

# PRELIMINARY ASSESSMENT OF THE IMPACT OF CLIMATE CHANGE AND VARIABILITY ON BIOMASS AND FOREST FIRES, THE IMPACT OF FOREST FIRES ON OZONE AND PM AIR QUALITY, AND THE REGIONAL CLIMATE RESPONSE TO THESE CHANGES IN THE SOUTHERN UNITED STATES.

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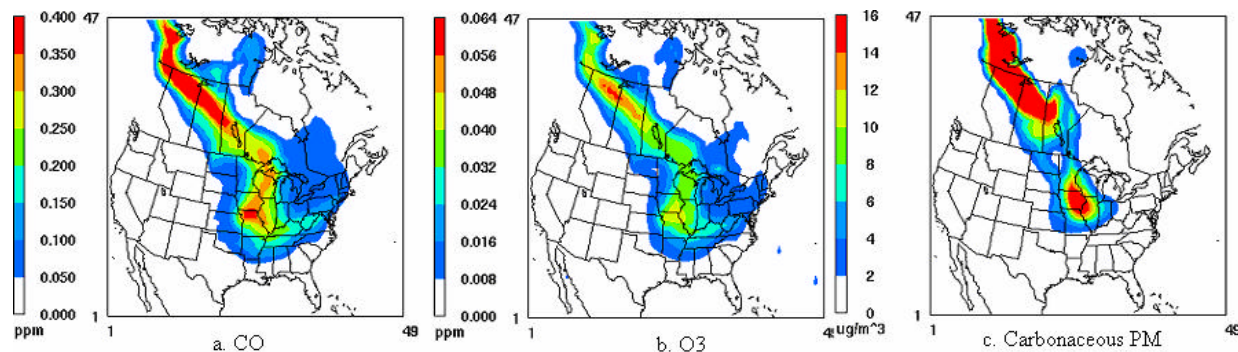
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## 1 BIOMASS, FIRES AND CLIMATE

The impacts of biomass burning on atmospheric chemistry and biogeochemical cycles have been studied at both global and regional scales (Crutzen et al. 1979; Crutzen and Andreae, 1990; Wotawa and Trainer, 2000; McKeen et al. 2002). These impacts are not only occur within the fire plumes but also can be felt over long distances due to long-range transport of the gas and particulate species either emitted directly, or indirectly formed by chemical transformations of their precursors in atmospheric photochemical reactions (Wotawa and Trainer (2000). Figure 1 illustrates the impacts of these fires on the concentrations of CO, O<sub>3</sub>, and carbonaceous PM as predicted by METCHEM (Xiu

et al., 2004;2003), an integrated meteorology-chemistry modeling system, which simulates the chemistry and transport of trace gases and particulate matter (PM) and their radiative feedbacks to atmospheric dynamics. Husar et al. (2000) found that the wildfires in Central America and Mexico during the spring of 1998 resulted in brief periods of abnormally high PM levels in the eastern U.S. For example, the 24-hour average PM<sub>10</sub> concentration reached 160 µg/m<sup>3</sup> in St. Louis, MO in May 1998. Much higher levels have been observed in Sumatra and Borneo during the biomass fires of 1997, leading to the recognition of biomass burning as a potential public health problem in that region (WHO, 1999).



**Figure 1:** METCHEM-simulated increases in surface level concentration (difference between simulations with and without fire emissions) resulting from the transport and chemical evolution of emissions from large Canadian forest fires at 1900 GMT on July 2, 1995.

Many of the emitted carbonaceous species from fires have an impact on the regional climate due to their absorption or scattering of incoming solar radiation. Black carbon (BC) has been shown in recent studies to be an important forcing on climate, estimated for example, to have a global average positive forcing on climate ranging from +0.20 to +0.78 W m<sup>-2</sup> (Haywood and Shine, 1995; Haywood and Ramaswamy, 1998; Jacobson, 2001; 2002), and to be responsible for 15-30% of global warming (Jacobson, 2001). Biomass combustion over the Indian subcontinent has also shown a significant contribution from SO<sub>2</sub> emissions (Venkataraman et al., 1999; Reddy and Venkataraman, 2002), which produce secondary sulfate, a major contributor to the aerosol negative radiative forcing. In turn, the short-term changes in climate variables that promote the growth of forests, such as precipitation and

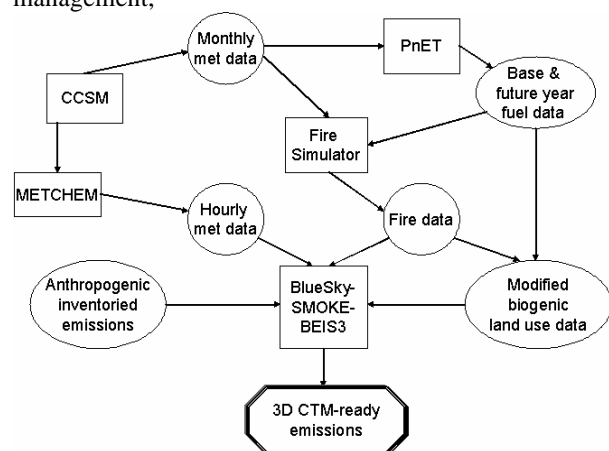
temperature, have a major impact on the conditions conducive to wildfires, and thus on the strength and frequency of fires (IPCC, 1997). However, most climate models do not currently capture these feedbacks. Further, while several of the more detailed atmospheric chemistry-transport models (CTMs) do simulate the air quality impacts of wildfire emissions, they lack the capability to assess the feedbacks of the fires to biogenic emissions and atmospheric dynamics through their impact on vegetation and air quality, as well as the potential benefits of fire management strategies to forestland (wildfires in the western U.S., for example, consumed approximately 26,000 km<sup>2</sup> of forestland in 2000). This lack could contribute to considerable uncertainty in the biogenic emissions, as well as in the biomass combustion emissions, which are input to air quality models, and which are critical for

reliably predicting ambient concentrations of criteria pollutants and their precursors.

## 2 AN INTEGRATED MODELING APPROACH

Under recent funding from the EPA (STAR Grant # RD 83227701-0), the METCHEM model is being used to investigate the feedbacks of aerosols and trace gases generated in fire events to the atmospheric radiation budget and, therefore, the dynamics that affect the distribution of these air pollutants and forest growth. The primary objectives of this study are to examine (1) the impacts of climate change on vegetative cover and fuel characteristics, the consequences for fire frequency and intensity, and feedbacks to biomass load and biogenic emissions under managed and wildfire scenarios; (2) changes in regional air quality due to the evolution of anthropogenic and biogenic emissions in response to various fire scenarios over several successive years; and (3) the feedback of the air quality changes to regional climate variables. Achievement of these objectives requires the coupling of several interdisciplinary modeling systems. Figure 2 gives a schematic of the forest growth and fire emission modeling system.

The modeling system includes PnET, a forest growth model developed at the University of New Hampshire to predict forest productivity and hydrology across a range of climates and site conditions (Aber and Federer, 1992, Ollinger et al., 1998, McNulty et al., 2000), and described in detail by Aber et al., (1995), and Ollinger et al., (2002). This model is currently being used by the USDA Forest Service for fire management,



**Figure 2.** Schematic of the integration of PnET, BlueSky, and SMOKE to generate fire emissions data

and will be linked in these investigations to provide fuel inputs to the BlueSky Emissions Modeling Framework developed by the USDA Forest Service, which will simulate smoke impacts from wildland and prescribed fires. These fire data will be processed by the publicly available Sparse Matrix Operator Kernel Emissions

modeling system (Houyoux and Vukovich, 1999), linked to the U.S. EPA Biogenic Emissions Inventory System Version 3 (BEIS3; Vukovich and Pierce, 2002) to create fire and biogenic emission inputs to METCHEM for a variety of fire scenarios. These will include the simulation of wild fires with and without the implementation of the National Fire Plan for a base year and selected future years. The METCHEM tightly couples the mesoscale dynamics of the Fifth Generation NCAR/Penn State Mesoscale Model (MM5; Grell et al., 1994) to the transport, chemistry and microphysics of atmospheric trace gas and particulate species simulated by the Multiscale Air Quality Simulation Platform (Mathur et al., 2005), and includes a radiative transfer module to model the radiative feedbacks of these chemical species to the dynamics. METCHEM simulations will be performed for the selected base and future year scenarios and the results will be examined to assess the changes in air quality, their intra- and inter-annual variability, and the impacts on key regional climate parameters under the various fire scenarios. The goal of these studies is to provide a significantly improved and readily accessible modeling system for understanding the complex and cyclical nature of the interactions between fire occurrence, climate change, and air quality. The following section summarizes the modeling tasks that will be undertaken with this system.

## 3 STUDY DESCRIPTION

PnET simulations will be conducted for a base year (2002) and selected future years (e.g. 2015, 2030 and 2050) using a variety of managed and wildfire fire scenarios. For example, one fire scenario may contain the full implementation of the level of hazardous fuels reduction called for in the National Fire Plan (<http://www.fireplan.gov/content/home>). Other scenarios may include variations in the extent of the prescribed burns, and/or in the species burned. The selection of the future years will also be somewhat dependent on the anthropogenic emissions inventories available. The monthly meteorological data for PnET will be provided by the NCAR Community Climate System Model (CCSM; see <http://www.cesm.ucar.edu/>), and will include monthly mean, minimum and maximum temperatures, solar radiation, and total precipitation. The PnET output data from the base and future year fire scenarios, specifically future year vegetation projections of fuel loadings, will be examined. Methodologies for implementing these data for each available species in the BlueSky Emissions Framework will be investigated. The horizontal resolution and spatial coverage of the PnET output data will mostly likely constrain the BlueSky Emissions Framework modeling and resulting air quality simulations to the regional scale and to the Southern and Eastern sections of the United States. A

methodology for mapping these data for use in the BlueSky Emissions Framework will be recommended and implemented. This linkage may be in the form of a preprocessor to BlueSky or as an additional routine to either the PnET or the fire simulation model in BlueSky. Additionally, a methodology to map the future year vegetation projections to the Biogenic Emissions Landcover Database version 3 (BELD3) (<ftp://ftp.epa.gov/amd/asmd/beld3/>) vegetation types used in BEIS3 will be generated. This will enable future year land-cover information to be input into BEIS3 to generate future-year biogenic emissions estimates.

There are two fundamental technical challenges to projecting future scenarios of forest fire emissions for air quality modeling. The first is the challenge of determining fuel loadings and the second is that of determining fire occurrence. PnET scenarios will provide the fuel loading data for various future year fire scenarios. A report by Brown et al. in 2002 ([Coarse Assessment of Federal Wildland Fire Occurrence Data](#), [CEFA Report #02-04]), and historical fire occurrence data (<http://www.fs.fed.us/fire/fuelman/fireloc1999/maps/fo1999.pdf>) and can provide a good suggestion as to the spatial distribution of wildfire. To actually generate a stochastic fire estimate, future year meteorology simulations from MM5 and the CCSM will be used to generate drought indices (Palmer 1965, Keetch & Byram 1968), the lightning ignition efficiency index (<http://www.fs.fed.us/land/wfas/wfas24.html>) and one or two fire potential indices (Haines 1988). These data will be used along with the National Fire Danger Rating System (NFDRS) parameters and historical data to build a fire simulator. Monte-Carlo techniques may be used as part of this fire simulator to estimate actual fire location, size and intensity. Given these and fuel loading data, BlueSky will be used to generate actual consumption of the biomass, which will, in turn, provide an estimate of the fire emissions.

The best available future year inventory databases will be acquired and processed using the SMOKE modeling system. Another option would be to project recent EPA emissions inventories (e.g. National Emissions Inventory for 2002) to desired future year(s) by using available economic data. The inventory data will be checked to eliminate any duplication among the fire and biogenic emission sources. All necessary ancillary data (spatial surrogates, temporal and speciation profiles) will be acquired or generated to support the SMOKE processing steps. SMOKE will also be used to generate the anthropogenic emissions estimates for the air quality simulations.

Future year biogenic emissions will be calculated using the mapping methodology chosen to map the PnET output vegetation data to BELD3 landuse types. These calculations will include the feedback to

vegetative cover from the fire model predictions on fuel consumption. The fire simulator produced during this task will be used with the First Order Fire Effects Model (FOFEM) (<http://fire.org/fofem/download/FOFEM5Using.pdf>) to feedback information to the BELD3 vegetation map to be used in BEIS3. The BEIS3 modeling will include the use of the MM5 temperature and solar radiation predictions along with the future year projections of land cover. The BEIS3 model will output air quality model-ready biogenic emissions for the desired modeling domain and episodes.

The three-dimensional fire emissions datasets produced by BlueSky/SMOKE and the biogenic emissions from BEIS3 will be merged with the anthropogenic emissions datasets to create emissions inputs to METCHEM. Other input data from the CCSM model's 21st century predictions will be developed, including the monthly climate parameters (minimum and maximum air temperature, total precipitation, and solar radiation) for the PnET model, and to provide initial and boundary conditions for METCHEM. Model simulations for a period of a few months (e.g., a season) or two representative months for prescribed and wild fires will be conducted over a domain covering the Southeastern U.S.

#### 4 OVERVIEW OF ANALYSES

Model results will be analyzed to gain insights into the modeling system performance and its responses to a variety of emission scenarios. For the base year, the modeling system will be calibrated by comparing species concentrations of SO<sub>4</sub>, NO<sub>3</sub>, elemental carbon, organic carbon and coarse aerosol mass with observations from the Interagency Monitoring of Protected Visual Environments (IMPROVE; Malm et al., 2000), the Clean Air Status and Trends Network (CASTNet; <http://www.epa.gov/castnet>) and EPA's Speciation Trends Network (STN; <http://epa.gov/ttn/amtic/files/ambient/pm25/spec/finlqmp.pdf>). Ozone and NO<sub>x</sub> mixing ratios will also be compared with available observations from the Atmospheric Infrared Sounder (AIRS) network (<http://www.epa.gov/air/data/aqsdb.html>). The future year simulation results will be examined to see how air quality, including the concentrations and distributions of trace gases (e.g., CO, O<sub>3</sub>, and NO<sub>x</sub>, and speciated PM, in particular, black carbon and sulfate) would be altered by the variability of key climate parameters as well as biomass and fires.

Among the meteorological parameters to be compared and analyzed are the surface temperature, precipitation rate, surface radiation budget, relative humidity, and boundary layer height. In analyzing the results for temperature the mean monthly changes in temperature and the change in daily variability in

temperature will both be considered. Change in the variability is important since it corresponds to the frequency of extreme events (Katz and Brown 1992). Changes in the shortwave radiation reaching the surface, as a result of the scattering of aerosols, affect the surface energy budget causing changes in turbulent fluxes of heat and moisture in the surface layer that affect the properties of the boundary layer; these have an impact on precipitation. The analysis of precipitation will consider mean daily precipitation, the probability of precipitation, and the median of daily intensity of precipitation.

Besides analyzing meteorological variables, the correspondence between specific meteorological parameters and evolution of pollutants will be investigated to better understand the two-way interactions between climate change, biomass, forest fires, and air quality. For example, the potential correlations between aerosols, relative humidity and clouds (Adams et al, 2001) will be examined. Similarly the relationship between changes in the boundary layer height and the ozone spatial distributions and vertical profiles will be investigated. Changes in aerosol characteristics such as aerosol size distribution parameters (e.g., number concentrations, geometric median diameters), and optical depths will also be examined.

The integrated modeling approach for the base case and future year climate scenarios as described above will enable examination of 1) the regional ozone and PM air quality associated with predicted changes in climate, and wild fires, and 2) the potential changes in regional climate due to these air pollution impacts. In a non-integrated modeling approach wherein a CTM is driven by prescribed meteorology, it is only possible to address the evolving air pollution patterns associated with the prevailing meteorological conditions, and not vice versa. The studies outlined here will provide the means to compare regional meteorological patterns using the integrated chemistry/metrology modeling approach with those from an “offline”, i.e., non-integrated modeling application for the same simulation period and emission inputs. Such analyses will provide valuable information regarding the spatial and temporal characteristics and the response of the atmosphere to pollution forcing. This is critical to investigations of climate change when air quality is considered, due to the regional nature of the spatial distribution of air pollutants and consequently their climate impacts.

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