Project Title: Evaluation and Improvement of Smoke Plume Rise Models

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I. Abstract

The purpose of this JFSP project was to evaluate and improve the performance of Daysmoke in simulating smoke plume rise of prescribed burning. A combined approach of field measurement, numerical modeling, and dynamical and statistical analysis was used. Smoke plume height was measured with a ceilometer for 20 prescribed burns in the southeastern U.S. The measured data was used to validate Daysmoke simulation. An empirical smoke plume rise model was developed based on the RAWS observations. Daysmoke was improved by including the number of multiple updraft cores. Regional air quality modeling was conducted with smoke plume rise provided by Daysmoke. A Daysmoke user interface was developed for smoke management applications. The key findings include (1) Smoke time and vertical structure appear in three patterns, two of which have significant fluctuations at different time scales. (2) Daysmoke is able to simulate plume heights at a reasonable level for most of the measured burns. (3) The regression model using three RAWS measurement elements of wind, fuel moisture and fuel temperature has good agreement with the measurements. (4) The inclusion of multiple smoke updraft core number improves Daysmoke simulation of vertical profile and in some cases plume height. (5) CMAQ simulations are improved with plume height provided by Daysmokewith multiple core property.

II. Background and Purpose

Smoke plume rise, also called plume height, is the height where the smoke particles can reach after they are ejected from wildland fires. It ranges from tens of meters for prescribed fires to thousands of meters for wildfires. Plume height is an important factor for local and regional air quality modeling. Fire emissions, if injected into higher elevations, are likely to be transported out of the rural burn site by prevailing winds and therefore possibly affect air quality nearby and remote populated urban areas in downwind direction. Plume rise is a parameter required by many regional air quality models such as the EPA Community Multi-scale Air Quality (CMAQ) model (Byun and Schere 2006).

Efforts have been made recently that led to the developments of a number of smoke plume models with various levels of complexity. Smoke plume height model evaluation, however, has been a big challenge because of the lack in smoke measurements. This makes it difficult to understand the performance and uncertainties of smoke models. Fire and smoke model validation is one of the fundamental research issues in the Smoke Science Plan, prepared for the U.S. Joint Fire Science Program (JFSP).

The study, funded by the Joint Fire Science Program (JFSP), was to evaluate and improve the performance of Daysmoke as well as other models in simulating smoke plume rise of prescribed burning. A combined approach of field measurement, numerical modeling, and dynamical and statistical analysis was used to obtain data, conduct simulation and evaluation, and improve the model. The specific research objective included:

1. Conduct smoke plume rise measurements,

2. Evaluate and improve plume rise estimates from Daysmoke,
3. Analyze Daysmoke plume rise modeling and evaluate the importance for regional air quality modeling, and
4. Improve Daysmoke feasibility and transfer it into field application tools.

III. Study Description and Location

A. Smoke measurement and analysis

Smoke plume height was measured with a Vaisala CL31 ceilometer, a device employing laser LIDAR (Light Detection and Ranging) technology (Munkel et al. 2007). A total of 20 prescribed burns were measured during 2009-2011 at the Ft Benning Army Base near Columbus in southwestern Georgia, the Oconee National Forest and the Piedmont National Wildlife Refuge in central Georgia, and the Eglin Air Force Base near Niceville in northwestern Florida (Fig. 1 and Table 1). Five burns occurred in winter, 13 in spring, and 2 in summer. The burn size was less than 500 acres for 4 burns, 500 ~ 999 acres for 6 burns, 1000 ~ 1999 acres for 8 burns, and 2000 acres and larger for 2 burns.

The properties of the measured smoke plume height were analyzed. Smoke patterns and the related time scales were identified based on fluctuation with time and using wavelet transform. Concentration of smoke PM_{10} (particulate matter with a size not greater than 10 μm) was obtained using a relation with ceilometer backscatter intensity (Munkel et al. 2007).

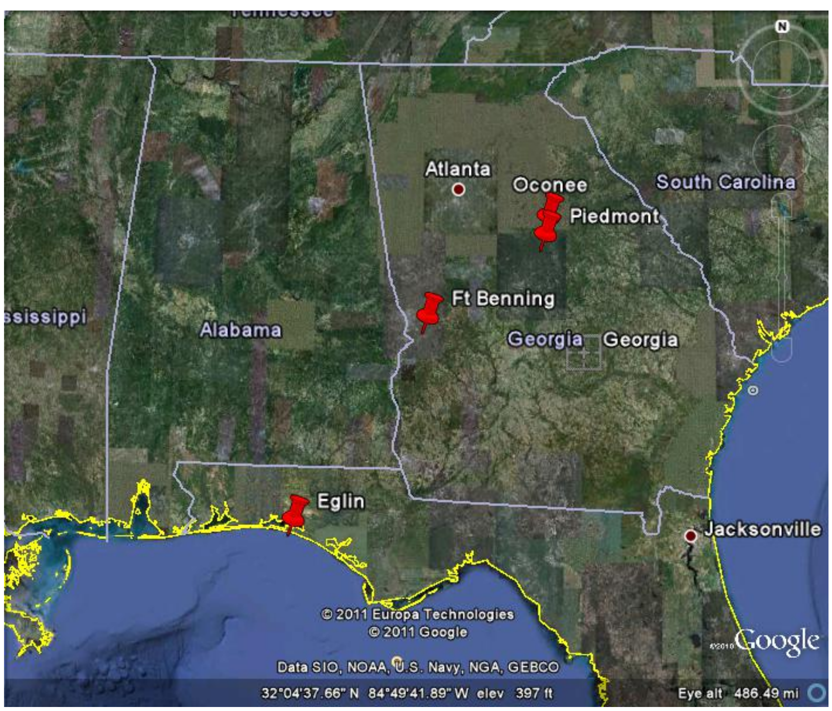

Fig. 1 Four burn sites of Ft Benning, Oconee, Piedmont, and Eglin in the southeastern United States shown on Google Earth.

Table 1 Prescribed burn information

Location	No	Date	Acre	Ignition method
Ft. Benning, Columbus, GA 32.33N, 84.79W	1	1/14/09	364	backing/strip head
	2	1/15/09	583	backing/strip head
	3	4/08/09	236	backing/strip head
	4	4/09/09	343	backing/strip head
	5	4/28/10	1000	ground
	6	4/29/10	447	ground
Oconee, Eatonton, GA 33.54N, 83.46W	7	3/24/09	1580	backing/aerial
	8	3/25/10	2500	aerial
	9	4/01/10	725	aerial
	10	4/02/10	1069	aerial
	11	4/07/10	996	aerial
Piedmont, Hillsboro, GA 33.15N, 83.42W	12	4/27/09	1195	backing/aerial
Eglin, Niceville, FL 30.32N, 86.29W	13	5/06/09	500	backing/head
	14	5/07/09	641	backing/strip head
	15	5/08/09	1058	backing/aerial
	16	6/06/09	1500	backing/aerial
	17	6/07/09	1600	backing/aerial
	18	2/06/11	1650	aerial
	19	2/08/11	2046	aerial
	20	2/12/11	500	ground

The MODIS and GOES satellite remote sensing techniques were used to detect smoke plume of the prescribed burns. MODIS has a resolution as high as 250m. GOES satellites in geosynchronous orbit provide continuous observation of smoke plume movement. The resolution is 1 km. In addition, ground $PM_{2.5}$ and CO measurements were conducted jointly with another JFSP project and a DOD project led by Dr. Talat Odman of the Georgia Institute of Technology. Measurements were made using Dustrak Real-time $PM_{2.5}$ monitors, Langan CO Monitors, and Draeger PAC III CO Monitors.

B. Smoke modeling and evaluation

Smoke plume rise was simulated with Daysmoke for the 20 measured prescribed burns. Daysmoke is an empirical and stochastic smoke plume model specific for prescribed burning. It simulates dispersion and transport of smoke particles. It was used recently as part of a regional air quality framework (SHRMC-4S) to provide plume rise and smoke vertical profile for CMAQ simulation. The total fuel load consumed was estimated using CONSUME 3.0 (Ottmar et al., 1993). Fire emissions were calculated by multiplying the consumed fuel by an emission factor appropriate for the fuel type and ignition plan (Mobley et al., 1976). The meteorological conditions were simulated with the Weather Research and Forecast (WRF) model (Michalakes et al. 2005). The domain covered the southeastern U.S. with a resolution of 4 km. There were 27 vertical layers. When used for Daysmoke simulation, 8 more layers were added in the low atmosphere through interpolation. Daysmoke simulations were also conducted for some other prescribed burns besides the measured ones.

Evaluation was made by calculating mean error (ME), root mean square error (RMSE) and their normalized values, and by comparing vertical distribution profiles with the measurements. Simulations and evaluations of smoke plume rise were also conducted with Briggs (Briggs 1975), WRAP (WRAP 2005), and FEPS (Anderson et al. 2004) models. The Briggs scheme was originally developed for power plant stacks and was modified by converting the heat flux from each fire to a buoyancy flux suitable for use with the Briggs plume rise algorithm for smoke plume. The Western Regional Air Partnership (WRAP) scheme uses a climatological method for smoke plume rise by specifying pre-defined plume top and a pre-defined diurnal temporal profile for each fire. Both Briggs and WRAP models are used in CMAQ. The Fire Emission Production Simulator (FEPS) is a widely used fire and smoke tool which has a scheme to estimate plume rise based on empirical values and increase rate of burn.

C. Development of new modeling tool

An empirical smoke plume rise model was developed based on smoke measurements. The purpose was to provide field managers with an efficient tool by using the Remote Automated Weather Stations (RAWS) observations, which provide hourly weather and fuel conditions at the locations often near where prescribed burns are conducted. Correlations of the measured smoke plume rise and various RAWS elements were first calculated. Those elements with significant correlation coefficients were selected to build an empirical relation with smoke plume rise using the multiple variant regression technique.

The regression model was used to calculate smoke plume rise for all 20 burn. The correlation coefficient between the simulated and observed plume rise series was used as a fitting rate. The following procedure was used to produce the prediction and observation series for bias calculation. (1) Build a regression equation using measured smoke plume rise and RAWS elements from 19 burns ($n \neq 1$); (2) predict plume rise for the burn $n = 1$ using the built regression equation and the RAWS elements for this burn; (3) repeat the two steps for $n = 2, 20$. This leads to a series of 20 predicted plume rise values and a series of 20 measured plume rise values. (4) Calculate modeling error.

D. Improvement in Daysmoke

Two major improvements in Daysmoke were made, that is, introduction of multiple updraft core number of smoke plume, and coupling with the Rabbit Rules to provide this number to Daysmoke. A single smoke plume may consist of several updraft cores, resulted from multiple ignitions at different locations within a burning site, smoke interactions, and other processes. The algorithm to describe multiple updraft core property was developed. Its importance for smoke plume rise modeling was analyzed using the Fourier Amplitude Sensitivity Test (FAST) (Cukier et al. 1973), a technique to identify which parameters in a model have the most important contributions to variability of a simulated property.

The Rabbit Rules, an experimental rule-driven fire spread model, was developed to simulate complex fire behavior including some phenomena associated with coupled fire-atmosphere interactions. This model was connected to smoke plume height simulation by providing updraft core data in three ways – the number of discrete low pressure centers generated by heat released from the fire on small scale, the number of independent ground-level wind circulations generated by heat released from the fire, and the number of heat centers contained by the burn.

E. Improvement in regional air quality modeling

The improvement in regional air quality modeling was made by applying Daysmoke to providing smoke plume rise for CMAQ simulations. Sensitivity of CMAQ simulations to Daysmoke simulation was analyzed. CMAQ was used to simulate the contribution of prescribed burns during a spring month in the Southeast with and without plume rise information used. Daysmoke was coupled with the adaptive grid CMAQ developed by a group from Georgia Institute of Technology.

F. Daysmoke User Interface

The development of the Daysmoke user interface was aimed at transferring Daysmoke from a research tool to a management one. The interface has two components. One component was developed in Visual Basic® and utilized the work conducted previously in the development of the CalSmoke user interface. The software compiles and formats the data needed by Daysmoke, executes the Daysmoke model, and retrieves and formats the modeling results to be displayed in ArcMap® or Google Earth®. The JFSP funding was utilized for the second component and a contractor was hired to develop the ArcMap user interface. The ArcMap user interface aids a person in producing a grid of modeling receptors where the elevation, latitude and longitude are calculated.

IV. Key Findings

A. Smoke plume measurement

Smoke time and vertical structure appear in three patterns. Two of them have significant fluctuations at different time scales. This feature would increase the difficulty in satellite detection and model simulation of smoke plume height.

Plume rise statistics Smoke plume height averaged over all burns is about 1 km (Fig. 2). Significant seasonal dependence is found with a close value to the average for spring, and lower (higher) by about 0.2 km for winter (summer). The standard deviation is about 160 m. The average height of about 1 km could be used as a first-order approximation of smoke plume height. A second-order approximation could be obtained by making a seasonal adjustment.

Smoke patterns (1) Uniform fast fluctuation (8 burns). For the burn shown in Fig. 3a, the fluctuation frequency is almost constant throughout the measured 4-plus hours. Also, plume height remains less varied around about 1 km high. (2) Slow fluctuations with irregular variations (8 burns). Smoke plume height in Fig. 3b reduces from about 1.5 km to about 0.8 km and then moves back to about 1.5 km. There are 3 peaks during the 5-hour measurement period. (3) Cap over or above smoke plume (4 burns). The cap is either an intense temperature inversion layer or cloud. In Fig. 3c, an inversion layer is about 1.2 km above the ground at the beginning and gradually decreases with time. A narrow smoke layer with a depth of about 0.1 ~ 0.4 km is right below the inversion layer.

Fluctuation scales The time scales identified are less than 5 min, noticeable mainly for the first and third smoke patterns, 6 ~ 10 min (third pattern), 15 ~ 30 min (all patterns), 45 ~ 75 min (all patterns), 150 and 300 min (second pattern). The 3 longer scales have large contributions to total variance.

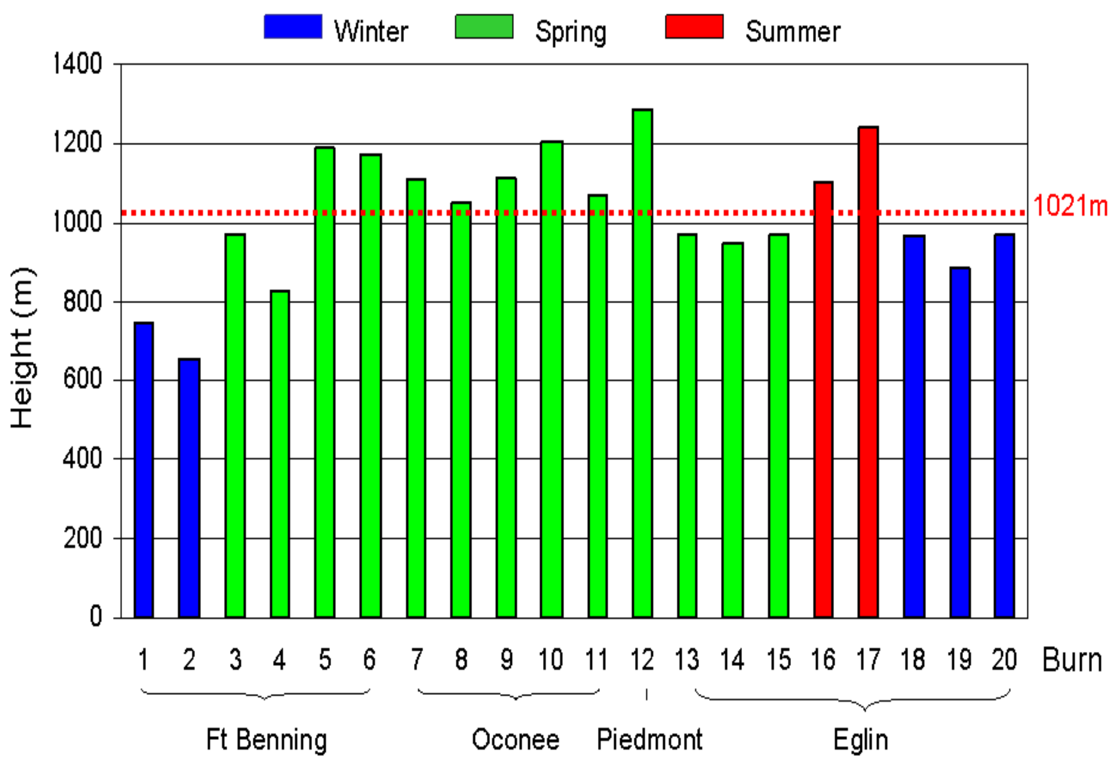

Fig. 2 Smoke plume height averaged over measurement period for each of the 20 burns. The dot line is the average height of all burns. Below the figure are burns and their locations (refer to Table 1 for details). Burns in different seasons are distinguished by colors.

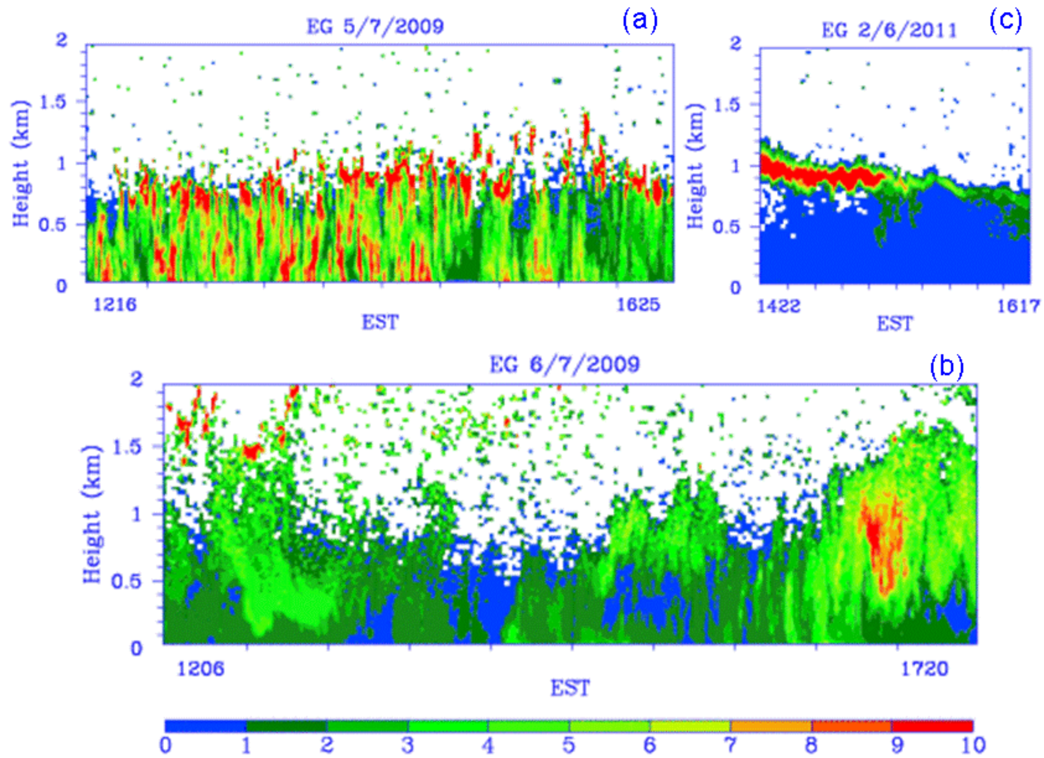

Fig. 3 Ceilometer backscatter signals of 3 burns at Eglin (a-c). Unit: $(10^3 \text{ srad km})^{-1}$. The numbers below each panel are start and end times of smoke measurement period.

B. Model evaluation

The evaluation using the measured prescribed burns in the southeastern U.S. shows some promising performance with Daysmoke in smoke plume height simulation. Other models (WRAP, Briggs, and FEPS) have the advantage of simplicity and therefore are easy to use by field managers, but they overall overestimate smoke plume heights.

The RMSE of Daysmoke simulation is 324 m, which is slightly high, but its normalized value is at a reasonable level of 1.73. The simulated plume height could be larger or smaller than the measured one (Fig. 4). Divide the magnitude of simulation errors into 4 levels, that is, < 100 m, 100 ~ 200 m, 200 ~ 300 m, and > 300 m. Daysmoke simulations have 4 burns at Level 1 4 at Level 2, 9 at Level 3, and 3 at Level 4. The errors at Level 3 are positive for 3 burns and negative for 6 burns, showing no clear trend. But errors at Level 4 are all positive, indicating overestimation when errors are extremely large. Simulations with the Briggs, WRAP, and FEPS schemes are systematically high. For FEPS scheme, for example, all burns are at Level 4.

C. Empirical model

The model uses three RAWS measurement elements of wind, fuel moisture and fuel temperature. This model takes the advantage of simplicity while with a reasonable level of accuracy.

Six elements, including a derived one, were examined. Wind, fuel moisture, and fuel temperature showed good relations with plume height. The correlation coefficients are -0.443, -0.64, and 0.66, respectively. The following regression equation was built:

$$H = 963.7 - 63.73\, W - 10.44\, M_f + 10.99\, T_f$$

where W, M_f and T_f are wind, fuel moisture, and fuel temperature, respectively.

This formula was used to calculate plume height. The fitting rate (i.e., correlation coefficient between the measured plume height series and the calculated one) is 0.838. The model was evaluated using the approach described in section III. The errors are relatively small with $RMSE_{normal}$ less than one. The correlation coefficient is 0.76.

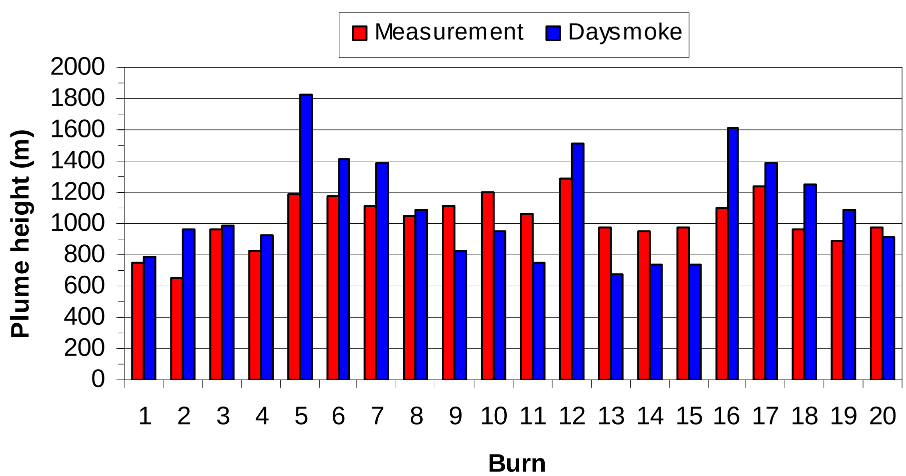

Fig. 4 Simulations of smoke plume height with Daysmoke for the prescribed burns in the southeastern U.S. and comparisons with measurements.

D. Daysmoke improvement

The inclusion of multiple smoke updraft cores improves Daysmoke simulation of vertical profile and in some cases plume height. On the other hand, it brings new uncertainty in smoke plume height modeling because this parameter currently is not measured.

Dependence of Daysmoke simulation on core number The simulated plume height shows a decline trend for many burns (Fig. 5). The magnitude of the decline is small, within 100 m for a change in core number between 1 and 12 cores for most burns. There are three burns with a magnitude more than 200 m. The simulated values with 1 core for these burns are larger than the corresponding measured plume heights by about 150 ~ 300 m. Thus, the simulation error will be reduced with a certain number of updraft cores used in simulation for each burn.

The impact of updraft core number is more significant on the simulated vertical profiles of smoke plume. For 1 core, a relatively large amount of smoke particles are found in the upper portion of smoke plume for most burns. This is different from the measured vertical structure. With increase in core number, the location of largest amount of smoke particles becomes lower.

Importance of multiple core number In a sensitivity analysis of 15 parameters using the FAST technique, smoke plume updraft core number is one of the two most important parameters to Daysmoke plume height simulation. Core number contributes to nearly one third of total variance of plume height.

Simulation of core number for Daysmoke Rabbit Rules model was coupled with Daysmoke to simulate fire spread, fire emissions, and smoke plume rise and dispersion for an aerial ignition prescribed burn conducted at Eglin AFB on 6 February 2011 as part of the RxCadre project. This was one of the burns measured with ceilometer for plume height. Rabbit Rules produces a 4-core updraft, agreeing with the number obtained from photography. This number together with emissions was specified in Daysmoke simulation, which produces a plume height close to the measured one.

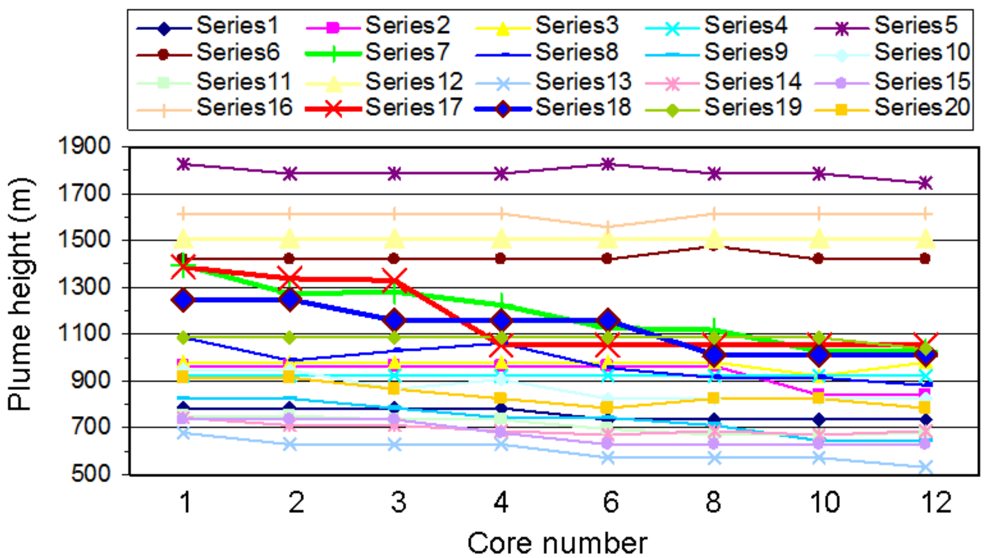

Fig. 5 Change of simulated plume height with core number specified in Daysmoke.

E. Improvement in regional air quality modeling

The differences in plume rise simulation are found to have substantial impacts on CMAQ simulation. In many burn cases, CMAQ simulations are improved with plume height provided by Daysmoke including multiple core property. Smoke plume height simulation is found important for evaluating regional air quality impacts of prescribed burning in the Southeast.

Improvement of CMAQ simulation The CMAQ simulation of a prescribed burn was improved by including multiple core number in Daysmoke, which provided smoke plume simulation for the CMAQ simulation. The ground measurement at Asheville, NC showed a peak $PM_{2.5}$ concentration of about 130 μg m^{-3} at 17 LST. The simulated peak level of $PM_{2.5}$ concentration is about 75 μg m^{-3} for the 1-core case, but about 120 μg m^{-3} for the 10-core case, much closer to the measurement.

Importance of plume height simulation CMAQ simulations for March 2002 were conducted for the air quality impacts of prescribed burning in the Southeast with and without Daysmoke plume height simulation (Fig. 6). With plume rise cases surface $PM_{2.5}$ concentration is reduced, especially in Georgia and part of northern Florida. The relative reduction of $PM_{2.5}$ with plume rise cases in this region ranges from 10-20%.

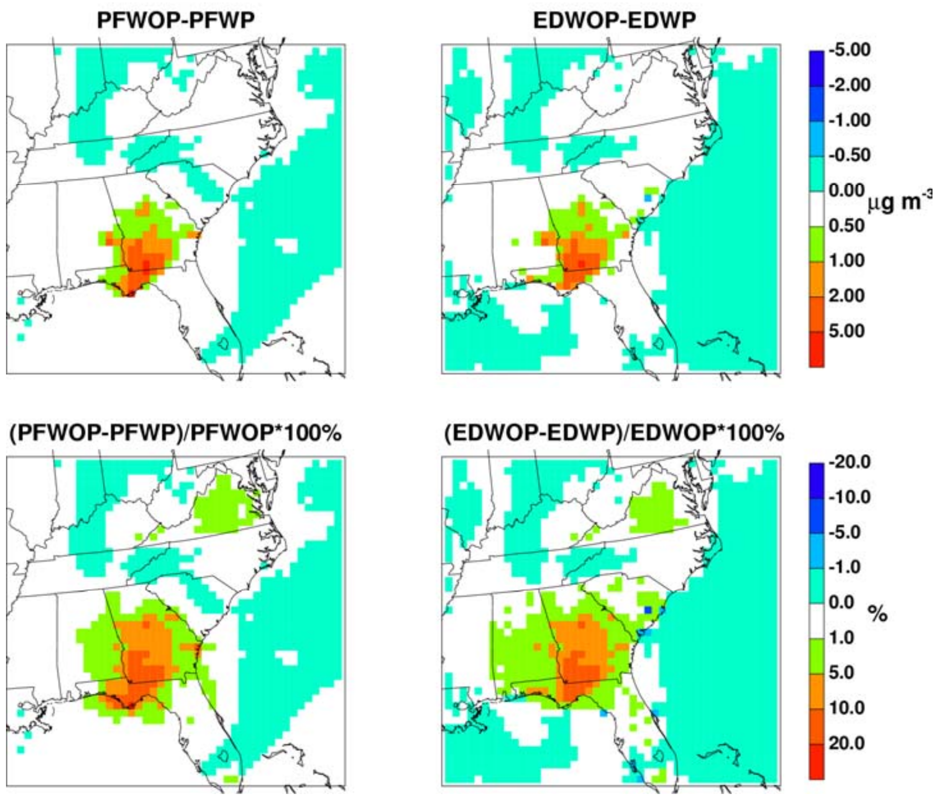

Fig. 6 Spatial distribution of difference (absolute and relative) of monthly mean surface $PM_{2.5}$ concentration between with plume and without plume rise cases.

V. Management Implications

A. Daysmoke as a management tool

VSMOKE is currently used as a smoke screening model for Forest Service applications in the Southeast. It gives land managers a quick and rough estimate of where smoke will go and how much will get there given their planned fire activity and prevailing weather. Plume rise, however, is one physical process that is not incorporated in VSMOKE. The user specifies a fraction of smoke that is released at the ground versus the amount released near the top of the mixing layer. Furthermore, VSMOKE is a steady state model. It does not account for vertical wind shear nor for changes in wind conditions during the course of the burn. The model assumes a spatial steady state and therefore is invalid for smoke plumes over complex terrain.

The Southern Region Air Resource Management specialists have been actively working with scientists who have developed atmospheric models that can be used to predict downwind concentrations of air pollution. Currently Software interfaces have been developed for HYSPLIT Ready (web version), PC HYSPLIT, and Calpuff. Daysmoke is a useful tool for smoke plume rise simulation. It has been mainly a research tool so far. Through the support from JFSP, a user interface for Daysmoke was added. With continuous efforts, Dyasmoke could be incorporated with a smoke modeling system as illustrated in Fig. 7 to provide particle movement both vertically (plume rise) and horizontally.

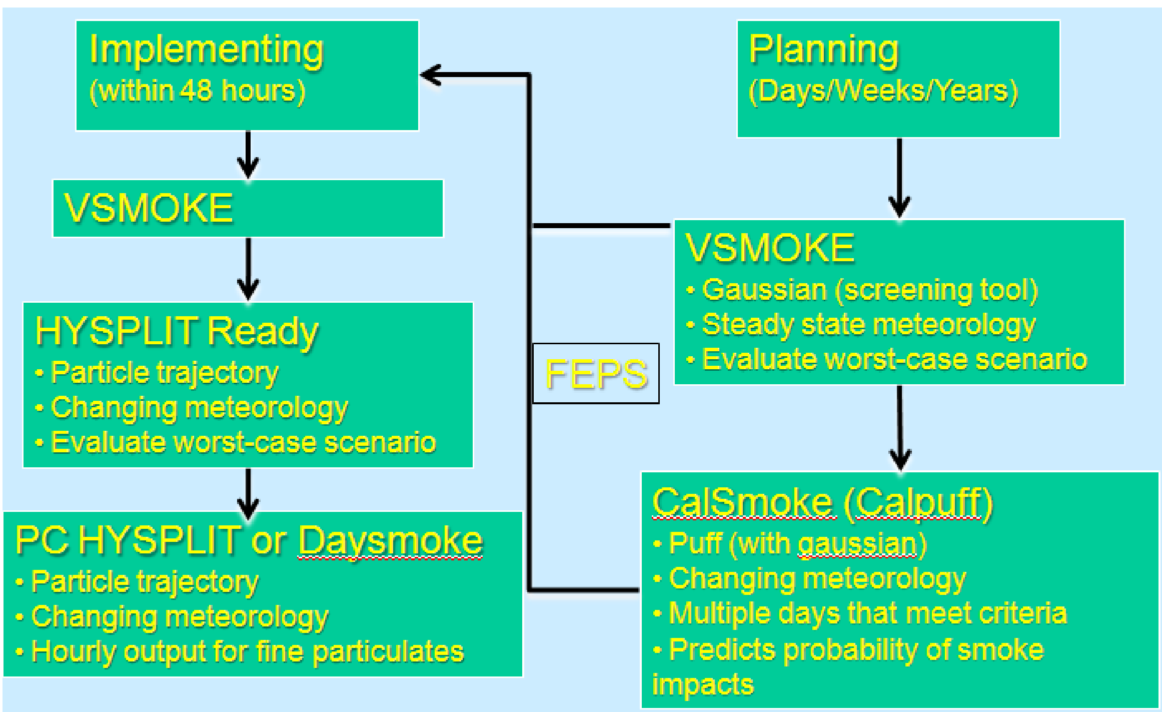

Fig. 7 Smoke dispersion models used in the southeastern United States by the USDA Forest Service and others.

B. Uncertainty in satellite smoke plume rise detection

Satellite remote sensing has emerged as a useful technique to detect and monitor wildfire and smoke by managers and researchers. Applications to prescribed burns were also reported. In comparison with wildfires, prescribed burns have relatively small size and short life time, and often occur in the understory, which make their detection from the space more difficult. A new factor added to the difficulty is the smoke feature of fluctuations. Even if satellite techniques such as MODIS and MISR happen to catch a smoke plume on the day and time when they pass over the burn site, the smoke plume at the detected moment may be substantially different from other times for these burns with significant temporal variations with time scales at minutes, tens of minutes, or longer. Thus, the detected smoke properties might be not robust and incomplete.

C. Uncertainty in plume height estimation

WRAP, Briggs, and FEPS models have been widely used in smoke management. The evaluation from this project indicates that they often overestimate plume rise of prescribed burns in the Southeast. This implies that the conditions for these models would limit their capacity in application to prescribed burning in this region. More evaluation is needed to understand the limitations.

The WRAP scheme was used for the development of emission inventory which deals with daily or multi-day wildland fire events. It specifies diurnal allocation for properties such as fuel consumption. As a result, fuel consumption and the related heat release and smoke emissions are relatively small at a specific hour. But plume rise is not necessarily low because very large reference values are specified based on size classes of daily burned area, which might be more appropriate for wildfires. A prescribed burn event of hundreds of acres or larger, however, can be short in the dry season in the Southeast, especially if aerial ignition is used. This was the case for many burns measured from this project. The fuel consumption rate is therefore relatively large during the short period. A very large plume rise for the smoke plume from this burning is expected from the WRAP scheme.

Exclusion of weather impact is another limitation. Although smoke plume from wildfire can penetrate over the top of atmospheric boundary layer, smoke plume from weak prescribed burning is most likely retained within PBL. Strong wind is another factor to suppress smoke plume rising. Without weather condition included, the WRAP and FEPS schemes are unable to reflect these impacts. The Briggs scheme includes wind and atmospheric stability. But when used in FEPS, the Pasquill classes are used for stability, which are always instable or neutral during day time. Thus, plume rise is expected to be overestimated for a prescribed burn under strong stable condition.

VI. Relationship to other recent findings and ongoing work

1. The Smoke and Emissions Model Intercomparison Project (SEMIP) funded by the Joint Fire Sciences Program analyzes and compares fire consumption, fire emissions, plume rise, and smoke dispersion models. Prescribed burning in the Southeast is one of the test cases. This project was involved in SEMIP and the measurement data and evaluation results from this project were provided to the SEMIP.

2. Two members of this research team joint a field measurement with the teams from University of Massachusetts and Georgia Institute of Technology. They compared measurements of a prescribed burn at Ft Benning between a Vaisala CL31 ceilometer and a millimeter-wavelength Doppler radar. Very similar plume morphology existed in both measurements. But the lidar backscatter was strongly attenuated above 1 km. The radar echo, on the other hand, extended further Tsai *et al.* (2009).

3. Satellite techniques such as the Multi-angle Imaging SpectroRadiometer (MISR) have been applied to smoke plume height detection. Raffuse *et al.* (2009) compared MISR measurements with FEPS modeling of wildfires across the U.S. and found relative good agreement in the southeastern U.S. MISR has a low return frequency of return day (9days). One team member of this project and his group checked MISR dataset, but did not find any data available for the 20 burns. So no comparison was conducted with MISR detection in this project.

4. Some studies of individual prescribed burns have indicated the fluctuation feature with smoke plume. For example, Lavrov et al. (2006) scanned smoke plume from an experimental prescribed burn with a lidar and found double peaks in horizontal distribution of smoke particle concentrations. Simulations with a Reynolds-averaged Navier–Stokes fluid dynamics showed downward motion of smoke plume in the spatial structure. These space features implied fluctuations with time at a specific location.

5. Georgia Institute of Technology (Ga Tech) has worked on another smoke model evaluation project funded by JFSP (081604). This project was closely coordinated with that project. The smoke measurements were conducted together for burns at Ft Benning in January 2009 and at Eglin in February 2011. Ga Tech was responsible for ground PM measurements, while this project for plume rise measurements. Daysmoke was used in their Adaptive-grid CMAQ to provide sub-grid smoke processes.

6. Three members of this team have participated in the FS R&D Wildland Fire Greenhouse Gas/Black Carbon (GHG/BC) Synthesis Project. This project is to review what is known about GHG/BC emissions from wildland fires across all biomes in the United States and produce a synthesis report on GHG/BC emissions from wildland fires. One synthesis issue is smoke modeling, including plume rise simulation. Dr. Warren Heilman is leading this task. Our team was asked to write plume rise modeling. The findings from this project will be used.

VII. Future work needed

1. This project indicated the importance of multiple updraft core number to smoke plume rise simulation. Research is needed to develop techniques to detect this property. Plume photographs have provided some guidance on the number of updraft cores, but these supply singular snapshots of the time varying plume structure. Full physics models provide an excellent means for examining plume behavior across a wide range of conditions and may be able to provide insight into plume structures which could be quite useful in examining various ignition techniques for prescribed fires. Furthermore, the core number changes with time and space, depending fire dynamics and smoke-atmosphere interactions. More measurement and analysis research is needed to understand and simulate the related processes and control factors.

2 This project was among the first attempts to systematically measure smoke plume in the Southeast. It provided useful data for evaluation of smoke plume rise modeling.

Future measurements are needed, including (1) measurement of plume rise of wildfire plume with ceilometer. Daysmoke was developed specifically for prescribed burning. But it has the potential for wildfire application. The measurements will provide the necessary data for evaluation. (2) Plume rise is dependent on fuel, burning process, and atmospheric processes. Some comprehensive field measurements have been planned or under way. Ceilometer measurement of plume rise can be part of these projects. Besides plume rise, the backscatter intensity detected by ceilometer needs to be compared with other aerial smoke particle measurements for evaluation of the existing relationship between PM concentration and backscatter intensity.

3. There are dynamic smoke plume rise models such as the one-dimensional dynamic entrainment plume model (Latham, 1994; Freitas, 2007). They consist of a set of equations, including the horizontal motion of the plume and the additional increase of the plume size, and are solved to explicitly simulate the time evolution of the plume rise and determine the final injection layer. Some dynamic models have been incorporated with high-resolution meteorological models such as WRF to simulate smoke plume rise and weather-fire interactions. The measurements of smoke from this project should be valuable for evaluation and improvement of dynamic smoke plume rise models.

4. A method for the Daysmoke user interface needs to be developed to retrieve MM5/WRF meteorology data for the region around the burn unit. It is strongly encouraged that any meteorology retrieval package be able to download data for the "next" 48 hours. One suggestion is to approach the National Weather Service to see if they can extract the data from their forecasts, and the information be posted for download anytime a spot weather forecast is requested. Additional work on the Daysmoke (FORTRAN) code needs to be accomplished to allow for the fire to spread across the burn unit and allow multiple burn units to be modeled at the same time.

VIII. Deliverables Cross-Walk

Proposed	Delivered	Status
Datasets 1. Plume rise and vertical smoke profiles, 2. ground concentration, 3. plume satellite remote sensing, 4. meteorology	1. Datasets of measured smoke plume rise and vertical profiles for 20 prescribed burns, 2. MODIS and GOES satellite images, 3. WRF simulations over Southeast with 4-km resolution, Original output and vertical profile format; RAWS data. 4. PM2.5 and other ground measurements at Ft, Benning and Eglin. The ground measurements were conducted mainly by GaTech through the JFSP project 081604.	Items 1,3, and 4 were stored in SHRMC computer cluster and ready to download; Item 2 was stored in Ga Tech computer
Plume rise model evaluation report	Daysmoke and other schemes were evaluated. The results are reported in Paper No.6.	Completed
Daysmoke improvement	Computer code and user guide for Daysmoke for PC and UNIX system; Manual and executable files for GIS interface	Code and user guide available for download from SHMRC
Module of Daysmoke	Fortran code of Daysmoek converted from PC to UNIX operation system.	Daysmoke was coupled with CMAQ offline
Report of regional modeling	Three CMAQ regional air quality simulations with smoke plume rise provided by Daysmoke: (1) A prescribed burn affecting Asheville, NC; (2) A prescribed burn at Ft Benning, GA; (3) Simulation of March, 2002 for southeastern U.S.	The results were reported in Papers No. 1, 2, 7, respectively.
Annual report		Submitted
Final report		Submitted
Refereed articles 1. 5-6 journal publications 2. 5-6 conference presentations	1. seven journal papers 2. eight presentations	1. One published, one accepted, three submitted, two completed. 2. Seven presented, one submitted
Additional requirement from JFSP: Validation data sets to SEMIP	1. Dataset of smoke measurement 2. Emission and meteorological datasets for Daysmoke simulation 3. Validation results of Daysmoke simulation	Submitted

Access to datasets stored in SHRMC computer:
Website link: http://shrmc.ggy.uga.edu/research_projects.php
Download: http://shrmc.ggy.uga.edu/upload

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