Evaluation and Improvement of Smoke Plume Rise Models

2009 Annual progress report (JFSP Project 08-1-6-06)

Summary

The major research activity planned for the first year (July 1, 2008 ~ June 30, 2009) was measurements of plume rise of about 10 burns. Other activities included ground fire emission measurements, collection and processing of satellite remote sensing data, and start of development of the Calsmoke software interface.

These activities were completed by the end of the research period. Plume rise was measured for 11 burns with a ceilometer. The MODIS and GOES satellite remote sensing images were collected. Ground $PM_{2.5}$ and CO concentrations were measured for four burns by another research group. The Calsmoke software interface was developed.

Using the field measurements, the temporal variations and vertical profiles of smoke plumes were analyzed. The results were submitted to and will be presented at professional conferences. The measurements will be used for smoke plume model evaluation and improvement for the second year of this project.

1. Plume rise measurements

a. Burns

The prescribed burns for smoke plume rise measurements during the winter and spring seasons of 2009 were located at four sites (Figure 1). Two of them are the Army base at Ft. Benning near Columbus, Georgia and Eglin AFB near Pensacola, Florida. Two other sites are the Oconee National Forest and the Piedmont National Wildlife Refuge, both in central Georgia. See Table 1 for the locations of these sites.

Four out of the 11 burns were at Ft. Benning, two in winter (January) and two in spring (April). The burned areas were relatively small at the size of a few hundred acres and ground ignition was applied. The plumes were not well developed. Besides plume rise, the ground fire emission concentrations were measured by a team from the University of Georgia. Five burns were at Eglin in late spring and early summer. Three of the burns were over 1000 acres. Some with well defined plumes were observed. Two burns were at the Oconee NF and the Piedmont NWR in mid-spring. Smoke plumes were mixed with clouds. The fuel and meteorological conditions varied among the burns. We had a trip for two burns at Ft. Benning, but no measurements were made because of unexpected weather conditions.

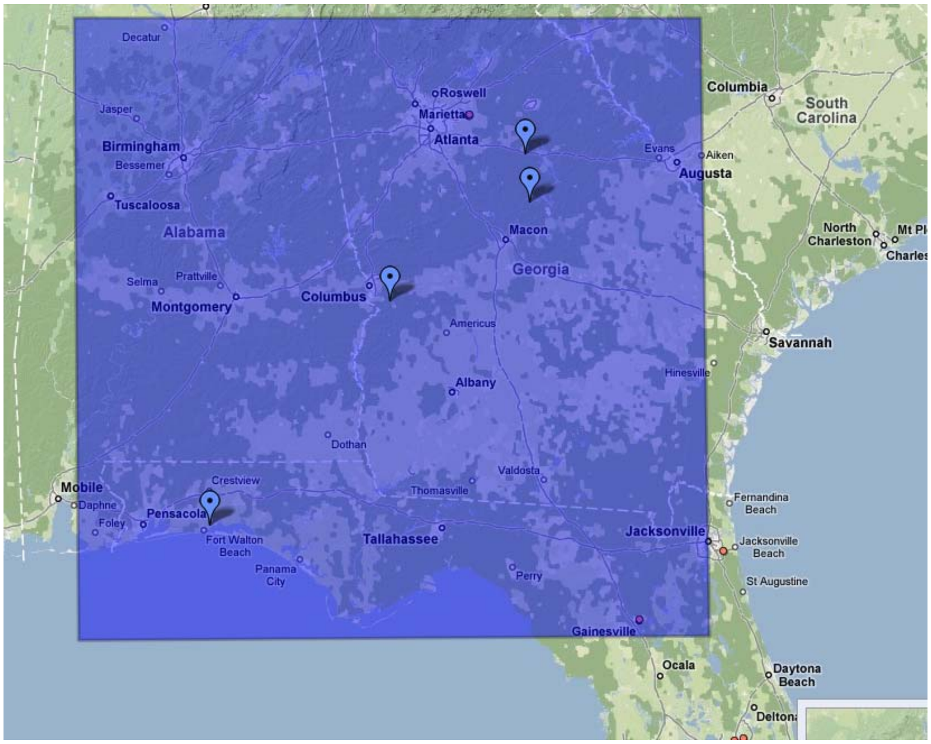

Figure 1 Locations of burn sites in the Southeast for plume rise measurements. The blue box is the domain for future regional meteorological and air quality simulations.

Table 1 Information on 2009 burns with plume rise measurements

Site[1]	Date	Acre	Ignition method	Fuel /weather conditions
Ft. Benning[2]	1/14	364	backing/strip head fires	Light wind
	1/15	583	backing/strip head fires	Strong wind
	4/8	236	backing/strip head fires	WSW wind
	4/9	343	backing/strip head fires	SW but very variable
Oconee	3/24	1580	backing/aerial	Pine litter, cloudy, 37% RH
Piedmont	4/27	1195	backing/aerial	Loblolly pine, SE wind
Eglin	5/6	500	backing/head	Wet fuel, strong SSW wind
	5/7	641	backing/strip head fires	SW wind 12-15
	5/8	1058	backing/aerial	Most clear, 46 RHS wind
	6/6	1500	backing/aerial	Understory of grasses, broomsedge, herbicide, clear 40% RH, light NW wind
	6/7	1600	backing/aerial	Most clear, 50% RH, light W-SW wind predicted

[1]Site locations:
Ft. Benning Army Base, Columbus, GA, 32.33N, 84.79W
Oconee National Forest, Georgia, 33.54N, 83.46W
Piedmont National Wildlife Refuge, Georgia, 33.15N, 83.42W
Eglin Air Force Base, FL, 30.15N, 86.55W
[2]Ground fire emissions were also measured for this site by University of Georgia.

b. Measurements

Plume rise was measured with a Vaisala CL31 Ceilometer (Figure 2) purchased for this project. The measurement heights range from 0 to 7.5 km (from 0 to 25,000 feet) for as many as three vertical layers of smoke plumes and clouds, and at a frequency as fast as 2 seconds. The ceilometer is connected to a PC for data storage and display. An application (CL-VIEW) is used to visualize the data. Another application is available to calculate the height of atmospheric boundary layer.

Besides the ceilometer, 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. Figures 3 ~ 5 show some fuel and burning, and smoke plumes. Figure 6 shows Forest Service staff participating in filed measurements (Ken Forbus, David Combs, Scott Goodrick, and Yongqiang Liu), and volunteer Ellen Forbus. People from the fields who helped the measurements include Tommy Hutcherson (Ft. Benning AB)), Kevin Heirs, Brett Williams, Jerry Coon, and Nathan Price (Eglin AFB), Tim Kolnik and Mike Caldwell (Oconee NF), Carl Schmidt and Joh Mason (Piedmont NWR), and Dustin Thompson (BF Grant Memorial Forest, Warnell School of Forestry and Natural Resources, University of Georgia).

(a) Ceilometer and other devices

(b) Display

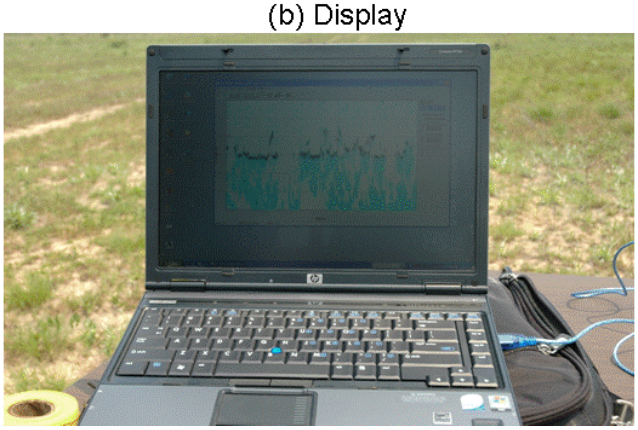

Figure 2 Plume rise measurements. Shown in panel a are the CL31 Ceilometer (white) in middle, PC for data storage and instant display to near right, generator (red) to far right, and portable weather station to far left. Panel b shows PC monitor.

Figure 3 Fuel at Ft Benning in January (left) and Eglin in May (right) on top and burning at Ft Benning in January at bottom.

Figure 4 Smoke plumes at Ft Benning in January, Oconee in March, and Eglin in May and June.

Figure 5 The spectacular display of smoke plume at Eglin in June.

Figure 6 The measurement team of five members, plus a “volunteer” to guide the members to the burn site.

c. Plume rise data

The measured data were stored in various files with specific format. They can be analyzed and displayed with CL-VIEW and other common statistical and graphic tools. Figures 7 and 8 depict examples of measured intensity and vertical profile, respectively. Each figure includes the burn cases without (January 14, 2009) and with (April 27, 2009) presence of clouds.

Preliminary analyses show significant temporal variability of smoke plume. Plume rise was between 2000 and 2800 feet most times (panel a, figure 7), with an averaged value of about 2400 feet for the first case (panel a, figure 8). However, smoke reached as low as 800 feet around 1:15 pm and as high as 3600 feet around 1:45 pm. Furthermore, the large emission concentrations were located at different heights throughout the burn period. It appeared at upper levels before about 2 pm and near the ground afterward for the second burn case (panel b, figure 7).

Clouds can noticeably modify smoke plume structure. Smoke plume was capped by the clouds (panel b, figure 7). Smoke plume rise was basically same as the height of cloud base (panel b, figure 8).

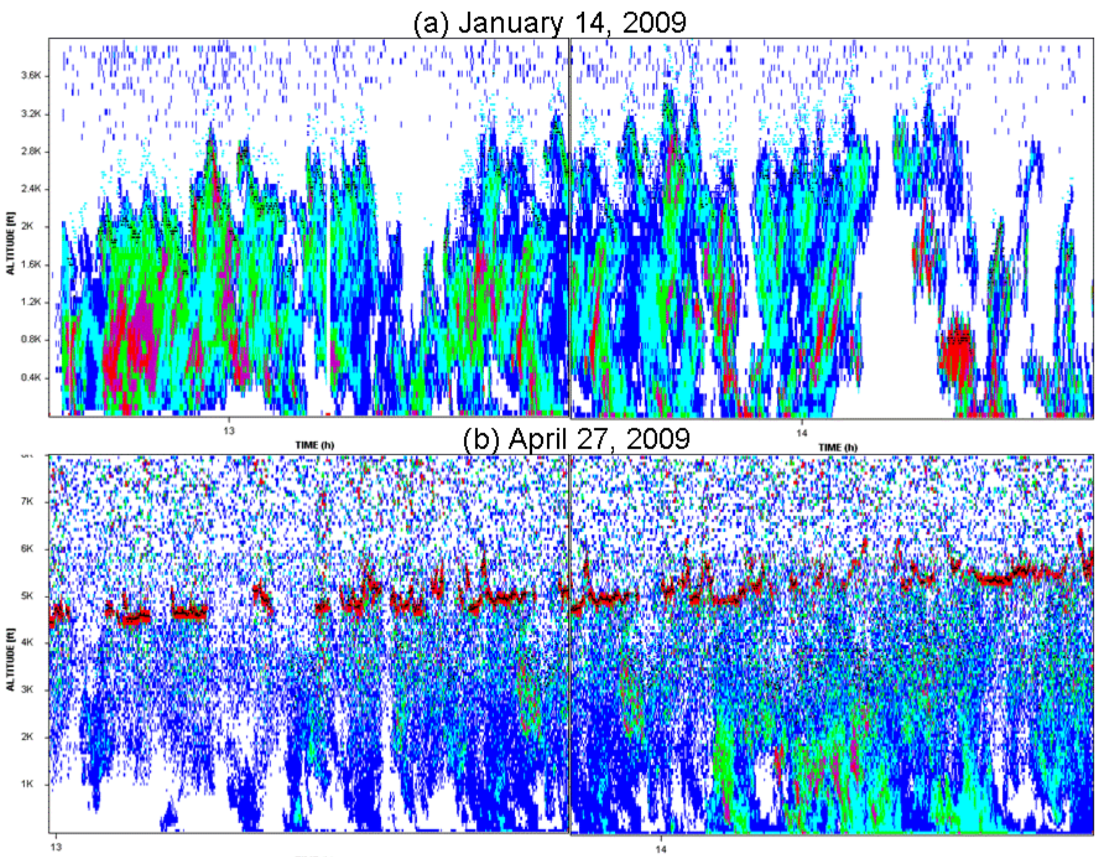

Figure 7 Smoke intensity (per 100*srad*km). (a) January 14 at Ft. Benning and (b) April 27, 2009 at Piedmont NWR. The horizontal coordinate is local time in hour and vertical coordinate is height in feet. Note the different scaling between the two panels. Red and blue represent the largest and smallest intensity, respectively.

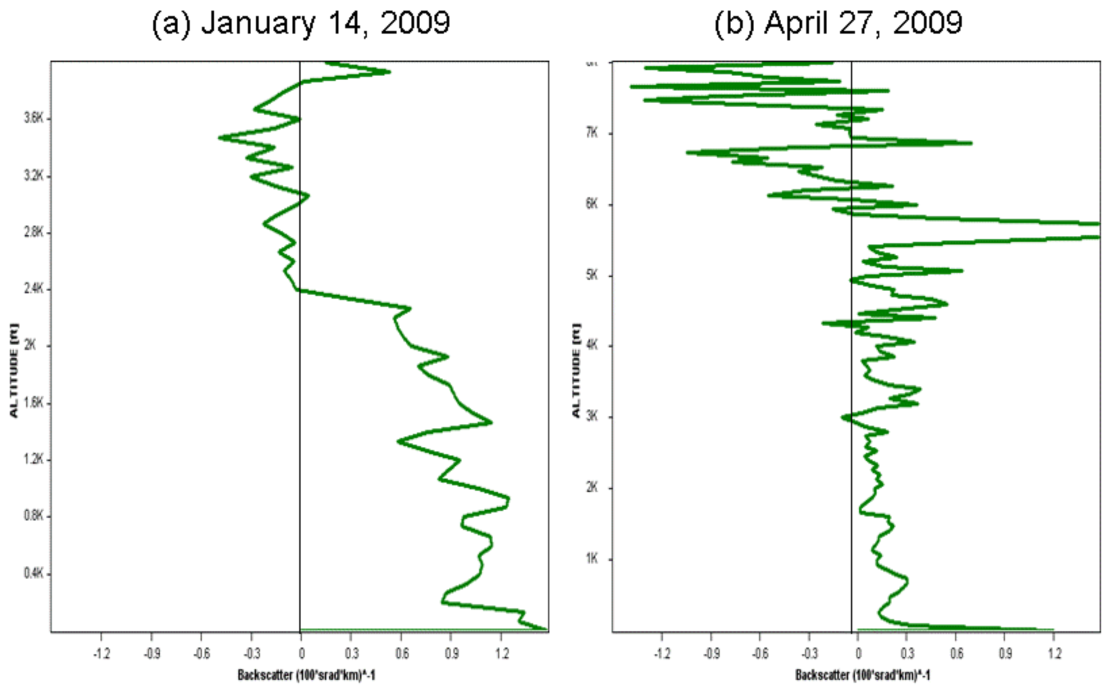

Figure 8 Vertical distribution of smoke intensity averaged over the measurement period. (a) January 14 at Ft. Benning and (b) April 27, 2009 at Piedmont NWR. The horizontal coordinate is backscatter (per 100*srad*km) and vertical coordinate is height in feet.

2. Other measurements and development

a. Ground concentrations

Ground $PM_{2.5}$ and CO measurements were conduced for the four burns at Ft. Benning by Dr. Luke Naeher and his team at the University of Georgia in collaboration with the JFSP and DOD projects of Mehmet Talat Odman of the Georgia Institute of Technology. The UGA team manually created a grid using an on-sight map and a 60 degree arc to establish three sample zones each assigned to a designated sampling truck. (Zone 1: 1-3 Km; Zone 2: 3-5 Km; Zone 3: 5-7 Km). They designated each truck a number to match the sampling zone for the burn. Each truck monitored multiple locations in its zone with a minimum of 30 minutes at each location. Sampling was started at ignition and continued until approximately one hour after completion. Initial sampling locations were on the most direct predicted downwind position from a burn location. Each subsequent position was chosen based on a combination of wind shifts, real-time equipment levels, and road availability. Each truck was equipped with a Dustrak Real-time $PM_{2.5}$ monitor, Langan CO Monitor, and a Draeger PAC III CO Monitor for all monitored burns. All three samplers were collocated at an 8 foot sampling height on the bed of a truck. All three monitors collect data in real-time and report samples in 30 second averages. Figures 9 and 10 show emission collector and $PM_{2.5}$ measurement results.

Figure 9 Fire emission collector mounted on a pickup during the ground measurements at Ft. Benning on January 14, 2009. The measurements were operated by the University of Georgia.

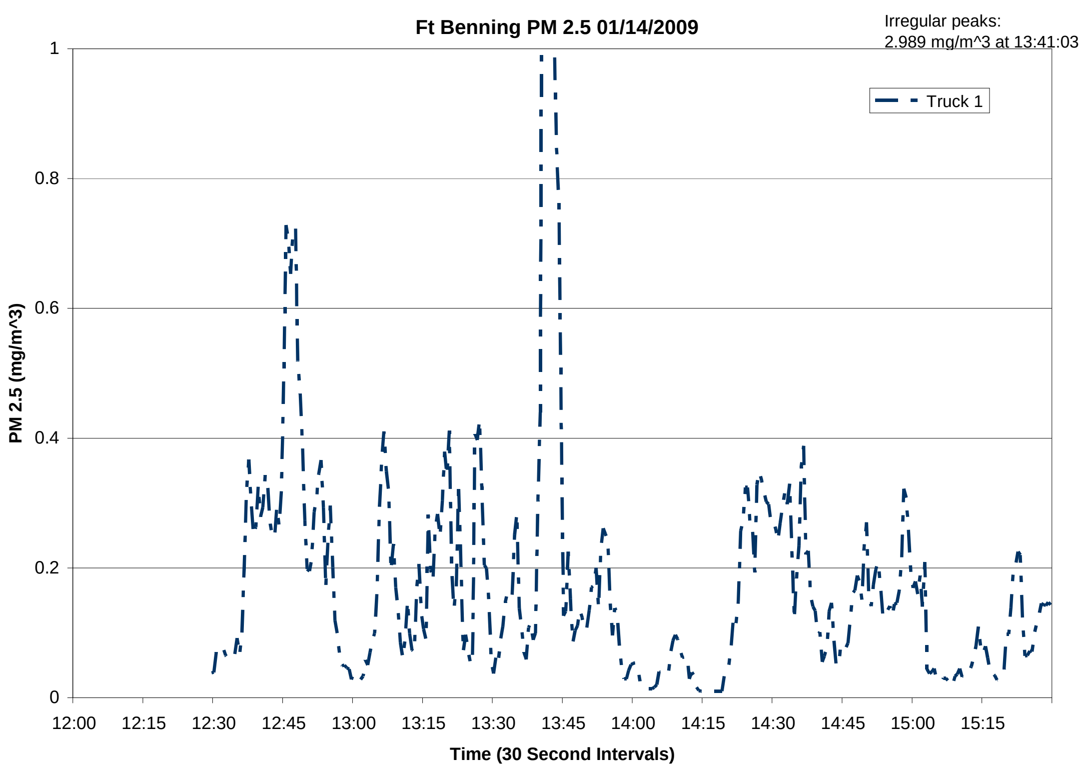

Figure 10 Ground $PM_{2.5}$ concentration for a burn at Ft. Benning on January 14, 2009. (Provided by University of Georgia).

b. Satellite

For burns at Ft Benning, MODIS true color images (500 m resolution) could observe smoke plume, but GOES images could not. On January 14, one MODIS image was cloud-free with relatively large smoke region. On January 15, the smoke was invisible in 10:30 MODIS image, but could be observed in 13:30 image with largest smoke region (mixed with high clouds and therefore hard to identify). On April 8, two MODIS images were cloud-free, the smoke plume was detectable but relatively small. On April 9, two MODIS images were cloudy and hard to identify smoke plume by programming. For cases at Eglin AFB, Oconee NF and Piedmont NWR, MODIS true color images were often covered by clouds, and GOES 12 images could not identify smoke plume. Figure 6 shows MODIS image of a burn. Smoke plume is visible but can not be clearly separated from the background. Further processing will be done to make the plume more clearly.

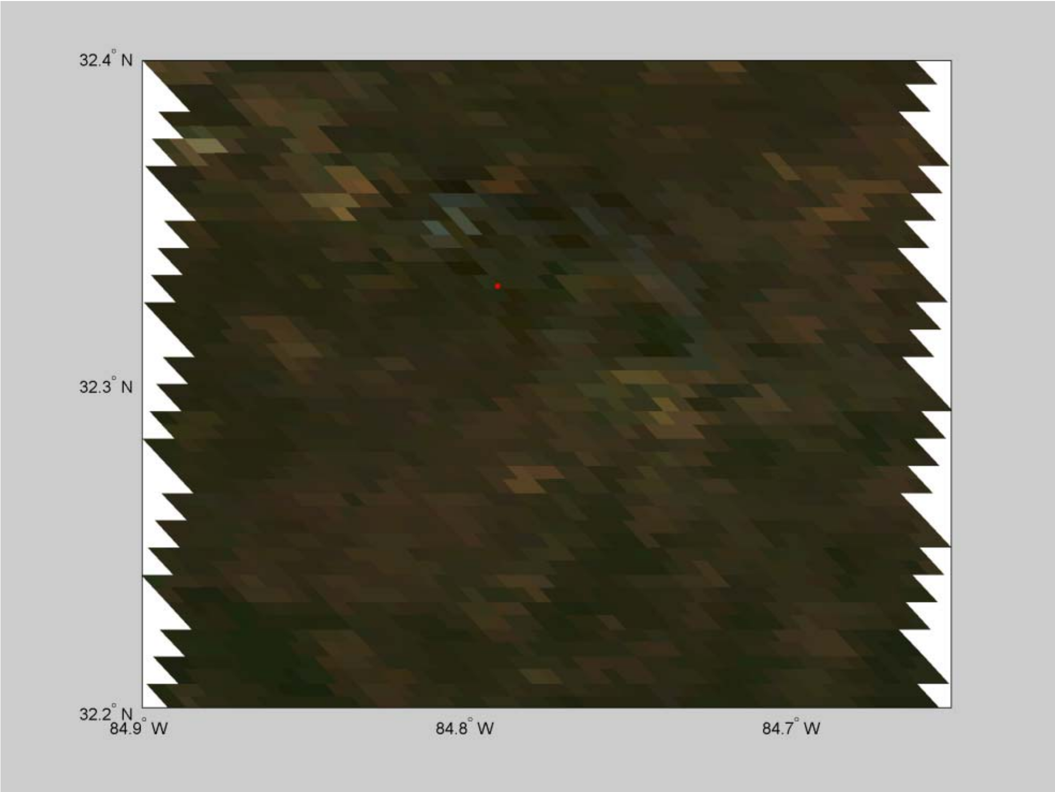

Figure11 MODIS image at 1:30 pm on January 14, 2009. The red point is the burn site at Ft. Benning, Georgia.

c. GIS version of Daysmoke

The GIS version of Daysmoke will be developed based on the framework and coding of Calsmoke. For Calsmoke, interface has been written to utilize FEPS results and emission. ArcGIS interface has been started. The user can lay out the modeling receptors and the burn units(s). ArcMap calculates information needed by CALPUFF and/or CALPOST. Also, maximum 24-hour or daily concentrations, and visibility impacts can be displayed at each receptor in ArcMap. Access database is completed. This database stores many of the default values (especially geographic), so the application can be exported to a new region.

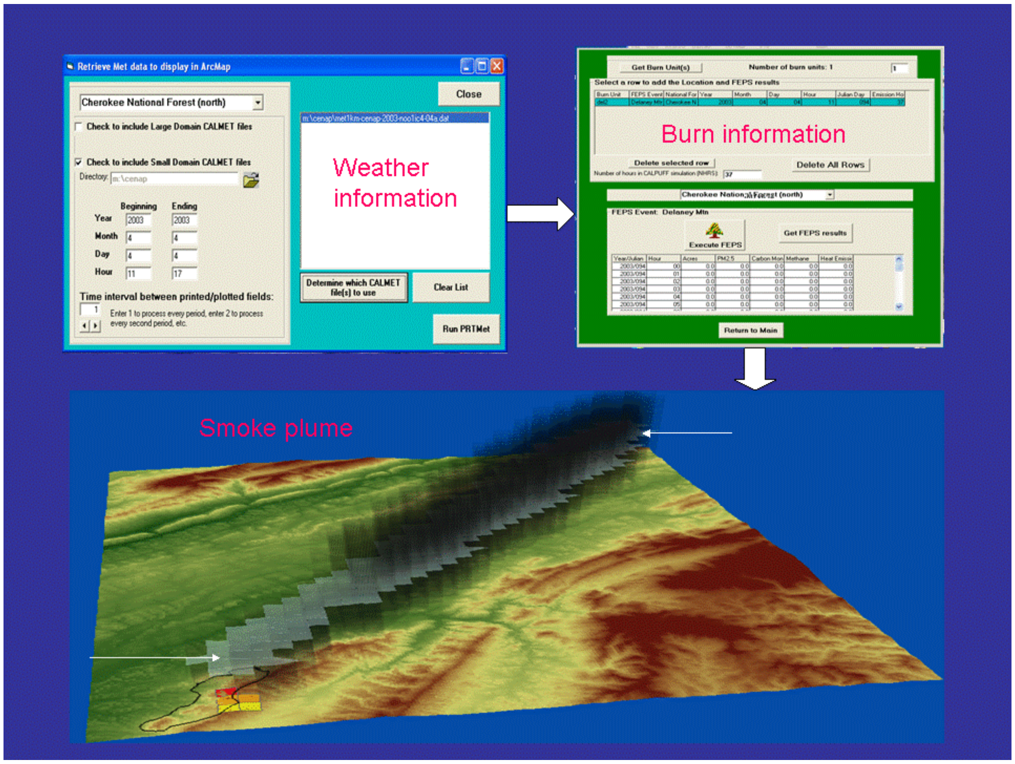

Figure 12 Framework for Clsmoke. It will be adopted for the GIS version of Daysmoke.

3. Deliverables

Liu, Y., Achtemeier, G.,Goodrick, S.L. 2009, Sensitivity and evaluation of smoke plume rise schemes for regional air quality simulation. 24th Tall Timbers Fire Ecology Conference, Tallahassee, FL, January 12-15, 2009.

Liu, Y.; Achtemeier, G.; Goodrick, S.L. 2009, Smoke plume rise measurements with a Ceilometer, 8th Symposium on Fire and Forest Meteorology, Kalispell, Montana, 13–15 October 2009. (Accepted for presentation)

Liu, Y.; Achtemeier, G.; Goodrick, S.L. 2009, Analysis and application of smoke plume rise measurements, 2009 CAMQ User Workshop, Chapel Hill, NC, October 19-21, 2009. (Accepted for presentation)