WILDLAND FIRE EMISSION MODELING FOR CMAQ: AN UPDATE

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1. 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. To properly simulate wildland fires, emissions need to be distributed hourly onto grid cells with sizes ranging from 4 km to 36 km. In this paper, we summarize efforts to improve the methods used for modeling wild land fire emissions both for retrospective modeling and real-time forecasting.

2. EMISSION MODELING APPROACHES

2.1 National Emission Inventory

The National Emission Inventory (NEI) approach for estimating wildland fire emissions is currently used by the EPA for modeling purposes. For 2001 and prior years, wildland fires have only been specified spatially by state and temporally by month (EPA, 2004). Emission estimates are calculated using Equation (1),

$$e_{state} = A_{state} \cdot C_{state} \cdot (1 + s_{state}) \cdot f_{state} \qquad (1)$$

where e_{state} is the wildfire emission by state, A_{state} is the wildfire acres burned by state, C_{state} is the state-level fuel consumption, s_{state} is the state-level smoldering augmentation factor, and f_{state} is the wildfire emission factor. Emissions are allocated to regions of a state using the forest land use as spatial surrogate. The Sparse Matrix Operator Kernel Emission (SMOKE) (Coats and Houyoux, 1996) system is then used to create gridded, speciated, hourly emission input into the chemical transport model.

2.2 Bluesky with CONSUME/EPM

One effort to improve wildland fire emission estimates adapts portions of the BlueSky (O'Neill et. al., 2003) fire emission modeling system to provide episodic inputs to regional-scale chemical transport models, such as the Community Multiscale Air Quality (CMAQ) modeling system. The BlueSky modeling framework combines emissions, meteorology, and dispersion models to generate predictions of smoke impacts across the landscape. BlueSky-EM (Emissions Model) has been derived from Bluesky and contains two Bluesky modules (CONSUME and EPM) that together are used to estimate emissions (Sandberg and Peterson, 1984). Bluesky-EM also includes updates to the SMOKE system. More details on BlueSky-EM can be found in Pouliot et al. (2005). CONSUME is a fuel consumption model that predicts total fuel consumed by a fire and includes both a flaming and smoldering component. CONSUME was designed for prescribed burning and it can be used for most forest, shrub and grasslands in North America (Ottmar et. al., 1993). EPM is a model that predicts the time rate of fuel consumption and emissions from wildland biomass burns and uses emission factors for each pollutant to estimate emissions on a per fire basis. CONSUME and EPM, however, do not contain the most recent knowledge of emission estimates from wildland fires. While the Fire Emission Production Simulator (FEPS) contains newer knowledge for estimating emissions (Anderson et. al, 2004), it is not yet part of the BlueSky framework. The FEPS user manual summarizes deficiencies in the CONSUME/EPM modules as follows: "the CONSUME/EPM program uses an integral method of prediction rather than a dynamic simulation, so it is limited to simple fires where area growth rates do not change significantly over

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the burning period. Although still usable, EPM is technically deficient for long smoldering fires and for fires that burn in several different fuel types or fire growth rates and is not suitable for most freely spreading wild-land fires." Three mapped fuel loadings are currently available in the BlueSky framework: (1) the Fuel Characteristic Classification System (FCCS) mapped for the western U.S. (McKenzie et. al, 2004, Sandberg et. al., 2001), (2) the Hardy (Hardy et. al, 1998) mapping of fuel loadings for the western U.S., and (3) the National Fire Danger Rating System (NFDRS) fuel load mapping available for the continental U.S. (Burgan et. al 1998). For CMAQ applications with BlueSky-EM, the NFDRS fuel loadings have been used. The U.S. Forest Service (S. O'Neill, 2005, personal communication) is planning, in the near future, to update BlueSky with a national coverage of the FCCS. Emission estimates in BlueSky are calculated on a per fire basis with spatially resolved information for fuel loadings.

2.3 Air Quality Forecasting

An initial attempt to characterize real-time emissions from wildland fires is underway. Our objective is to adapt and begin testing a "real-time" algorithm for estimating emissions from biomass burning (primarily wildland, prescribed, and agricultural fires) in the National Weather Service's ETA-CMAQ air quality forecast system to support implementation of a national PM2.5 air quality forecast. A description of the emission processing system and the interfacing of the ETA meteorological model with CMAQ can be found in Otte et.al,(2005). Estimates of emissions from wildland fires on a real-time basis will be based on less information than for retrospective modeling. Therefore, our first attempt at characterizing emissions from wildland fires has several crude assumptions. The main assumption is that all fires detected by a single satellite pixel are assumed to be of the same size and have the same emissions. The Hazard Mapping System (HMS) product is available daily from NOAA/NESDIS and is used to identify locations of biomass burning. The HMS product is available ONCE daily with a preliminary product typically available around 7 GMT and final quality-checked product by 10-11 GMT. This may be important depending on the forecast cycle. The burn area for each "fire" is assumed to be 22.3 ha (based on an analysis of the 2001NEI dataset of the total annual burn area and total number of fires). For operational forecasts, we assume that 16.7 hectares burn per day (75% of total burn area). Finally, we assume that the $PM_{2.5}$ emission factor is 225 kg/ha, which is based on a review of emission factors that exhibit a wide range from 20 to 800 kg/ha. The $PM_{2.5}$ emission factor is a composite of fuel loading, fuel consumption, and emission factors.

3. COMPARISON OF EMISSIONS

A comparison of the NEI and the CONSUME/EPM emission estimates illustrates the uncertainty associated with emissions from wildland fires. The Florida Department of Forestry has provided a detailed inventory of all wildland fires that occurred in Florida during 2001. Using this activity dataset, we compared the $PM_{2.5}$ emission estimate for Florida during 2001 using the combination of CONSUME/EPM and the NEI approach. For the 2001 NEI, the $PM_{2.5}$ emission estimate for wildfires in Florida was 111,276 short tons per year. For BlueSky, the $PM_{2.5}$ emission estimate for wildfires in Florida was 10, 667 short tons per year. The factors contributing to this large difference are summarized in Table 1. Each parameter used in the emission calculation is different for both models as shown in Table 1. For CONSUME/EPM, the average for all fires is shown as each fire has its own value. As noted above, the CONSUME/EPM approach probably underestimates total emissions. On the other hand, a review of the NEI method revealed that the state level fuel consumption factor Florida was overestimated. The average fuel consumption for Florida was changed from 19.7 to 6.6 on April 13, 2004 per follow-up memo from Bruce Bayle (EPA, 2003). The fuel consumption factor was calculated originally using assumptions from the western US and the revision was made do to differences between fuels in Florida compared to the western US. Using this revised factor for the NEI, the total $PM_{2.5}$ emissions are estimated to be 37,280 tons per year. The resulting composite PM2.5 emission factor is approximately 171 kg/ha for Florida, which is consistent with the 225 kg/ha factor used in the Air Quality Forecasting application.

Table 1: Comparison of the assumptions used for estimating 2001 Florida emissions using the NEI and the CONSUME/EPM approaches using FL activity dataset

	NEI	CONSUME/EPM	NEI (revised)
Acres burned	401,431	401,431	401,431
Fuel loading (tons/acre)	19.7	4.43 (average)	6.6
Smoldering augmentation factor	1.167	1.058 (average)	1.167
Emission factor (lbs $PM_{2.5}$/tons of fuel)	24.1	11.32 (average)	24.1
Total $PM_{2.5}$ emissions (tons)	**111,276**	**10, 667**	**37,280**

4. SUMMARY OF PLUME RISE

To prepare wildland fire emissions for input into a chemical transport model, a plume rise algorithm is needed to place the emissions into the various model layers. Two approaches are currently available in the SMOKE system. The Western Regional Air Partnership (WRAP) has developed an approach by which each fire is given a pre-defined plume bottom and plume top and a pre-defined diurnal temporal profile. (WRAP, 2005) The plume top and bottom are simply a function of the fire size in virtual acres. A smoldering fraction is used to estimate the emissions placed in layer 1. This method results in a "gap" in the vertical distribution of emissions, with a portion in layer 1 and the remaining portion several layers above that and disjoint from layer 1. Additionally, the plume bottom and top heights are calculated independently from any dynamic meteorological data. The BlueSky-EM approach estimates the heat flux from each fire, which we have converted to a buoyancy flux suitable for use with the Briggs plume rise algorithm (Pouliot et. al, 2005). Using the Briggs layer-by-layer approach (Byun et. al., 1999), we developed a dynamical plume rise algorithm for wildland fires and have incorporated it into SMOKE as an alternative to the WRAP approach. To account for smoldering, we used the actual fire size (rather than the virtual fire size) and the WRAP lookup table that relates fire size to smoldering fraction to estimate a smoldering fraction. We distributed the smoldering fraction into all layers below the plume bottom rather than only in layer 1.

5. PRELIMINARY RESULTS

5.1 2001 National Emissions Inventory

Our analysis for retrospective air quality modeling focuses on the month of May 2001 for the state of Florida, based on the availability of a detailed wildfire activity dataset and the occurrence of large fires during this month. For this analysis, the 36-km continental U.S. evaluation modeling domain from CMAQ was used. Figure 1 shows the logarithm of the monthly to`tal $PM_{2.5}$ NEI emission estimates. The poor spatial representation of the wildfire emissions is evident in the "smearing" of the fire emissions across most of the grid cells.

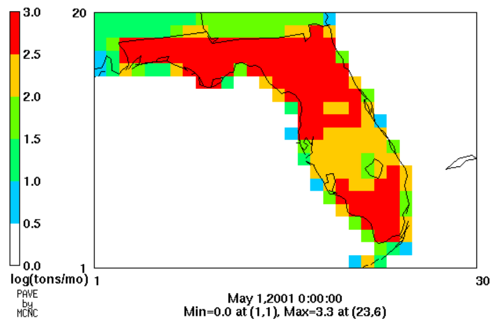

Figure 1. Logarithm (base 10) of gridded total monthly $PM_{2.5}$ emissions from the NEI for May 2001.

Figure 2 shows monthly average $PM_{2.5}$ from a simulation using CMAQv4.4 as part of the evaluation for the 2004 release. The unrealistic $PM_{2.5}$ concentration pattern over Florida is evident and is a result of the poor spatial distribution of the wildfire emissions. Figure 3 compares the model to observed $PM_{2.5}$ concentrations for Florida from the IMPROVE network. This comparison shows that $PM_{2.5}$ is overpredicted, apparently because of the poor representation of wildland fire emissions in Florida.

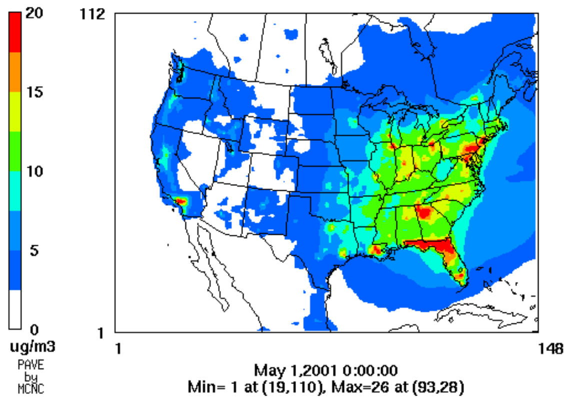

Figure 2. Monthly average $PM_{2.5}$ concentrations for May 2001 from the 2004 CMAQ release using the NEI fire emission estimates.

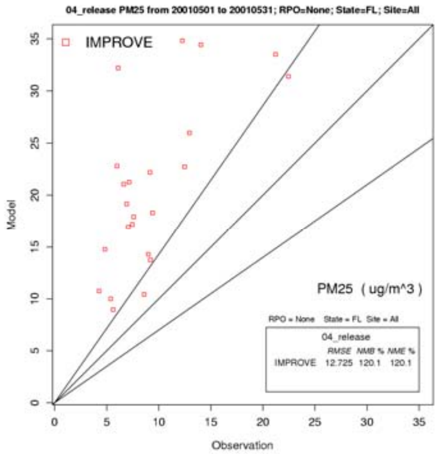

Figure 3. Comparison of modeled (CMAQ with the NEI estimates) and observed (IMPROVE) monthly average PM2.5 concentrations for May 2001 for Florida.

5.2 Bluesky with CONSUME/EPM

The detailed wildfire activity dataset from the Florida Department of Forestry was used to construct a spatially and temporally resolved wildfire emission inventory for May 2001. Emission estimates were derived using CONSUME/EPM from the BlueSky framework. The plume rise algorithm using Briggs layer by layer approach as described in section 4 was used with these emission estimates. Figure 4 shows the logarithm of the $PM_{2.5}$ emissions using the CONSUME/EPM approach. As noted in section 3, emission estimates from CONSUME/EPM are much lower than from the 2001 NEI. Figure 5 shows the monthly average concentration of PM2.5 using the 2004 release of CMAQ with this emission inventory and fire plume rise. The unrealistic average concentration in the state of Florida is no longer present. However, the impact of wildfires from Florida is likely underestimated since the emission estimates from CONSUME/EPM were likely too low.

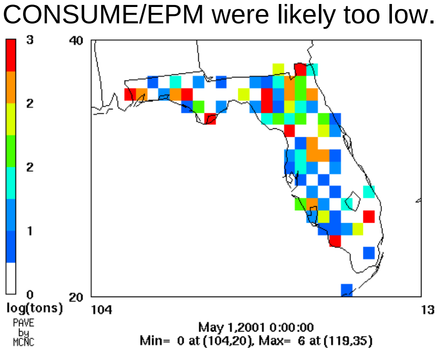

Figure 4. Logarithm (base 10) of total monthly $PM_{2.5}$ emissions using the Florida Department of Forestry Dataset and CONSUME/EPM for May 2001.

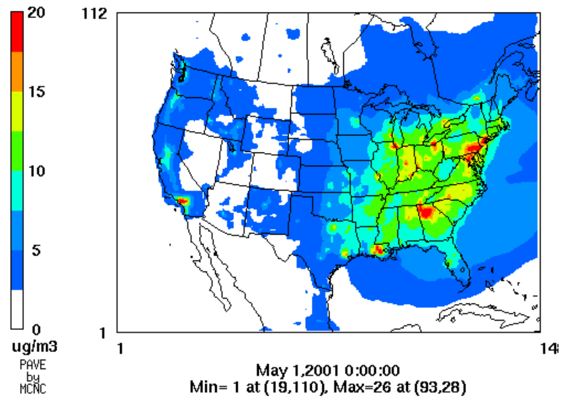

Figure 5. Monthly average $PM_{2.5}$ concentrations for May 2001 from the 2004 CMAQ release using the CONSUME/EPM approach and the Florida activity dataset. emission estimates.

5.3 National Emissions Inventory with Plume Rise

Because the CONSUME/EPM emission estimates are likely too low for the Florida wildfire emissions, we used the revised fuel loading with the NEI methodology and the Florida Department of Forestry activity dataset to construct another emission inventory as shown in Figure 6. All other parameters are the same as used for the 2001 NEI. We also included the plume rise algorithm for wildfires for this simulation. This emission estimate was used for the evaluation of the 2005 CMAQ release (CMAQv4.5). A comparison of the $PM_{2.5}$ concentrations from the CMAQ 2005 release simulation with this inventory observed data from the IMPROVE network is shown in Figure 7.

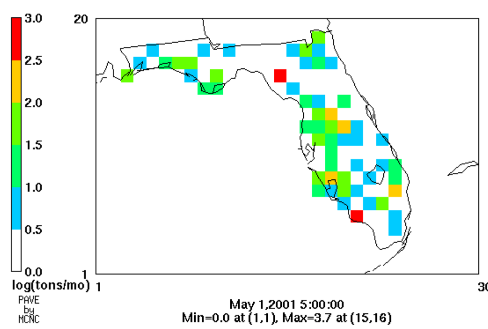

Figure 6. Logarithm (base 10) of total monthly $PM_{2.5}$ emissions using the Florida Department of Forestry activity data and the revised NEI fuel loading for emission estimates for May 2001.

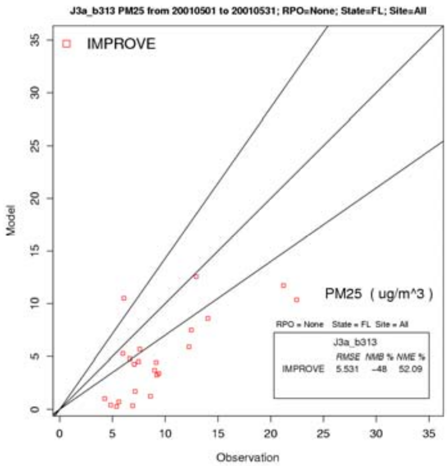

Figure 7**.** Comparison of IMPROVE vs CMAQ (2005 release) model $PM_{2.5}$ concentrations for May 2001 Florida using the Florida Department of Forestry activity data, plume rise for fires, and revised fuel loading for Florida.

The statistics show that the revised inventory affects the performance of CMAQ across Florida, with the normalized mean bias changing from +120% to -48%. Although the new approach removes the large overprediction in PM2.5, a slight underprediction is still evident that may be attributed to state-level assumptions for all fires in the NEI method. We compared the evaluation statistics for Georgia for May 2001 and for Florida for April and June 2001. In all cases, the normalized mean bias and normalized mean error were similar between the 2004 and 2005 CMAQ releases, suggesting that the change in model performance in Florida for May 2001 was due primarily to changes in the emission estimates for wildland fires.

5.4 Air Quality Forecasting

Our first test of the Eta-CMAQ air quality forecast system with real-time wildfire emission estimates derived from the HMS product was for a three-day test period during August 2004. This time period did not contain any significant wild land fires, just a large number of smaller fires located mostly in the Mississippi Valley. This first test is simply to test the robustness of the system to ingest real-time emission estimates, as the large uncertainty with the fire emission estimates is appreciated. Future plans include revisions of the underlying crude assumptions for fire sizes and fuel loadings and tests of the air quality forecast system with major wildfire events. Future plans also include the incorporation of other pollutants and the use meteorological variables for the hourly temporal allocation of the emissions. Figure 8 shows the maximum difference in hourly surface $PM_{2.5}$ concentrations over a three-day period.

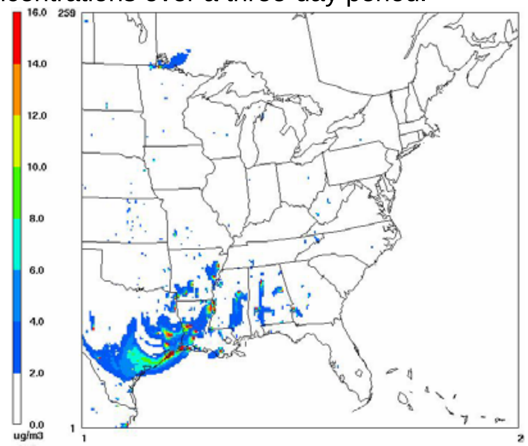

Figure 8. Maximum difference between hourly $PM_{2.5}$ concentrations using the HMS-derived fire emissions and no wildland fire emissions in the Eta-CMAQ air quality forecast system for August 14-16, 2004.

6. SUMMARY

We have provided an overview of several new approaches for estimating wildland fire emissions for the CMAQ chemical transport model. Key improvements include the linkage of the BlueSky Framework with the SMOKE system and the inclusion of a new plume rise algorithm within SMOKE for wildland fires. We have shown that improved spatial and temporal resolution of wildland fire activity as well as improved emission estimates is important in the simulation of wildland fires and to the evaluation of CMAQ.

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9. DISCLAIMER

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