AIR QUALITY EFFECTS OF FLORIDA PRESCRIBED FIRES SIMULATED WITH CMAQ

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1. INTRODUCTION

Wildland fires release a large amount of particulate matter (PM), CO, SO_2, NO_x, and volatile organic compounds (VOC), which can cause degradation of air quality. All these components except VOC are criteria air pollutants subject to the National Ambient Air Quality Standards (NAAQS) (EPA, 2003). EPA also issued the Interim Air Quality Policy on Wildland and Prescribed Fire to protect public health and welfare by mitigating the impacts of air pollutant emissions from wildland fires on air quality (EPA, 1998). Development and application of modeling tools for evaluating the impacts of wildland fires on air quality are needed to assist fire and smoke managers and policy makers in meeting air quality regulations and defining implementation plans.

The South is heavily forested. About 8 million acres of forest, range, and cropland are burned annually mostly for hazard reduction, wildlife habitat improvement, and range management (Wade et al., 2000). Prescribed fires are also used to reduce accumulation of understory debris and, as a result, reduce the risk of wildfire. Different from the West, where wildfires are dominant, prescribed fires in the South are comparable to wildfires in magnitude of emissions (Liu, 2004). Efforts have been made at the USDA Forest Service Southern High-Resolution Modeling Consortium to develop a coupled prescribed fire-air chemistry modeling framework called the Southern Smoke Simulation System (SHRMC-4S, Achtemeier et al. 2003). SHRMC-4S simulates and predicts chemical concentrations of smoke components and assesses their effects on regional air quality by using the EPA Models-3 community multiscale air quality (CMAQ) modeling system (Byun and Ching, 1999), with some modifications for the specific source of fire emission. A major modification is to use DAYSMOKE (Achtemeier, 1998), a dynamical model to simulate movement and deposition of smoke particles injected from fires, to provide plume rise and vertical distribution of smoke particles for CMAQ simulation. This paper presents some preliminary results from the simulations of 2002 prescribed fires in Florida with SHRMC-4S.

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2. MODEL AND SIMULATIONS

SHRMC-4S consists of fuel and fire models for estimating smoke emissions (the components of Fire Data and Emission Calculation in Fig.1) and the Models-3 for modeling air quality (the components of SMOKE-Sparse Matrix Operator Kernel Emissions Modeling System (Houyoux et al. 2002), CMAQ, and Visualization). Meteorological fields simulated by MM5 (NCAR/Penn State Mesoscale Model, Grell et al., 1994) are used for emission calculation, and SMOKE and CMAQ simulations.

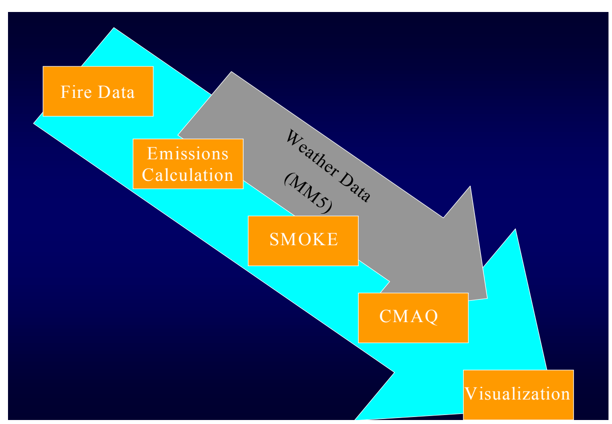


Fig.1 An overview of the SHRMC-4S framework

SHRMC-4S is another framework for wildland fire and air quality research and application in addition to BlueSky (O'Neill et al., 2003), with a focus on prescribed burning in the South. To be consistent with the efforts of VISTAS in air quality simulation of 2002 in the Southeast, CMAQ has been included in SHRMC-4S for air quality simulation. DAYSMOKE has been linked with CMAQ to estimate vertical distribution of smoke particles of prescribed burning in SHRMC-4S.

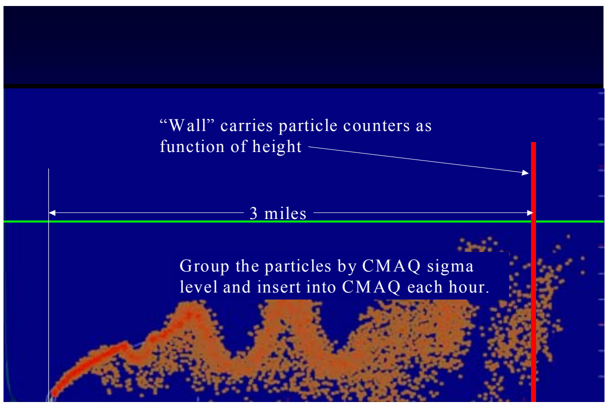


Fig.2 Construction of DAYSMOKE vertical plume profile. The red dots are smoke particles from a prescribed burn predicted by DAYSMOKE. The green line is the top of the planetary boundary layer.

DAYSMOKE consists of the following four models: (a) Entraining turret plume model. The plume is assumed to be a succession of rising turrets. The rate of rise of each turret is a function of its initial temperature, vertical velocity, effective diameter, and entrainment. (b) Detraining particle trajectory model. Movement within the plume is described by the horizontal and vertical wind velocity within the plume, turbulent horizontal and vertical velocity within the plume, and particle terminal velocity. Detrainment occurs when stochastic plume turbulence places particles beyond plume boundaries, plume rise rate falls below a threshold vertical velocity, or absolute value of large eddy velocity exceeds plume rise rate. (c) A large eddy parameterization. Eddies are two-dimensional and oriented normal to the axis of the mean layer flow. Eddy size and strength are proportional to depth of the planetary boundary-layer (PBL). Eddy growth and dissipation are time-dependent and are independent of growth rates of neighboring eddies. Eddy structure is vertical. Eddies are transported by the mean wind in the PBL. (d) Relative emissions production model. Particles passing a "wall" three miles downwind from a burning are counted for each hour during the burning period (Fig.2). A percent of particle number of each layer relative to the total particle number is assigned to SMOKE/CMAQ simulations.

Simulations were conducted with SHRMC-4S for the prescribed burning in Florida during March 6-9, 2002 (Julian day 65-68). Both burning number and area were large during the late winter and early spring of this year (Fig.3). There were 180, 170, 147, and 156 prescribed burnings with the burned areas of 111, 100, 73, and 30 acres in these days, respectively. Burnings are assumed to start at 10:00. The largest emissions occur at 12:00-14:00, during which three fourths of total emissions are released. A domain of 12 km resolution with 95X47 grid points is used. The integration period is from 8:00 to 18:00.

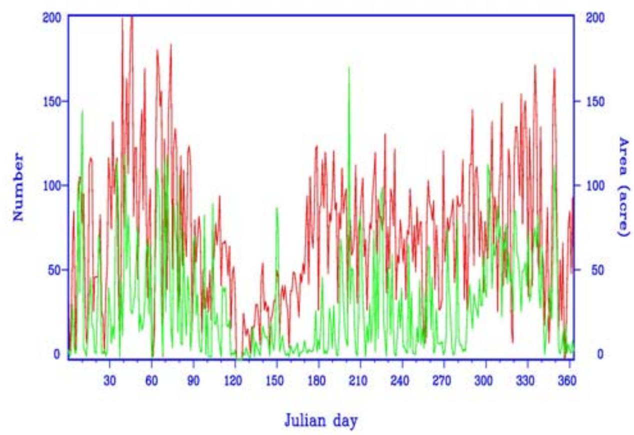


Fig.3 Seasonal variations of number (red) and averaged area (green) of daily prescribed burning in Florida, 2002.

3. RESULTS

3.1 Plume Rise and Vertical Distribution

The simulation of March 6 is used to illustrate the results. Fig.4 shows the height of smoke plume (plume rise) and vertical profile of the smoke particle number percent. The plume rise estimated using DAYSMOKE first gradually increases from about 0.25 km at 9:00 to 1.2 km at 12:00 and 13:00, and then gradually decreases to 0.25 km at 17:00. This daily cycle agrees with the development of PBL. A majority of smoke particles occurs in the upper portion of smoke plume until 14:00, with the largest percent found at a level a few hundreds of meters below the plume rise. The level then lowers its height and is near the ground in the late afternoon.

The plume rise and vertical profile are much different from those estimated using the “layer fraction method” in SMOKE/CMAQ, in which the Briggs formulas, originally developed for stack (Briggs, 1971), are used to calculate smoke plume rise and the plume is distributed into the vertical layers that the plume intersects based on the pressure in each layer. The plume rise calculated using the Briggs formulas reaches a height of 12 km in the afternoon with the largest percent found at about 3 km.

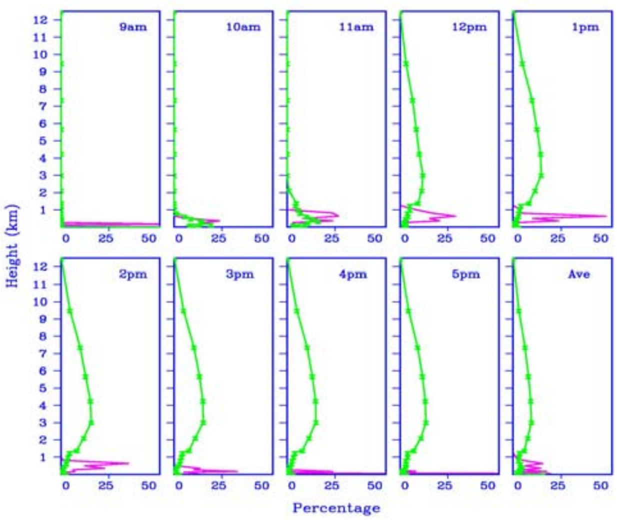


Fig.4 Vertical distribution of smoke particles estimated using DAYSMOKE (pink) and Briggs scheme (green) on March 6, 2002.

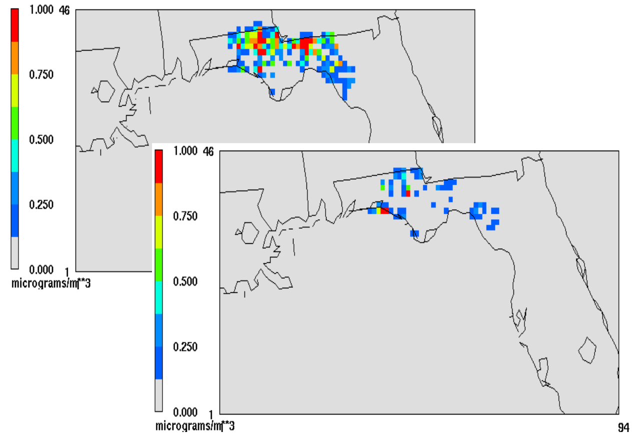
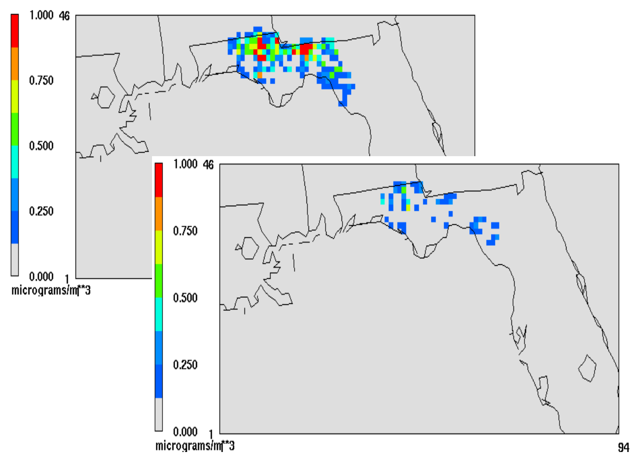


Fig.5 CMAQ simulation of PM concentration with plume rise estimated using DAYSMOKE (background) and Briggs scheme (foreground) of the surface layer at 14:00 on March 6, 2002.



Figu.6 Same as Fig.5 except for σ=0.91.

3.2 Spatial Distribution

Fig.5 shows the simulated PM of the surface layer. There is a large concentration in the northwestern Florida. The magnitude simulated using DAYSMOKE is about 1 $\mu g\ m^{-3}$. The magnitude simulated using the layer fraction method is much smaller. This difference, visible at the height up to about 1 km (Fig.6), indicates that CMAQ with DAYSMOKE produces larger concentrations on the ground and in PBL. Apparently, this is resulted from the differences in the plume rise and vertical profile between DAYSMOKE and the layer fraction method, as shown in Fig.4.

3.3 Temporal Variations

The PM concentration simulated by CMAQ with DAYSMOKE increases with time until 15:00 and decreases thereafter (Fig.7). The largest concentration occurs near the top of the plume before 13:00 and on the ground after that hour, respectively. The plume reaches about 1 km by 12:00, 1.2 km by 14:00, and 2 km in the late afternoon. In comparison, the simulated plume using the layer fraction method extends up to about 7 km. The concentrations on the ground and in PBL are relatively smaller. The magnitude is about one third of that simulated using DAYSMOKE.

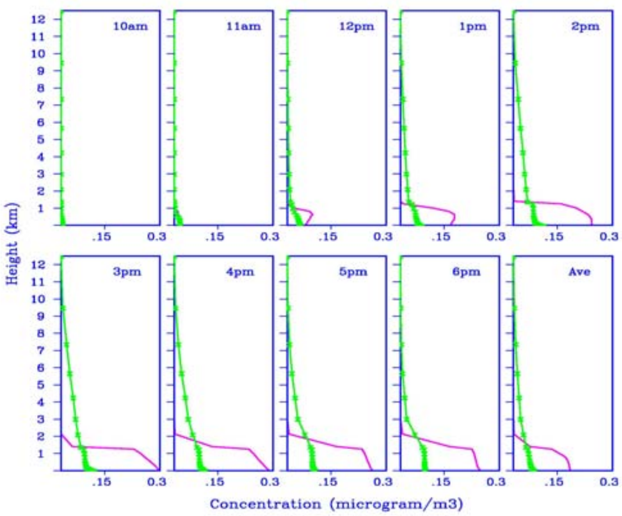


Fig.7 CMAQ simulation of PM concentration with plume rise estimated using DAYSMOKE (pink) and Briggs scheme (green) on March 6, 2002.

4. DISCUSSION

SHRMC-4S has been developed as a framework for smoke and air quality research focused on prescribed fires in the South. DAYSMOKE has been linked as an alternate to the layer fraction method in SMOKE/CMAQ for smoke plume rise calculation and vertical profile specification. The SHRMC-4S simulations of the Florida cases using DAYSMOKE obtained lower plume rise and larger concentration in PBL than those obtained using the layer fraction method. The results with DAYSMOKE could have important implications for the adverse impacts of prescribed fires on health of human being and ecosystem because more smoke particles are trapped near the ground.

Although some measurements were used for the development and validation of DAYSMOKE, more measurements are needed for further validation of this model and comparison with the existing methods in SMOKE/CMAQ. In addition, more fuel and fire information are needed for improving the performance of SHRMC-4S. A number of efforts have been proposed, including radar observations of prescribed burn plumes, comparisons with high-resolution simulations of smoke plume using the Weather Research and Forecast (WRF) model, and applications of aerial photographs of smoke plumes.

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