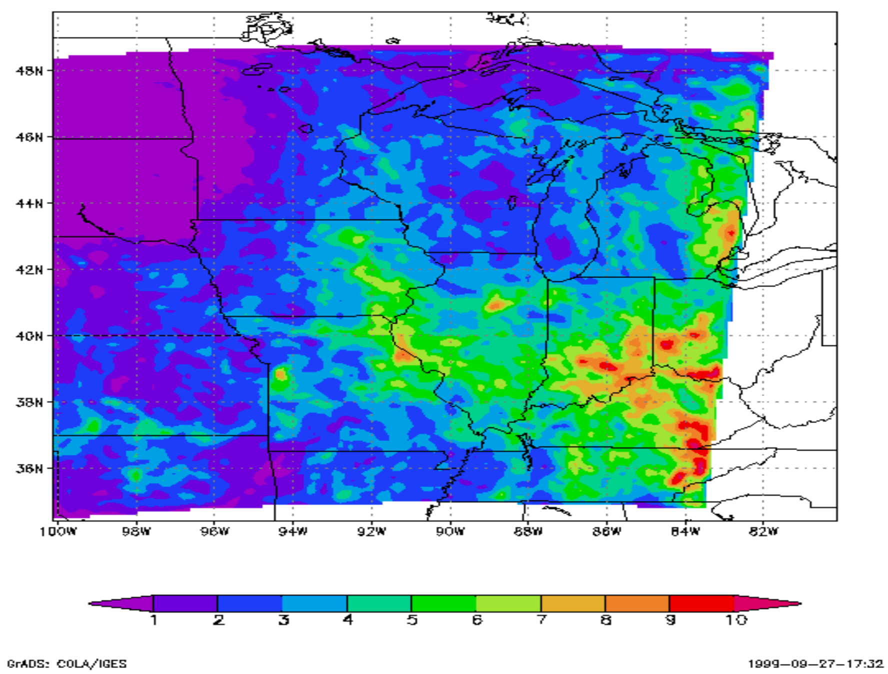
Workshop Report

Bridging the Climate Information Gap

held at Argonne National Laboratory
September 29, 1999

by

John Taylor



Mathematics and Computer Science & Environmental Research Divisions

Argonne National Laboratory

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Preface

This document summarizes the discussions held at a one-day workshop at Argonne National Laboratory on the topic of *Bridging the Climate Information Gap.* The meeting provided an opportunity for open discussion by scientists with an interest in regional climate science and in downscaling global climate model output for use in climate impact assessment for the Midwest and Great Plains. More than forty experts in the fields of regional climate science and high-performance computing attended the meeting and undertook discussions in five working groups. This document provides a record of those discussions; it is not intended to be a comprehensive summary of the field of regional climate science. Comments on the content of this document are welcome.

John Taylor

Argonne National Laboratory

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Introduction

In a recent report entitled *The Regional Impacts of Climate Change*[1] it was concluded that

> [T]he technological capacity to adapt to climate change is likely to be readily available in North America, but its application will be realized only if the necessary information is available (sufficiently far in advance in relation to the planning horizons and lifetimes of investments) and the institutional and financial capacity to manage change exists.

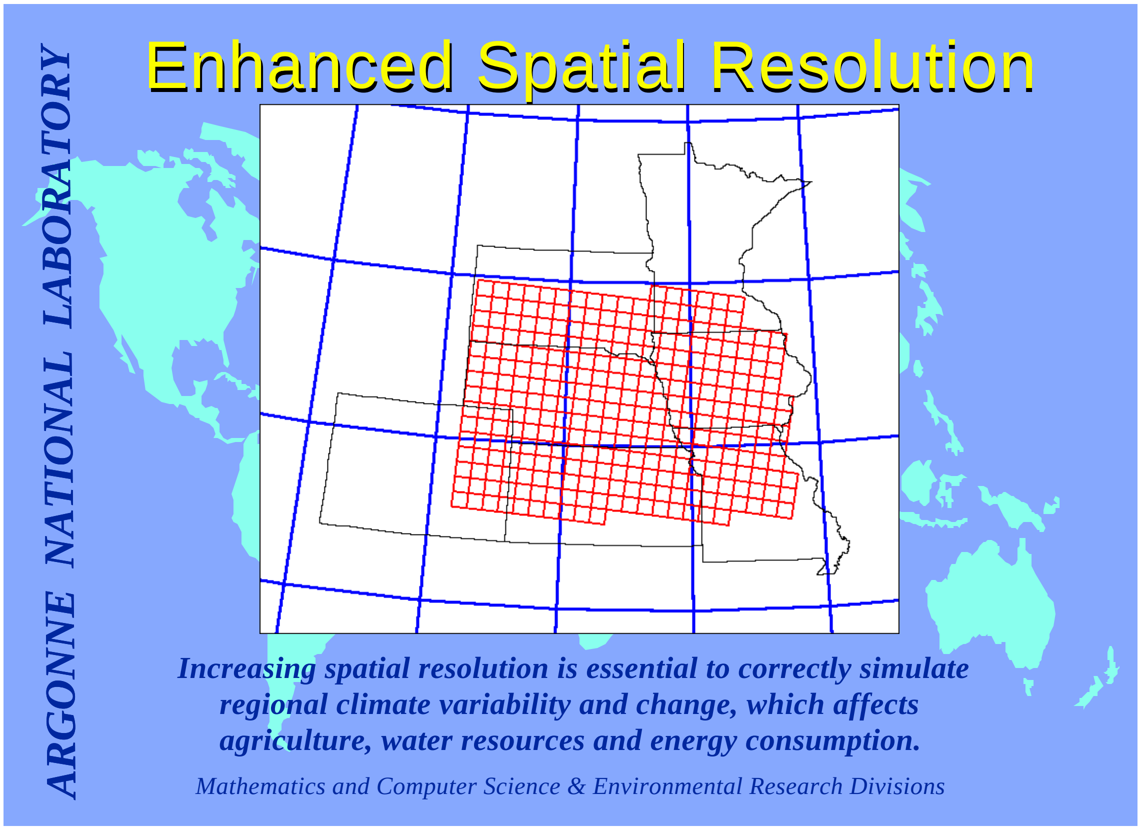
The report also acknowledged that one of the key factors that limit the ability to understand the vulnerability of subregions of North America to climate change, and to develop and implement adaptive strategies to reduce that vulnerability, is the lack of accurate regional projections of climate change, including extreme events.[1] In particular, scientists need to account for the physical-geographic characteristics (e.g., the Great Lakes, coastlines, and mountain ranges) that play a significant role in the North America climate and also need to consider the feedback between the biosphere and atmosphere.[1]

The potential impacts of *global* climate change have long been investigated based on the results of climate simulations using global climate models with typical model resolutions on the order of hundreds of kilometers. However, assessment of the impacts of climate change at the *regional* and local level requires predictions of climate change at the 1-10 kilometer scale. Model predictions from global climate models with such high resolutions are not likely to become widely available in the near future.

Accordingly, researchers at Argonne National Laboratory have begun a program to develop and use regional climate models that lead to high-quality projections of regional climate at kilometer resolution; the focus is on the U.S. Midwest. These regional climate projections can be used both at Argonne and by the wider research community to assess the vulnerability of the U.S. Midwest to climate change; in turn, such assessments can be used by policy makers to develop appropriate response strategies.

Regional climate models typically are nested within a global climate model. The figure below illustrates the principle of nesting a regional model within a coarse-resolution global model.

[1] Intergovernmental Panel on Climate Change (IPCC), The Regional Impacts of Climate Change, R.T. Watson, M.C. Zinyowera and R.H. Moss (Eds.), Cambridge University Press, Cambridge, UK, 1998.



Background to the Workshop

In conjunction with the Argonne effort to develop regional climate models, Argonne scientists are working to establish a Regional Collaborative Climate Center (RCCC). The primary objective in establishing such a center is to link the predictive global climate modeling capability with the impact assessment and policy-making communities. The primary technical challenge is to downscale global climate model output to the regional scale. The focus area is the Midwest and Great Plains region of the United States.

The necessary ingredients for a regional climate collaboration center include the following:

- A digital library for Midwest regional climate model data and derived information.
- A curator of this digital library providing a center of expertise enabling quality control, archiving, and annotation.
- Computational resources for regional runs and selected global runs, generating downscaled and other derived data products.
- A collaboratory for multidisciplinary research across multiple institutions.

- Support, including networks; state-of-the-art downscaling tools; consulting; and engineering support for construction, operation, and continuing development of the center.

The intended users of the center are climate change researchers and members of the impacts analysis and assessment communities. These users must be able to perform large-scale processing of numerous, diverse, very large, and relatively raw data sets, to distill regionally significant information and to fulfill requests for information by policy makers. We assume most users will bring a high degree of problem-specific knowledge but will possess varying proficiency with computational, data handling, analysis, visualization, and remote access technologies.

In addition to these primary users, the center will engage other users, for example, students and educators at the university as well as K-12 levels studying climate change.

Since many of these users will be accessing the RCCC remotely, the center should be implemented as a *virtual facility.* The center should support a mix of computation and data access for unique runs and should be transparent with regard to how and where operations are performed, while ensuring adequate performance and appropriate levels of authentication and security.

The planned focus of efforts at the RCCC is as follows:

- Development of state-of-the art software tools for assessing the local-scale effects of climate change and climate variability, using the unique combination of scientific, technical, and advanced computational resources available at Argonne, in collaboration with leading researchers in the Midwest and Great Plains.
- Information dissemination via specialized quality assured data products delivered over the Web.
- Expert assistance to the assessment community and to government and private-sector decision makers.
- Service to the assessment community by providing them with the tools, products, and information they require for their assessment work.

Outreach is intended to play a central role in the climate center activities. At Argonne we are particularly interested in assisting the scientific community working on Midwest and Great Plains climate issues. Accordingly, we arranged a meeting at Argonne National Laboratory entitled “Bridging the Climate Information Gap.” The meeting provided an opportunity for open discussion by scientists with an interest in studying regional climate science and in downscaling global climate model output for use in climate impact assessment for the Midwest and Great Plains. Specifically, the purpose of the meeting was threefold:

- Identify the key scientific uncertainties associated with downscaling Global Climate Model (GCM) output for use in climate impact assessment for the Midwest and Great Plains.

- Determine how these uncertainties could be addressed, in both the short term and the long term, in order to improve regional climate prediction.
- Formulate a mandate for Argonne’s role in delivering downscaled climate projections for impacts assessment, providing computational infrastructure, and serving the academic research community needs.

Approximately forty researchers from laboratories and universities nationwide attended the workshop. The participants were divided into five working groups, as follows (the chairpersons are given in parentheses); for further information, see Appendixes 1 (the workshop schedule), 2 (a list of workshop participants), and 3 (the working group members).

- Downscaling (John Taylor and Linda Mearns)
- Hydrology (Bob Oglesby and Jay Larson)
- Energy (Rao Kotamarthi and Don Wuebbles)
- Planetary Boundary Layer (Marv Wesely)
- Computing (Ian Foster and John Michalakes)

Each working group was asked to address the following points:-

- *Long-term goals* reflecting the key scientific and computational issues that need to be addressed in order to advance our ability to downscale the output of global climate models and to deliver that data to the impact assessment community for use in future national assessments.
- *Immediate goals* based on currently available resources (i.e., a list of high-priority tasks that we might begin working on over the next year).

The next section of this document presents the report of each working group. The last section summarizes the results and presents conclusions about Argonne’s role in establishing and operating a regional collaborative climate center for the Midwest.

Working Group Reports

Group 1: Downscaling

Long-Term Goals

The Downscaling group identified five areas of long-term research: downscaling methods, uncertainties in regional climate modeling, candidate regional climate models, data management issues, and regional climate runs.

(i) Downscaling methods

It was recognized that two key approaches to downscaling would provide the basis for a Midwest Regional Collaborative Climate Center at Argonne: physically based modeling; and statistical/empirical-based modeling.

Physically based modeling involves the development of regional climate models appropriate to the region of interest. For the Midwest a regional climate must include a set of physical parameterizations for processes associated with the influence of the Great Lakes, land surface parameterizations, improved representation of the planetary boundary layer, and radiative transfer that can take into account the role of particles.

Statistical/empirical-based modeling may also play a role in downscaling global climate model (GCM) output. A wide range of approaches to statistical modeling are available, and their suitability for downscaling over the Midwest needs to be investigated. Statistical-based methods would be limited to a few key climate variables for which adequate data sets of observations were available for calibration purposes. Very few comparisons between statistical/empirical and physically based downscaling have been undertaken to date, and such comparisons will be needed in the long term.

It was also recognized that downscaling could be both linear, in that it distributes the larger scale global climate model averages at a finer scale, and nonlinear, in that the GCM provides the boundary conditions to a regional climate model, which generates a nonlinear downscaling by taking into account the physical, biological, and chemical processes at a much finer scale than the parent GCM.

(ii) Uncertainties in regional climate modeling

The following were identified as key uncertainties that would need to be addressed in the development of a regional climate model for the Midwest:-

- pinup,
- ability to do long-term simulations,
- quality of GCM inputs,
- climate drift,
- consistent physics, and
- lateral boundary conditions and two-way nesting.

A key concern was the quality of the GCM inputs and their role in determining the ability of regional climate models to produce reliable predictions of climate change. Supported by lessons learned from PIRCS (summarized in the box below), the group emphasized the importance of continued development of GCMs in providing improved boundary conditions for regional climate modeling over the Midwest.

(iii) Regional climate models

Possible candidates to provide the basis for the development of a regional climate model for the Midwest include the following:

- NCAR MM5v2 mesoscale model
- NCAR MM5v3 nonhydrostatic mesoscale model
- RegCM2 hydrostatic regional climate model
- ARPS storm prediction model

The NCAR MM5v3 modeling system was considered the most appropriate basis for commencing development of a new generation of climate models. It was also recognized

Lessons from PIRCS

***Precipitation prediction needs improvement*:**

- **Orographic effects tend to be handled well**
- **Subtler dynamics are handled less well**
- **Problem areas: Deep South in cool season, central U.S. in warm season**
- **Snow and snow melt are problematic, but an important climate signal**

***Multiple models are needed*:**

- **Model-to-model spread is large**
- **"Naïve ensemble" gives good results**

that considerable experience has already been gained using MM5v2 and RegCM and that model comparisons will play an important role in establishing the uncertainty associated with downscaled climate model predictions. Nevertheless, the group emphasized that performing regional climate simulations at 1-5 kilometer resolution must be regarded as a new research frontier.

(iv) Data management issues

In the long term, a wide range of data products will be needed. Examples include the following:

- Raw GCM data sets used as input to regional climate model runs
- Monthly means and variances of GCM inputs

- Reanalysis data sets
- Regional climate simulation data sets
- Monthly means and variances of regional climate simulation data sets
- Observational data sets in a form appropriate for comparison with regional climate model simulations

To ensure accessibility, these data sets must be made available over the Web via interactive tools for analysis, display, and downloading.

Achieving the best possible data quality for regional climate simulations will necessitate several tasks:

- Using multiple-input GCM boundary conditions for regional climate model simulations
- Achieving an appropriate level of model testing against observations
- Performing model comparisons
- Maintaining "best practice" in performing model simulations based on prevailing U.S. and international standards
- Carrying out peer review of the conduct and output of regional climate simulations

(v) Duration of regional climate runs

Current computing resources allocated to regional climate modeling in the United States allow regional climate runs up to 10 years at 50 km resolution, but not on a routine basis. In the long term, the following needs have been identified:-

- Ability to perform high-resolution (<10 km) model runs for 10+ years *routinely*
- Ability to perform long model runs driven by GCMs for 100+ years (e.g., 2000-2100)
- Ability to perform model runs for the duration of available reanalysis data sets 50+ years for the purpose of model evaluation
- Ability to perform ensemble runs

Given the uncertainties noted above, a wide range of sensitivity studies will be needed in order to evaluate and improve the quality of the downscaled climate projections. This translates into the need for a substantial increase in computing resources available for investigating the performance of regional climate models and for downscaling the output of GCMs.

Immediate Goals

In the more immediate term, four research goals were deemed feasible and of high priority: downscaling experiments with MM5v3, additional experiments, statistical downscaling, and development of analysis tools.

(i) MM5v3 downscaling experiments

An initial experiment was proposed that would build on the existing PIRCS effort. Specifically, model runs for the period 1978-1988 have been completed with the RegCM2 and HIRHAM regional climate models for the Midwest at a nominal 50 km resolution. It was recommended that

- This experiment be repeated using MM5v3 with a 50 km grid over the entire continental United States, 23 vertical levels and 100 mb model top, variable SST and NCEP/NCAR 6 hourly reanalysis as boundary and initial conditions for MM5v3.
- The results of this experiment be compared with RegCM2 and HIRHAM and with the observational data already available.
- A nest at ~17 km resolution be added in order to assess the benefits of using a finer spatial resolution.

Sensitivity studies could also be undertaken with and without the OSU land-surface model and with the Grell and KF convective precipitation schemes. Extending the lateral boundary relaxation conditions will also require investigation; it was proposed that this experiment be undertaken using the ARPS model.

The box below summarizes current plans for the development of MM5v3 by NCAR for application to regional climate simulations.

Short-Term Research Goals for MM5v3

- Continue improvements to land-surface model
- Implement RRTM longwave radiation and better shortwave scheme
- Put in variable SST as lower boundary condition
- Add 1-d lake model
- Generalize surface/LSM/PBL components for increased flexibility in linking PBL and LSM options
- Adapt preprocessing to handle climate model output – a standard input format for MM5v3 system exists already
- Evaluate model in long-term simulation driven by historic reanalysis data sets

(ii) Additional experiments

The experiment described above could usefully be extended to include additional lateral boundary condition data sets derived from reanalysis projects and global climate models after completion of the first phase of experiments. The following high-priority lateral boundary condition data sets were identified:

- NCEP – II reanalysis data
- ECMWF reanalysis data
- NCAR Climate Systems Model (CSM) six-hourly input data for the period 1980-1998 for comparison with RegCM2.
- HADCM2 six-hourly data

Performing ensemble runs was also recognized as an important tool for model evaluation. However, available resources currently limit our ability to undertake ensemble experiments.

(ii) Statistical downscaling

A useful first step would be to undertake a comparison of regression, condition models, and neural net approaches commonly applied in statistical downscaling.

Further development of analysis tools for working with the output of regional climate simulations was also identified as a priority for enhancing productivity. It was proposed that useful short-term activities would be to

- evaluate the utility of existing packages (e.g., PCMDI developed at LLNL),
- investigate new tools under development (e.g., GSP project at NCAR), and
- build Web-based analysis tools.

Group 2: Hydrology

Long-Term Goals

The Hydrology group identified two major long-term scientific objectives, each of which also has major implications for impact assessment and policy/decision making:

- *Prediction of water levels in the Great Lakes*. Lake levels can have a strong impact on shipping, recreation, and other important uses of the lakes. Previous studies have suggested lake levels are likely to drop with greenhouse warming, but it remains unclear by how much (or whether it will happen at all). These changes could occur during the coming century as current expectations call for a doubled CO_2 by 2070.
- *Agriculture*. Of particular interest are the effects of increased CO_2, which could dramatically affect both the amount of water available and the water demand through

enhancing evapotranspiration needs. One important aspect concerns a northward shift of the mean position of the jet stream, which could lead to increasingly dry weather in the southern part of the Midwest, and wetter weather in the upper Midwest. Another major concern is a possible link between reduced snow cover (due to warmer winters) and reduced amounts of soil water in late spring and summer, which could exacerbate any reduction in precipitation. Long-term impacts on ground water aquifers can also be important, especially to the Great Plains, though such changes are difficult to model. Much of the western Midwest and West rely on irrigation for agriculture; precipitation over distant catchments (e.g., mountain snow) is of importance.

The group also developed a model evaluation strategy that has two key components aimed at an overall assessment of model uncertainties:

- Assessment of how well the model simulates the present-day climate by making a comparison of model results with station or remote-sensing data.
- Comparison of model results for specific time periods of the past several thousand years, with climate data derived for those time periods from the geological record.

To undertake the first activity, the regional model (MM5) must be run for an appropriate Midwest domain, with NCEP, ECMWF, and/or DAO reanalyses providing the lateral boundary forcing. The domain has yet to be defined; but to accomplish the overall goals, it must contain at least one of the Great Lakes. Thus the initial domain will likely cover the upper Midwest region. After appropriate evaluation, the regional model will be forced at the lateral boundaries using a GCM (most likely the NCAR CCM). This is the same global model that will ultimately be used for climate change scenarios.

Two components are involved in the second activity. The first of these addresses questions of historical variability. GCM runs over the past 1000 years (currently being made at NCAR and elsewhere) will provide the boundary forcing, with historically appropriate land-use changes imposed. Examples include 17^{th}-18^{th} century runs with MM5, the medieval warm period from A.D. 1000 to A.D. 1400, and the “Little Ice Age” of the late 1600s. The second element involves study of paleoclimate (i.e., time periods previous to the historical record) for which geologic reconstructions for the upper Midwest are well known. An obvious example is simulations for 3k, 5k, 6k, 7k, 9k BP, for which considerable prior global modeling exists and for which extensive geologic reconstructions have been made.

Ultimately scientists will be moving toward simulations of possible future climatic change (e.g., under an enhanced greenhouse world), so that the two long-term scientific objectives can be realized.

Six other long-term issues meriting future work were identified during the meeting:

- Coupling of ocean and atmosphere models and regional models to better simulate and understand long-term low-frequency variability.
- Differentiation of “quality” – that is, distinguishing a good simulation from a bad simulation.

- Data assimilation. Will it be possible, and desirous, to develop a regional data assimilation system analogous to what is currently done with global models to create analysis and reanalysis data sets?
- Severe events: These are of obvious importance, but a strategy must be defined for how to use model simulations to determine what sorts of severe events might be expected, and some estimate of their probability of occurrence.
- Ground water. This topic is clearly important for the western part of the Midwest region, which depends on ground water for irrigation and other water uses. The time scales are longer than those of mesoscale weather; nevertheless, it should be possible, ultimately to model ground water.
- Sensitivity to climate change off-line using RCM output.

Immediate Goals

Our short-term goals for the next year are aimed at developing and implementing a regional model system that is capable of simulating climate for the upper Midwest, including the Great Lakes. The proposed region has yet to be defined fully, but is likely to be based on the north-central region of GCIP. Focusing on this limited-scale area will enable researchers to take advantage of the tremendous amount of work already being done for this region through GCIP; three members of the Hydrology team (Oglesby, Marshall, and Lapenta) are also current GCIP principal investigators.

The following are needed for model development:

- A dynamical model for Great Lakes. AVHRR data exist for lake surface temperatures that could be used to initialize the lake model. Also required is a comprehensive study of thermal structure of Lake Superior, yielding lake-water temperature distribution in the Great Lakes. While work is already under way on this, a certain amount of support (~$200k / yr) would greatly expedite this undertaking.
- Study of different land-surface packages in MM5V3, with an emphasis on how well the surface and subsurface hydrology is handled. Examples of such land surface packages include BATS, LSM (NCAR), and OSU.

Two factors must be kept in mind as this preliminary regional model run is designed and implemented:

- Research must be coordinated with GCIP to avoid duplication of effort.
- BC’s should be taken from NCEP II (not NCEP I) reanalysis. This should serve as forcing for the first, prototype run. ECMWF can be used next (holding off on DAO until their next reanalysis).

If the necessary model developments are successfully undertaken, researchers should be able during the coming year to make an initial five-year run for the upper Midwest domain, using MM5v3 and the most suitable land surface package, forced by NCEP II.

Group 3: Energy

Long-Term Goals

The Energy group identified five primary objectives: (1) assessing energy consumption and generation scenarios over the next 100 years for the Midwest; (2) developing and collecting greenhouse gas source/sink estimates on a local scale; (3) developing and collecting emission scenarios for precursors of air pollution and aerosols on the local scale; (4) performing assessment calculations to evaluate the impacts of these emissions on climate and the effect of climate change on these estimates; and (5) preparing impact assessments for the regions' air quality, agricultural production, and human health

(i) Energy production/consumption

Development of energy consumption/production scenarios is a crucial task because of the proposed energy utilities deregulation and the possible decommissioning of aging nuclear energy generation infrastructure that generates a significant portion of the current Midwest energy supply. The choices made for future energy generation could dictate the location of the power plants and, as a result, the emissions of greenhouse gases and air pollution precursors in the region. The group identified potential parties that may be actively pursuing this task, including some at Argonne. It was agreed that the relevant parties, starting with those located inside Argonne, should be included in future meetings and a discussion started with them immediately. Moreover, in developing and assessing currently available modeling frameworks for estimating regional energy requirements and consumption, consideration should be given to the impact of decisions made on a countrywide and international scale. There should be feedback from these model outputs into the global-scale models, in order to develop realistic assessment scenarios.

(ii) Greenhouse gas budgets

Developing tools for detailed analysis of greenhouse gas emissions and sinks on a local scale was considered a necessary priority for the center. In this context, the center could emulate the work performed by the Iowa Department of Natural Conservation in developing greenhouse gas sink/source estimates to the level of local farms. The focus of the Iowa effort was to develop policies to make that state a net zero greenhouse gas emitter. This type of inventory-making capability should be acquired by the center and a demonstration performed to show that better decision making would result from better tools.

(iii) Integrated assessment modeling

The most effective tool the center could develop to serve users across a broad cross-section of society, from research scientists to policy makers, is an integrated assessment model. These types of models are frequently used in the IPCC assessments on a global scale and integrate across a range of process-scale models representing energy production, consumption, emissions, and impacts of greenhouse gases and pollutants. Such models provide an excellent opportunity to study the feedback between climate and the biosphere, atmospheric trace gas abundance, and the energy production/consumption in various sectors of the economy in an integrated framework. The development of integrated assessment tools is still in its infancy, and the center could make a strong bid for leadership in this area..

(iv) Science issues

Science issues of interest include the impact of further urban sprawl on oxidants and aerosols, effects of land use change on regional climate, and impacts of agricultural practices on climate and chemistry. The relationship between energy use and agriculture, in particular, should be a focus of the center's science activities. Below is a list of science issues that were discussed:

- Agricultural activities, including emissions from agriculture, changes in land use, and changes in carbon sources/sinks at the level of farms as a result of climate change, and the effect of these factors on climate change itself. The group recommended that this area be a centerpiece of the RCCC's long-term research efforts.
- Regional air pollution and its impacts on climate, particularly in relation to aerosols.
- Particle emissions from the biogenic activity and the impact of climate change on the emissions.
- Effect of agricultural practices such as the use of nitrogenated fertilizers on regional-scale production greenhouse gases, ozone, and other oxidants and aerosols.
- Role of heterogeneous chemistry on aerosol surfaces in the production and loss of atmospheric oxidants.
- Impacts of climate change on biogenic emissions, regional-scale oxidizing capacity, and particulate production.
- Impacts of climate change on vegetation and ecosystems unique to Midwest.

(v) Modeling tools

The group identified the following process models to evaluate the energy-chemistry-biosphere-climate interactions on a regional scale:

- Emission estimates/models, to develop emission estimates of energy consumption for each sector of the economy
- Air pollution transport/chemistry models with gas-phase chemistry drivers and aerosol process modules
- Meteorology drivers and the development of couplers between meteorology models and chemistry/transport models
- Chemical boundary conditions drivers for the regional-scale model based on observations and global-scale CTMs
- Biogeochemical interface, including surface exchange models, biosphere models, and crop/agricultural models

Several of these models are available within the group, and it was decided to examine available options for the remaining modules.

(vi) Uncertainties

The following uncertainties were listed as items for consideration in the regional-scale modeling efforts described above:

- Downscaled temperatures and humidities. Temperature and humidity impact a wide range of chemical and biospheric processes, including emissions, reaction rates, particle formation, and oxidative capacity.
- Emission uncertainties due to errors in projections, partly resulting from uncertainties in climate model predicted inputs to emission models.
- Shortcomings in current understanding of physical/chemical/biological processes, such as deposition, washout, chemistry, and plant physiology.

(vii) Computing and data storage and handling

The following list of priorities was discussed at the meeting:

- Development of massively parallel versions of chemistry-transport and biosphere models.
- Runs of regional-scale models for the chemistry and biopshere on both seasonal and annual scales (rarely done at present).
- Development of fast visualization tools to analyze large databases of model outputs. Typically the outputs from these models could be 60 to 100 times larger than the mesoscale meteorological model outputs.
- Development of a database of measurements of trace gas concentrations on the regional scale.

Immediate Goals

In the short term, energy research should focus on GHG budgets and regional-scale assessment models.

(i) GHG budgets

Two activities were identified for immediate consideration:

- Check current modeling/accounting work done, with a focus on Midwest forecasting of carbon budgets.
- Determine what kinds of models are currently used, whether any will be readily available, and which downscaled products from the climate models will be useful for these models.

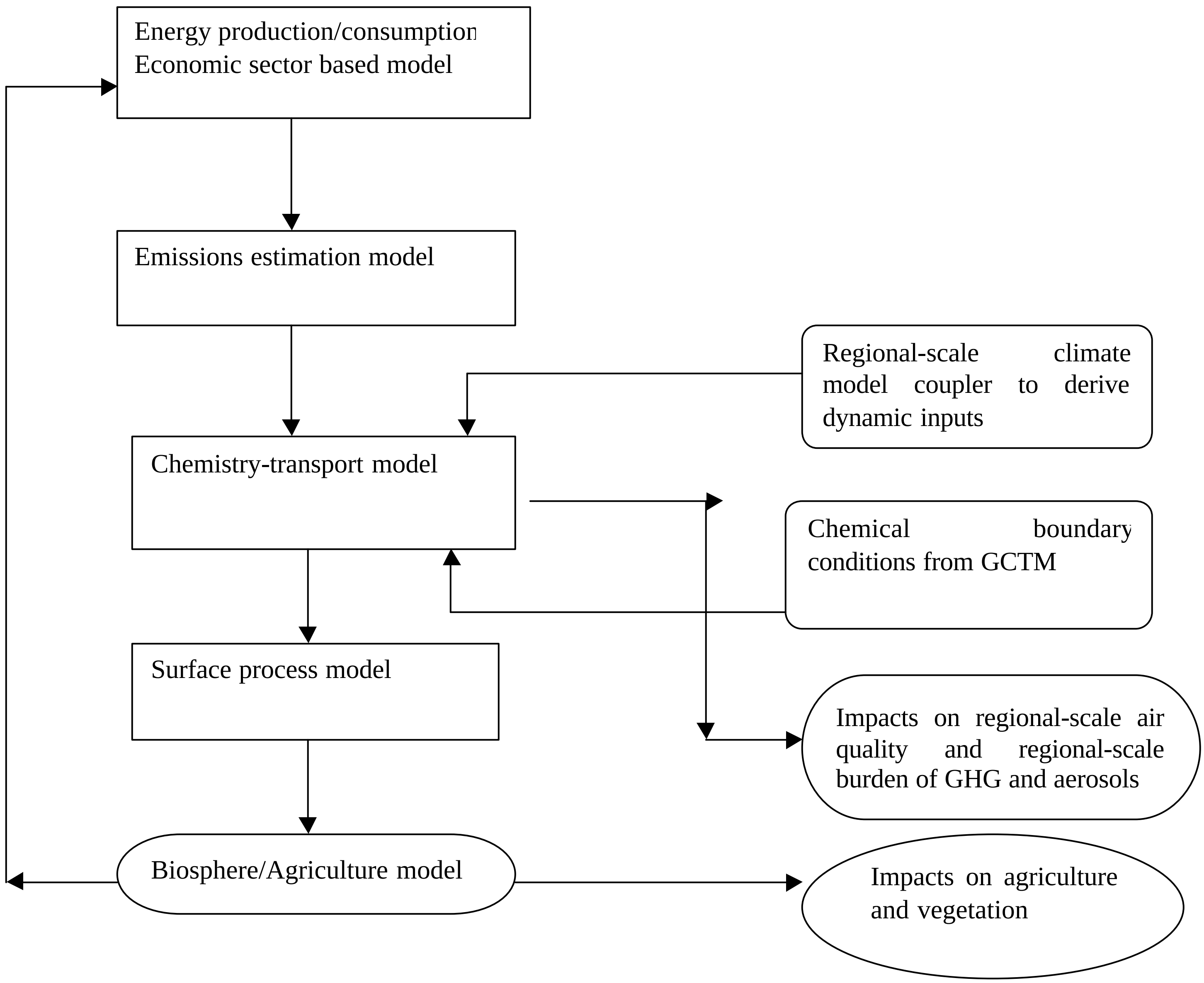
(iii) Integrated regional-scale assessment models

A prototype model calculation was recommended as a first step toward developing a comprehensive integrated assessment model for the regional scale. This calculation should involve development of interfaces between models calculating energy production/consumption based on sector analysis, an emissions calculation model that uses the output from the energy model to compute emissions of pollutants, and GHGs. This calculation in turn would feed into a chemistry-transport model linked to the regional-scale climate model to drive the model transport. The chemical model boundary conditions would be set from global-scale CTM outputs, by developing couplers between the regional-scale code and the GCTM. The RCTM would be connected to a surface process model with the capability of computing deposition rates and emissions from biosphere. The final step would link this model to a crop-nutrient-cycle model to calculate soil emissions and effects of deposition from the gas phase on the nutrient-cycle in the soil. The outputs would in turn be fed back to the energy component model to improve the decisions made on energy consumption/production in each sector of the economy, so as to minimize the impacts on the biosphere and air quality. The prototype would function with models readily available, and missing components would be filled with shell interfaces for the prototype calculation.

As a part of this process, the group identified the following issues to be analyzed and summarized in a report to be submitted by the end of next year:

- Sorting available modeling tools and identifying those most appropriate for the center
- Preparing data sets for model evaluation at the time and spatial scale necessary for the purposes of the center.
- Evaluating data on energy use and emissions, including models used to make projections.
- Identifying measurement needs to evaluate/validate the models
- Developing concepts for an integrated assessment model on a regional scale.

The figure below shows the proposed prototype calculation setup.



Proposed prototype calculation setup

Group 4: Planetary Boundary Layer

Long-Term Goals

Long-term goals for the planetary boundary layer (PBL) effort can be considered in three broad categories: service, data products, and research.

Service identifies the potential "customers," a useful consideration before defining research goals. These customers are involved in agriculture, hydrology, urban and regional planning, air pollution meteorology, ecology, economics, and research at a variety of private and government organizations.

Data products associated with the PBL include storm frequency, especially extremes in precipitation amounts; length of the growing season; extremes in winds (e.g., with regard to loading on buildings and soil erosion); extremes in temperature as they affect vegetation and soil freezing depth; and atmospheric stability as it affects the vertical and horizontal transport of trace substances. Parameters most directly involved with many of these data products are surface temperature, near-surface temperature and humidity, the diurnal variation of the PBL height and vertical density stratification, surface energy exchange, and local mesoscale circulations. Processes such as solar irradiance, water drainage, irrigation, and changes in land use patterns must also be considered.

Research necessary to ensure an adequate description of the PBL in regional climate scenarios requires both the accurate simulation or parameterization of PBL processes and the achievement of a sufficiently fine spatial resolution. The daytime PBL over homogeneous terrain with known properties is fairly well understood, but the effects of surface heterogeneity and of very stable conditions at night remain subjects of research. Models with high spatial and temporal resolution must continue to be developed. These models can be used to develop parameterizations for regional- and large-scale models or be used as nested models in regional-scale models. Also needed are intensive observations using both in situ and remote sensing systems. In addition, long-term observations are often necessary to examine the full range of conditions that occur throughout the year; data sets need to be made readily available to researchers. Such observations provide information necessary to improve PBL models and parameterizations and can serve as a benchmark for evaluating nested models.

To achieve fine spatial resolution, extensive data bases are needed on surface quantities such as soil moisture, vegetative types, green leaf areas, senescent vegetative coverage, agricultural practices, extent of urbanization, and fractional snow cover. Remote sensing data obtained from satellites provide an important source of such information, especially when used with surface stations for "ground truth." For example, mesoscale models require periodic updates on soil moisture conditions to avoid "drift" in simulate soil moisture content, which is important in affecting evapotranspiration rates and cloud formation, surface temperatures, and atmospheric stability. The nondimensional difference vegetation index, infrared temperature, and microwave surface brightness in the L-band are examples of parameters based on surface radiances detected from satellites that can used to estimate soil moisture content. However, because spatial variability in the surface properties can be large on very fine scales, often less than 200 m in the Midwest and the Great Plains, methods of aggregrating descriptions of surface properties are often necessary to provide effective inputs to regional- and large-scale models. Better methods of describing surface conditions such as aerodynamic surface roughness, surface energy balance components, soil moisture content, and surface temperature averages over scales spanning large changes in surface conditions need to be developed.

Immediate Goals

Several ongoing research efforts in which progress is possible during the next year or so were identified with regard to PBL processes:

- Use available data as a testbed for PBL models in the Midwest and Great Plains. For example, data from the Atmospheric Boundary Layer Experiments (ABLE) facility in Kansas are readily available for model developers.
- Develop methods of evaluating soil moisture content to minimize "drift" in modeled estimates such as made with MM5 by use of surface observations and estimates of soil moisture made with remote sensing data from satellites.
- Construct and assemble data sets on surface characterization for target regions. A current practical spatial resolution is about one kilometer.
- Suggest better coordination of data sets generated for the Midwest and the Great Plains. Opportunities for coordination might be presented in by efforts such as AmeriFlux, the Illinois State Water Survey's Water & Atmospheric Resources Database, the GEWEX Continental-Scale International Project, the Oklahoma Mesonet, and ABLE.
- Encourage comparisons of land surface models, such as through the Project for Intercomparison of Land-Surface Parameterization Schemes and the NASA Land Surface Hydrology Program.
- Develop "effective parameters" as an alternative approach to the "mosaic" approach to describe spatial aggregation of surface conditions.
- Continue research on vertical diffusion in the very stable nighttime PBL. Experiments conducted by the Cooperative Atmosphere-Surface Exchange Program in 1999 will provide an unprecedented amount of high-resolution data on the properties of the stable boundary layer.

Group 5: Computing

Argonne has been working closely with the NCAR Mesoscale and Microscale Meteorology Division, Pacific Northwest National Laboratory, and a number of collaborating institutions (see http://www.mmm.ucar.edu/mm5/CRCM) to develop a Community Regional Climate Model based on MM5, the fifth-generation Penn State/NCAR Mesoscale Model. The CRCM effort will fold previous MM-based Regional

Climate Models (RegCM, PNNL RCM, IFU RegCM) into a single community resource developed and maintained as part of the parallel MM5 community mesoscale model. Many capabilities for long climate-scale regional simulations already exist in MM5, including the ability to run on large distributed SMP-cluster parallel computers. Additional enhancements for regional climate are described in the table below; these include both long-term and short-term efforts.

Such enhancements will require significant computing capabilities. Currently, we estimate that a typical experiment will involve a number of computationally intensive and data-intensive runs of a regional climate model to downscale large global reanalysis or climate model data sets over a period of several months to years. The regional model would be run at significantly higher (and therefore more costly) resolution (3-10 kilometers per grid cell) than the input (50-200 kilometers). To achieve one year's simulation for a domain 1000 km square, a regional climate model run at 10 km resolution will require 40 Gflop/second sustained performance for 24-hour turnaround and will generate 50 Gbytes of hourly history output. To run the same domain at 3.33 kilometers resolution requires 27 times the performance, 1.1 Tflop/second, and generates 9 times the data volume.

We expect a more complete picture of computing and infrastructure requirements to emerge over time, as a result of interactions and planning with the scientific users,

Long-Term Goals

For the long term, we propose that the RCCC have at least enough dedicated supercomputer resources to support the equivalent of several (5-10) 10-year high-resolution (3 km or less) studies per year. In addition to computational requirements, the center will require multiterabyte data storage and archiving capabilities, presumably in concert within a larger DOE metacomputing infrastructure (e.g., the Earth System Grid project). Also required will be Web-enabled visualization and analysis software and hardware, desktop and workspace remote collaboration tools, network connectivity and bandwidth, quality of service, and secure access to support the virtual concept of the RCCC.

Short-Term Goals

The relatively modest requirements for a short-term (first-year) set of downscaling experiments (see Downscaling section) may be met by purchasing time on resources currently available to participating institutions:

- Argonne National Laboratory: IBM SP, SGI Origin, Beowulf cluster, HSM
- NCSA: SGI Origin, disk storage
- UNM: Beowulf Linux cluster
- NCAR: Alpha cluster, IBM SP, historical and simulated climate data sets

- U. Wisconsin/U. Chicago: coupled ocean/atmosphere simulation data
- Networks: MREN, vBNS
- Access Grid: ANL, NCSA, NCAR

Software resources available to support first-year center prototype goals include the following:

- Other models: FOAM, CCM3, Paleoclimate
- Pre-/postprocessors: RCM (CCM to MM5), standard MM5 and CCM software
- Analysis and visualization: Vis5D/AD, IDL, NCAR Graphics, PCMDI
- Data formats, converters: NetCDF, HDF5, GRADS, GRIB, …
- Portal tools and portals: MM5 Workbench, Java CoG Kit, EHAT software
- Data grid software, middleware: Globus, Earth System Grid
- Index, searching, resource discovery
- Collaborative software: VIC/VAT, Access Grid, NetMeeting

Short Term	Current Capability	Needed in CRCM	Provides	Effort
Improved Radiation	CCM2 RRTM (Longwave)	- CCM3 or equivalent shortwave	Radiation balance for long-term simulation	Modest
Subgrid Scheme	Available in PNNL RCM	Integrate and parallelize in CRCM	Complex terrain, surface types	Moderate to High
Lake Model	Available in RegCM and PNNL RCM	Integrate and parallelize in CRCM	Great Lakes, other large bodies	Modest
Land Surface	OSU / MRF	- VIC, BATS - Generalize PBL	Flexibility	Modest
SST	Part of lower boundary, read in initially	Periodic forcing	Long-term forcing with variable SST	Modest
Scalars and Tracers	Set moisture fields, No tracers	Arbitrary number of scalars/ tracers	Chemistry, etc.	Moderate

Long Term	Current Capability	Needed in CRCM	Provides	Effort
Chemistry	Available in Grell/IFU RCM	Chemical transport, reaction; Coupling	Aerosol impact on radiation balance, Urban climate	Moderate to High
Bio-geochemical	None	BGC (U. Montana), Others	Multi-year effect of/on Vegetation	High
Hydrological	Some, but no runoff	Runoff, coupling	Impacts assessment, Model evaluation	Moderate to High
Cloud Fraction	CCM2 (Marginal; Diagnosed from humidity)	Better diagnostic scheme; eventually predictive	Accurate radiation balance for long-term simulation	Diagnostic: Modest Predictive: High
Linkage to GCMs and global datasets	None	Generalize to other GCM's	Flexibility	Modest
Improved Numerics	Explicit time-split non-hydrostatic	WRF	Accuracy	High

CRCM Capabilities

Conclusions

Providing high-resolution regional climate information has long been recognized as critical information necessary for the assessment the impacts of climate change and to develop and implement adaptive strategies to reduce that vulnerability. The discussion, as reported above, provides a concise summary of the many high-priority scientific and technical challenges that must be addressed if region-specific climate information is to be used on a routine basis to assess the potential impacts of climate change on the Midwest. If the challenges identified above are to be addressed, then the development of strong interdisciplinary research programs and research teams that can provide comprehensive coverage of the scientific and technical issues is urgently, and inevitably, needed.

Appendix 1: Meeting Agenda

Bridging the Climate Information Gap
Argonne National Laboratory
September 29, 1999
Agenda

7:45 - 8:15AM	Shuttle van from Argonne Guest House Entrance to Bldg. 221 Lobby
8:00 - 8:30AM	Registration and Travel Reimbursement Coffee and Rolls
8:30 - 8:40AM	Welcome - *Rick Stevens*, Director MCS
8:40 - 9:00AM	Introduction to ANL Regional Climate Group & Meeting Objectives *John Taylor*, ANL
9:00 - 10:30AM	Working Groups - Long term scientific goals Downscaling - *John Taylor* - Bldg. 221-A216 Energy - *Rao Kotamarthi* and *Don Wuebbles* - Bldg. 203-C230 Water - *Bob Oglesby* and *Jay Larson* - Bldg. 221-A261 PBL - *Marv Wesely* - Bldg. 203-E142 Computing - *Ian Foster* and *John Michalakes* - Bldg. 221-C101
10:30-10:45AM	BREAK - Coffee in A216
10:45-11:30AM	Working Groups – cont.
11:30 - 12:30PM	Plenary Session - Long term scientific goals - Bldg. 221-A216
12:30 - 1:30PM	No Host Lunch - Dining Room A in Cafeteria - Bldg. 213
1:30-2:00PM	Regionalization Strategies for Climate Change Scenario Development: Perspectives from the IPCC Third Assessment Report (TAR)– *Linda Mearns*, NCAR
2:00-3:30PM	Working Groups - Immediate scientific goals Downscaling - *John Taylor* - Bldg. 221-A216 Energy - *Rao Kotamarthi* and *Don Wuebbles* - Bldg. 203-C230 Water - *Bob Oglesby* and *Jay Larson* - Bldg. 221-A261

	PBL - *Marv Wesely* - Bldg. 203-E142 Computing - *Ian Foster* and *John Michalakes* - Bldg. 221-C101
3:30-3:45PM	BREAK – Refreshments in A216
3:45-5:00PM	Working Groups – cont.
5:00 - 6:00PM	Plenary Session - Immediate scientific goals - Bldg. 221-A216
6:00PM	Adjourn - Shuttle van from Bldg. 221 Lobby to the Argonne Guest House

Appendix 2: List of Participants

Arritt, Raymond
Associate Professor
Iowa State University
3010 Agronomy Hall
Ames, Iowa 50011
rwarritt@iastate.edu
515-294-9870
515-294-2619

Carmichael, Gregory
Professor, Center for Global & Regional Environmental Research & Dept. of Chemical & Biochemical Engrg.
University of Iowa
204 IATL
Iowa City, IA 52240
gcarmich@icaen.uiowa.edu
319-335-3333
319-335-3337

Chen, Fie
Scientist-I
NCAR
3450 Mitchell Lane
Boulder, CO 80301-2260
feichen@ucar.edu
303-497-8454
303-497-8401

Dudhia, Jimy
Dr., MMM Division
NCAR
P.O. Box 3000
Boulder, CO 80307-3000
dudhia@ucar.edu
303-497-8950
303-497-8171

Evard, Remy
Manager of Advanced Computing Technologies and Networking (ACTN)
Argonne National Laboratory
MCS 221, 9700 S. Cass Avenue
Argonne, IL 60439
evard@mcs.anl.gov
630-252-5963
630-252-5986

Foster, Ian
Senior Computer Scientist
Argonne National Laboratory
MCS 221, 9700 S. Cass Avenue
Argonne, IL 60439
foster@mcs.anl.gov
630-252-4619
630-252-5986

Grimmond, Sue
Associate Professor
Indiana University
Dept. of Geography, Atm. Science Program
701 E. Kirkwood Ave
Bloomington, IN 47405-7100
grimmon@indiana.edu
812-855-7971
812-855-1661

Hammond, Steve
Head, Computational Science Section
NCAR
1850 Table Mesa Drive
Boulder, CO 80303
hammond@ncar.ucar.edu
303-497-1811
303-497-1286

Jacob, Robert
Research Associate, Dept. of Geophysical Sciences
University of Chicago
5734 S. Ellis Ave.
Chicago, IL 60637
rob@geosci.uchicago.edu
773 834-2788
773 702-9505

Jain, Atul
Dr., Dept. of Atmospheric Sciences
University of Illinois
105 South Gregory Street
Urbana, IL 61801
jain@atmos.uiuc.edu
(217) 333-2128
(217) 244-4393

Johnson, Tom
Director and Professor
Large Lakes Observatory
Univ. of Minnesota-Duluth
Duluth, MN 55812
tcj@d.umn.edu
218-726-8128
218-726-6679

Kotamarthi, Rao
Meteorologist
Argonne National Laboratory
Bldg. 203, J-177
9700 S. Cass Ave.
Argonne, IL 60439
vrkotamarthi@anl.gov
630-252-7164
630-252-5498

Kristovich, David
Professional Scientist
Illinois State Water Survey
Department of Natural Resources and
University of Illinois at Urbana-Champaign
2204 Griffith Drive
Champaign, IL 61820-7495
dkristo@uiuc.edu
217-333-7399
217-333-6540

Lapenta, William
Atmospheric Research Scientist
Global Hydrology and Climte Center
NASA
977 Explorer Blvd.
Huntsville, AL 35806
bill.lapenta@msfc.nasa.gov
256-922-5834
256-922-5723

Larson, Jay
Earth System Science Interdisciplinary Center
Univ. of Maryland
NASA
Code 910.3 - NASA GSFC
Greenbelt, MD
jlarson@dao.gsfc.nasa.gov
301-614-6246
301-614-6297

Larson, Sue
Associate Professor
University of Illinois
Dept. of Civil & Environmental Engrg., 3230
Newmark Cel, MC-250 N. Mathews Ave.
Urbana, IL 61801
smlarson@uiuc.edu
217-333-0047
217-333-6968

Liang, Xin-Zhong
Assoc. Professional Scientist
Illinois State Water Survey
Department of Natural Resources and
University of Illinois at Urbana-Champaign
2204 Griffith Drive
Champaign, IL 61820-7495
xliang@uiuc.edu
217-244-6864
217-244-0220

Marshall, Susan
University of North Carolina-Charlotte
Department of Geography and Earth Sciences-
9201 University City Boulevard
Charlotte, NC 28223
susanm@uncc.edu
704-547-3498
704-547-3182

Mearns, Linda
Scientist III
NCAR
P.O. Box 3000
Boulder, CO 80307-3000
lindam@ucar.edu
303-497-8124
303-497-8125

Michalakes, John
Software Engineer/Visiting Scientist
NCAR, MMM Division
3450 Mitchell Lane
Boulder, CO 80301
michalak@ucar.edu
303-497-8181

Moore, Thomas L.
Geologist
Energy Systems Division
Argonne National Laboratory
9700 South Cass Avenue – Bldg. 362
Argonne, IL 60439
tmoore@anl.gov
630-252-5856
630-252-9281

Nefedova, Veronika
Postdoctoral Appt
Argonne National Laboratory
MCS 221, 9700 S. Cass Avenue
Argonne, IL 60439
nefedova@mcs.anl.gov
630-252-5666
630-252-5986

Oglesby, Bob
Associate Professor
Purdue University
Dept. of Earth & Atmospheric Sciences
West Lafayette, IN 47906
roglesby@purdue.edu
765-494-9531
765-496-1210

Reilly, Chris
Director, Environmental Reseach
Argonne National Laboratory
ER 203, 9700 S. Cass Avenue
Argonne, IL 60439
creilly@anl.gov
630-252-3879
630-252-2959

Rowe, Clinton M.
Associate Professor
University of Nebraska-Lincoln
Dept. of Geosciences, 305C Bessey Hall
Lincoln, NE 68588-0340
crowe1@unl.edu
402-472-1946
402-472-4917

Salisbury, Chuck
Scientific Programmer
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439
salisbur@mcs.anl.gov
630-252-7573
630-252-6104

Schmid, Hans Peter (HaPe)
Assistant Professor
Indiana University
Dept. of Geography, Atm. Science Program
701 E. Kirkwood Ave
Bloomington, IN 47405-7100
hschmid@indiana.edu
812-855-6125
812-855-1661

Shepson, Paul
Professor
Purdue University
1393 Brown Building
West Lafayette, IN 47906
pshepson@purdue.edu
765-494-7441
765-494-0239

Sorbjan, Zbigniew
Res. Assoc. Professor
Marquette University
Dept of Physics
Milwaukee, WI 53201
sorbjanz@mu.edu
414-288-7458
414-288-3989

Stevens, Rick
Director, MCS Diviision
Argonne National Laboratory
Bldg. 221, A-209, 9700 S. Cass Ave.
Argonne, IL 60439
stevens@mcs.anl.gov
630-252-3378
630-252-6333

Taylor, John
Computational Scientist
Argonne National Laboratory
Bldg. 203, C-245, 9700 S. Cass Ave.
Argonne, IL 60439
jtaylor@mcs.anl.gov
630-252-4213
630-252-5986

Ting, Mingfang
Assoc Prof. UIUC/FRA at ANL
Argonne National Laboratory
Bldg. 203, J-158, 9700 S. Cass Ave.
Argonne, IL 60439
ting@anl.gov
630-252-1152
630-252-5498

Tobis, Michael
Research Scientist
University of Wisconsin
1225 W. Dayton St.
Madison, WI 53706
tobis@ssec.wisc.edu
608-263-2566
608-249-3321

Wesely, Marv
Senior Meteorlogist
Argonne National Laboratory
Bldg. 203, J-143, 9700 S. Cass Ave.
Argonne, IL 60439
mlwesely@anl.gov
630-252-5827
630-252-7164

Wilhelmson, Bob
Professor of Meteorology
University of Illinois
105 South Gregory Drive
Urbana, IL 61801
bw@ncsa.uiuc.edu
217-333-8651
217-244-4393

Wuebbles, Donald
Head, Dept. of Atmospheric Sciences
University of Illinois
105 South Gregory Street
Urbana, IL 61801
wuebbles@atmos.uiuc.edu
217-244-1568
217-244-4393

Xu, Yiwen
Posdoctoral Appt.
Argonne National Laboratory
ER 203, 9700 S. Cass Avenue
Argonne, IL 60439
yiwen_xu@anl.gov
630-252-6139
630-252-5498

Xue, Ming
Senior Research Scientist
University of Oklahoma
SEC, Rm 1110, 100 E. Boyd
Norman, OK 73019
mxue@ou.edu
405-325-6037
405-325-7614

Appendix 3: Working Groups

John Taylor
Downscaling
Arritt, Raymond
Dudhia, Jimy
Liang, Xin-Zhong
Mearns, Linda
Xue, Ming

Ian Foster
C*omputing*
Evard, Remy
Hammond, Steve
Jacob, Robert
Michalakes, John
Nefedova,Veronika
Salisbury, Chuck
Tobis, Michael
Wilhelmson, Bob

Bob Oglesby
Hydrology
Johnson, Tom
Lapenta, William
Larson, Jay
Marshall, Susan
Moore, Thomas
Rowe, Clinton
Ting, Mingfang

Rao Kotamarthi
Energy
Carmichael,Gregory
Jain, Atul
Larson, Sue
Shepson, Paul
Wuebbles, Donald

Marv Wesely
PBL
Chen, Fie
Grimmond, Sue
Kristovich, David
Schmid, Hans Peter (HaPe)
Sorbjan, Zbigniew
Xu, Yiwen