Evaluation and Improvement of Smoke Plume Rise Models

2010 Annual progress report (JFSP Project 08-1-6-06)

SUMMARY

A number of research activities were implemented in the second year (2010) of this project following the proposed work plan: continuing smoke plume rise measurement, improving and evaluating Daysmoke, and continuing development of GIS-version Daysmoke. The following are major accomplishments:

- Smoke plume rise and ground concentrations were measured for 7 prescribed burns.
- Temporal variation and spatial structure of smoke plume were analyzed using the measured data and statistical tools including wavelet transform.
- Daysmoke was analyzed to identify important parameters using the Fourier Amplitude Sensitivity Test, the Community Multiscale Air Quality (CMAQ) model sensitivity to multiple-core updraft, and importance of Daysmoke plume rise to regional air quality simulation.
- Dasymoke was improved by including multiple-core, and evaluated using the measured data.
- Receptor locations, burn unit(s), burn location, and Google Earth display were created with the GIS version of Daysmoke.

The major findings include:

- Smoke plume displays eddy-type fluctuations with typical scales of 5~10 and 20~30 minutes.
- Entrainment coefficient and number of updraft cores are the most important parameters for determining smoke plume rise with Daysmoke.
- Simulations of Daysmoke and CMAQ could be improved by a better understanding and specification of smoke updraft cores.
- The PM2.5 surface concentrations from prescribed burns are over-estimated by 10-20% in GA and part of southern FL without plume rise calculation.
- Plume rise simulated with Daysmoke is in good agreement with measurement for one burn case but considerably different for another case at Ft Benning, GA.

These findings were presented in a number of conferences and described in three research papers.

ACCOMPLISHMENTS

1. Plume rise measurements

Measure measurements of about 10 prescribed burns were proposed for each of the first two years of this project. Seven burns were measured during the burn season of 2009-10 (11 burns measured during 2008-09; total 18 burns measured so far). The measurements were made at Oconee National Forest, GA on March 25, April 1, 2, and 7, and at Ft. Benning Army Base, GA on April 28, 29 and 30. The major smoke property measured is plume rise using a Vaisala CL31 Ceilometer purchased for this project. A DustTrak II Aerosol Monitor (purchased with money from other projects) was added this year to measure ground smoke concentrations. In addition, a portable weather station was used to measure wind speed and direction, temperature, and humidity. A GPS instrument was used to locate latitude and longitude of the measurement location.

The number of burn cases measured is 3 less than that planned. A major reason was that this burn season started later and lasted shorter than a normal year because of the cooler and wetter conditions in the Southeast related to the El Nino event. In addition, a couple of changes occurred for measurements at Ft Benning and Eglin bases. Joint measurements with other partners at Ft Benning had been planned, but were called off because of a change with the partner's ground measurement team. Eglin started this year to request submission in advance of a plan to conduct field activities. We submitted a plan and got it approved. But it was too late to measure burns because the burn unit had to shift focus from burning to the Gulf oil spill. We have planned measurements for the coming season as part of multiple institute smoke measurements at the two sites.

2. Analysis of smoke plume features

Statistical analyses were made using the measured data to understand temporal and spatial features of smoke plume. Figs. 1 and 2 show the results for two burns with different patterns. For the burn case on January, 14, 2009 at Ft Benning, there were trends in smoke plume change with time, but they are not significant. The top of smoke plume was a little below 1 km all the time. The smoke plume, however, displayed eddy-type structure, as indicated by the fluctuations during the burn period. The typical time scales obtained from the wavelet transform were about 5 minutes and 20~25 minutes.

In contrast, for the burn case on June 7, 2009 at Eglin, there were significant trends. The top of smoke plume started at about 1.5 km. It gradually decreased to about 1 km, and then went back to about 1.5 km. Same as the first case, Plume rise fluctuated during the burn period. The typical time scales were about 5~10 minutes and 20~30 minutes.

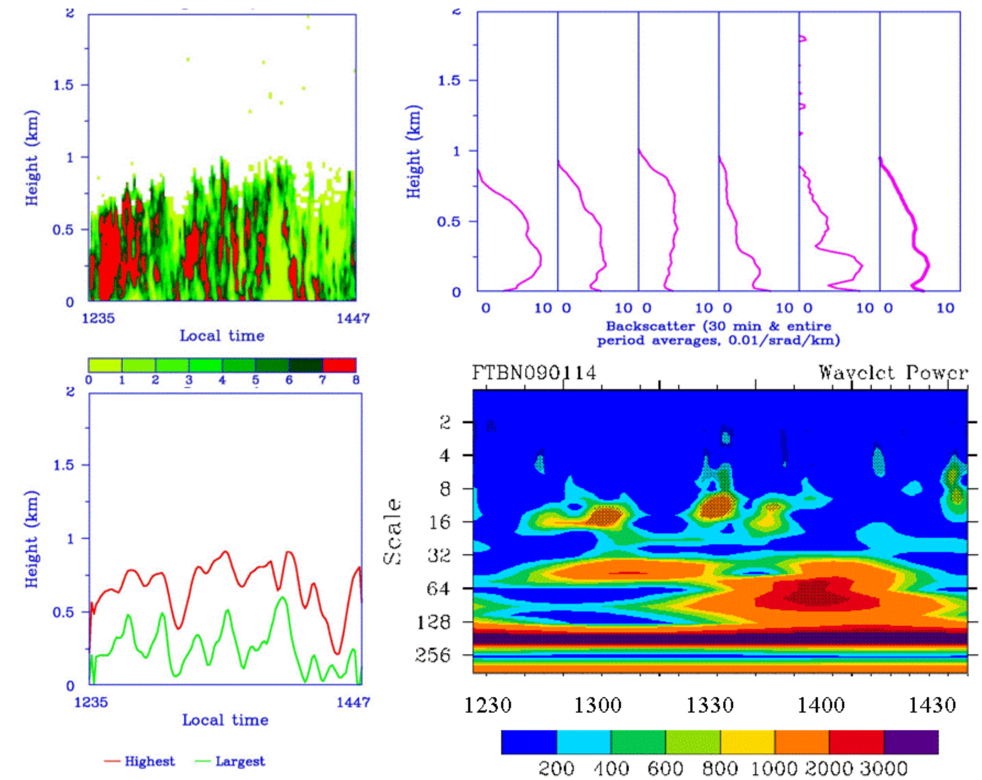

Figure 1 Smoke plume from prescribed burn on January, 14, 2009 at Ft Benning, GA: backscatter image (upper left), vertical provides (upper right), temporal variations of plume rise and the height of largest backscatter values (bottom left), and wavelet transform (bottom right).

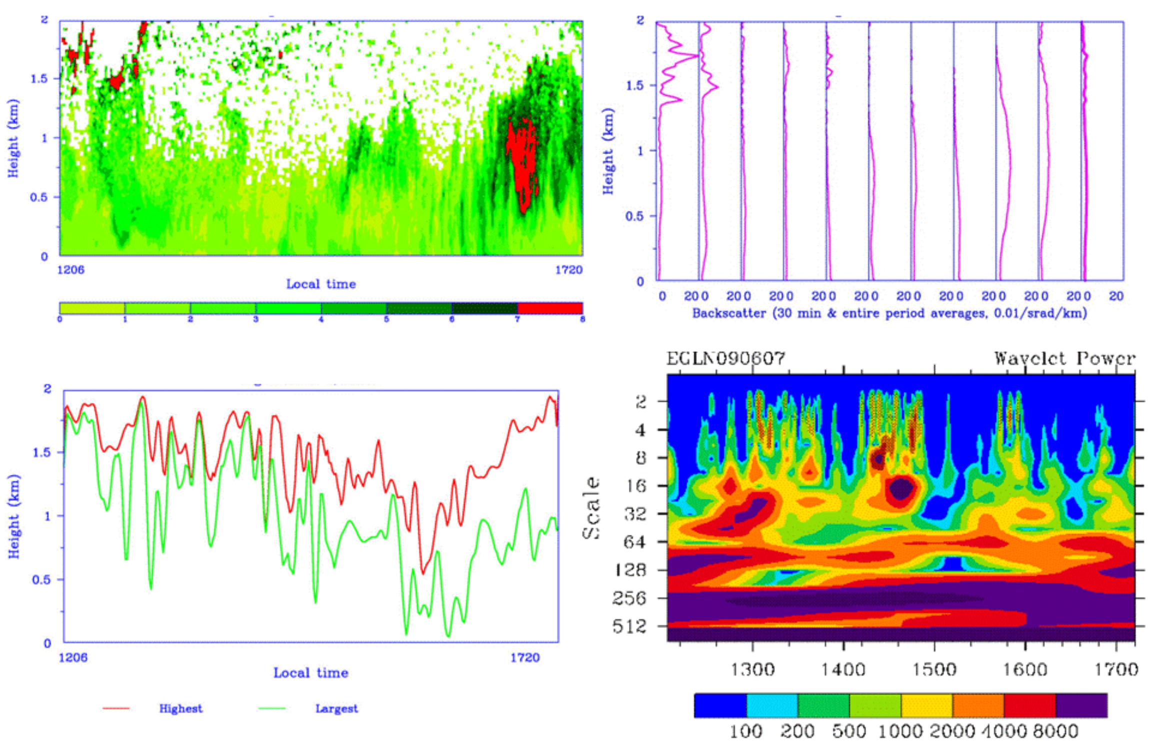

Figure 2 Same as Figure 1 except for June 7, 2009 at Eglin, FL.

3. Daysmoke Analysis

Daysmoke includes a large number of parameters describing the dynamic and stochastic processes of particle upward movement, fallout, fluctuation, and burn emissions. Some of them are determined based on empirical estimates, leading to uncertainty in model applications. One approach used to improve Daysmoke was to analyze sensitivity of Daysmoke plume rise simulations to model parameters and reduce number of parameters by removing those either less important or specified without observational and / or solid physical basis.

Three analyses were made. First was the Fourier Amplitude Sensitivity Test (FAST) to the prescribed burn in Cherokee National Forest, TN on March 18, 2006. The result (Fig. 3) indicated that, for the specified value ranges of 15 parameters, entrainment coefficient and number of updraft cores are the most important for determining smoke plume rise. Initial plume temperature anomaly, diameter of flaming area, and thermal stability also contribute to a certain extent. The second analysis was simulations for a couple of different updraft core numbers with CMAQ. The simulated ground $PM_{2.5}$ concentration is much closer to the measurements with multiple updraft cores than single core (Fig.4), suggesting that simulations of Daysmoke and CMAQ could be improved by a better understanding and specification of smoke updraft cores. The third analysis was sensitivity of CMAQ simulations in the Southeast during a spring month to smoke plume rise simulated with Daysmoke. The result (Fig. 5) indicated that the $PM_{2.5}$ surface concentrations without plume rise are larger 10-20% than with plume rise over GA and part of southern FL, suggesting that plume rise could significantly affect $PM_{2.5}$ surface concentration.

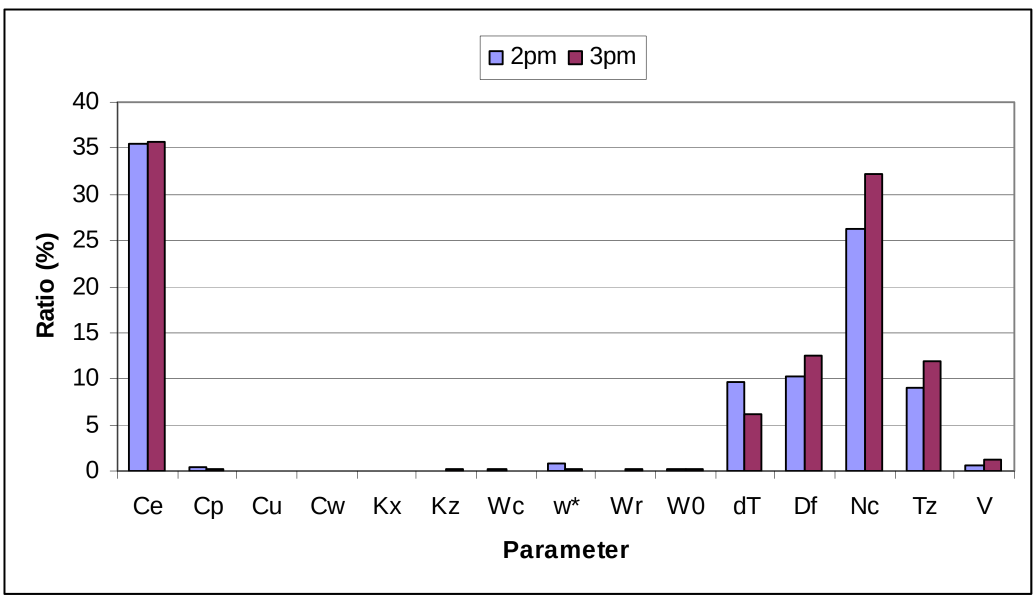

Figure 3 Fast sensitivity analysis of Daysmoke. The horizontal coordinate lists the model parameters. The vertical coordinate is the ratio (%) of partial variance of the parameter to total variance.

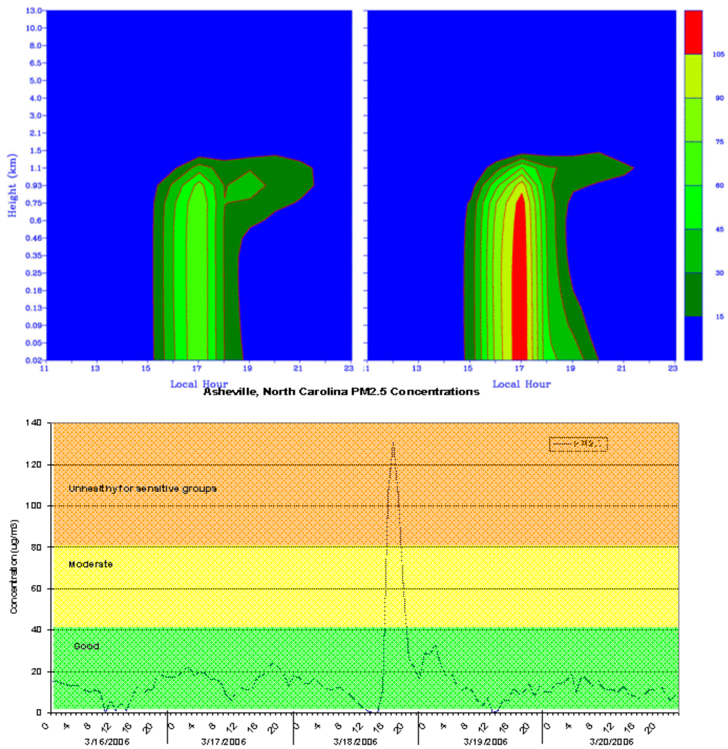

Figure 4 CAMQ simulations of ground PM2.5 at Asheville, NC, on March 18, 2006 for single (upper left) and multiple cores (upper right) updrafts. The bottom is measurement.

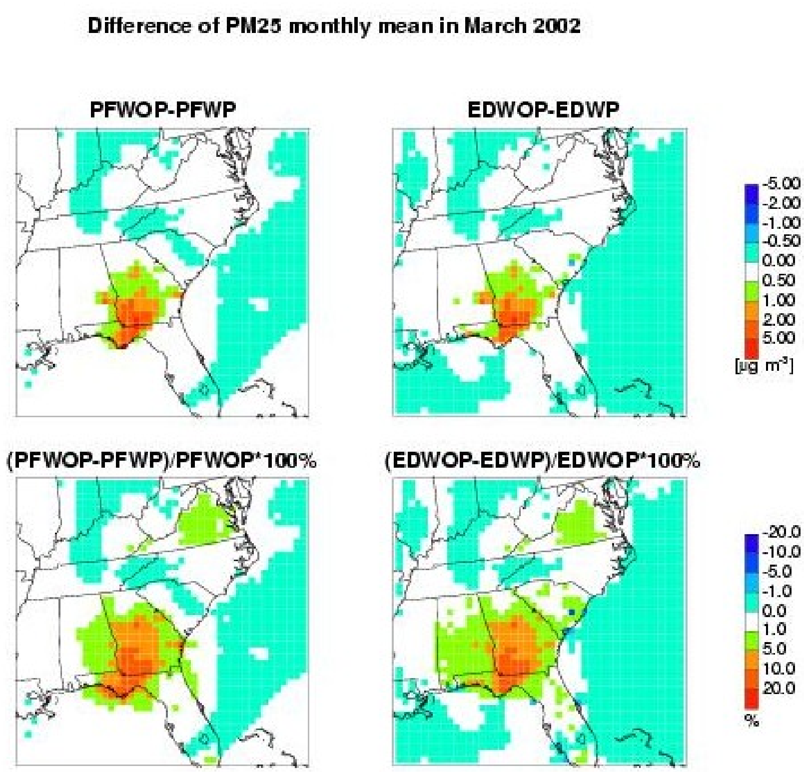

Figure 5 Monthly surface PM2.5 difference between with plume and without plume rise.

4. Daysmoke Improvement and Evaluation

A major improvement to Daysmoke made recently was to introduce the concept of multiple-core updrafts. Modeling a prescribed fire plume with empirical models that represent fire emissions as a single cylindrical plume may give reasonable predictions for plume top height for a single-source fire such as a trash pile burn. Fire with a prescribed burn spreading over a landscape would be better simulated by replacing the single (1-core updraft) plume with a string of smaller (*n*-core updraft) plumes that comprise the whole plume associated with the burn. Algorithms were developed to include the impacts of multiple-core updrafts on smoke in the calculation of plume heat energy and other plume properties with Daysmoke. A multiple core flux is one of a normalized distribution of the total number of multiple-cores that sum to yield the total flux.

Daysmoke was used to simulate about 10 prescribed burn cases at Ft Benning, GA. The measurements for model evaluation have been coordinated between two JFSP project (a smoke model development and evaluation project led by Georgia Institute of Technology and this project), and with other projects. The measurements from this project were used for evaluation of plume rise simulations with Daysmoke.

Two burn cases are shown here. Fig. 2 displayed above shows the time history of the January 14, 2009 plume as measured by lidar. After 1300 LST, plume top heights consistently ranged between 800-900 m. Dense smoke (red) was distributed throughout the plume. Fig. 6 shows part of a 4-core updraft Daysmoke plume for 1400 LST. Dense smoke was confined to the upper part of the plume but was available to be down-mixed by convective mixing. The plume top height was consistently 800 m.

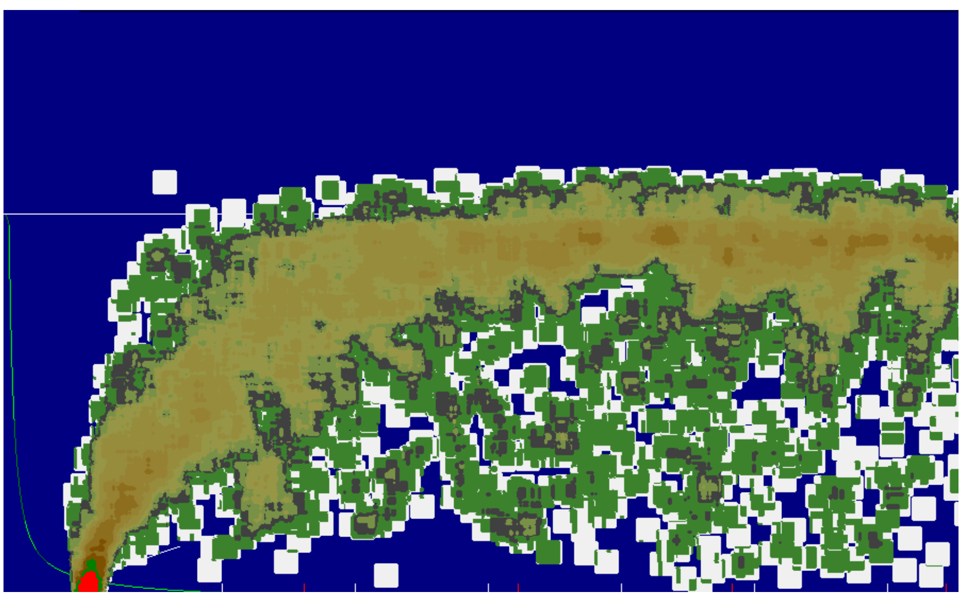

Figure 6. The 4-core updraft Daysmoke plume for 1400 LST 14 January 2009. White tic marks at the bottom of the figure denote 1 km intervals. White tic marks up the right side denote 100 m intervals. The solid white line shows the top of the mixing layer.

Figure 7 shows the time history of the January 15, 2009 plume between 1250-1350 LST as measured by the ceilometer from a location of 1 mile (1.6 km) from the burn site. From 1300-1320 LST, the plume top ranged between 400-600 m in altitude. Then the plume top climbed to between 700-800 m thereafter. Maximum backscatter was mostly below 250 m. Fig. 9 shows the 10-core plume at 1330LST as simulated by Daysmoke. The plume top levels off around 500m. However at the 1 mile (1.6 km) range the plume is still in ascent and its top is 400 m. Maximum smoke mass is found between 200-300 m. Thus, overall, this smoke plume was not well-represented by Daysmoke.

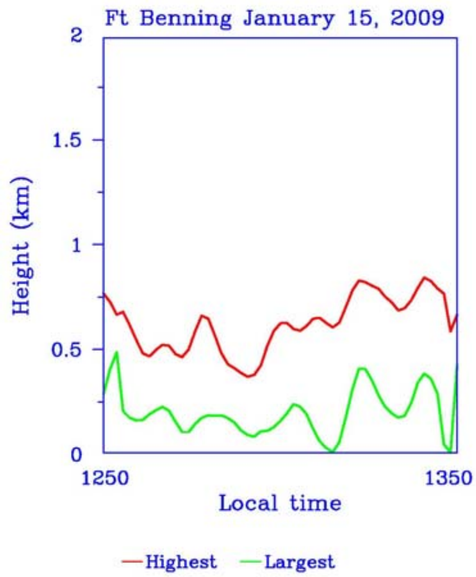

Figure 7 Measured plume height on 15 January 2009 at Ft Benning, GA.

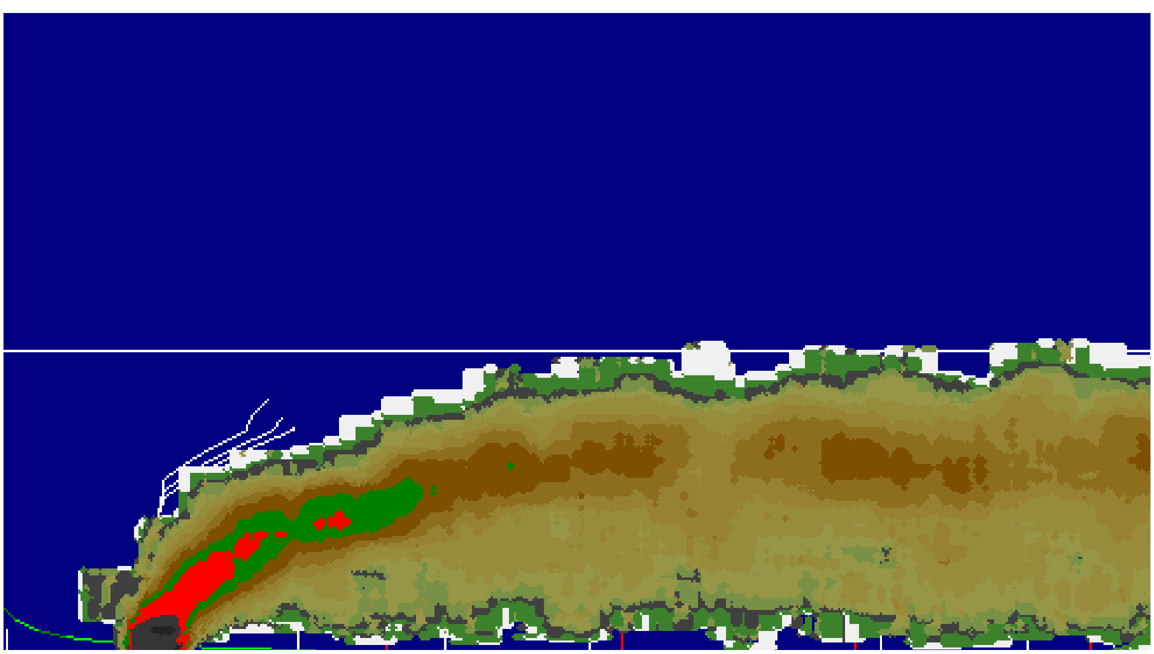

Figure 8 Same as Figure 6 except for 1330 LST 15 January 2009.

5. GIS version of Daysmoke

The GIS version of Daysmoke was developed to increase feasibility of Daysmoke so that this model can be used as a tool for smoke plume rise estimates not only by researchers but also by fire managers. The following were done during the past year:

(1) Used ArcMap to create receptor locations of where we would like Daysmoke estimates of PM2.5. Each receptor has a lat, long, and elevation value. Currently, Daysmoke is limited to 100 receptors and hopefully the program can be compiled to allow 10,000 receptors.

(2) Used ArcMap to create a burn unit(s) (square or rectangle) and join the FEPS results and make an emissions input file to be used by Daysmoke. At some point I will need to send some information (inputs and outputs) to you to make sure I am performing the emission input calculations properly.

(3) Created routine that does/can calculate the hourly area in an active fire phase and the center coordinates for the area.

(4) Added the function to display the results (using hourly AQI color values) in Google Earth, and the routine should be finished by November to display the results in ArcMap.

Fig. 9 displays an application of the GIs version of Daysmoke to the Brush Creek burn (Cherokee National Forest, Tennessee) on March 18, 2006. The simulation started at 16:00 and ended at 35:00 and the computation time was about 45 minutes.

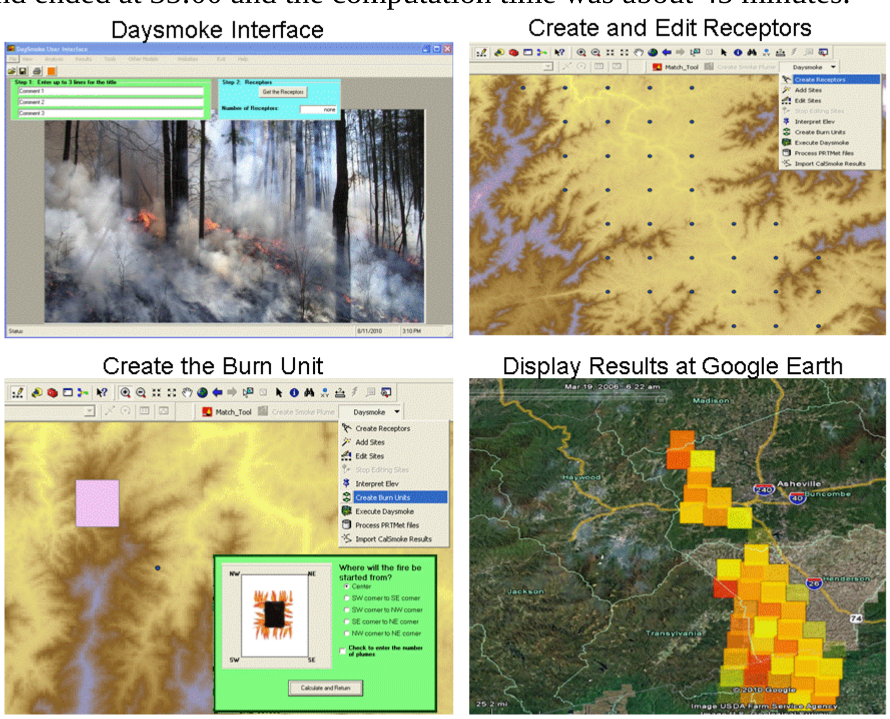

Figure 9 An example of Daysmoke-GIS application

DELIVERIES

1. Manuscripts

Liu, Y. –Q., Achtemeier, G. L., Goodrick S. L., Jackson, W. A., 2010, Important parameters for smoke plume rise simulation with Daysmoke, *Atmospheric Pollution Research* (in press).

Chao L., Wang, Y, Liu, Y.-Q., Zeng, T., 2010, Effects of burn frequency and plume rise on simulating air quality impacts of prescribed fires in southeastern United States. (completed and to be submitted to *Environmental Science and Technology*).

Liu, Y. –Q., Achtemeier, G. L., Goodrick S. L., 2010, Measurement and analysis of smoke plume rise of prescribed burns in southeastern United States (in writing. targeted journal: *International Journal of Wildland Fire*).

The first two manuscripts to be uploaded to the JSFP website.

2. Presentations

Liu, Y.-Q., Achtemeier, G.L., Goodrick, S.L., 2009, Smoke plume rise measurements with a Ceilometer, 8th Symposium on Fire and Forest Meteorology, Kalispell, Montana, 13–15 October 2009.

Liu, Y.-Q., Goodrick, S.L.,Achtemeier, G.L., Qu, J., Sanjeeb, B., 2009. Measurement and Simulation of Smoke Plume Rise. In proceedings of the Fourth International Fire Ecology and Management Congress: Fire as a Global Process, Savannah, GA, November 30-December 4, 2009.

Liu, Y.-Q, Achtemeier, G. L., Goodrick, S.L.,Jackson, W.A., Qu, J., 2009. Evaluation and Improvement of Smoke Plume Rise Modeling. In proceedings of the Fourth International Fire Ecology and Management Congress: Fire as a Global Process, Savannah, GA, November 30-December 4, 2009.

Achtemeier, G. L., Y. –Q. Liu, S. L. Goodrick, L. P. Naeher, A. Gray, M.T. Odman, S. J. Frasier, and P. S. Tsai. 2010. Results from Daysmoke for weak smoke plumes. 16th Joint Conference on Applications of Air Pollution Meteorology, 11.6. 90th Annual Meeting of the American Meteorological Society, Atlanta, GA, 17-21 January 2010.

Liu,Y.-Q., G. Achtemeier, S. Goodrick, J. Qu, and S. Bhoi. 2010. Simulation and evaluation of smoke plume rise. 16th Joint Conference on Applications of Air Pollution Meteorology, 90th Annual Meeting of the American Meteorological Society, Atlanta, GA, 17-21 January 2010.