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COMBINING WILDFIRE EMISSIONS FROM THE COMMUNITY SMOKE EMISSIONS MODEL (CSEM) WITH A REGIONAL-SCALE AIR QUALITY MODEL

Michael G. Barna and Douglas G. Fox
CIRA/Colorado State U., Fort Collins, CO 80523

1. INTRODUCTION

This paper presents preliminary results of an effort to develop an emission inventory for wildfires, and to incorporate these emissions into a regional air quality model. Air quality is the result of many different sources of air pollution emissions being transported, dispersed, chemically transformed, and removed by both wet and dry deposition. Simulation of all the processes involved requires a complex model that is equally dependent on detailed emissions data and complex meteorological fields as it is on dispersion, chemical transformation, and removal process parameterizations.

Obtaining detailed and accurate emissions data for forest fires for application in air quality simulations is especially difficult. The regional nature of the problem lends complexity in that hourly emissions are required for an extended period of time (e.g., up to a year) and often cover a large spatial scale (e.g., continental). In this paper we present the first results from a newly developed Community Smoke Emissions Model (CSEM). The model, based on linking mesoscale meteorological information with existing US Forest Service tools, will be described. CSEM will be applied to generate emissions from wildfires for July - August 1996 for the western United States. These fire emissions data, aggregated to a 36 km grid, will form the forest fire input to a regional-scale air quality model. Results from an upcoming air quality simulation, with and without simulated fire emissions, will be compared with air quality data from the national IMPROVE network (IMPROVE, 2003).

Modeling the impact of forest burning on air quality is done for a variety reasons. A recent assessment of smoke management needs suggests organizing smoke management along strategic planning, tactical planning, and operations (Fox, and Riebau 2000). Strategic planning applications include the regional haze regulations as well as National Forest plans and State and Tribal Implementation Plans (S/TIPS). Strategic planning requires regional scale analysis, projections of potential future conditions, and considering differences as a result of alternative management decisions. CSEM is specifically designed for this application. Tactical planning generally requires tracking individual burns in relatively greater detail, the ability to consider airshed loading from multiple fires and alternative management strategies associated with these burns. Tactical planning includes permit related activities and smoke management programs. Operational activities also involve tracking in detail individual plumes and airshed loadings as well as forecasting smoke impacts.

2. COMMUNITY SMOKE EMISSIONS MODEL – CSEM

CSEM is specifically designed to provide historical fire emissions estimates for use in regional scale air quality models such as CMAQ (Byun and Ching), CAMx (Environ, 2003), and REMSAD (ICF, 2003). In order to predict emissions from forest fires, it is first necessary to estimate fires that have burned, are burning or will burn in the region. These data are known as “activity” data, and include the date and time that the fire started, fire size progression, and fire end time for all fires above a selected size criterion. After fire activity data are collected the next tasks are to determine the amount of fuel combusted in the fire and the characteristics of that fuel. Finally, the fuels consumed are combined with appropriate emission factors to predict the emissions. The following seven steps are common to any smoke emissions modeling:

1. Read fire activity data (including fire start time, location, fuel type, area of the burn, pre-burn fuel loading, fire type and any other data available);
2. Based on the fire location, determine the fuel loading for the fire;
3. Determine (from data or modeling) current and antecedent meteorological conditions at each fire;
4. Calculate fuel consumption (either as a function of time or total) for each fire;
5. Calculate emissions for each species of concern (e.g., CO, CO_2, CH_4, PM2.5, PM10) and heat released for each fire;
6. Calculate the plume rise for each fire;
7. Accumulate the fire emissions and format them as input files to the regional modeling system.

Figure 1 presents an outline of how CSEM accomplishes these tasks by combining meteorological model predictions with existing forest fuel and emission models and datasets. Details about individual components of CSEM are provided below.

2.1 Fire Activity Data

Fire data is read from an inventory of fire activity. Critical activity data for each fire include 1) location, 2) start and end time, 3) fuel type, 4) fire type (e.g., crown, smoldering), and 5) whether the fire is natural or prescribed (Peterson 2001). At present there is no national database that includes all of this information, although new tools, such as the GeoMAC Wildland Fire Support system (USGS, 2003) are being developed that provide many of the requisite data. For the purpose of this paper we have applied CSEM with a sampling of activity data that was developed by the Western Regional Air Partnership's (WRAP) Fire Emissions Joint Forum (FEJF) (WRAP, 2002). These data are not yet officially released by the WRAP FEJF and therefore any comparison between model results and actual fire emissions is inappropriate. We utilize these activity data simply as an illustration of CSEM functionality.

2.2 Fuel Loadings

Currently, CSEM uses default values of fuel loading from the National Fire Danger Rating System (NFDRS) (Deeming et al., 1987). Specifically, the NFDRS Fuel Model Map (USFS, 2003a), which provides a national fuels coverage derived from satellite remote sensing data as well as extensive on-the-ground data collection, was used to provide fuel loading at a 1 km resolution. Unfortunately, there are problems when applying the NFDRS to generate fuel loadings. For example, the NFDRS is a fire danger rating tool, and is primarily designed to identify potential forest flammability. As such, the fuel models it uses may not be accurate representations of actual fuel loadings but rather contain a representation of the fuel characteristics that are typical of that location. Also, NFDRS fuel models do not reflect fuel buildup or past management practices, so they are unable to represent the dynamic occurrence of different fuel loadings and their changes over time. Nevertheless, for the purposes of this initial application of CSEM the NFDRS fuel map is considered adequate, and future refinements may include, for example, the incorporation of fuels datasets from the Coarse-Scale Spatial Data for Wildland Fire and Fuel Management (USFS, 2003b).

2.3 Meteorology

CSEM requires meteorological information to diagnose fuel moisture as well as predict plume rise. Fuel moisture is a key parameter in estimating consumption, and the meteorological data needed for the estimation of fuel moisture includes humidity, temperature, and precipitation. These data are provided by the MM5 (Mesoscale Model Version 5) regional scale weather model (Grell et al., 1994).

2.4 Fuel Consumption

The Consume model (Ottmar et al., 1993) estimates the mass of fuel (i.e., woody material, litter and duff) consumed by a fire. These estimates are based on weather data, the amount and fuel moisture of fuels, and a number of other factors. The fraction of fuel consumed during flaming (versus smoldering) combustion is also calculated.

2.5 Emissions Speciation and Heat Release Rates

The Emissions Production Model (EPM) (Sandberg and Peterson, 1984) is linked to Consume and is used with updated emission estimates (Leenhouts, 2000) to predict temporally varying emissions of CO, CO_2, CH_4, PM2.5, and PM10, as well as heat released during the fire. Further refinements will be made to assign organic carbon and elemental carbon fractions to the total PM2.5 mass (Ward and Hardy, 1989; Kaufman et al., 1992) to facilitate comparisons with IMPROVE aerosol measurements.

2.6 Example CSEM Wildfire Emissions

Example wildfire PM 2.5 emissions from CSEM are shown in Figure 2 for a four day period in August 1996. As discussed above, these results reflect a subset of the WRAP-FEJF fire activity data, and hence are not yet directly comparable to existing fire emission inventories. Eventually, however, these emissions will be evaluated against other inventories to determine biases in the CSEM predictions. Also, to refine CSEM predictions, new fire activity data and fuel models will be incorporated.

3. DEVELOPING FIRE EMISSIONS FOR THE REMSAD AIR QUALITY MODEL

REMSAD, the Regional Modeling System for Aerosols and Deposition, is a prognostic, Eulerian-grid air quality model designed to simulate the formation and long-range transport of aerosols and their precursors (SAI, 2002; Seigneur et al., 1999). REMSAD has been optimized to be computationally efficient, allowing the simulation of long time periods (e.g., monthly or yearly) over large model domains (e.g., continental-scale). This is achieved in part through the highly simplified treatment of organic species in the chemistry mechanism. REMSAD predicts the physical and chemical processes that affect atmospheric pollutants and their precursors, including advection, turbulent diffusion, wet and dry deposition, and chemical transformation. The REMSAD model domain covers the contiguous US and northern Mexico. A geodetic (latitude/longitude) horizontal coordinate system is used, with a model grid resolution of approximately 36 km. The vertical dimension is defined in terrain-following sigma-pressure coordinates. Thirteen vertical layers are used, with thinner layers specified near the surface and thicker layers aloft. The top of the model domain is set to 50 mb.

Fire emissions similar to those shown in Figure 2 are being reformatted for use in REMSAD. In particular, each fire is treated as a buoyant plume source with attendant plume rise characteristics such as initial plume temperature. Unlike air quality models such as CMAQ, REMSAD calculates plume rise internally, and hence the plume rise algorithms used in CSEM will be adapted to run within REMSAD. The first application of simulating wildfire impacts to regional air quality using CSEM emissions will be to the two month period of July – August 1999.

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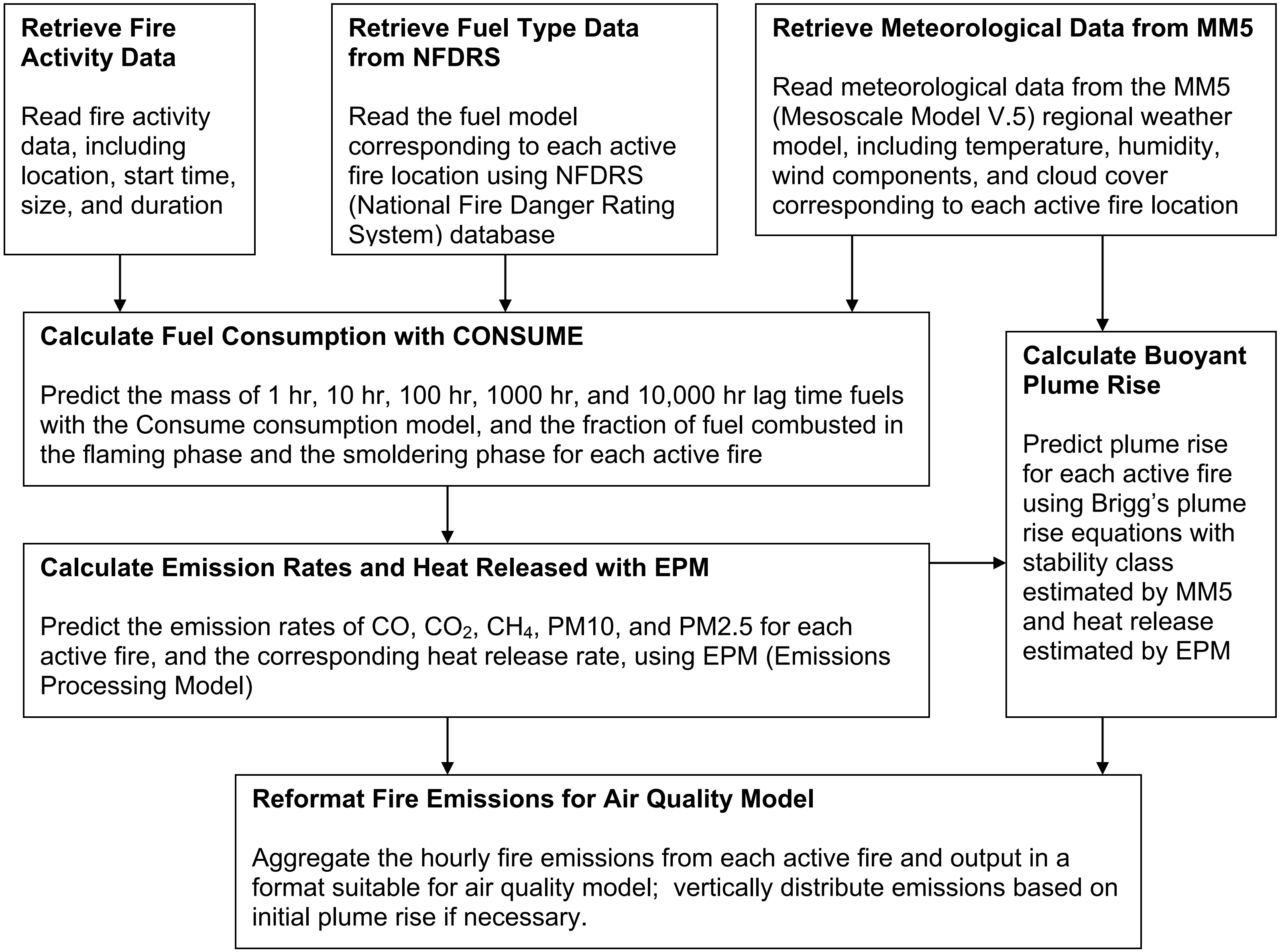

Figure 1. Overview of the input data and model components of the CSEM.

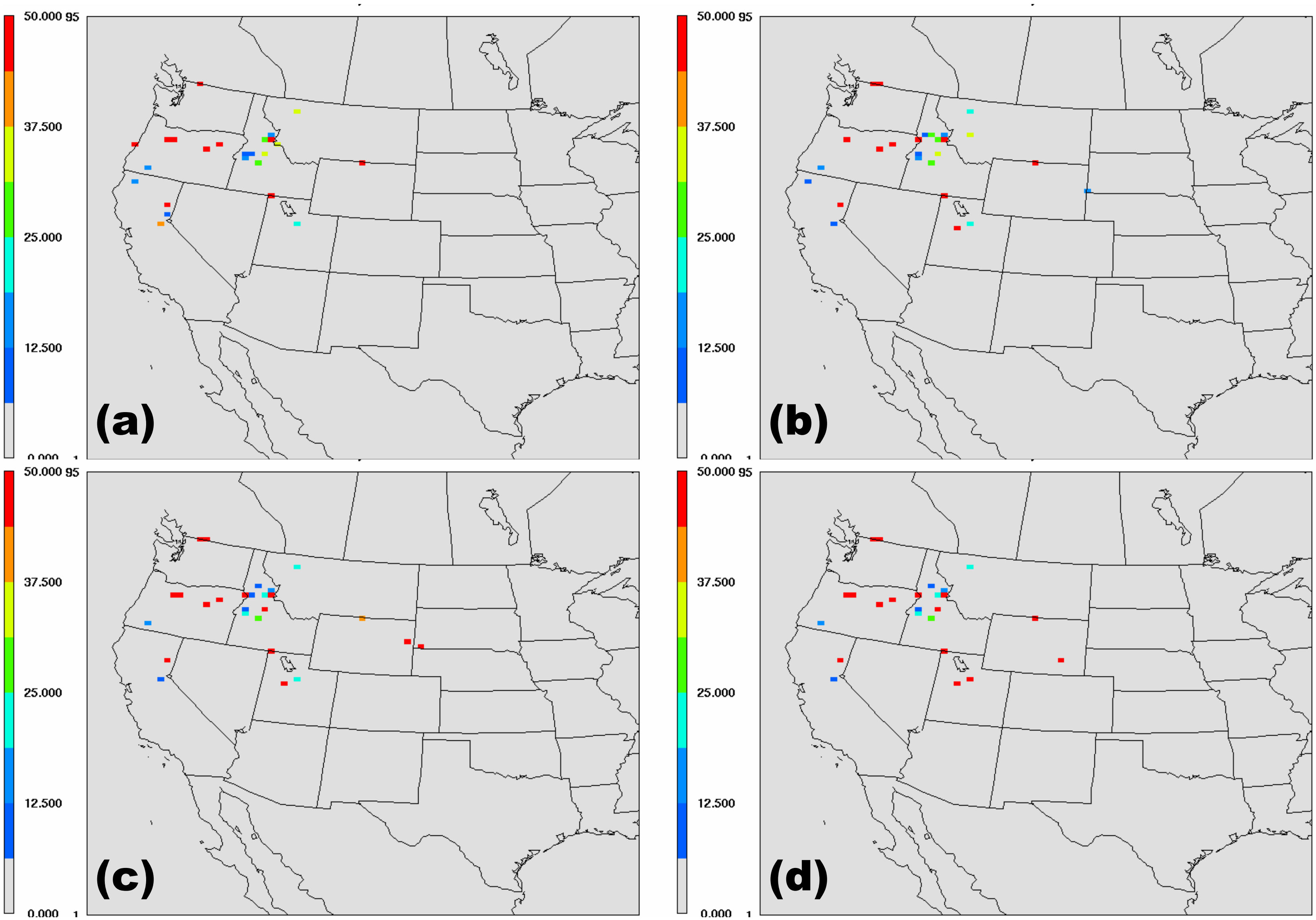

Figure 2. Example 24 hr average PM2.5 emissions (g s^{-1}) calculated by CSEM for (a) 1 August, (b) 2 August, (c) 3 August, and (d) 4 August 1999.