NCER Assistance Agreement Annual Report Summary

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Title: Implications of Climate Change for Regional Air Pollution, Health Effects and Energy Consumption Behavior

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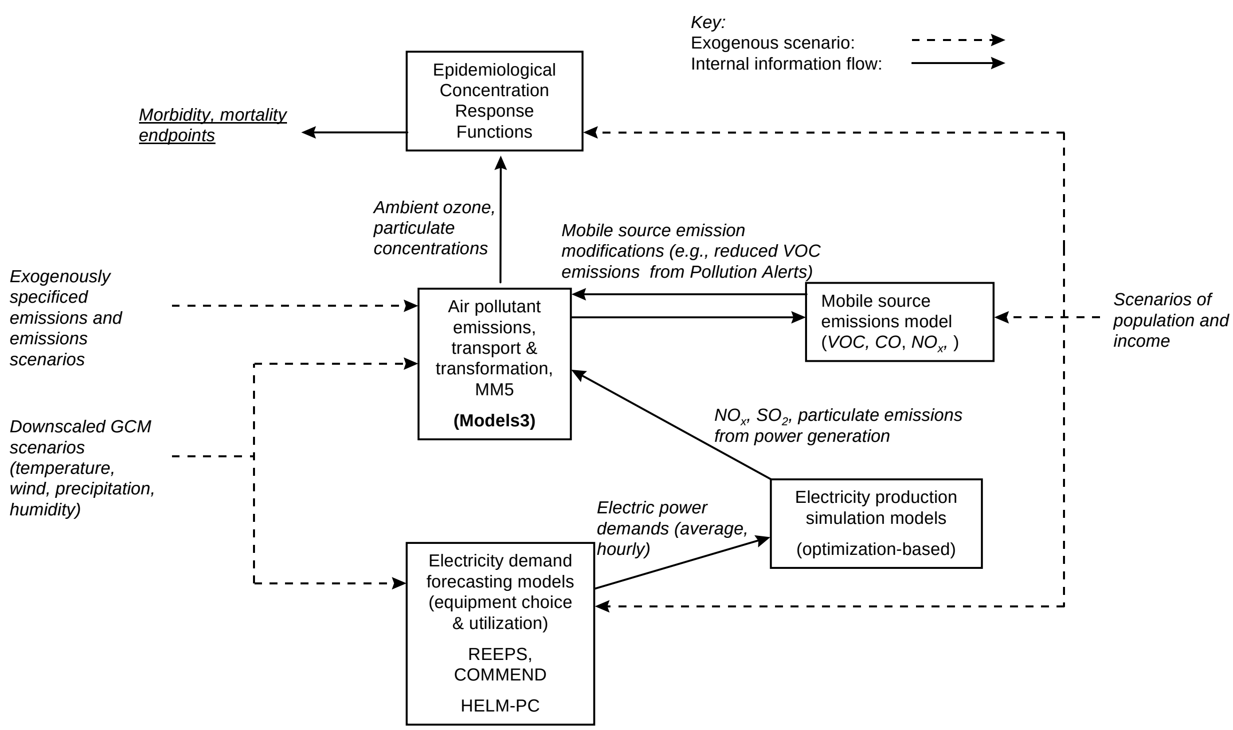
Institution: The Johns Hopkins University

Research Category: Assessing the Consequences of Interactions between Human Activities and a Changing Climate

Project Period: 02/08/2001 – 02/07/2004

Objective of Research: : This research program has four major modeling elements: climate change and variability, electrical energy demand and production, regional air pollution, and human health effects associated with air pollution exposure. Our overall objective is to develop a scientifically credible modeling facility that will help policy makers and analysts understand the effects of human activities on climate change and variability as well as the possible human responses and adaptations to climate change and variability. The overall connections among the modeling elements listed above are shown schematically below.



Progress Summary/Accomplishments: Progress is described below, divided into three categories, following the three main modeling activities.

Electricity Demand Modeling and Forecasting **– F. Joutz and Christian Crowley**

The focus of the energy demand section has been on short-run effects of climate change and volatility on energy consumption specifically electricity demand and motor vehicle miles driven. The role of climate change-driven effects on electrical energy demand and production is the focus of this modeling effort. We are undertaking two general tasks. The first requires detailed, disaggregated models that can link hypothesized climate change perturbations to specific demand effects in the residential and commercial sectors. This requires consideration of end-use equipment penetration, load shape forecasting, and creation of detailed (one-hour) short-term forecasts. The end-use and load shape forecasts will be used to explore general relationships between climate and energy use on a regional scale. These models will be used in developing long-term projections of human adaptation to climate change and variability. These projections will then be translated into hourly load forecasts that fully reflect the variability of loads and their correlations with the meteorological conditions that also affect pollutant transport and transformation. These forecasts will be used to analyze interactions between climate, pollution, and energy use on a detailed temporal scale. In the second general task, we will consider the impact of unique events and conduct econometric analyses of the effects of pollution alerts on hourly electricity usage.

In general, aggregate analyses have found that commercial and residential uses are much more sensitive to temperature increases than industrial uses, justifying the focus of this proposal on the former. These studies have usually concluded that climate warming would produce a few percentage point increase in cooling requirements, and a similar decrease in heating requirements (Scott et al., 1994; Morris et al., 1996; Sailor and Munoz, 1997); the canceling of the two effects often implies that the net impact on annual energy use may be relatively small (e.g., Darmstadter, 1993). As an example of such a study, Baxter and Calandri (1992) projected that a 1.9^{o} C warming would increase California's annual electricity requirements by 2.6%. What is more relevant, however, is how that change is distributed within the year. In particular, the greatest increases are likely to occur during weekdays during the air conditioning season, precisely at those times that tropospheric ozone violations occur. For instance, Baxter and Calandri's (1992) analysis indicates that their assumed 1.9^{o} C increase would magnify peak summer electricity demands by 3.7%. It is possible that the proportional increase during periods of high ozone may be even higher; however, no studies have analyzed climate's effect on energy demands on a fine enough temporal scale to consider this possibility. One of this project's purposes is to fill that gap.

The result of using load duration curves in a long-run production simulation model is a set of estimates of average cost and emissions by generating unit type for a given period of time. This will permit a general assessment of the strength of the linkage between regional climate change and emissions of criteria pollutants. However, because of the high correlation between time varying electricity demands (and thus emissions) and the meteorological conditions that influence ambient pollutant concentrations, the impact of that linkage upon concentrations and ensuing health effects must be based upon a detailed chronological simulation of both power system operations and pollutant transport and transformation. Utility experience across the U.S. shows that variations in weekday demands are most strongly associated with temperature, although wind, humidity, and cloud cover are also factors that are frequently considered in short-term models. Typically, 80% or more of the variation is associated with weather, and for systems we have studied, peak electric demands in the summer can easily vary by 25% or more because of day-to-day changes in temperature.

This year one progress report describes the progress on modeling the impact of climate change on electricity consumption behavior. The major accomplishment is the construction of an hourly data base of electricity loads for the Pennsylvania-New Jersey-Maryland Interconnection (PJM) in the aggregate and by utility control region. A standard set of hourly forecasting models has been estimated for the whole PJM accounting for autoregressive components, heating and cooling degree temperature effects, trading day variation for holidays and weekends. Short-run elasticities have been calculated for the heating degree day and cooling degree day effects. The forecasting power of the model has been evaluated and the (absolute) percentage errors range from one-half a percent to two percent of hourly loads. A simple simulation over two three-day events of particularly hot temperatures during July and August 2000 was performed. The experiment looks at the impact of a 2F increase in the daily temperature. We find a small but positive impact during the periods before and just after the peak in the daily electricity load.

Electric Power System Impacts **- B.F. Hobbs, Y. Chen**

The objective of this portion of the project for the first year was to establish the linkage between climate change and power sector emissions in the short-term (see Fig. 1). The tasks accomplished include:

1. identification of a study region,
2. compilation of regional data base of generator cost and emission characteristics,
3. formulation of transmission-constrained and unconstrained power system dispatch models for calculating emissions from demand scenarios, and
4. quantification of changes in power sector emissions in short run (2000) from hypothetical climate warming scenario.

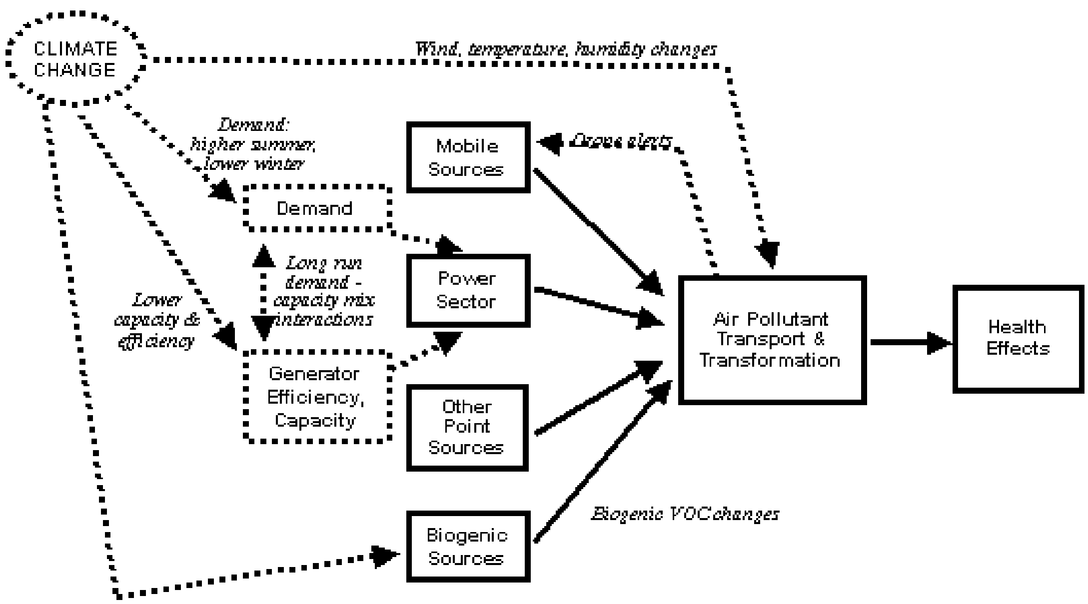


Fig. 1. Schematic of Linkages Among Project Modules

In sum, given our assumptions about climate change, our analysis shows that a respective average increase of 6.83% and 6.13% for NO_x and SO_x during typical 3 consecutive summer days for the region considered (Pennsylvania-Jersey-Maryland system, Virginia, West Virginia, Ohio). The percentage impacts are relatively high in New Jersey and relatively low in West Virginia.

To estimate the impact of climate change on total emissions of the power sector, we constructed a least-cost dispatch model using linear programming (LP) framework. The model requires extensive data inputs concerning individual generation unit characteristics, such as heat rates, forced outage rate, and NOx and SO2 emissions, and provides estimates of power sector output over time and space. Such detailed outputs are required by the pollutant transport and transformation analyses. Our initial database covers eight states and contains 1,700 generating units with a total capacity of 130,000 MW; in Year 2, it is being expanded to include portions of two additional states whose emissions are important to mid-Atlantic tropospheric ozone levels.

In the short run, climate change would affect power system emissions in two different ways. First, it changes the consumption amount and pattern of temperature-sensitive appliances, such as air conditioners. Based on published analyses of short-run demand responsiveness to temperature, we assume an increase of 1% in load corresponding to an increase of 1˚F in temperature in an initial set of analyses. Later in this project, we will use more refined estimates developed by the GWU team. Second, climate change affects the thermal capacity and energy conversion efficiency of power lants. These effects are estimated based upon a literature review, published data, and Carnot efficiency calculations. For instance, average heat rate increases 0.07% and 0.06% per 1˚F rise in temperature for gas turbine and steam plants, respectively.

For the purposes of this progress report, we consider a 3-day period of July 31st to August 2nd, 2000 with a peak load of 97,000 MW. A hypothetical temperature rise of 4.5˚F is assumed as a consequence of climate change. We first generate base-case total emissions. Then we adjust demands, capacities, and thermal efficiencies to reflect assumed climate warming, and use the dispatch model to estimate shifts in total emissions. Figure 2 describes the total emission impact on system-wide level. In comparison with base case, the impact of load alone reveals a super-linear relation, a 4.5% increase in load translating to 6.25% and 5.63% increase in NO_x and SO_x emission, respectively. In contrast, the generator performance accounts for only 0.5% and 0.4% on NO_x and SO_x emission. The joint impact is 6.83% increase in NO_x and 6.13% in SO_x, roughly equal to sum of two effects.

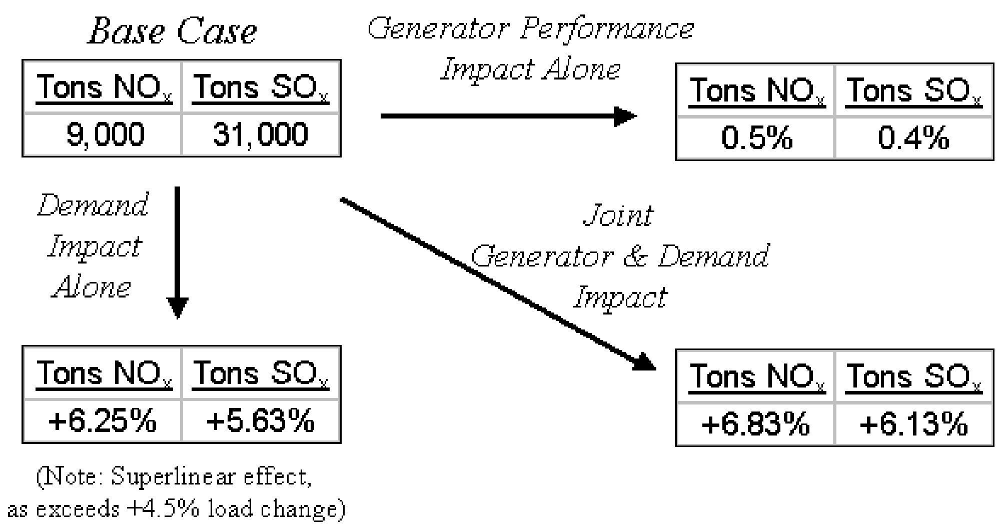


Fig. 2. Emission Impacts of a 4.5 ^{o}F Increase During Three Midsummer Days, Decomposed into Demand & Generator Performance

The above impacts are disaggregated to the state level in Figure 3. While comparisons of tonnage figures shows, for instance, that Ohio has higher changes in tonnages of emissions, it is also useful to examine percentage change. A comparison of relative impacts shows that the effect of climate warming is relatively high in New Jersey (21.5% and 15.1% increases for NO_x and SO_x) while West Virginia is relatively low (4.04% and 3.771% for NO_x and SO_x.) Nearly all 90% of changes are due to changes in steam coal generators which make up to 50% of generating capacity of our study region. The changes are relatively greater in New Jersey because marginal shifts in loads are met by changes in the peaking capacity which is relatively predominant in that state.

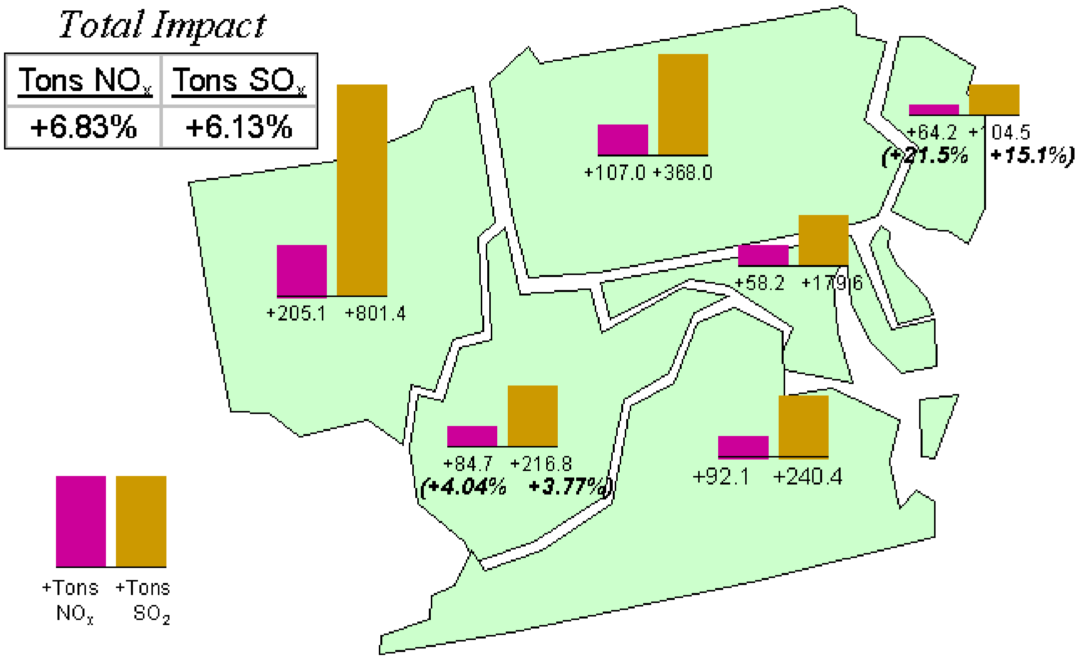
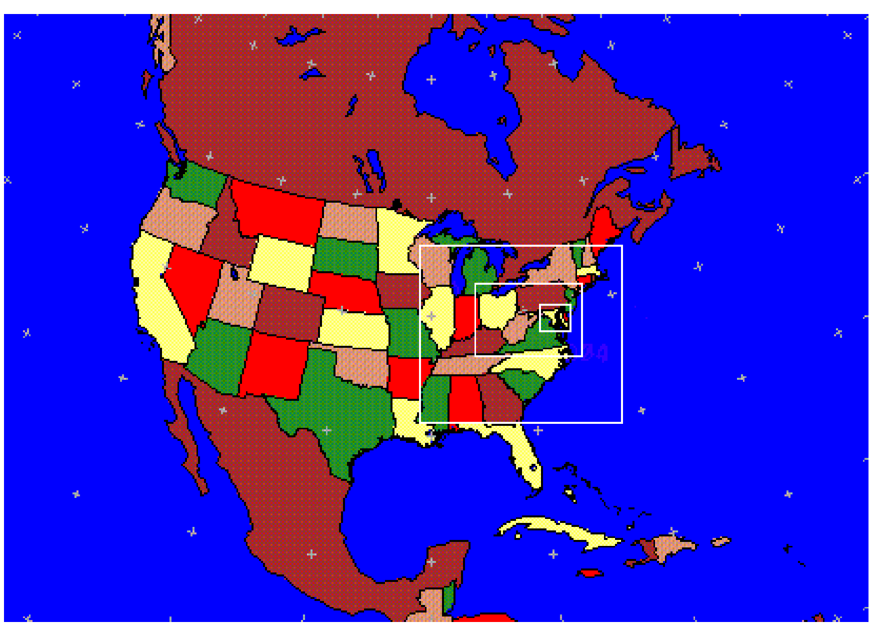


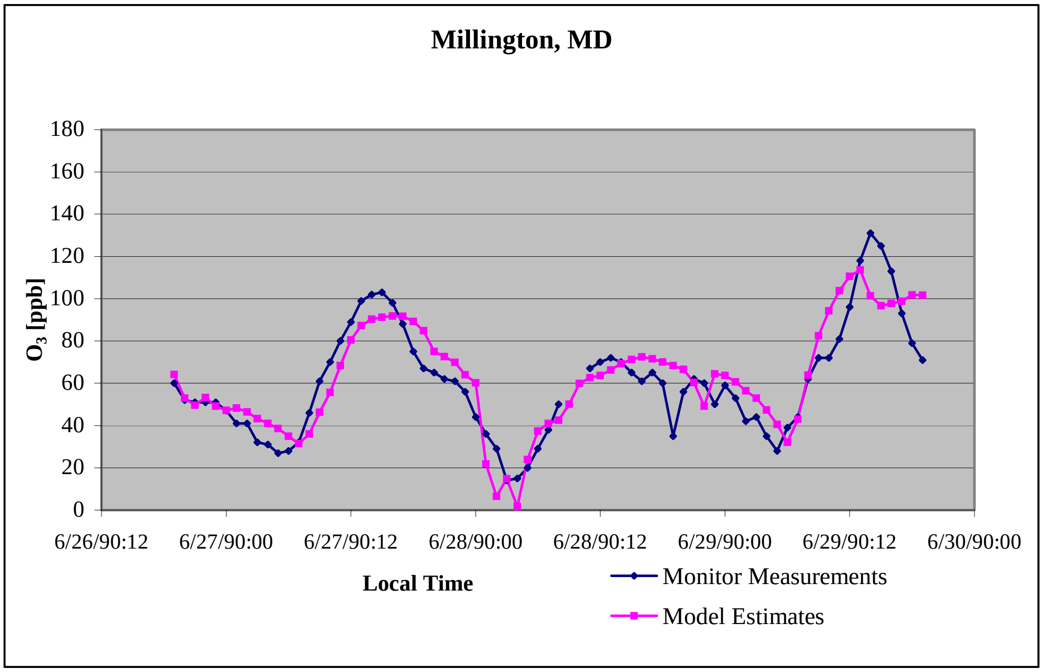
Fig. 3. Location Matters: Emissions Changes Vary Over Space

Regional Air Pollution Modeling and Health Effects Characterization **– J.H. Ellis and M. L. Bell**

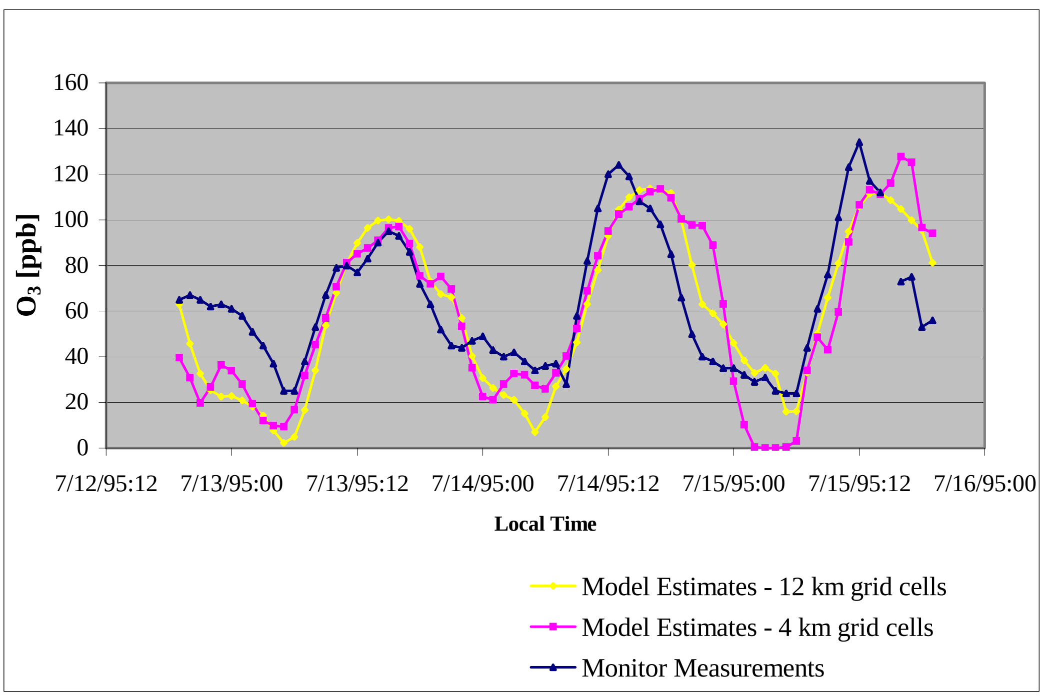
Installation and testing of the Models-3 Framework (air pollution modeling system) and MM5 Version 3-4 (meteorological model) were completed. Modifications were made to the meteorological model to allow one-way nesting and fdda (four dimensional data assimilation). Several three-day episodes of high ozone were simulated using multiple time periods and the Baltimore/Washington, DC region. The nested spatial domains used are shown below (the largest 108km domain is used only in MM5, the inner domains used in both MM5 and CMAQ have 36, 12 and 4km grid cells).



Extensive model assessment using graphical and statistical measures, including those recommended by EPA, showed good agreement between model estimates and measurements. The modeling system also fared well when compared with other assessments of tropospheric ozone modeling. An example comparison with ozone measurements at a Maryland location is shown below.



We also consistently found that there were relatively small differences between results generated at the 12 and 4km cell resolutions, an example of which follows for the Suitland, MD monitoring location:



Numerous epidemiological studies were reviewed and selected for further analysis based on specific critiera (e.g., location of study). A subset of the studies were used to generate concentration-response functions that can be used to assess changes in health outcomes corresponding to changes in tropospheric ozone levels. Total and cause-specific mortality, hospital admissions, and emergency room visits were examined.

Publications/Presentations:

Bell, M.L., and H. Ellis (2002). Comparison of the 1-Hour and 8-Hour National Ambient Air Quality Standards for Tropospheric Ozone. In preparation.

Bell, M.L., and H. Ellis (2002). Sensitivity Analysis of Tropospheric Ozone to Modified Emissions for a Case Study Episode. In preparation.

Presentations:
Bell, M.L. (2002). Tropospheric Ozone Modeling - A Case Study. International Air Pollution and Energy/Climate Policy Collaboration Workshop; Vancouver, Canada.

Bell, M. L. (2002). Evaluation of the 8-Hour National Ambient Air Quality Standard for Ozone Using an Air Pollution Modeling System. Poster at the Air & Waste Management Association Annual Conference; Baltimore, MD.

Ellis, H., and M. L. Bell (2002). Regional Ozone and PM Modeling for Baltimore and Atlanta Using Models3. Regional Air Quality Modeling and Data Analysis Meeting. Sponsored by the Mid-Atlantic Regional Air Management Association (MARAMA), Baltimore, MD.

Y. Chen and B.F. Hobbs, "NOx and Power Market Simulations: Emissions, Climate Change, and Market Power," IEEE Transactions on Power Systems, to be submitted.
T. Munson, S. Leyffer, Y. Chen, and B. Hobbs, "Comparisons of MPEC Algorithms for a Leader-Follower Market Equilibrium Problem: Electric Power and NOx Allowance Markets", Computational Management Science, to be submitted.

Future Activities:

Electricity Demand Modeling and Forecasting: There are several research areas we intend to work on testing and improving the models. The first area involves the collection of hourly temperature data for PJM and the utility control areas. At present we only have daily high and low temperatures. These two measures may not provide adequate resolution of the impact of temperature variability and its impact on electricity loads. Second, the specification of the model can be modified to try and capture more of the seasonal and temperature dynamics. The current set of hourly models covers PJM as a whole; the goal is to develop hourly models for each of the control regions. So far we have not been able to obtain loads by sector (residential, commercial, industrial, and other). This is another area for data collection and modeling we expect to report on in the future. The literature and our own experience suggests that the residential and commercial sector are more sensitive to climate variation than the industrial and other sectors.

Electric Power System Impacts: The analysis performed so far disregards the transmission constraints, which are likely to have important effects on interregional shifts in demand due to climate warming. Other relevant environmental regulations, especially NO_x cap-and-trade program were not included in analysis as well. Furthermore, the assumption of perfect competition needs to be relaxed, given the presence of large generating firms and transmission constraints that isolate markets. Therefore, in the following year, our primary tasks will involve in:

1. Incorporate transmission constraints in our model, along with strategic generator behavior (Cournot model).
2. Integrate regional NO_x cap-and-trade program and allow NO_x control option variable in model. The plants will have choice regarding least-cost control options, such as LNB, SCR or purchases of allowances to meet environmental requirements.
3. Refine boundary conditions: power import and export from regions adjacent to our study region. We will also expand the data base to include eastern Indiana and Kentucky, whose emissions are important to the mid-Atlantic region.
4. Develop a long-run market model for capacity mix to simulate response of the structure of the power generation system to climate warming-induced changes in demand and generator characteristics.
5. Develop scenarios for energy technology availability and economics. This data is necessary for creating a long-term market model.

Regional Air Pollution Modeling and Health Effects Characterization: We are now in the final stages of making operation the latest standalone CMAQ version (released July 2002) including V1.4 of the SMOKE emissions processing system and as well, using gridded spatial surrogates obtained from the Unified Grid developed by Alpine Geophysics. (An important related issue – the use of precomputed gridded spatial surrogates means that we no longer need ARC/Info and SAS). With this updated system, we will then be able to initiate longer-term simulations that will be driven by the electrical demand and dispatch modeling results described above. We also have a lead on a novel method for introducing climate change inputs (from a GCM) to MM5, through the specification of MM5 initial and boundary conditions. We are attempting to obtain the code that translates GCM output to MM5 input.

Supplemental Keywords: regional air pollution, electricity demand forecasting, electrical system dispatch, health effects, ozone, particulate matter, climate change

Relevant Web Sites: www.cmascenter.org

References:

Baxter, Lester W., and Kevin Calandri. “Global warming and electricity demand; A study of California.” *Energy Policy* March (1992): 233-244.

Darmstadter, Joel. “Climate change impacts on the energy sector and possible adjustments in the region.” *Climatic Change* 24 (1993): 117-129.

Jaeger, C., G. Dürrenberger, H. Kastenholz, B. Truffer. “Determinants of environmental action with regard to climatic change.” *Climatic Change* 23 (1993): 193-211.

Morris III, Samuel C., Gary A, Goldstein, Ajay Sanghi, and Douglas Hill. “Energy Demand and Supply in Metropolitan New York with Global Climate Change.” *Annals New York Academy of Sciences* Volume (PubDate): 139-150.

MetrixND: The Premier Forecasting Tool, (2001), Regional Economic Research, Inc. San Diego, CA.

Sailor, David J., and J. Ricardo Muñoz. “Sensitivity of electricity and natural gas consumption to climate in the U.S.A. – Methodology and results for eight states.” *Energy* 22, No. 10 (1997): 987-998.

Sailor, David J., Jesse N. Rosen, and J. Ricardo Muñoz. “Natural gas consumption and climate: a comprehensive set of predictive state-level models for the United States.” *Energy the International Journal*, 23, No. 2 (1998): 91-103.

Scott, Michael J., Laura E. Wrench, and Donald L. Hadley. “Effects of Climate Change on Commercial Building Energy Demand.” *Energy Sources* 16 (1994): 317-332.