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Wildfire Emission Modeling: Integrating BlueSky and SMOKE

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Abstract

Atmospheric chemical transport models are used to simulate historic meteorological episodes for developing air quality management strategies. Wildland fire emissions need to be characterized accurately to achieve these air quality management goals. The temporal and spatial estimates of emissions from fires, both wild and prescribed, have been problematic primarily because of uncertainty in the size and location of sources, and their temporal and spatial variability. Therefore, methods to estimate wildfire emissions that characterize their temporal and spatial variability are needed. The US Forest Service (USFS) and the US Environmental Protection Agency (EPA) have signed an interagency agreement to improve the episodic modeling of fires with improved fuel loading data, fire location information, and fire behavior modeling (including plume behavior), using meteorological inputs. The USFS has developed a tool known as BlueSky to predict cumulative impacts of smoke from forest, agricultural, and range fires. The BlueSky modeling framework combines state of the art emissions, meteorology, and dispersion models to generate predictions of smoke impacts across the landscape. The Sparse Matrix Operator Kernel Emission (SMOKE) processing system is a tool that creates gridded, speciated, and temporally allocated emission estimates for use in atmospheric chemical models. Portions of these tools have been combined to allow for an accurate characterization of fuel loading, temporal and spatial distribution of fire emissions, and a more accurate representation of fire plumes. By combining these two tools, the ability to simulate the impact of wildfires on air quality and develop air quality management strategies will be enhanced. This paper shows results from combining these two tools and an example from an air quality modeling simulation.

Introduction

Emission from wildland fires remains one of the largest uncertainties for modeling pollution from fine particles. The current national inventory (2001) crudely resolves emissions from fires at a state level and on a monthly basis[1]. To properly simulate wildland fires, emissions need to be distributed hourly onto grid cells with sizes ranging from 4 km to 36 km. The goal of this effort is to extend the BlueSky fire emission modeling system so that it provides episodic inputs to regional-scale chemical transport models such as the Community Multiscale Air Quality (CMAQ) modeling system.

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BlueSky ([2], www.fs.fed.us/bluesky/) is an integrated smoke modeling framework that has been built and tested by the U.S. Forest Service's Pacific Wildland Fire Sciences Laboratory and EPA Region X as a smoke management tool for the Pacific Northwest. BlueSky uses interchangeable components for characterizing fuel loadings, fuel consumption, and for modeling plume behavior. It has proven to be a reliable emission tool for predicting wildland and prescribed fire emissions in the Pacific Northwest, and it appears to be well-suited for application with regional air quality models. This effort complements work underway between EPA and the USFS. The proposed system should enable the air quality modeling community to more accurately characterize the temporal and spatial contribution of wildland fire emissions to fine particulate pollution. By leveraging upon the work of the U.S. Forest Service, which is charged with predicting and managing wildland fires, we can create a scientifically-advanced tool for estimating episodic emissions in support of State Implementation Plans (SIPs).

BlueSky

To integrate BlueSky with an emission processing system, only the emission estimating portion of the modeling framework is used. The emission processing portion of the BlueSky smoke modeling framework is comprised of mapped fuel loadings and an emission and fuel consumption model. Three mapped fuel loadings are currently available in the BlueSky framework: (1) the Fuel Characteristic Classification System (FCCS) mapped for the Western US [3], (2) the Hardy et al. [4] mapping of fuel loadings for the Western US, and (3) the National Fire Danger Rating System (NFDRS) fuel load mapping available for the Continental US [5]. Thus given a fire location, fuel loadings can be obtained from one of these three sources and input into the EPM/CONSUME v1.02 model [6] to predict daily emissions from each fire. EPM is a model that predicts the time rate of fuel consumption and emissions from wildland biomass burns [6]. CONSUME predicts the amount of fuel consumption and emissions from the burning of logged units, piled debris, and natural fuels based on the amount and fuel moisture of fuels. CONSUME was designed for the management of prescribed burning and it can be used for most forest, shrub and grasslands in North America [7]. These two models have been embedded within BlueSky and have not been updated as part of the initial integration with SMOKE.

SMOKE

The environmental community has developed advanced numerical air quality models (AQMs) to understand the interactions among meteorology, emissions (both manmade and biogenic), and pollutant chemistry and dynamics. Emissions data from emissions models and regulatory inventories are one of the most important inputs to these air quality models. Scientists use air quality modeling for a number of purposes: for state and federal implementation plan development, for research on improved modeling methods, and most recently for air quality forecasting. In all of these cases, the trend has been to model larger regions, at a finer grid resolution, with more emissions sources, and for more purposes (e.g., ozone, particulates, toxics). These needs require a computationally efficient, user-friendly, and flexible emissions data processing system. The Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System has been developed with high-performance-computing (HPC) sparse-matrix algorithms [8]. It provides a mechanism for preparing specialized inputs for air quality modeling research, and it makes air quality forecasting possible.

The purpose of SMOKE (or any emissions processor) is to convert the resolution of the emission inventory data to the resolution needed by an air quality model. If wildland fire emission inventories are available at least on a daily basis and can be located spatially, the SMOKE processing system has already been designed to create emissions data on an hourly basis for each model grid cell and for each model layer and for each model species. Consequently, the emissions processing for wildland fires involves transforming a daily emission inventory with geospatial information with temporal allocation, chemical speciation, and spatial allocation (both vertical and horizontal), to achieve the input requirements of the AQM.

Integration of the Two Models

To integrate BlueSky with SMOKE, several portions of the SMOKE system were changed or upgraded. First, the ability to model the plume rise of wildland fires was added to SMOKE. The current version of SMOKE (version 2.1) only estimates plume rise for anthropogenic point sources where stack parameters are known. For wildland fires, the BlueSky framework calculates a heat flux for each fire on a daily basis. The key parameter in plume rise formulas is the initial buoyancy flux. The heat flux output from the BlueSky framework can be converted to a buoyancy flux usable in the plume rise calculation [9]:

$$F = Q * 0.00000258 \tag{1}$$

where F = buoyancy flux (m^4/s^3)
Q = heat flux (BTU/hr)

A plume rise for wildland fires can then be calculated using the Briggs plume rise algorithm found in [10]. With this equation, the layer by layer approach as described in [10] can be applied to wildland fires. Both a plume top and a plume bottom are calculated using this layer by layer approach. However, to account for smoldering we have distributed the emissions into the layers below the plume bottom as and into the layers between the plume top and bottom. This effectively permits emissions to be at all model layers up to the plume top. A smoldering fraction of the total emissions is used to split the emissions into a smoldering part (distributed into the layers below the plume bottom) and the remaining part (distributed into the layers between the plume bottom and plume top). We derived a relationship between the Bouyant Efficiency (the portion of heat release from a fire that produces buoyancy, BE) and fire size by calculating a “best fit” curve using a simplification of the Western Regional Air Partnership (WRAP) method for estimating the smoldering fraction: [11]

$$BE_{size} = 0.0703 * \ln(acres) + 0.3 \tag{2}$$

where BE_{size} = buoyant efficiency
acres = fire size in acres

The smoldering fraction (S_{fract}) was calculated from the Bouyant efficiency as follows:

$$S_{fract} = 1 - BE_{size}\,. \tag{3}$$

The simplification of the WRAP method includes using the actual acres burned rather than the virtual acres burned. In the WRAP method, virtual acreage is calculated from the actual fire size and then multiplied by the square root of the normalized pre-burn fuel loading. The other simplification is that BE_{size} is calculated on a per day basis rather than on a hourly basis (as was done in the WRAP method) because we are using dynamical meteorological information to estimate plume top. This approach for modeling the plume rise from fires is based on dynamical meteorological fields (wind, temperature, pressure). Other methods for modeling plume rise from fires have been developed use a climatological approach. The Western Regional Air Partnership (WRAP) has used pre-defined plume top and bottom based on fire size [11]. The fire plume rise algorithm is included in the SMOKE module called LAYPOINT. Therefore, the data flow in the SMOKE processing system is maintained with this integration. The main difference is that fire emissions are now treated as point sources rather than area sources.

A second update that was needed is a tool to convert the BlueSky output to a format suitable for SMOKE. This tool simply creates an easy way to take the emission and heat flux information from wildfires and create day specific input files readable by SMOKE. Finally, we note that temporal allocation and chemical speciation are already built into SMOKE and therefore these aspects of the emission processing can be utilized when integrating the two models.

Preliminary Results

To test the integration of BlueSky and SMOKE, we created wildfire emission estimates for May 2001 for the state of Florida. This case was chosen for three reasons: (1) A detailed fire inventory for Florida was readily available for input into BlueSky/SMOKE. (2) A large wildfire occurred during the latter part of May in north central Florida. This fire, called the Mallory swamp fire, lasted for many days and produced a plume on a large scale easily seen in satellite images. (3) An annual MM5 simulation was readily available at 36 km for 2001. This meteorological simulation had already been used with the 2001 National Emission Inventory as input to the CMAQ model.

The Mallory Swamp Fire plume was initially directed inland toward Jacksonville on May 23, 2001 (Figure 1). By May 24, meteorological conditions changed and the plume was directed offshore (Figure 2). The plume then wrapped around and moved back towards Florida, heavily impacting Tampa, St. Petersburg, Bradenton and Sarasota. According to news reports, St. Petersburg and surrounding areas experienced reduced visibility and poor air quality because of the plume from the Mallory swamp fire [12].

Figure 3 shows the May 24 15Z concentration of primary organic particulate matter from a 36km national domain simulation with CMAQ. The BlueSky/SMOKE emissions from the Mallory Swamp were used to replace the NEI wildfire emissions for the state of Florida. Qualitatively, the estimated PM2.5 concentration from CMAQ closely agrees with the satellite photo in figure 2. Within the next few days, the fire plume moved east toward the Tampa Bay/St. Petersburg area as noted in [12]. This feature appears to have been captured by the CMAQ simulation as the plume turned back toward the coast in shown in Figure 3.

Conclusions

Spatial and temporal resolved fires can be modeled using a new tool that combines the emission estimates from BlueSky with the temporal and spatial allocation available in SMOKE. A plume rise algorithm for wildland fires has been developed and incorporated into the SMOKE system. This new tool, which we will initially call Bluesky-EM, for estimating emissions from wildfires and applying a plume rise to these emissions provides a new way to model wildfire emissions when spatially and temporally resolved wildfire inventories become available. Bluesky-EM needs to be evaluated in conjunction with the meteorological model and the chemistry model of an air quality modeling system. When an annual national wildfire inventory becomes available at a sufficient temporal and spatial scale, this tool can then be tested by evaluating it with the full suite of national networks of particulate matter. In the near future, BlueSky-EM will become available to the general community as part of future updates to SMOKE.

Figure 1: NOAA-14/AVHRR satellite image of the Mallory Swamp Fire (23 May 2001 21 UTC)

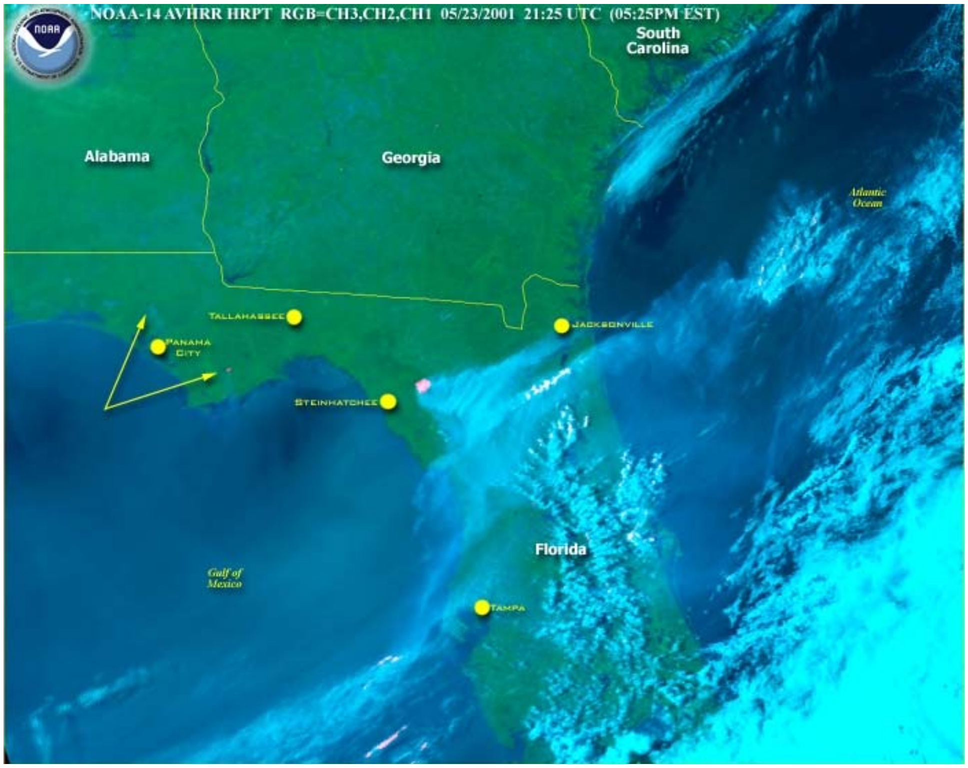


Figure 2 : GOES 8 Satellite Image of Mallory Swamp Fire (24 May 2001 15 UTC)

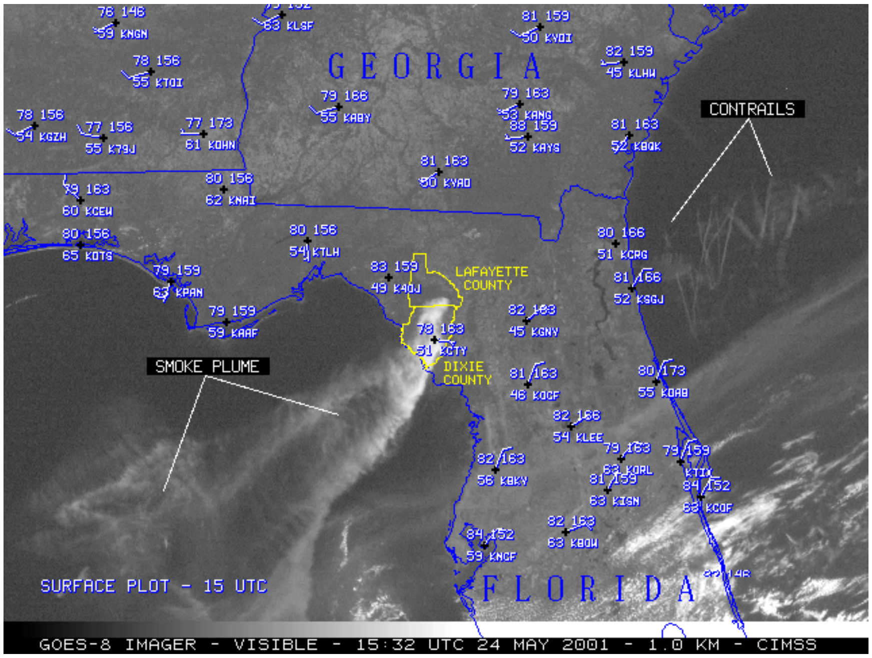
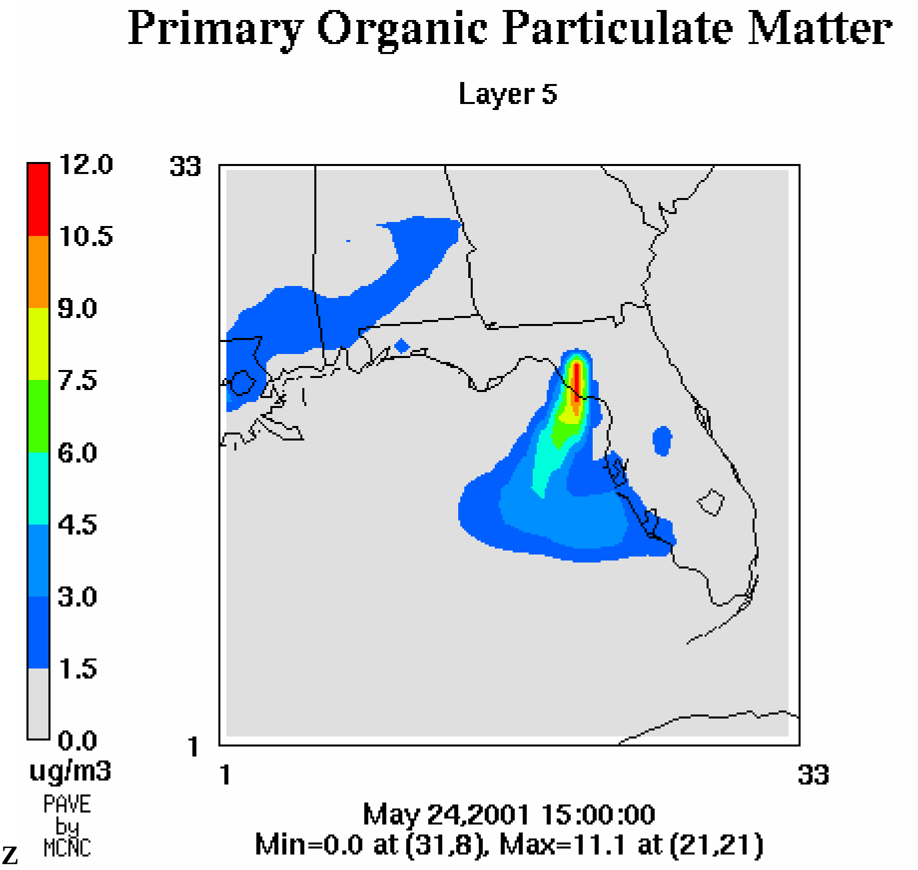


Figure 3 Layer 5 CMAQ simulation Primary Organic Particulate Matter 5/24/01



15Z

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DISCLAIMER

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KEYWORDS

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