Creating an Emission Inventory for Modeling Global Climate Change Effects on Regional Air Quality

William G. Benjey,* Ellen Cooter,* and Alice Gilliland*
Atmospheric Science Modeling Division, Air Resources Laboratory
National Oceanic and Atmospheric Administration
Research Triangle Park, NC 27711
benjey.william@epa.gov

Anne E. Grambsch
U.S. Environmental Protection Agency
Office of Research and Development, Global Change Research Program
8601D Ariel Rios Bldg., 1200 Pennsylvania Avenue, NW
Washington, D.C. 20460

Evelyn L. Wright, Chris D. Geron, and Cynthia Gage
U.S. Environmental Protection Agency
Office of Research and Development, National Risk Management Laboratory
Air Pollution Prevention and Control Division (E305-02)
Research Triangle Park, NC 27711

Darrell A. Winner
U.S. Environmental Protection Agency
Office of Research and Development, National Center for Environmental Research
Ariel Rios Bldg. (RRB-51158), 1200 Pennsylvania Avenue, NW
Washington, DC. 20460

ABSTRACT

The U.S. Environmental Protection Agency (EPA) has established a Global Change Research Program (GCRP) in support of the U.S. Global Change Research Program. The EPA GCRP is assessment-oriented with four areas of emphasis: human health, air quality, water quality, and ecosystem health. In order to assess the effect of global climate change on regional air quality, EPA will conduct regional air quality modeling for the year 2050, using the EPA Community Multiscale Air Quality (CMAQ) model, with climate change inputs from regional climate model simulations. Emissions must be projected to the year 2050 in order to capture the direct and indirect effects of changes of biogenic and anthropogenic emissions. In order to create scenarios of projected emission values, many natural, economic, and technological factors must be considered. This paper will address the methodologies to be used to generate a North American inventory for 2050. The methodologies to be used include (1) modeling of future electric generation and transportation technologies and their emission implications, using the MARKAL model (an energy systems optimization model) and updates to the MOBILE6 on-road motor vehicle emission model; (2) the projection of economic growth factors by emission source category and geographic region, possibly using an updated EPA Economic Growth Analysis System (EGAS); (3) determination of the most likely land use change scenarios for North America, including urban-rural population shifts, principal road network changes, and commercial development patterns; and (4) spatial and species composition changes in vegetation land cover, which in turn affect biogenic emissions. The projected emission scenarios will be compared with the continental-scale emission scenarios used by the Intergovernmental Panel on Climate Change (IPCC), but will demonstrate more

*On assignment to the National Exposure Research Laboratory, U.S. Environmental Protection Agency

spatial and emission source sector variability in keeping with more detailed spatial analysis.

Plans are to test first the influence of climate change alone on air quality, and to then examine the combined effects of climate change and potential future emissions. This approach is taken so that the sensitivity of air quality to climate change can be measured independently and in combination with future scenarios of air quality emissions.

INTRODUCTION

Air pollution is a major concern in the United States: it can threaten human health, damage ecosystems, cause haze and reduce well-being. At the same time, the Earth's climate system has the potential to both affect, and be effected by, air pollution. The atmospheric sciences community recognizes that climate and air quality are linked through atmospheric chemical, radiative, dynamic processes at multiple scales. The results of a limited number of studies of the relationship between weather and pollutant concentrations, the effects of temperature on atmospheric chemistry, and the sensitivity of emissions to weather and land use suggest that climate change could adversely affect air quality. However, the community's understanding of the many climate-air quality links is still limited.

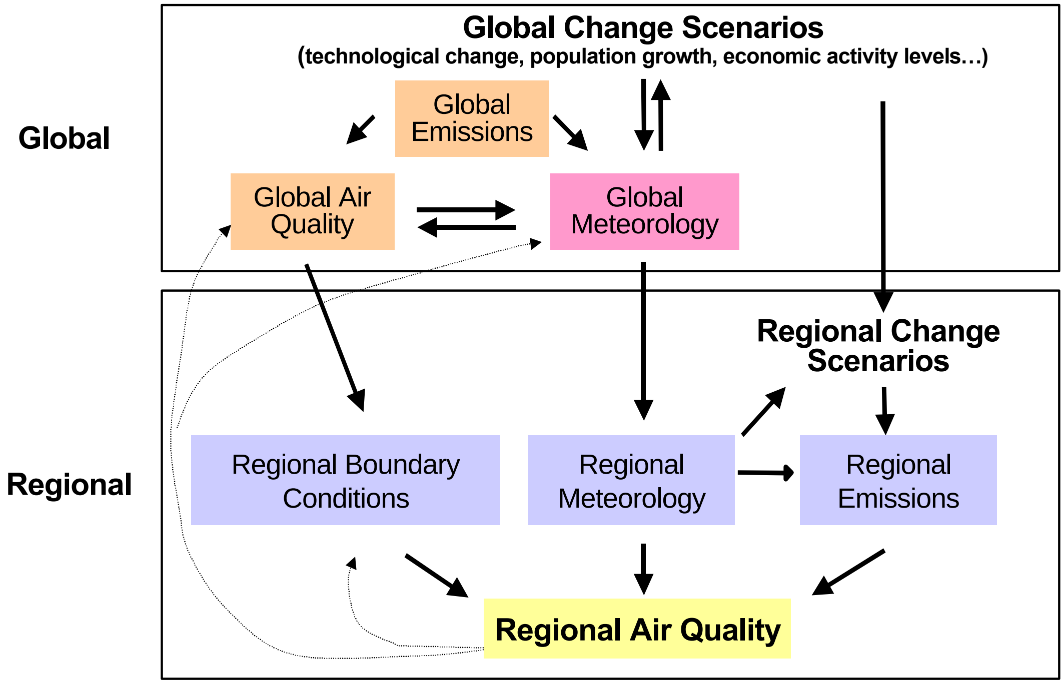
The U.S. GCRP, in which EPA participates, has documented the widespread potential effects of climate change.[1] Global climate change will likely result in changes in regional and local weather. Changes in meteorology may affect air pollution levels by altering (1) rates of atmospheric chemical reactions and transport processes; (2) anthropogenic emissions, including adaptive responses involving changes in fuel combustion for power generation; and (3) biogenic emission rates from natural sources. Ultraviolet radiation affects chemical activity in the troposphere and can have either positive or negative effects on ambient concentrations of air pollutants. Finally, patterns of land use can influence biogenic and anthropogenic emissions (e.g., increased urban sprawl may result in higher emissions from transportation sources or construction that lead to fugitive dust).

Improving our understanding of the relationships between climate, atmospheric chemistry, and air quality and our ability to assess future states of the atmosphere will require more comprehensive model testing of local and regional-scale air quality models coupled with global-scale climate and chemistry models which, in turn, are coupled with global-scale climate and chemistry models. This paper presents a research plan for developing these scenarios at the regional scale for the United States, a new challenging need that comes with more comprehensive studies of air quality and climate change.

Proposed Global Air Quality Framework

The EPA's GCRP is conducting an assessment of climate change on regional air quality over the continental domain of the United States, consistent with the national strategy for climate change research, and prior EPA planning for investigation of the effects of climate change on air quality.[2,3] This national air quality assessment will include modeling simulations to test air quality impacts from potential global change conditions in the future. The purposes of this assessment is to investigate the possible effects on air quality related to synoptic-scale meteorological change associated with global climate change. Additionally, the assessment will include analysis of meteorological and air quality data to identify historical trends and correlations, which are not discussed further here.

Figure 1. An Integrated Air Quality Assessment Framework



The research framework that EPA GCRP proposes to use for these modeling studies is illustrated in Figure 1. Models will be used to simulate the relationships between the components illustrated in Figure 1, and to test their responses to changes related to climate change and future changes that impact air quality emissions. Reflecting the program's emphasis on place-based regional assessments, research and assessment activities will focus on "downscaling" to the regional level and developing regional-scale inputs (e.g., regional meteorology, regional emissions) for the air quality simulations. We plan to use existing models and tools for this research including:

- The EPA Community Multiscale Air Quality (CMAQ) model[4] for regional air quality modeling;
- The Fifth Generation Pennsylvania State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5)[5] for regional climate; and
- Downscaling information from a Global Climate Model (GCM)[6] and a Global Chemical Transport Model (GCTM)[7,8] to provide global-scale climate change drivers for the regional climate and boundary concentration fields for CMAQ.

We plan to carry out a series of incremental analyses to assess the relationships between regional air quality and GCM projected global change. By regional scale, we mean that the spatial resolution of the modeling domains consist of grid sizes that are small enough to resolve synoptic-scale meteorological events (e.g., 36 km). First, simulations will be performed using a current emission scenario under climate change conditions to isolate climate effects on air quality. Increases in emissions could far outweigh the influence of climate change. We will develop long-term (i.e., 50 or more years into the future) emission scenarios for the second phase of simulations to assess the impact of future climate change conditions under potential future emission scenarios. These long-term future emission scenarios are likely to have large uncertainties due to many factors including biogenic emissions, landscape and urbanization changes, and technology advancements, so that a range of scenarios will be needed. The results from the first incremental base simulations are planned for an EPA GCRP 2007 air quality assessment report, and results from the second increment of simulations including future air quality emission scenarios, will be included in a second assessment report planned for 2010.

The Need for Modeling Inventories for North America

Modeling of regional climate change effects on air quality for the United States requires projected high resolution spatial and temporal emission inventories. Antecedent meteorology and emissions for most of Canada and Mexico as well as the United States are needed to establish suitable model boundary conditions. Because available emission-related data for Canada and Mexico differ from data for the United States, particularly for anthropogenic sources, it will be necessary to approximate projected Canadian and Mexican emissions for 2050 using available information - possibly based on IPCC projections.

Basis of Current Modeling Emission Inventories

Current and near-term regional air quality modeling with CMAQ is performed with spatially gridded, temporally-resolved, chemically-speciated emission inventories. Preparation of a modeling-ready inventory requires data taken from an annual inventory, such as a U.S. EPA National Emission Inventory,[9] and spatially allocated to a user-defined map projection and grid. Emission sources with discrete locations (latitude and longitude) are assigned directly to a model grid cell. Emission sources reported as county or other political entity totals must be reallocated to grid cells, usually with the aid of high-resolution Geographic Information System(GIS) coverages of other representative data (surrogates), such as population. Model grid cells are typically 36 km or smaller on each side.

Regional air quality models model hourly concentrations of pollutants, so emission data must be temporally disaggregated through application of seasonal and diurnal hourly temporal profiles. Temporal profiles are derived from observations of the diurnal emission variations of specific emission processes. A temporal profile is applied to each source category code. Finally, the chemical species accounted for by the annual inventory must be aggregated to those species required by the chemical mechanism of the regional air quality model. There are three mechanisms commonly used with CMAQ, including Carbon Bond 4 (CB4),[10,11] Regional Acid Deposition Model 2 (RADM2),[12] and the Statewide (California) Air Pollution Research Center (SAPRC) mechanism.[13]

Some meteorology-dependent emission data are modeled (i.e., not from an inventory) using the same hourly meteorological data used by CMAQ. These include biogenic emissions (modeled by the Biogenic Emission Inventory System, Version 3)[14,15] and on-road mobile source emissions modeled by the U.S. EPA MOBILE6 mobile source emission model.[16] Other emission data not taken from inventories include the measured hourly emission data (continuous emission monitoring data) from large electric utility plants in the United States are available, and may be merged directly into the modeling inventory. All of the emission modeling and processing described, is currently accomplished by EPA for use in CMAQ by the Sparse Matrix Operator Kernel Emission (SMOKE) model.[17] SMOKE will be used to prepare current and 2050 emission inventories for use with planned CMAQ model runs.

Future Year Emission Inventory Needs

Preparation of modeling emission inventories representative of 2050 requires that the underlying data and assumptions of the inventories also be estimated for 2050. The components needed to prepare inventories for 2050 include: changes in emissions reflecting changes in activity by source category, changes in technology affecting emissions, changes in vegetation land cover, and changes in human land use. If financial and time resources allowed, the economic, land use, and population data specific to each locality could be gathered at the census tract or county level. The data could then be projected reflecting both local and regional variations, and a range of modeling techniques and assumptions could be used and compared. However, because of program resource limitations, it is necessary that we use a more limited range of data and modeling tools. Because of the long-time frames involved in this effort, we will use a "scenario" approach, that is, a range of plausible local variations will be developed and compiled into a suite of national growth scenarios. The range of scenarios will not include every possible scenario variant because of the resource constraints.

- Emission data are typically projected to future years in the United States by applying economic growth factors to emission source categories, with regional growth adjustments. Economic and demographic projections are implicit in the growth factors. U.S. EPA uses the Economic Growth and Analysis System (EGAS) to accomplish the projections.[18] EGAS is based on regional economic projections prepared by Regional Economic Models Inc. (REMI). The REMI projections for each North American Industry Classification System (NAICS) code (formerly Standard Industrial Codes) are applied to the appropriate emission source categories to create the EGAS data base for future years. We will use an economic projection model to project current emission data to 2050, except for biogenic and mobile source emissions, which will be modeled to reflect 2050 meteorology. If resources allow, we may extend the REMI model and EGAS to 2050 to project the emission data. Economic growth results from REMI will be compared with the Special Report on Emission Scenarios (SRES).

  We will apply the results of current research on mobile source technologies to the MOBILE6 model. MOBILE6 contains future year information on emission technology, vehicle fleet mix, vehicle maintenance, fuels, etc., that are combined and expressed as emission factors by pollutant by vehicle mile traveled (VMT). It will be necessary to update and extend model year information contained in MOBILE6 to 2050, in addition to projection of regional VMT data.

- The results of research on the application of future technology changes, including known regulatory requirements, particularly in electricity generation and mobile source propulsion, will be applied to the relevant source emission categories. It will be necessary that we resolve any conflicting technology assumptions in the economic-growth based projections (such as from EGAS) for electric utilities. Similarly, we will apply the results of current research on mobile source technologies to MOBILE6.

- Vegetation land cover and human land use will be extended to 2050 for North America, to the extent resources allow. Because land cover and land use interact, alternative scenarios of change will be compared and reconciled. We will use the resulting vegetation land cover scenarios to model biogenic emissions for 2050. The reconciled land use scenarios will be used to project and spatially allocate area and mobile source emissions.

<u>Selection of Regional Emission Scenarios</u>

Global Climate Model output will define the North American boundary conditions of the regional climate model (Regional Climate Model implementation of MM5) used to drive CMAQ in order to maintain consistency with the global climate change scenarios. Similarly, we will compare our emission scenario results with the range of North American regional emission scenarios from the IPCC

SRES used for regional climate change modeling.[19] This will indicate the degree to which more spatially resolved emissions based on relatively detailed information are consistent with continental or national-level emission estimates, such as those in SRES. Less detailed, but consistent 2050 emission scenarios for Canada and Mexico will also be prepared for modeling. Because of the difficulty in determining the uncertainty in future year emission projections, we will generate at least three emission inventory variations for North America in 2050, reflecting conservative, mid-level, and larger demographic and economic growth assumptions, as modified with more specific state and county-level economic, technology change, land cover, and land use information.

INFORMATION FOR FUTURE YEAR (2050) MODELING EMISSION INVENTORIES

Components From Human Activities

Determination of Technology Changes and Assignment to Emission Categories

Anthropogenic emissions in 2050 can be expected to depend heavily on the degree and nature of technological change in emission-intensive activities. Because of the inherent uncertainty of the technology innovation process, as well as of the research, policy, and economic environment in which innovation takes place, simple business-as-usual extrapolation of recent trends is inappropriate over such a long time horizon. We will take a scenario approach to the assessment of technological change.

Our initial work will focus on technologies in two sectors: transportation and electricity generation. Each of these sectors account for approximately one-third of U.S. Carbon Dioxide (CO_2) emissions. Transportation also accounts for about fifty percent of ozone (O_3) precursors (Nitrogen Oxides [NOx] and Volatile Organic Compounds [VOCs]) and 25 percent of fine particulate matter ($PM_{2.5}$). Electricity generation accounts for 25 percent of Nitrogen Oxides and about six percent of PM2.5.[20] Ideally, a detailed range of technological changes data for all economic sectors of activity would be investigated for this work. They may be the focus of future technology assessment work. For the present study, we will be constrained to project emissions in these additional sectors by varying the demographic and economic input data of the emission projection (possibly EGAS) framework.

Our goal is to develop and assess a set of scenarios that together cover a range of plausible futures in the transportation and electricity generation sectors. Scenarios are internally consistent depictions of how the future may turn out, given assumptions about future economic, social, political, and technological developments. In general, scenarios explore plausible futures by using a model or models to generate a set of outcomes consistent with a set of motivating assumptions about the driving forces for change. The GCRP will use the MARKAL energy-technology-economic modeling framework, described below,[21,22] to evaluate the consequences of a range of assumptions for each of the following driving forces:

- technology development
- energy, technology, and environmental policy
- energy resource availability and costs
- economic growth and change
- population growth and regional distribution
- land use change and land use policy

Of these driving forces, the first three will be considered explicitly through the MARKAL modeling framework. The remaining driving forces influence the level and location of end-use energy service demands and hence technology activity and emissions. As scenarios for these driving forces are developed to support the economic-based projection of emission data and SMOKE work, they will also be incorporated into the MARKAL modeling through a set of end-use energy service demand drivers that will model how energy service demands change in response to economic and population change.

The MARKAL modeling framework will be used to generate scenarios from a set of scenario driving force assumptions. MARKAL is a data-intensive energy system economic optimization model. We must specify the structure of the energy system to be modeled, including resource supplies and the technologies available to process and convert energy carriers (for example, oil refineries and electric power plants) and to satisfy end-use demands. We will also specify the level of end-use demands to be met (e.g. vehicle miles traveled (VMT), lumens of light) and/or the relationship of these demands to economic demand drivers. MARKAL then calculates the most economically efficient subset of technologies to meet the specified demands and the evolution of this technology system over time. MARKAL thus offers a way to rapidly calculate the consequences of changes in assumptions about end-use demands and technology and resource costs and availability.

MARKAL requires that each technology represented in its energy system be characterized through a set of technical and economic data parameters, including capital and operating costs, technical efficiency, and availability. We will construct a reference case of energy system data, derived primarily from Department of Energy projections, and the model outputs will be calibrated to the Annual Energy Outlook, the Department of Energy’s annual reference case energy projections. For the development of scenarios, a second round of data collection will cast a wide net seeking to capture all available projections from government, industry, and academic research sources for alternative technologies. Data collection will encompass the range of researcher projections for the cost, performance, and availability of alternative future technologies.

In the transportation area, our initial work will focus on alternative technologies for personal vehicles, including advanced diesel and gasoline internal combustion engine vehicles; gasoline and diesel hybrid electric vehicles; fuel cell vehicles and associated fuel infrastructures; and biofuels, including ethanol and biodiesel. Future work in the transportation area will examine technologies for freight transport and mode switching for passenger transport.

In the electricity generation sector, alternative technologies to be examined include advanced coal and natural gas; advanced nuclear; renewable energy, including solar, wind, and biomass; stationary fuel cells; carbon capture and sequestration; combined heat and power; and decentralized vs. centralized generation.

We will use a combination of quantitative and qualitative methods to construct scenarios out of this set of data. Monte Carlo techniques will be used to efficiently explore the combinatorial space and to determine which technology data generate sensitivity in the model's outcomes. Technology specialists in each alternative technology will identify targeted sets of assumptions for model runs corresponding to key uncertainties and possible trajectories in their technology areas and evaluate the model results for consistency with the underlying scenario assumptions. This qualitative scenario development process will include attention to policy, economic, and social factors that may influence a technology's development and adoption.

We will select a set of representative scenarios from model runs resulting from the use of these techniques, with the goal of selecting scenarios that together cover the range of possible technological futures. Each scenario will be tied directly to a set of assumptions and motivating driving forces through its corresponding model runs. This approach will indicate the range of potential air quality impacts from technological change and the key variables that influence how these impacts evolve over time.

<u>Demographic Shifts, Including Changes in Spatial Patterns, and Demographic Projection Methods</u>

Population growth and demographic composition are central to developing future emission scenarios. Population is a key determinant of economic growth as it determines (along with participation rates) the supply of labor and is a source of demand for final product. It also drives, among other factors, VMT growth and land use. The population projections that we will use in developing emission scenarios are based on the "cohort component" method. Under this methodology, knowledge of the current age and sex composition of the population allows imputation of future age-sex distributions since sex does not change while age advances with the passage of time. Major demographic components of change - births, deaths, and migration - differentiated by age, can also be determined and projected. Combining estimates of the base population with the components of change results in projections of future populations.

Population projections that we will use in developing emission scenarios will largely be based on the US Census projections. Through 2025, the Census projections are nearly identical with the population projections underlying the IPCC SRES A1 and B1 scenarios (Table1).[23] After 2025, the Census projects slightly higher population growth such that by 2050, their projections are about halfway between the A2 and A1-B1 population projections. Finally, the Census projections are "launched" from an estimated resident population as of January 1, 1999, which in turn was based on the 1990 Census. For comparison, population estimates based on the 2000 Census are included in the table. The discrepancy between the 2000 projections and estimates based on the 2000 Census are due in part to changes in net undercount between the 1990 and 2000 Census.

Table 1. U.S. Population Projections: 2000, 2025, 2050 (in millions)

	2000	2025	2050
SRES Scenarios			
■ A1, B1	277	336	383
■ A2	278	349	417
■ B2	278	332	348
Census - Middle Projection	275	338	404
Census 2000 Estimate	281		

Emission Components from Vegetation Change

<u>Changes in Plant Physiology and Species Composition</u>

It has been established that short-term climate fluctuations can impact a plant's capacity to emit biogenic VOCs (BVOCs).[24,25,26] However, for small long-term mean changes in temperature and radiation predicted by climate models, the changes in emission factors are poorly understood, but are also likely to be small. Furthermore, the emission factors can be affected by the mean CO_2 concentration in which a plant develops, but the magnitude, or even the direction, of these changes are very uncertain. For these reasons, little change in emission factors for BVOC emission factors will probably be assumed for the effects of light, temperature, and CO_2 levels. However, we will attempt to incorporate the effects of moisture stress and relative humidity. These effects can be important in many cases. We will also consider biotechnological factors which affect plant productivity and therefore (in many cases) BVOC emission capacity. Cultural modifications such as irrigation and fertilization can also increase both emission factors and the amount of leaf area in a given area.

Dramatic changes in land use and plant species composition are expected in many parts of the United States by 2050. These include considerable loss of forests in the expanding urban areas of the southeast. An expansion of industrial forest plantations in the rural southeast is also expected to replace some agricultural lands, but will also impact lands previously covered by mixed hardwood or pine hardwood forests. On the other hand, early successional natural hardwood forests are reclaiming agricultural lands in other parts of the United States. We will use U.S. Department of Agriculture economic projections to account for these changes in land use and land cover and resulting emissions of biogenic VOC and NO_X.

We will also attempt to use existing models and data to estimate the affects of temperature and drought stress on vegetation species ranges. Precipitation affects soil NOx emission as well and will be important in determining NOx/VOC ratios in many agricultural areas. Air pollutants such as O_3 are known to impact emission rates of biogenic compounds. We will attempt to account for these affects as well, in at least a qualitative sense.

Scenarios of Spatial Changes in Vegetation Land Cover

Land cover change can impact drivers of global change as well as responding to them. For instance, land surface changes can change the radiation balance by altering the Earth's surface albedo, alter the fluxes of sensible and latent heat to the atmosphere and modify the distribution of energy within the climate system. Numerous studies have addressed the impact of global and large-region vegetation change on carbon sequestration and release.[27,28] The implications of these, and smaller scale vegetation changes for greenhouse gases such as O_3 and certain O_3 precursors are far less well-studied.

Land cover influence on O_3 production and O_3 precursor emission is usually introduced through global and national scale land cover databases. Examples of national scale vegetation cover databases representing present conditions throughout the United States include The North American Land Cover Characteristics (NALCC) version 2 database, the Biogenic Emissions Landcover Database (BELD3) and the National Land Cover Database (NLCD). The NALCC database consists of 1-km resolved land cover classes derived from Advanced Very-High Resolution Radiometer (AVHRR) satellite data.[29] BELD3 combines the NALCC data with U.S. Forest Service and U.S. Department of Agriculture databases so that tree and crop cover (230 species) are resolved to 1 km. The NLCD is based on Landsat-TM data and is available at ~30 meter resolution.[30] Although all bear many similarities, isoprene emission estimates for the Tennessee Valley region have been shown to vary by a factor of two depending on the vegetation cover data source.[31]

These surface cover databases synthesize natural and anthropogenic land cover factors that are expected to change 50 to 100 years in the future, but projections are highly uncertain. For example, Bachelet et al. considered equilibrium (Mapped Atmosphere-Plant-Soil System, or MAPSS) and dynamic (MC1) natural vegetation models and a combination of 7 future climate scenarios, four equilibrium global climate models (GCMs) and three transient GCMs for 1961-1990 and 2061-2099 time frames across the United States.[32] Regional differences were noted as the result of spatial resolution (10km grid vs 50 km grid), vegetation model type (MAPSS vs MC1), and GCM scenarios.

Although an active area of research, it is yet unclear how one might project land cover change associated with economic and population change.[33,34,35,36] Pozzi and Small consider this question using

1990 U.S. Census Bureau population counts at the block level and vegetation fraction estimates derived from Landsat TM validated with Ikonos MSI imagery and NLCD land cover information.[37] They identify consistent relationships between vegetation fraction and population density for large cities, e.g., New York, Chicago and Los Angeles, but note that such relationships are highly impacted by significant differences in physiographic environment and urban structures. They were unable to identify any single consistent relationship between suburban population density and vegetation abundance in the United States.

Model results such as those summarized above provide a starting place for research into future land cover change and biogenic emissions, but many important questions remain to be answered. For instance, what is the role of multiple stressors such as drought and fire regime in vegetation change and air quality? These events impact vegetation cover and air quality through independent as well as joint occurrence. Drought-related forest decline was mentioned previously, but there are also interactive effects of CO_2 productivity enhancement countered by physiological moisture stress and litter conditions favorable to wildfire. Drought conditions impact air quality through possible increased frequency of stagnation conditions, physiologic bioemission response while wildfires may act as episodic sources of organic particulate. Even if the biogenic modeling issues described above were resolved, we are still faced with challenges such as how best to include the surface cover feedbacks from vegetation to climate through heat and moisture flux impacts or how to best characterize wildfire smoke emissions and regional transport.

In light of this and other uncertainties in our knowledge of current process and future change, our initial, baseline analysis will use a present-day land cover data base to represent both current and future conditions. Later analysis will consider the impact of projected climate on natural vegetation using models similar to those discussed above. To the extent that successful models are identified, we will develop land cover scenarios reflecting changes in natural land cover as well as changes associated with scenarios of projected economic and population change.

Ancillary Emission Model Input Data

Because area source emission inventory data, including those projected data resulting from the MARKAL technology scenario modeling work, are usually reported as annual totals by source category and county they must be spatially allocated to modeling grid cells. This is accomplished by weighting the data according to more spatially resolved surrogate data, for example population, thought to reflect the spatial distribution of the data in question. For example, emissions from residences may be assigned consistent with housing GIS data drawn from the U.S. Census. There are currently 21 different spatial surrogates used with the SMOKE model. Most of the surrogates are different aspects of population, housing, roads, and land use. Currently, EPA is creating new, more detailed, spatial surrogates at 4km spatial resolution for the United States, and portions of Canada and Mexico (described at www.epa.gov/ttn/chief/emch/spatial/rpo_spatial.pdf), which will be available for preparation of climate change emission data for this research. The new surrogates will triple the current number available, improve the accuracy of assignments surrogates to source category codes, as well improve spatial resolution. For consistency with projected emission data, we need to project the components underlying the surrogate data to 2050, including their spatial distribution. Further, the surrogate data should have variations consistent with the different regional scenarios used. It is possible that additional, or different spatial surrogates will be determined to be appropriate for use with future year data. However, resource limitations may limit or preclude the projection of surrogate data for this research. Fortunately, many of the surrogates are subsets of land cover and population, which will be separately projected to 2050 for other (non-spatial allocation) aspects of emission modeling. Temporal profiles and chemical speciation profiles of emissions should change little by 2050, except as altered by technology changes.

IMPLEMENTATION OF THE EMISSION INVENTORY PLAN

The challenge that we face in executing the EPA GCRP emission research lies as much with maintaining logical consistency in assembling the many parts, as with the difficulty of projecting each of the many components to 2050. Initial air quality simulations reflecting the climate in 2050 will be accomplished without projected emission data. The EPA National Emission Inventory (NEI) for 1999, plus available emission data for Canada and Mexico, will serve as the base year. Running CMAQ without projected emissions will serve as a sensitivity test to determine the potential effect on air quality without changed emissions for the North America, although global scale emission changes will be implicit in the meteorological data passed from the global climate model to define the boundary conditions for CMAQ. However, these changes will be minor relative to the more spatially and temporally resolved projected emission scenarios to be applied in this research.

When projected inventories reflecting different scenarios are assembled for 2050, our first steps will include determination of basic sets of population and economic projections for the United States. It will be necessary to use available projections for anthropogenic emissions for Canada and Mexico. Our general procedure will be to:

- Specify a range of demographic and economic change assumptions for 2050, in order to bound the problem. We will compare them with the IPCC North American assumptions as a point of reference.
- Project scenarios of land use, growth or change by economic sector, and spatial distribution of activity will be consistent with the basic demographic and economic scenario assumptions. For example, we must run emission projections (possibly EGAS) with the same range of demographic and economic scenarios as used for land use change.
- Apply different (perhaps 4 or 5) technological changes to transportation and electrical generation to one or more of the demographic scenarios, in addition to technological changes within the emission projection model (possibly EGAS), depending upon the likelihood of affecting a change. It will be crucial that we ensure technological changes within the emission projection model (possibly EGAS) are consistent with the others for each scenario.
- Project land use to 2050 using consistent demographic and economic assumptions. The changes in land use will also affect vegetation land cover projections and biogenic emissions
- Each demographic-economic scenario, with its technology change variations, will be used in CMAQ runs, for comparison of the effects on air quality induced by emission changes.

We anticipate that although there is a plan, we must be flexible enough to incorporate new knowledge gained as we progress, for example from the EPA Science To Achieve Results (STAR) grants now being awarded to climate change and air quality researchers.

DISCLAIMER

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

REFERENCES

1. National Assessment Synthesis Team, *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, U.S. Global Change Research Program, Cambridge University Press, Cambridge, United Kingdom, 2001, 620pp.

2. U.S. Climate Change Science Program. *Draft Strategic Plan for the Climate Change Research Program*, U.S. Climate Change Research Program, Washington, D.C., 2002, available on the Internet at http://www.climatescience.gov/Library/stratplan2003/default.htm.

3. Science Applications International Corporation, "Proceedings and Recommendations from the Workshop on the Impact of Climate Change on the Air Quality of the United States"; EPA Contract No. 68-C7-0011, Work Assignment No. 4-37, Prepared for the U.S. Environmental Protection Agency, Office of Air and Radiation, Research Triangle Park, NC. 2002.

4. Byun, D.W.: Ching, J.K.S.: Eds. *Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System*, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. 1999; EPA/600/R-99/030, 1051 pp.

5. Grell, G.A.; Dudhia, J.; Stauffer, DR. *A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5)*, National Center for Atmospheric Research, Boulder, CO, 1994; NCAR/TN-398+STR, 122 pp.

6. Dai, A.; Wigley, M.L.; Boville, B.A.,; Kiehl, J.T.; Buja, L.E. "Climates of the 20^{th} and 21^{st} Centuries Simulated by the NCAR Climate System Model", *Journal of Climate*. 2001, 485-519.

7. Wang, Y.; Jacob, D.J.; Logan, J.A. "Global Simulations of Tropospheric O^3 - NOx - Hydrocarbon Chemistry 1. Model Formulation", *Journal of Geophysical Research*, 1998, 103, 10713-10725.

8. Adams, P.J.; Seinfeld, J.H.; Koch, D.M. "Global Concentrations of Tropospheric Sulfate, Nitrate, and Ammonium Aerosol Simulated in a General Circulation Model", *Journal of Geophysical Research*, 1999, 104, 13791-13823.

9. Tooly, R.L. *Procedures Document for National Emission Inventory, Criteria Air Pollutants 1985-1999*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 2001; EPA-454/R-01-006, 405 pp.

10. Gery, M.; Whitten, G.Z.; Killus, J.P.; Dodge, M.C. "A Photochemical Kinetics Mechanism for Urban and Regional Scale Computer Modeling", *Journal of Geophysical Research*, 1989, 94(12), 12925-12956.

11. Carter,W.P.L.; Atkinson, R. "Development and Evaluation of a Detailed Mechanism for the Atmospheric Reactions of Isoprene and NOx", International Journal of Chemical Kinetics, 1996, 28, 497-530.

12. Stockwell, W.R.; Middleton, P.; Chang, J.S. "The Second Generation Regional Acid Deposition Model Chemical Mechanism for Regional Air Quality Modeling" *Journal of Geophysical Research*, 1990, 95, D10(16), 343-16,367.

13. Carter, W.P.L.; "Documentation of the SAPRC-99 Chemical Mechanism for VOC Reactivity Assessment", Contract 92-329 and Contract 95-308 Report, prepared for the California Air

Resources Board by the Air Pollution Research Center and College of Engineering, University of California, Riverside, CA. 2000.

14. Pierce, T.; Geron, C.; Bender, L.; Dennis, R.; Tonnesen, G.; Guenther, A. "Influence of Increased Isoprene Emissions on Regional Ozone Modeling", *Journal of Geophysical Research*, 1998, 103, 25611-25629.

15. Pierce,T.; Geron, C.; Pouliot, G.; Kinnee, E.; Vukovich, J. "Integration of the Biogenic Emissions Inventory System (BEIS3) into the Community Multiscale Air Quality Modeling System". In *Proceedings of the Annual Meeting of the Air and Waste Management Association*, Air and Waste Management Association: Pittsburgh, PA, 2002, 2 pp.

16. Office of Transportation and Air Quality. *User's Guide to Mobile6.1 and Mobile6.2: Mobile Source Emission Factor Model*, U.S. Environmental Protection Agency, Ann Arbor, MI, 2002; EPA420-R-02-028, 264 pp.

17. Carolina Environmental Programs (CEP). *Sparse Matrix Operator Kernel Emission (SMOKE) Modeling System*, University of North Carolina, Carolina Environmental Programs, Research Triangle Park, NC, Available on the Internet at http:www.cmascenter.org (Accessed on February 27, 2003)

18. E.H. Pechan and Associates, Inc. "Economic Growth Analysis System: Version 4.0 User's Guide"; Pechan Report No. 01.01.003/9008-404, Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency by E.H. Pechan and Associates, Inc., Durham, NC. 2001.

19. Nakicenovic, N.J.; Alcamo, J.; Davis, G.; de Vries, B.; Fenhann, J.; Gaffin, S.; Gregory, K; Grubler, A.; Jung, T.Y.; Kram, T.; La Rovere, E.L.; Michaelis, L.; Mori, S.; Morita, T.; Pepper, W.; Pitcher, H.; Price, L.; Raihi, K.; Roehrl, A.; Rogner, H.-H.; Sankovski, A.; Schesinger, M.; Skukla, P.; Smith, S.; Swart, R.; van Rooijen, S.; Victor, N.; Dadi, Z. *IPCC Special Report on Emissions Scenarios*; Cambridge University Press; Cambridge, United Kingdom, 2000, 599 pp.

20. Nizich, S.V.; Pope, A.A.; Driver, L.M.; Pechan-Avanti Group. *National Air Pollutant Emission Trends Report, 1900-1998*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 2000; EPA-454/R-00-002, 236 pp.

21. Seebregts, A.J.; Goldstein, G.A.; Smekens, K. "Energy/Environmental Modeling with the MARKAL Family of Models". *In Proceeding of the OR2001 Conference*, University of Duisburg-Essen. Duisburg, Germany, 2001.

22. Fishbone, L.G.; Giesen, G.; Goldstein, G.A.; Hymmen, H.A.; Stocks, K.J.; Vos, H.; Wilde, D.; Zicher, R.; Balzer, C.; Abilock, H. *User's Guide for MARKAL (BNLIFKA Version 2.0): A Multi-period Linear-programming Model for Energy Systems Analysis*. Brookhaven National Laboratory, Upton, NY, USA, and Kernforschungsanlage Julich, Federal Republic of Germany, 1983.

23. IPCC Working Group III. *Emissions Scenarios, Summary for Policymakers*, Intergovernmental Panel on Climate Change, Geneva, 2000. 21 pp.

24. Sharkey, T.D.; Singsaas, E.L.; Lerdau, M.T.; Geron,C. "Weather Effects on Isoprene Emission Capacity and Applications in Emissions Algorithms", *Ecological Applications*, 1999, 9(4), 1132-1137.

25. Geron, C.; Guenther, A.; Sharkey, T.D.; Arnts, R.R. "Temporal Variability in the Basal Isoprene Emission Factor", *Tree Physiology*, 2000, 20(12), 799-805.

26. Petron, G.; Harley, P.; Guenther, A. "Seasonal Temperature Variations Influence Isoprene Emission", *Geophysical Research Letters*, 2001, 28(9), 1707-1710.

27. Solomon, A. M.; Prentice, I.C.; Leemans, R.; Cramer,W.P. "The Interaction of Climate and Land Use in Future Terrestrial Carbon Storage and Release" *Water, Air, and Soil Pollution.* 1993, 70, 595-614.

28. VEMAP Members. "Vegetation/ecosystem Modeling and Analysis Project: Comparing Biogeography and Biogeochemistry Models in a Continental Scale Study of Terrestrial Ecosystem Responses to Climate Change and CO_2 Doubling" *Global Biogeochemical Cycles*, 1995, 9, 407-437.

29. U.S. Geological Survey. *North American Land Characteristics Database*, U.S. Geological Survey, Washington, D.C., 2001 Available on the Internet at : http://edcdaac.usgs.gov/glcc/na_int.html (accessed February 27, 2003)

30. U.S. Geological Survey, *National Land Cover Database*, U.S. Geological Survey, Washington, D.C., 2002. Available on the Internet at : http://landcover.usgs.gov/natlandcover.html (accessed February 7, 2002).

31. Pierce, T.; Pleim, J.; Kinnee, E.; Joyce, L., "Intercomparison of Alternative Vegetation Databases for Regional Air Quality Modeling." In *Preprints, 12th Joint Conference on the Applications of air pollution Meteorology with A&WMA*, American Meteorological Society: Boston, MA, 2002; pp. 67-68.

32. Bachelet, D.; Neilson, R.P; Lenihan, J.M.; Drapek, R.J. "Climate Change Effects on Vegetation Distribution and Carbon Budget in the U.S." *Ecosystems*, 2001, 4, 164-185.

33. Wang, Y. ; Zhang, X. "Land Cover Change of Metropolitan Chicago Area from 1972 to 1997 and the Impact to Natural Communities in the Region," In *Proceedings of GeoInformatics '99*, University of Michigan: Ann Arbor, MI, 1999.

34. Chen, K., "An Approach to Linking Remotely Sensed Data and Areal Census Data." *International Journal of Remote Sensing*. 2002, 23, 37-48.

35. Pozzi, F.; Small, C. "Exploratory Analysis of Suburban Land Cover and Population Density in the U.S.A." In *Proceedings of the IEEE Joint Workshop on Remote Sensing and Data Fusion Over Urban Areas*, IEEE: Rome, Italy, 2001; pp 250-254.

36. Radeloff, V.C., et al. "Exploring the Spatial Relationship Between Census and Land Cover Data." *Society and Natural Resources*, 2000,13: 599-609.

37. Pozzi, F.; Small,C. "Vegetation and Population Density in Urban and Suburban Areas in the U.S.A.", 2003 (in press).

KEYWORDS

Emission Inventories
Emission Projection
Climate Change
Emission Modeling