Using Smoke Modeling Tools for Prescribed Fire Planning and Implementation

A Quick Set of Instructions

(Revised December 2017)

Fire Management Officers (FMOs) in Region 8 are using smoke modeling more often in both the prescribed fire planning process as well as in the implementation of those plans. The Air Resources Team is available to provide training to FMOs on smoke modeling tools, including the Fire Emissions Production Simulator (FEPS), VSMOKE and VSMOKE-GIS, and PC HYSPLIT.

- FEPS is used to estimate emission and heat release rates from the prescribed fire event. FEPS yields inputs to both the VSMOKE and the HYSPLIT models.
    - As part of its calculations, FEPS requires user inputs for fuel loading and/or consumption for the unit that is being burned. Site specific fuel plot data will be the best source for these inputs, but if such data are not available FEPS also provides canned fuel loading and consumption data for various types of forest stands.
- VSMOKE is a simple screening model for prescribed fire planning. Using FEPS outputs, various meteorological conditions are entered into the VSMOKE model to simulate certain scenarios and assess the worst-case predicted downwind concentration from the proposed fire.
- PC HYSPLIT
    - The Ready version of HYSPLIT is a web-based model that uses many assumptions to estimate predicted downwind pollution concentrations. At this time, the R8 Air Resource Team does not recommend the Ready version because of concerns about over-prediction of downwind concentrations.
    - The PC version of HYSPLIT provides a more refined prediction of downwind concentrations. The Air Resources Team can model HYSPLIT for field personnel, if requested.

This document outlines the steps necessary to run FEPS, VSMOKE and HYSPLIT. Since both VSMOKE and HYSPLIT use emission and heat release rates from FEPS, instructions to run that program are presented first. Then, instructions for running VSMOKE for planning purposes start on page 5. Finally, on page 13, the instructions to run HYSPLIT PC begin.

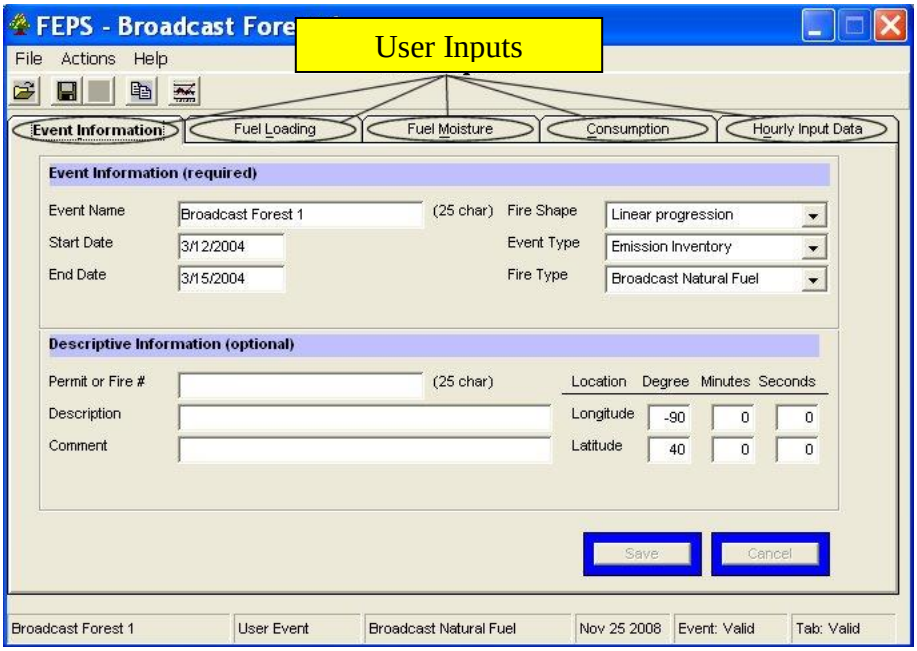
If anyone needs assistance to better understand these instructions, members of the R8 Air Resource Team are available to provide train and/or assist with a particular problem. Contact information is:

- Bill Jackson (828-257-4815): North Carolina, Cherokee, Francis Marion - Sumter, Savannah River, and Chattahoochee-Oconee
- Judy Logan (501-321-5341) : Ouachita, Ozark-St. Francis, Kisatchie, Texas, Mississippi
- Melanie Pitrolo (828-257-4213): Any Forest
- Daniel Stratton (828-257-4226): Any Forest

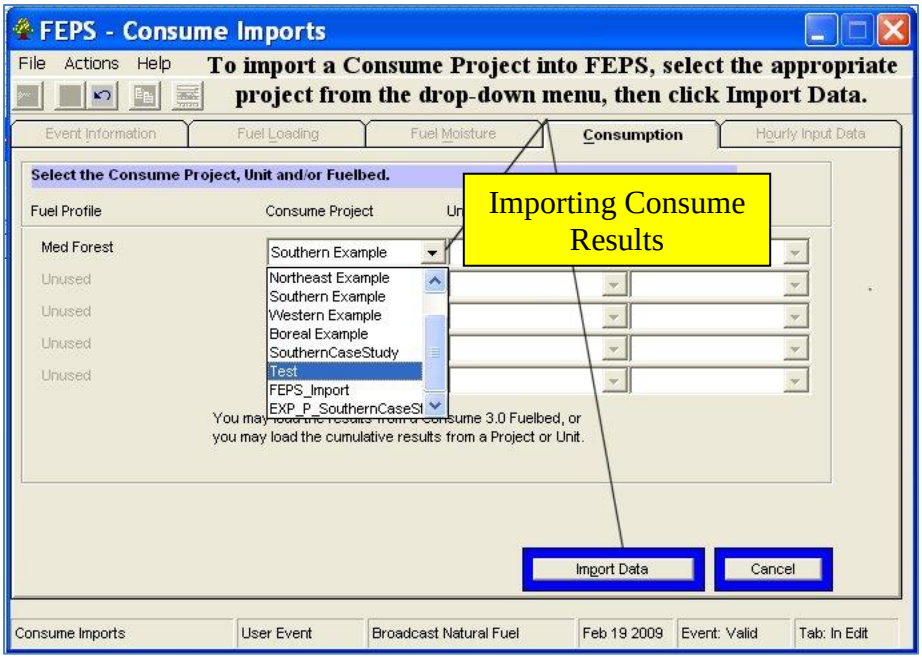
Use FEPS to Create Emissions and Heat Input Files for VSMOKE and HYSPLIT

To estimate downwind concentrations from a prescribed fire event, first calculate the hourly emission rates and heat release rates from the fire. Use the Fire Emissions Production Simulator (FEPS) to calculate hourly emission rates and heat release rates. The paper, "Using FEPS Results as Inputs to Smoke Dispersion Models: Identifying the Relative Importance of Parameters within the Tool," gives detailed information about how to run FEPS. As a refresher, the basic steps used to obtain the emissions, heat release, and plume profile for the fire from FEPS are listed below:

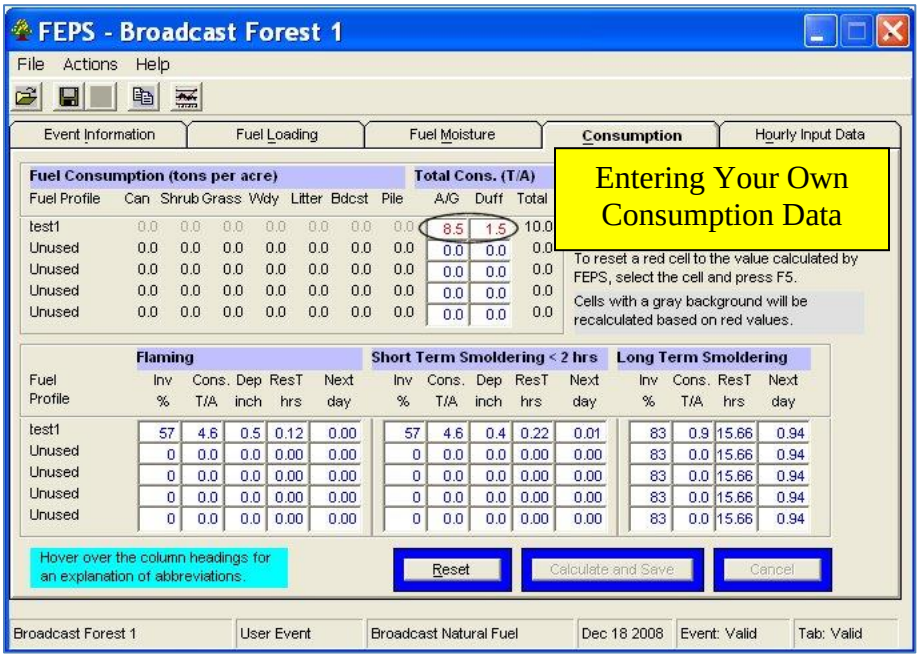
1. Open FEPS, either from the VSMOKE form or from the Windows start menu; and create or load a prescribed burn event. Once an event is created/loaded, the main FEPS screen with its five user input tabs appears. Enter the fire event information (start and end date) in the left side of the form, then click save.



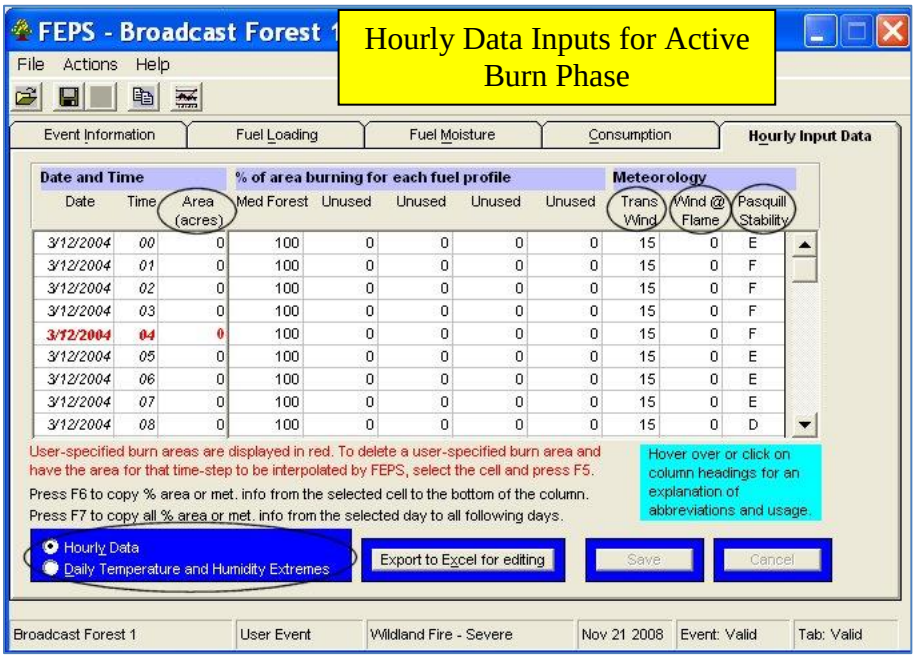
2. To obtain consumption information, there are three options: Use FEPS to calculate the consumption, import consumption information from the CONSUME software program, or directly enter consumption based on your best professional judgment.
    a. If you use FEPS to calculate consumption, go to the Fuel Loading tab and enter the fuel profile name and select the fuel bed type. Then, in the Fuel Moisture tab, pick the fuel moisture. In the Consumption tab, select "calculate and save".
    b. If you are not using FEPS to calculate the consumption, go to the Fuel Loading tab, clear the fuel bed information, and then create a name for the fuel profile. Next, go to the Fuel Moisture tab and set the fuel moisture at "Very Dry". Then go to the Consumption tab to either import or type in the consumption.
        i. To import a CONSUME file, click on Actions→Import Consumption→Import from Consume 3.0. Use the drop down menu, as shown below, to select and import the CONSUME project. Note that the Unit and Fuelbed may be selected as well.



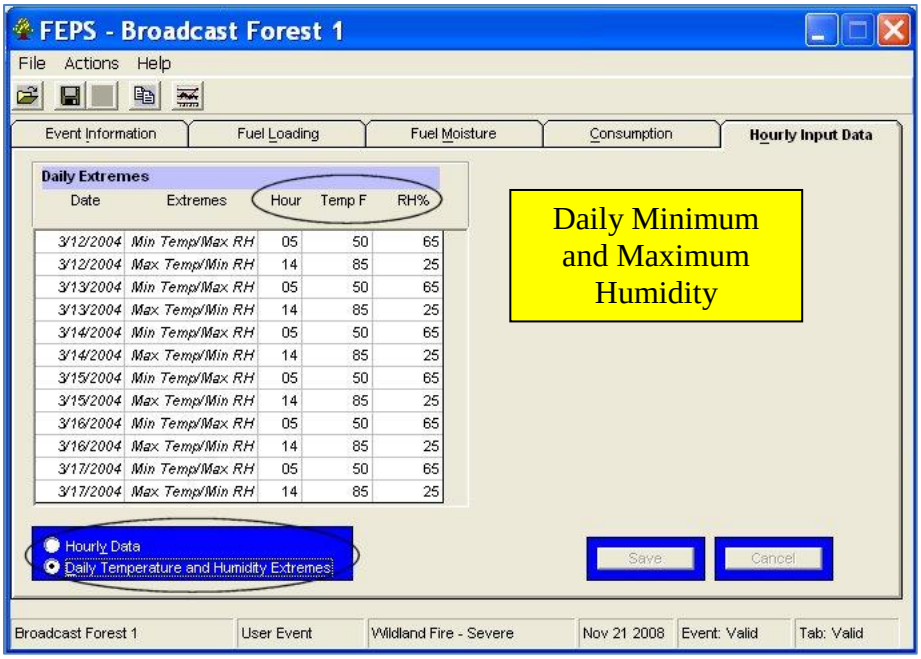
ii. If you know what the consumption will be, either from field measurements or by best professional judgment, manually enter that information into FEPS as shown below.



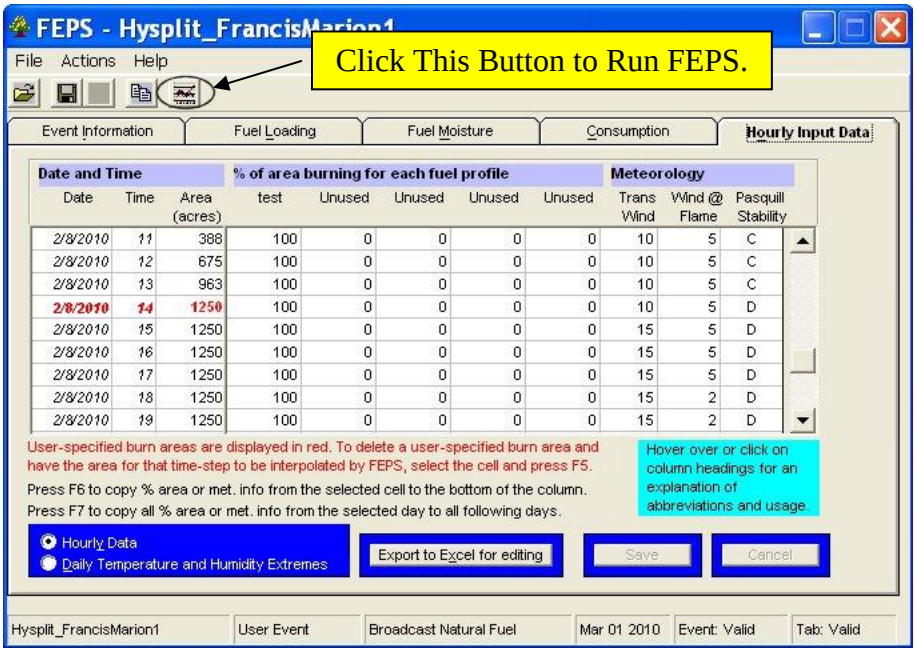
3. After entering the consumption information for the prescribed fire event, go to the Hourly Input Data tab. Enter the hourly meteorological data, along with the fire spread information, for each hour of the active burn phase. There are two views within this tab: the "Hourly Data" and the "Daily Temperature and Humidity Extremes".
   a. The "Hourly Data" view is below. You must enter the hourly information for the active burn phase, including the rate of spread of the fire, the transport and mid-flame (**not** surface) wind speeds, and the stability class. Note that in the absence of site-specific met data, mid-flame wind speeds are assumed to be 40% of the surface wind speed values (e.g., a surface wind speed of 5 miles per hour is assumed to have a mid-flame wind speed of 2 miles per hour).



b. The "Daily Temperature and Humidity Extremes" view is on the next page. You must enter in the humidity information (daily minimum/maximum and the hours that they occur).



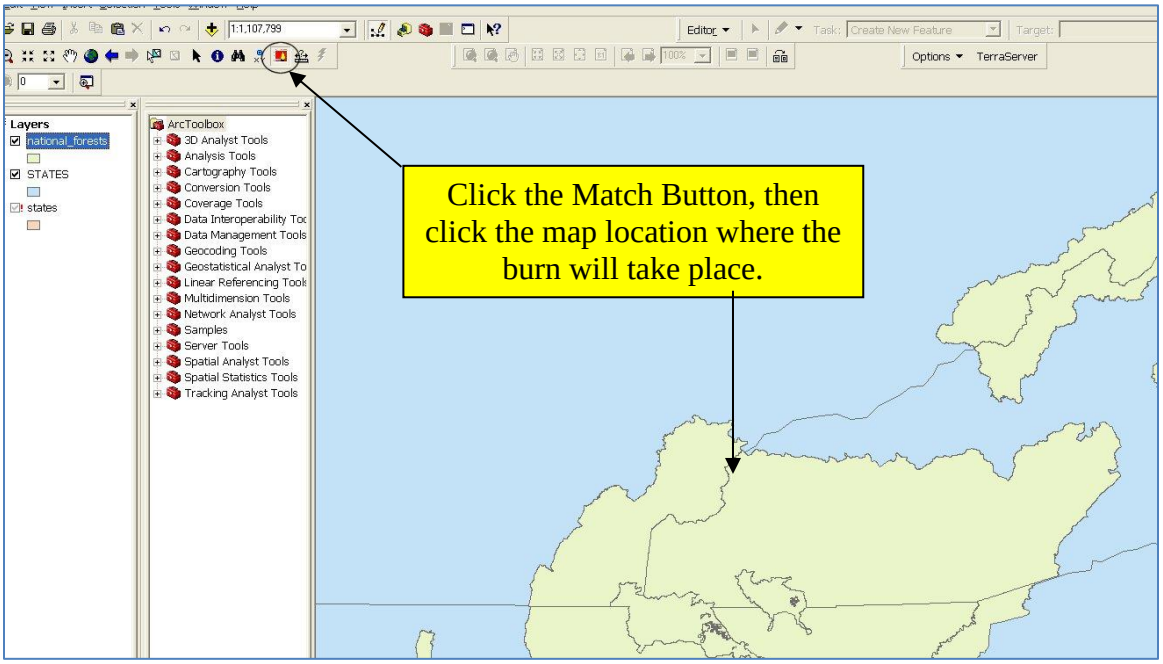
4. Run FEPS by clicking on the button below and to the right of the Help menu. After clicking on this button, you can exit the program. Results are ready to be used in either VSMOKE or HYSPLIT.



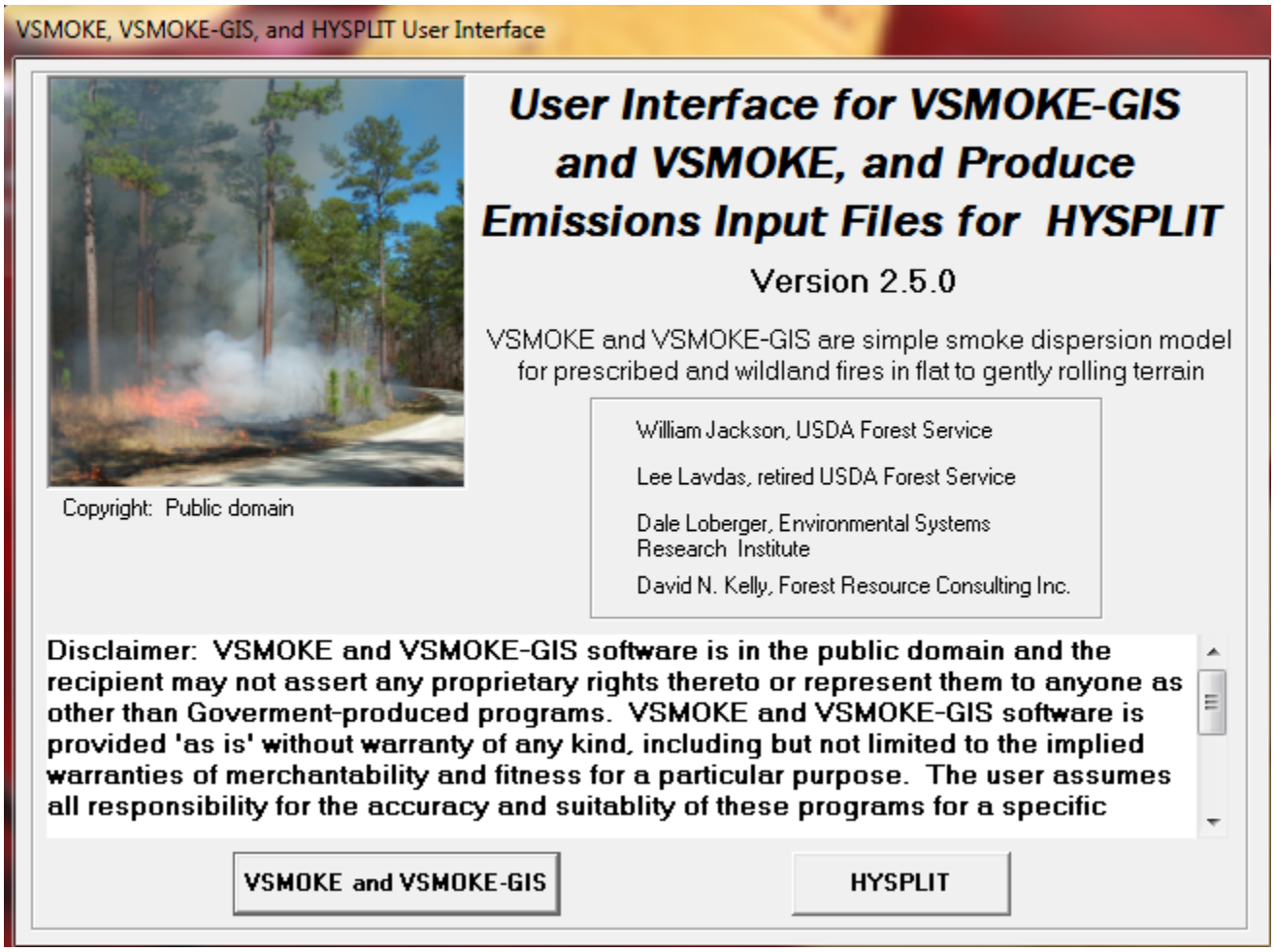
Running VSMOKE or VSMOKE-GIS

There are two ways to run the VSMOKE model. Either use the Arc GIS interface, or simply use the VSMOKE form. If you use ArcMap to display the VSMOKE results graphically, follow all of the instructions below. Otherwise, skip down to 2.

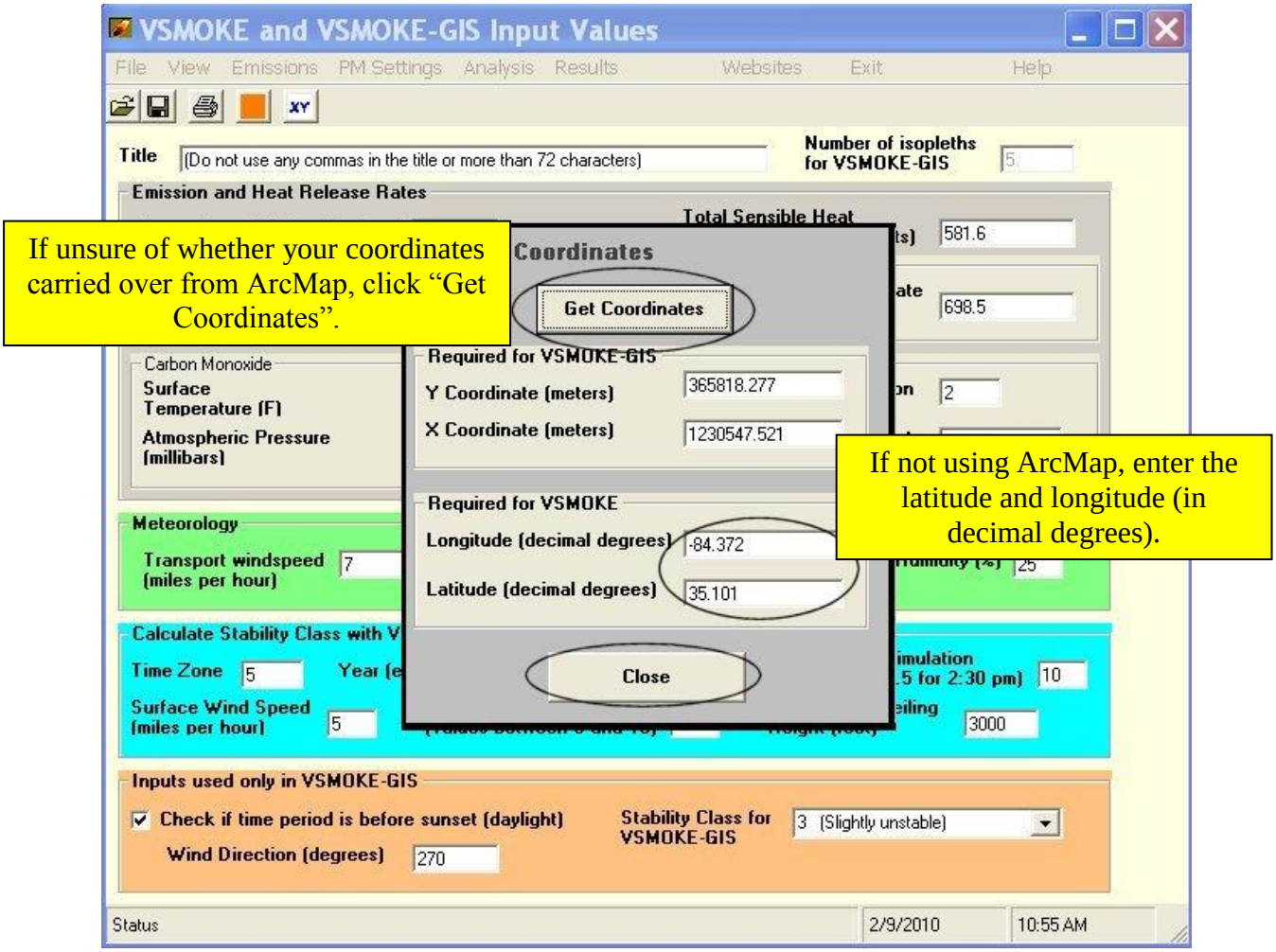
1. Navigate to the c:\vsmkgs folder. Click on the **c:\vsmkgs\vsmoke.mxd** file which opens the ArcMap project. (Some desktops contain an icon named **vsmoke.mxd**. If so, simply double click on it to open the ArcMap project.) Once the ArcMap project is open, add any layers needed in the VSMOKE project, *i.e.* forest boundary, burn units, etc. At that point click on the match button as shown on the following screen capture, and then click the map location where the burn will take place.



2. After either clicking on the map, or opening "VSMOKE and HYSPLIT Interface" from the Windows Start Menu, the VSMOKE dialogue box will open. The screen that is shown below will appear. Click on "VSMOKE and VSMOKE-GIS."



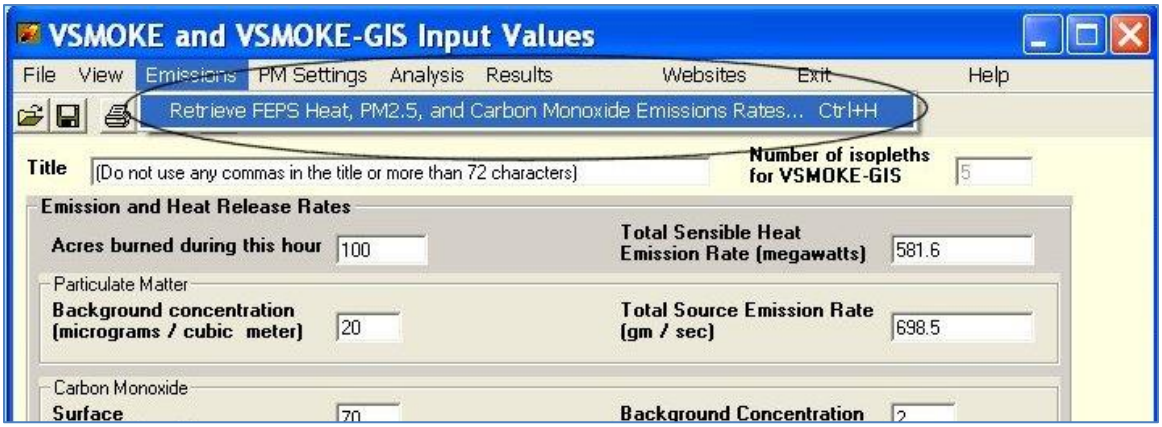
3. The X and Y Coordinates screen will appear. If you clicked on an ArcMap project to open VSMOKE, the coordinates are already populated with the values you chose. Otherwise, enter the latitude and longitude in decimal degrees. Click Close.



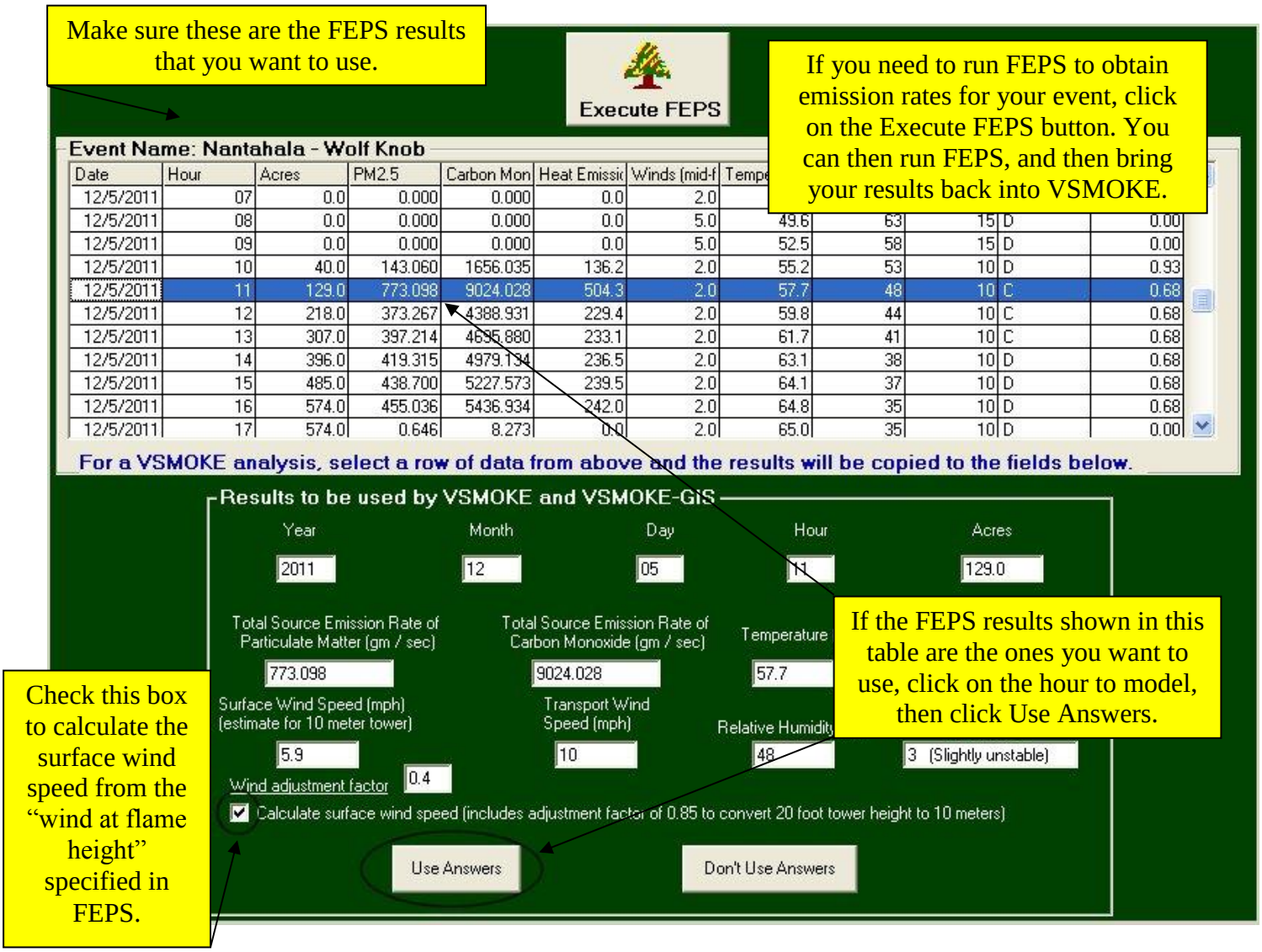
If unsure of whether your coordinates carried over from ArcMap, click "Get Coordinates".

If not using ArcMap, enter the latitude and longitude (in decimal degrees).

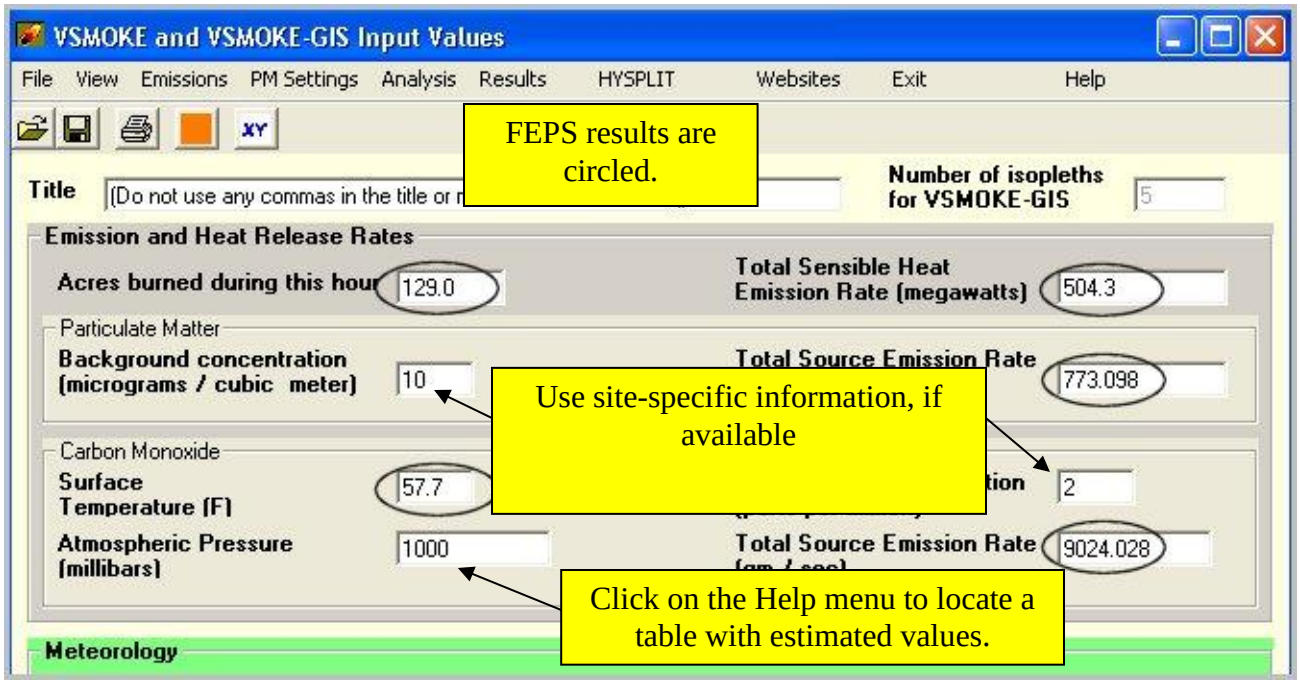
4. The main VSMOKE input screen appears. Retrieve the FEPS results first by clicking **Emissions**, then click **Retrieve FEPS…Emission Rates**, as shown below.



5. The screen shown on the next page appears. Results from the last FEPS run are populated in the table. If this is the desired run, simply select the desired hour to model (typically the hour with the highest $PM_{2.5}$ emission rate), confirm those data and press "Use Answers." If a new FEPS run is necessary, press the "Execute FEPS" button and the FEPS program will appear. Pages 1-4 of this document provide instructions for FEPS. If you do run FEPS from here, you will need to retrieve your results after returning to VSMOKE.

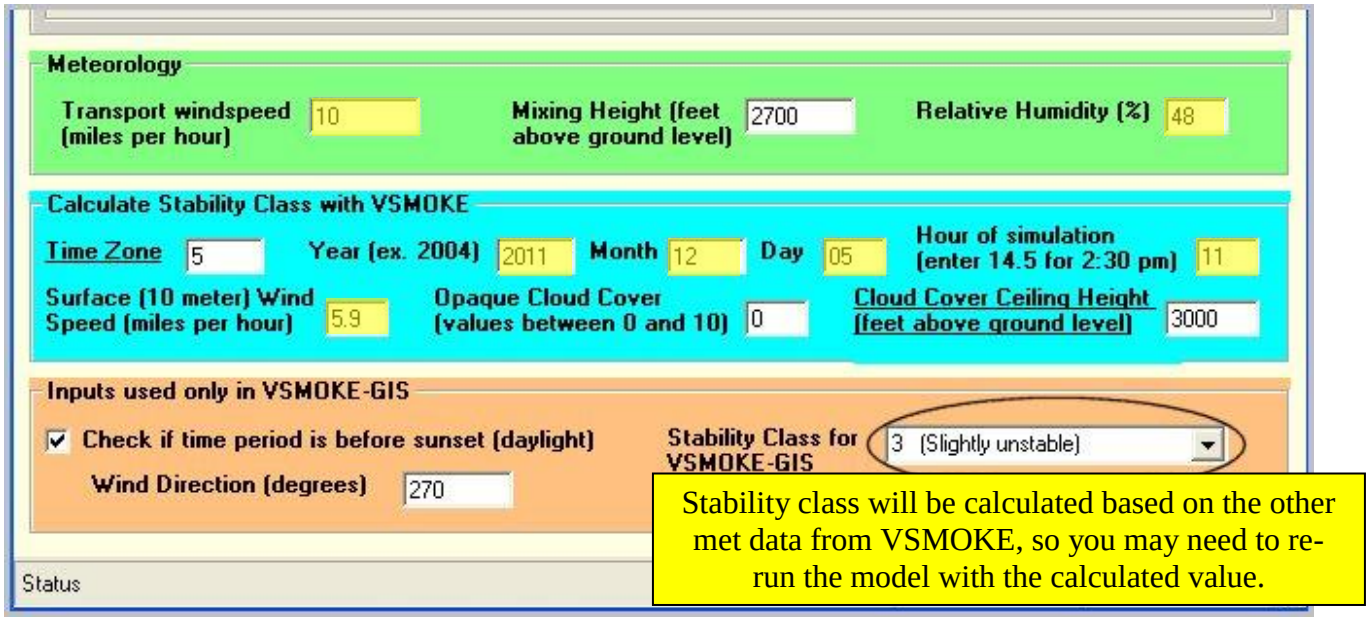


6. The main VSMOKE input screen appears next. FEPS populates the values into the VSMOKE form, as shown on the next page. Illustrated first is the **top** of the VSMOKE form. The default values for background concentration levels of $PM_{2.5}$ and CO are acceptable, although if you know the site-specific information, you can use those values. In this case, the background concentration of $PM_{2.5}$ was set to 10 $\mu g/m^3$ (as opposed to the default value of 20). The default background concentration for CO of 2 ppm was maintained. When available, you should use the actual atmospheric pressure rather than the pressure at sea level. The Help file for VSMOKE (http://webcam.srs.fs.fed.us/tools/vsmoke/VSMOKE_Interface.pdf) has a table that can be used to approximate atmospheric pressure at varying elevations.



7. Next, the **bottom** view of the VSMOKE input screen is illustrated. This is where you put in your meteorological information, as well as information for plotting the smoke plume in ArcMap. Although the FEPS file populates some of this information, make sure that the values correspond to the selected specific weather forecast. You can also use the Region 8 guidelines to conduct several runs using different meteorological data, and compare their results.

   The bottom portion of the VSMOKE form is shown below, with results from the FEPS file highlighted.



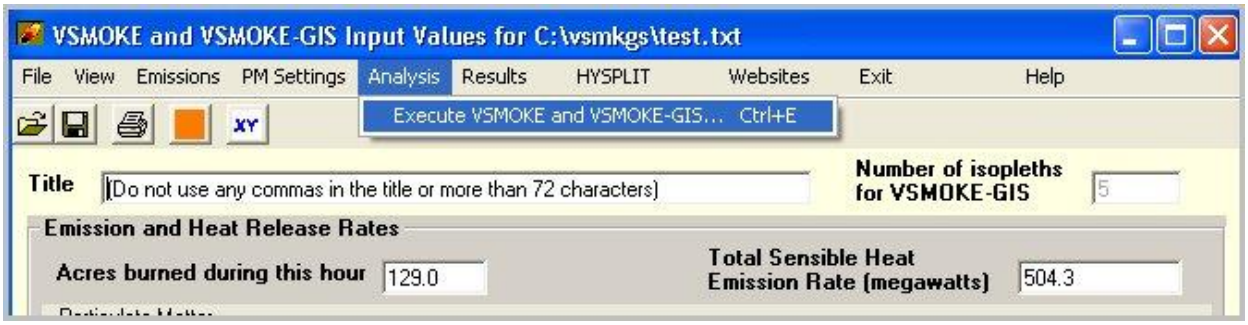
   The weather forecast may not contain **"**Time Zone", **"**Opaque Cloud Cover", "Cloud Cover Ceiling Height", and "Stability Class for VSMOKE-GIS".

   a. Find the time zone by clicking on the Websites menu. Valid numbers for the continental United States are: Eastern daylight time = 4.0, Eastern Standard Time = 5.0, Central Daylight Time =

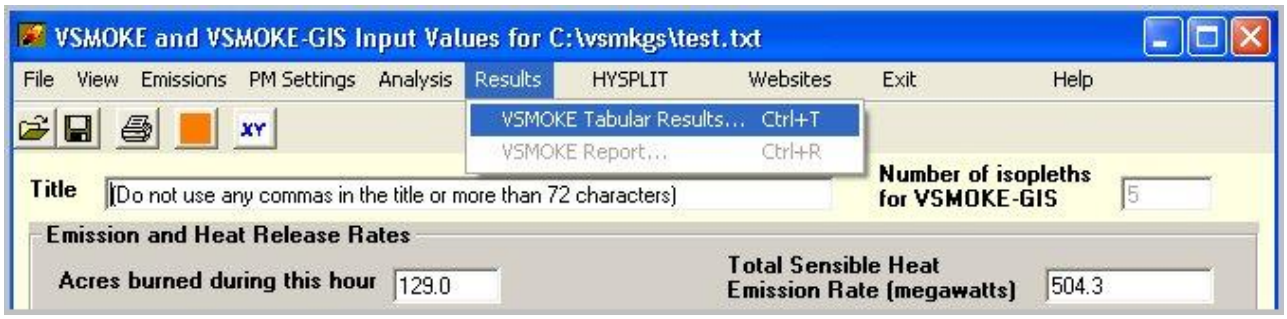
5.0, Central Standard Time = 6.0, Mountain Daylight Time = 6.0, Mountain Standard Time = 7.0, Pacific Daylight Time = 7.0 and Pacific Standard Time = 8.0

b. Estimate cloud cover from the forecast; opaque cloud cover is a scale where "0" equals clear, and "10" equals overcast.
c. A NWS website shows the cloud cover ceiling height linked from the Websites menu.
d. VSMOKE calculates the stability class, so you can make an educated guess the first time you run the model based on information found in a section of the help files under Estimating Stability Class/Field. This value is only used by VSMOKE-GIS, so you can re-run the model with the value calculated by VSMOKE if different than what was originally entered.

8. Fill all fields on the VSMOKE input form, then save the results. Then, click on Analysis, Execute VSMOKE and VSMOKE-GIS to run VSMOKE, as shown below.

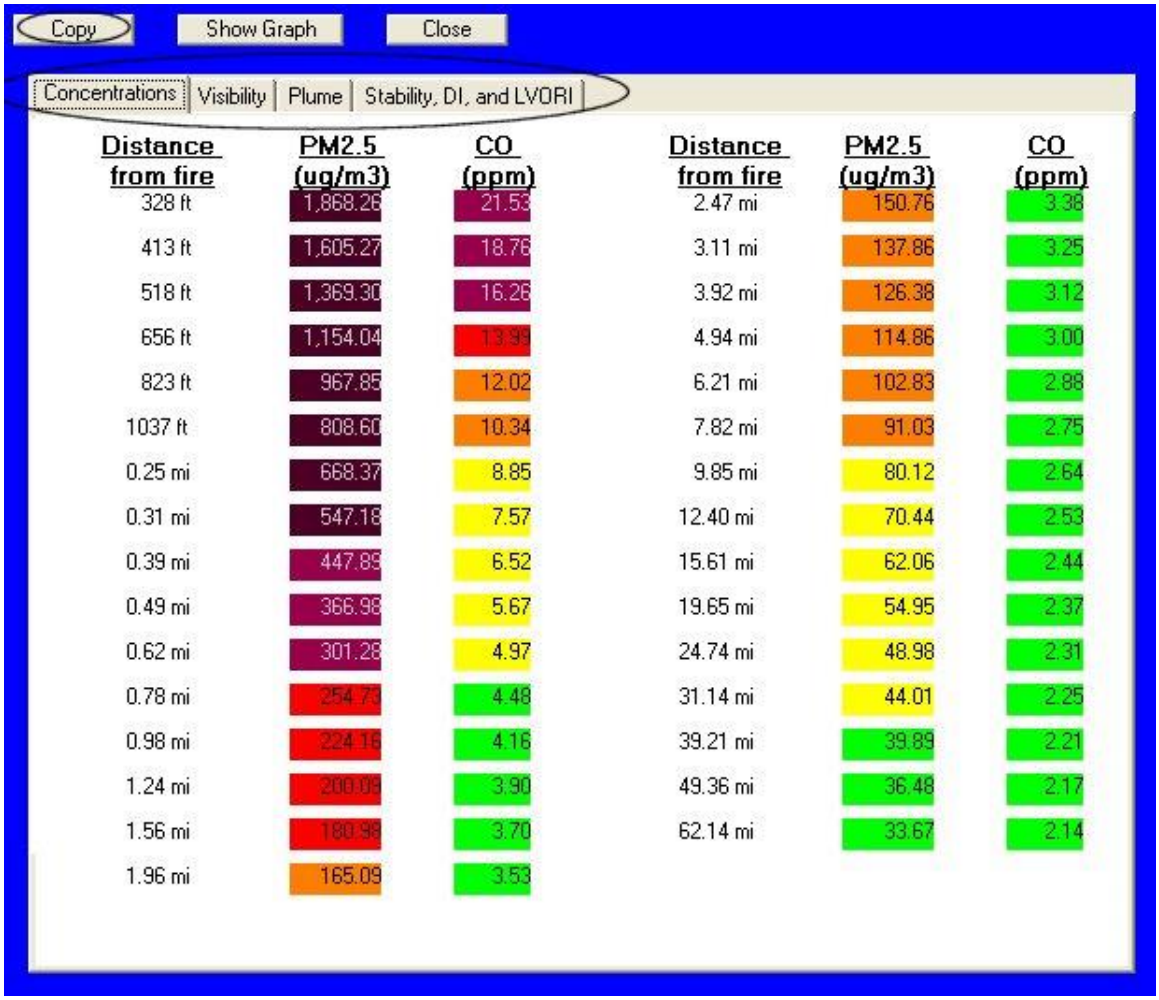


9. View results, first in a tabular format, and then in ArcMap if running VSMOKE-GIS. First click on "Results", then "VSMOKE Tabular Results…" as shown below.



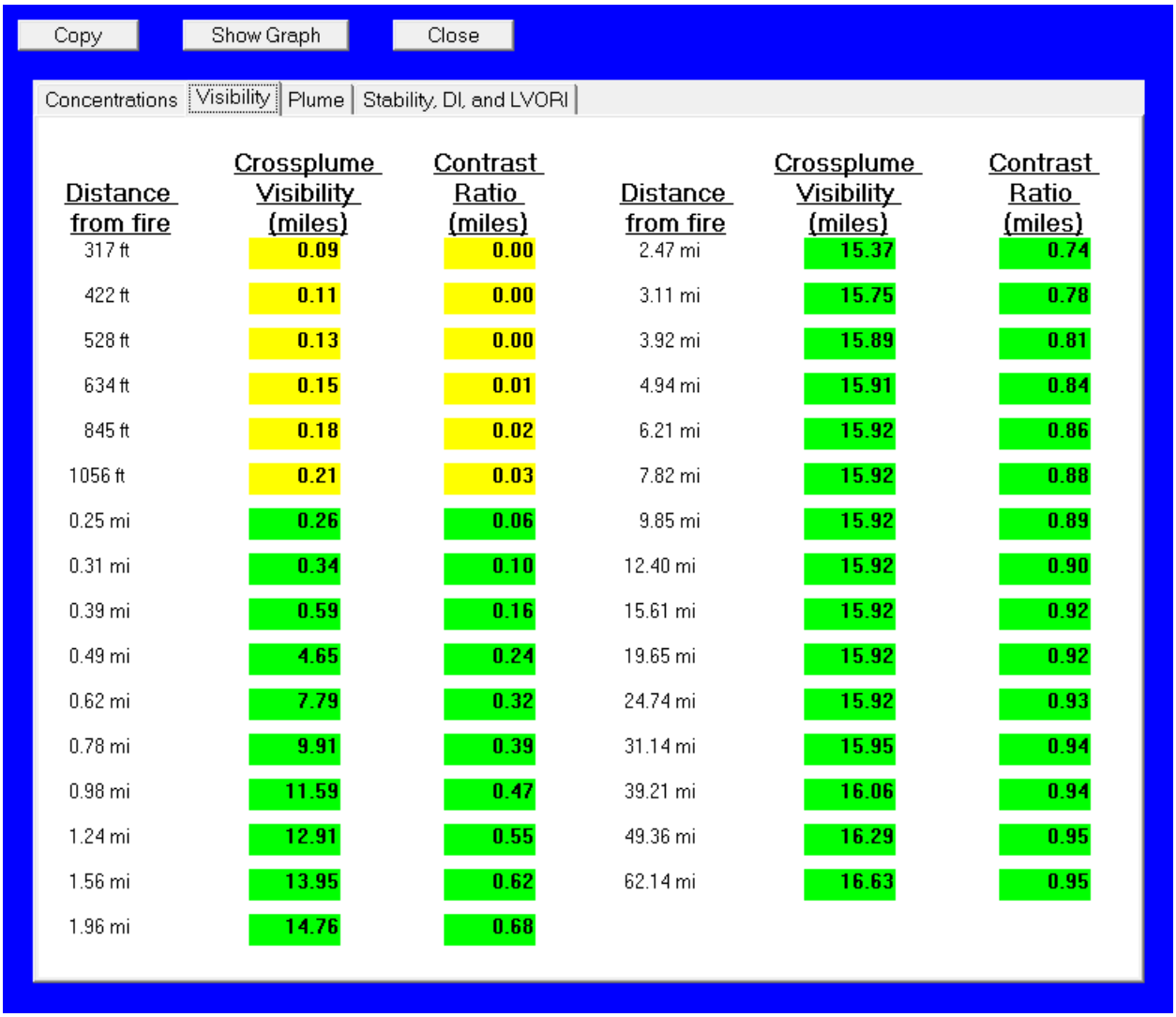
10. Results are displayed in a new window that has four separate tabs (Concentrations, Visibility, Plume, and Stability/DI/LVORI).

    a. The first tab, "Concentrations", shows the predicted downwind concentrations of both $PM_{2.5}$ and CO, color coded in accordance with the Air Quality Index (AQI).



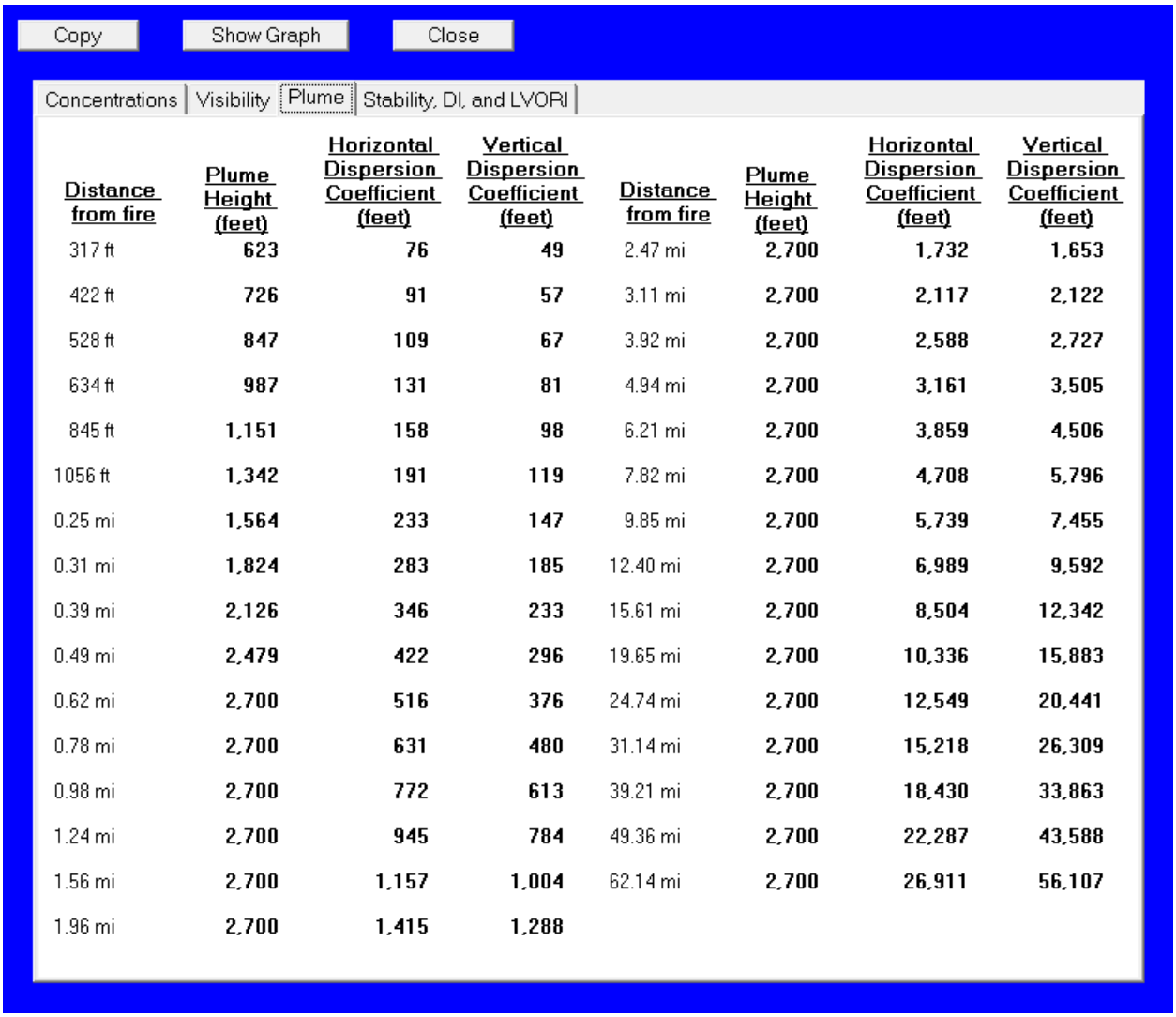
Distance from fire	PM2.5 (ug/m3)	CO (ppm)	Distance from fire	PM2.5 (ug/m3)	CO (ppm)
328 ft	1,868.26	21.53	2.47 mi	150.76	3.38
413 ft	1,605.27	18.76	3.11 mi	137.86	3.25
518 ft	1,369.30	16.26	3.92 mi	126.38	3.12
656 ft	1,154.04	13.99	4.94 mi	114.86	3.00
823 ft	967.85	12.02	6.21 mi	102.83	2.88
1037 ft	808.60	10.34	7.82 mi	91.03	2.75
0.25 mi	668.37	8.85	9.85 mi	80.12	2.64
0.31 mi	547.18	7.57	12.40 mi	70.44	2.53
0.39 mi	447.89	6.52	15.61 mi	62.06	2.44
0.49 mi	366.98	5.67	19.65 mi	54.95	2.37
0.62 mi	301.28	4.97	24.74 mi	48.98	2.31
0.78 mi	254.73	4.48	31.14 mi	44.01	2.25
0.98 mi	224.16	4.16	39.21 mi	39.89	2.21
1.24 mi	200.09	3.90	49.36 mi	36.48	2.17
1.56 mi	180.98	3.70	62.14 mi	33.67	2.14
1.96 mi	165.09	3.53			

b. The second tab gives the predicted downwind visibility impacts.



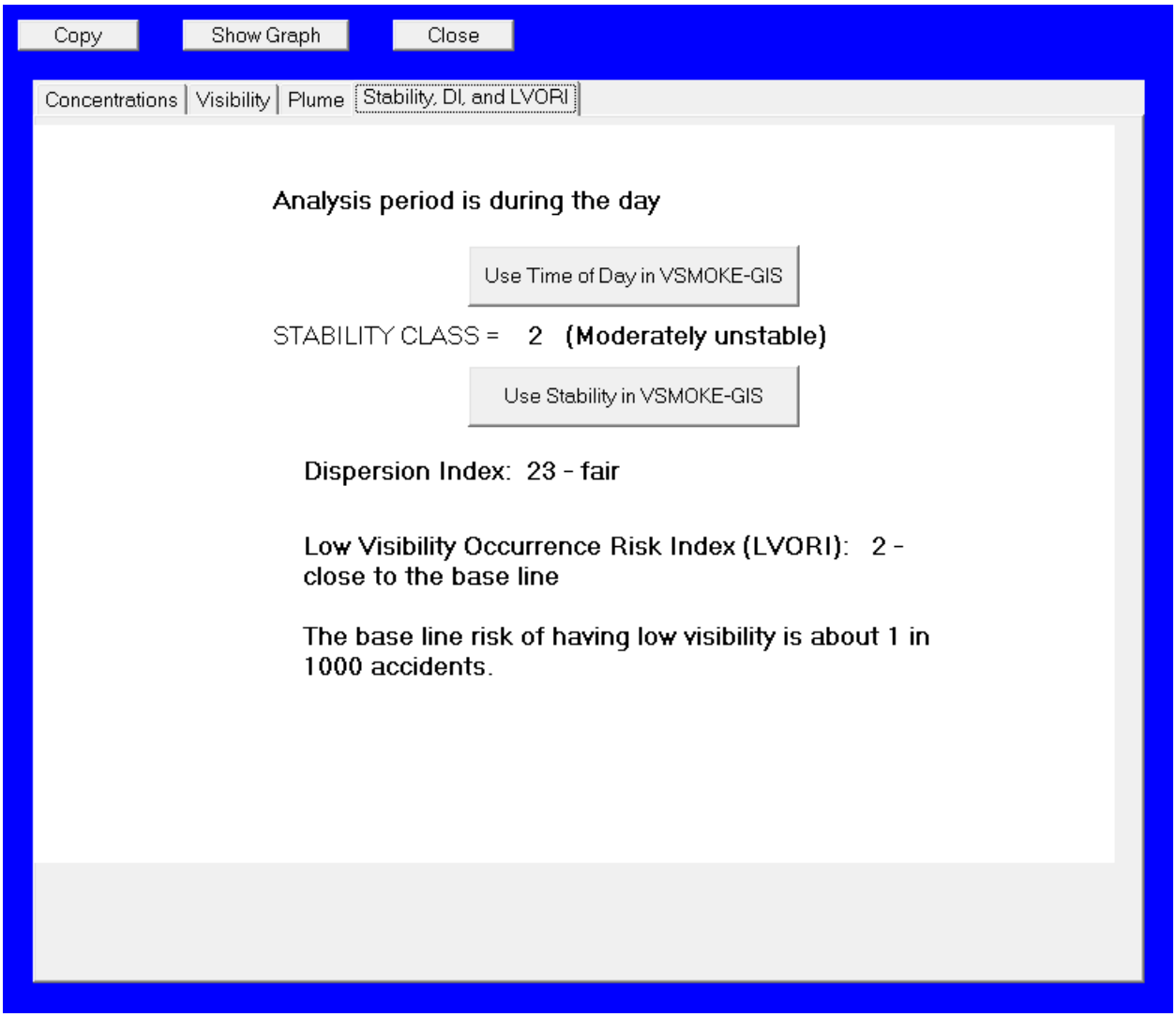
Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)	Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)
317 ft	0.09	0.00	2.47 mi	15.37	0.74
422 ft	0.11	0.00	3.11 mi	15.75	0.78
528 ft	0.13	0.00	3.92 mi	15.89	0.81
634 ft	0.15	0.01	4.94 mi	15.91	0.84
845 ft	0.18	0.02	6.21 mi	15.92	0.86
1056 ft	0.21	0.03	7.82 mi	15.92	0.88
0.25 mi	0.26	0.06	9.85 mi	15.92	0.89
0.31 mi	0.34	0.10	12.40 mi	15.92	0.90
0.39 mi	0.59	0.16	15.61 mi	15.92	0.92
0.49 mi	4.65	0.24	19.65 mi	15.92	0.92
0.62 mi	7.79	0.32	24.74 mi	15.92	0.93
0.78 mi	9.91	0.39	31.14 mi	15.95	0.94
0.98 mi	11.59	0.47	39.21 mi	16.06	0.94
1.24 mi	12.91	0.55	49.36 mi	16.29	0.95
1.56 mi	13.95	0.62	62.14 mi	16.63	0.95
1.96 mi	14.76	0.68			

c. The third tab shows calculated plume rise



Distance from fire	Plume Height (feet)	Horizontal Dispersion Coefficient (feet)	Vertical Dispersion Coefficient (feet)	Distance from fire	Plume Height (feet)	Horizontal Dispersion Coefficient (feet)	Vertical Dispersion Coefficient (feet)
317 ft	623	76	49	2.47 mi	2,700	1,732	1,653
422 ft	726	91	57	3.11 mi	2,700	2,117	2,122
528 ft	847	109	67	3.92 mi	2,700	2,588	2,727
634 ft	987	131	81	4.94 mi	2,700	3,161	3,505
845 ft	1,151	158	98	6.21 mi	2,700	3,859	4,506
1056 ft	1,342	191	119	7.82 mi	2,700	4,708	5,796
0.25 mi	1,564	233	147	9.85 mi	2,700	5,739	7,455
0.31 mi	1,824	283	185	12.40 mi	2,700	6,989	9,592
0.39 mi	2,126	346	233	15.61 mi	2,700	8,504	12,342
0.49 mi	2,479	422	296	19.65 mi	2,700	10,336	15,883
0.62 mi	2,700	516	376	24.74 mi	2,700	12,549	20,441
0.78 mi	2,700	631	480	31.14 mi	2,700	15,218	26,309
0.98 mi	2,700	772	613	39.21 mi	2,700	18,430	33,863
1.24 mi	2,700	945	784	49.36 mi	2,700	22,287	43,588
1.56 mi	2,700	1,157	1,004	62.14 mi	2,700	26,911	56,107
1.96 mi	2,700	1,415	1,288				

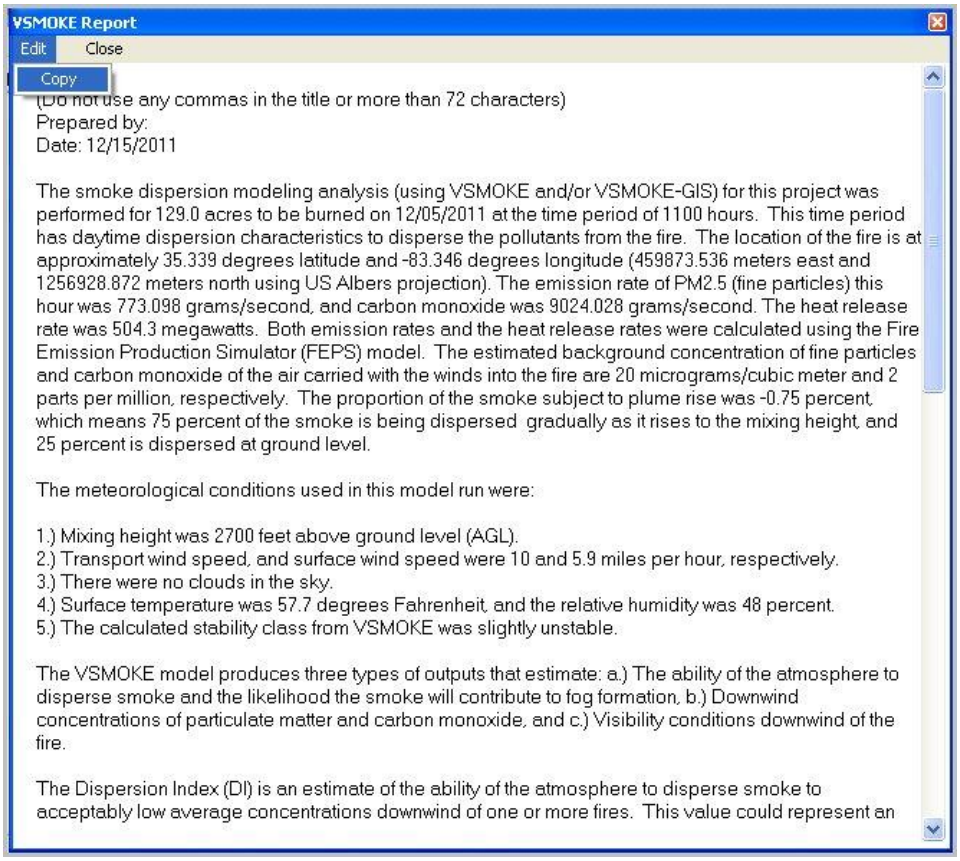
d. To view the stability class that was calculated by VSMOKE, click on the last tab, “Stability, DI, and LVORI”; if it is different than what was entered, rerun VSMOKE with the proper stability class in order to display results in VSMOKE-GIS.



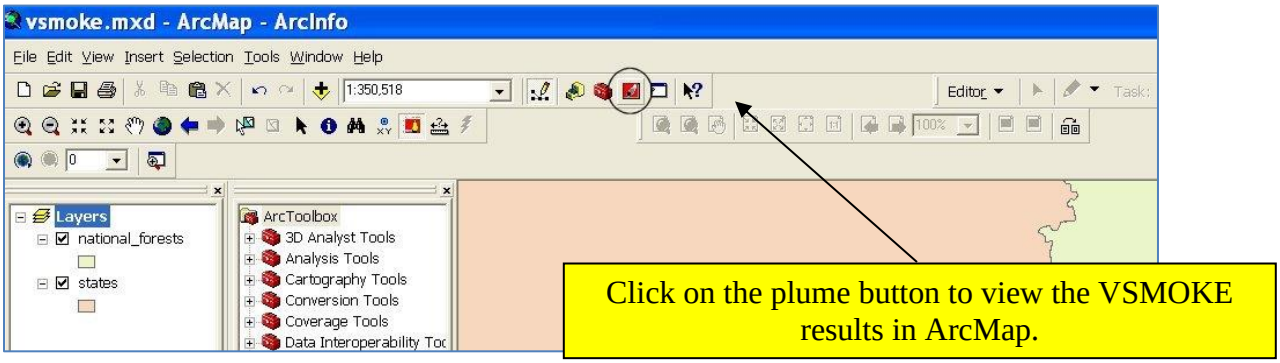
AQI Code	*$PM_{2.5}$ Concentration ($\mu g/m^3$)*	*CO Concentration (ppm)*	*Description*
Green	< 39	< 4.5	Good
Yellow	39 – 88	4.5 – 9.4	Moderate
Orange	89-138	9.5 – 12.4	Unhealthy for Sensitive People
Red	139 – 351	12.5 – 15.4	Unhealthy
Purple	352 – 526	15.5 – 30.4	Very Unhealthy
Maroon	527 +	30.5 +	Hazardous

11. Tabular results display, and the draft report created by VSMOKE appears. Click on “Results”, then “VSMOKE Report…”. The report appears in a separate screen. Click “Edit, Copy” to copy the report and

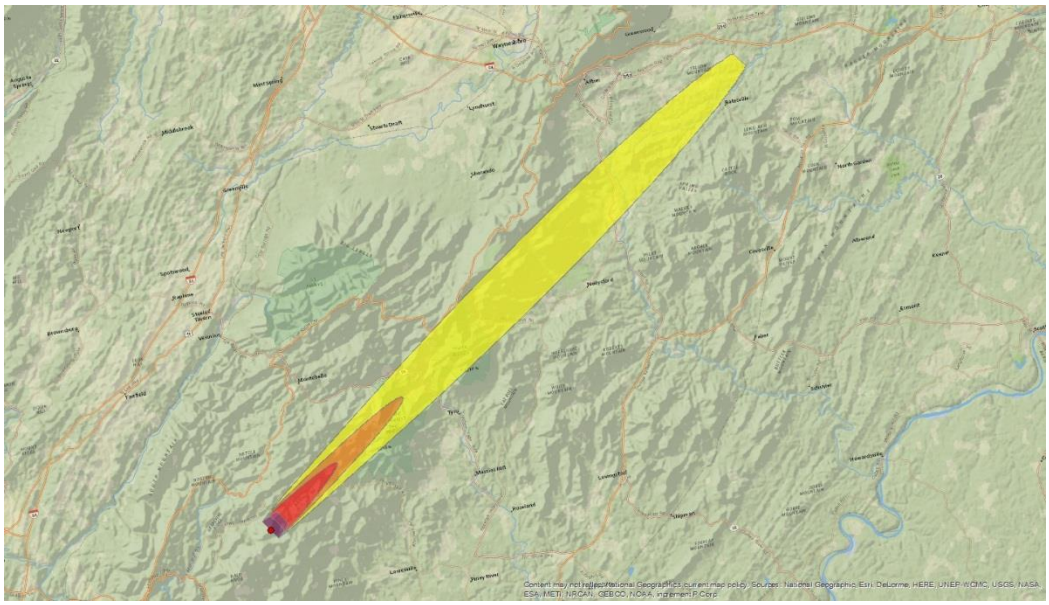
then paste it into a Word document for editing. Once you have created a report, you can go back to your tabular results and click on the "Copy" button to copy any of the results into the report.



12. To view the results in ArcMap, minimize the VSMOKE program so that ArcMap again appears then select the plume button to show the plume.



13. Here is an example of a VSMOKE-GIS plume.



The VSMOKE-GIS plume extends out approximately 30 miles. In this example, observe that AQI Code Orange or worse concentrations are predicted approximately one-quarter to one-third of that distance, or 10 miles from the burn unit.

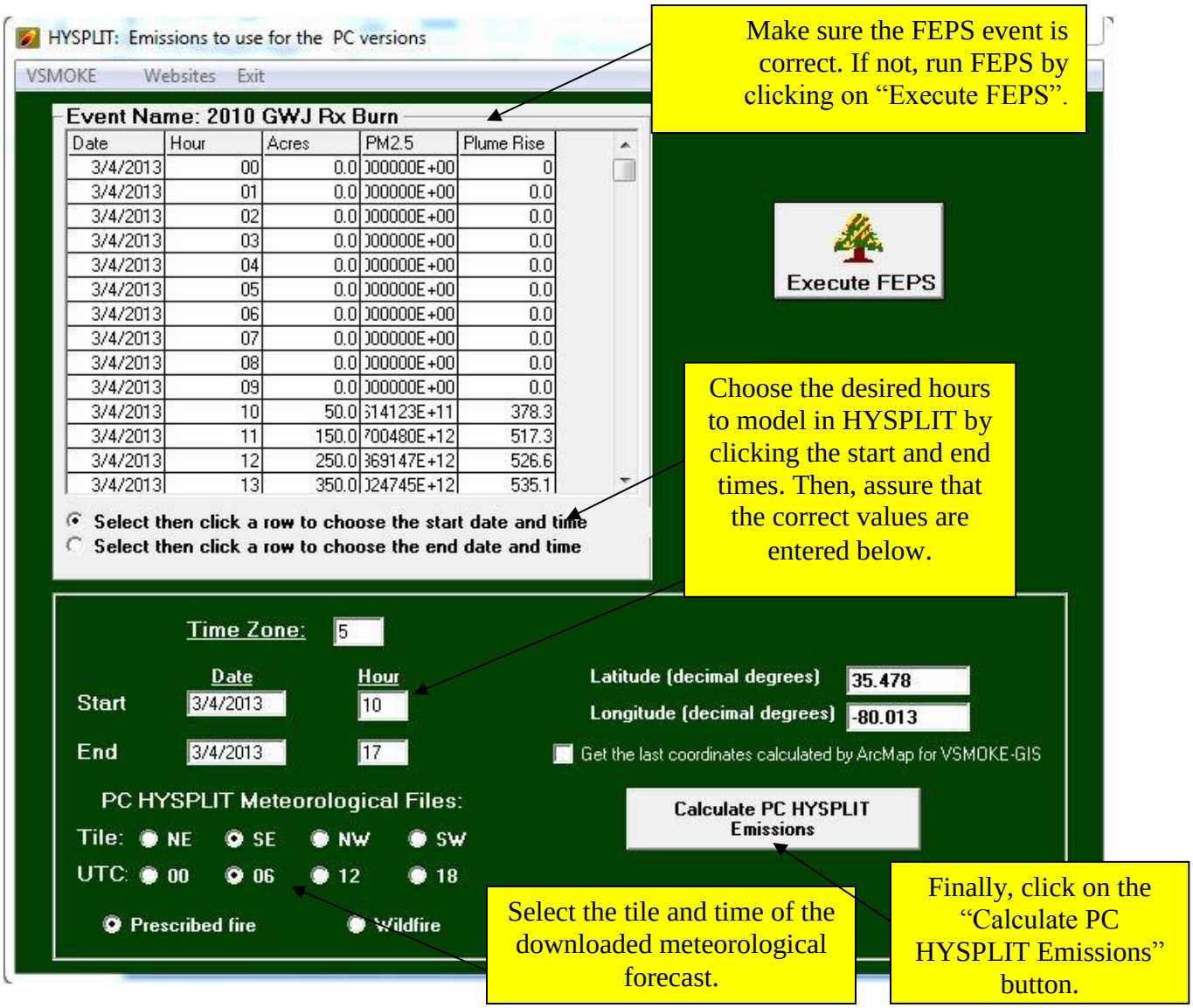
Running HYSPLIT

Fire Management Officers (FMOs) in Region 8 are using HYSPLIT more often to evaluate smoke dispersion the morning of a planned burn. The R8 Air Resources Team works with HYSPLIT developers at NOAA-Air Resources Laboratory (ARL) to improve the accuracy of HYSPLIT's projection of $PM_{2.5}$ concentrations. The instructions included here are designed to provide FMOs with an easy-to-use method of developing parameters to input into HYSPLIT for each prescribed fire project. Note that ARL requires that proper citations be used in all reports referencing HYSPLIT results; these citations are given at the end of this document. [1/]

1. Use the instructions found on pages 1-4 of this document to obtain your emission and heat release rates using FEPS.

2. Create Your HYSPLIT Inputs in the "VSMOKE and HYSPLIT Interface". The interface is configured to not only use the FEPS results to conduct a VSMOKE screening analysis; it will also calculate the user inputs to the HYSPLIT model.

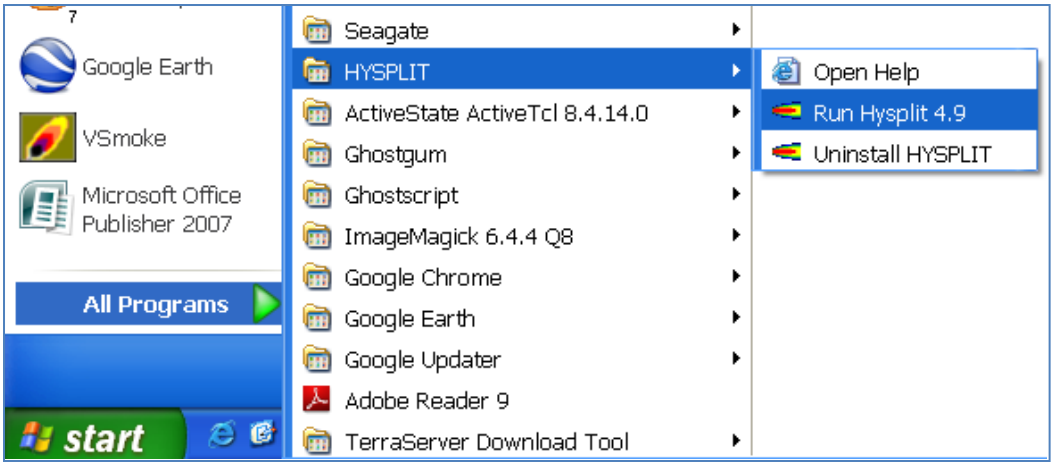
    a. Open up the "VSMOKE and HYSPLIT Interface" form, either through ArcMap or by the smoke.exe icon (found on your desktop or at c:\vsmkgs) and click on "HYSPSLIT". Enter the coordinates of the burn unit. The following screen appears.



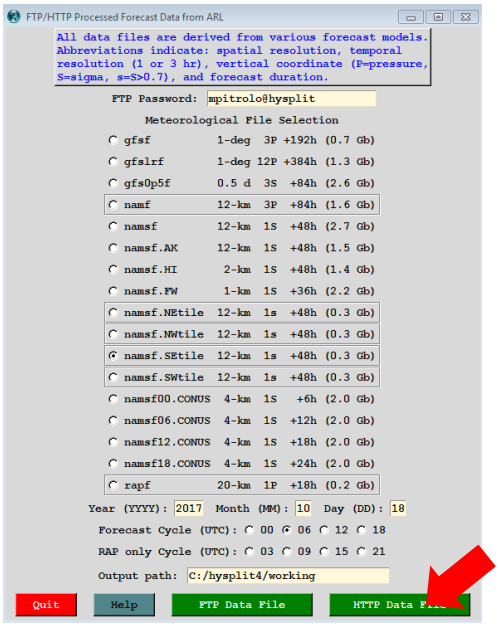
3. After you click on the "Calculate HYSPLIT Emissions and Plume Rise for Ready Version", HYSPLIT input values appear, including the total $PM_{2.5}$ emissions in micrograms, the average height of the plume in meters, and the time and duration of the active fire phase in UTC.

4. At this point, you can close the "VSMOKE and HYSPLIT Interface."

5. Open the HYSPLIT atmospheric dispersion model. You may have an icon on your desktop; otherwise, click on the *Start* menu and find HYSPLIT as shown below.

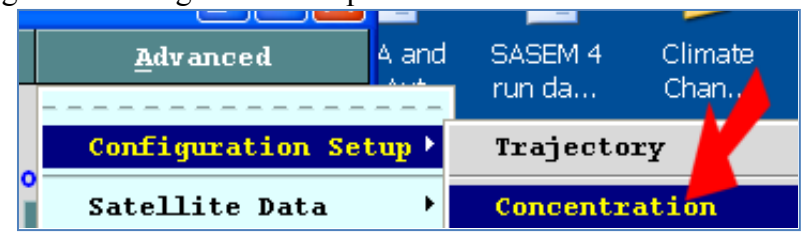


6. Retrieve today's forecast data for your geographic region (most recent is typically 06 UTC). For most of Region 8, the SE forecast will be appropriate, but some areas in VA will need the NE forecast. Click on "HTTP Data File" to start the download.

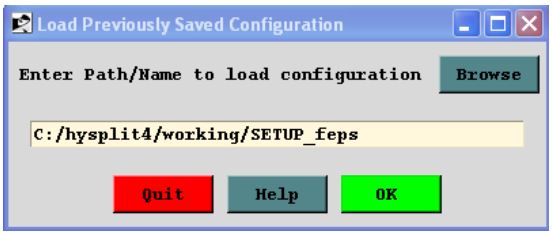


Be aware that it can take approximately 5 minutes for the data file to download if you directly connect to a USDA Forest Service network and up to 15 minutes if you are using a wireless connection.

7. Retrieve the Setup_FEPS file produced by the HYSPLIT user interface by going to the **Advanced** tab and navigating through the "Configuration Setup" to "Concentration".



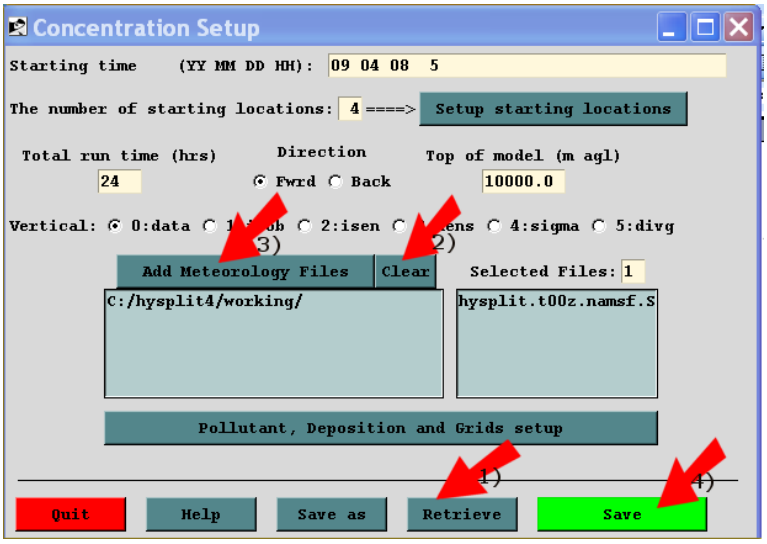
On the next screen press **Retrieve** and then search for the Setup_FEPS file in the "C:\hysplit4\working" directory. Press **OK** when finished and then **Save**.



Be sure to redo this step (retrieving the Setup file) each time the run involves a new FEPS file….browse and select the "Setup_FEPS" file. Do not just assume it is selecting the newest file just because it is showing up in the pathname. The same applies to the next step where you will retrieve a "Control_FEPS" file.

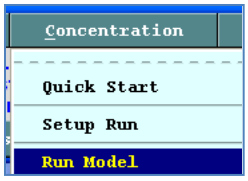
8. Next, setup the HYPLIT run by selecting the "Concentration" dropdown menu followed by "Setup Run."

   a. **Retrieve** the Control_feps file from the "C:\hysplit4\working" directory.
   b. Check that the HH value for the "Starting Time" is the same as the meteorology file. For example, if you download the hysplit.t06z.namsf.SEtile then the HH value should be set to a value of 6.
   c. Save

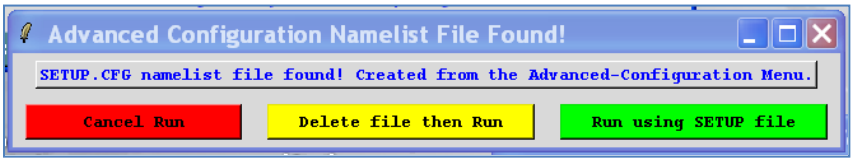


Be sure to redo this step (retrieving the Control file) each time the run involves a new FEPS file….browse and select the "Control_FEPS" file. Do not just assume it is selecting the newest file just because it is showing up in the pathname.

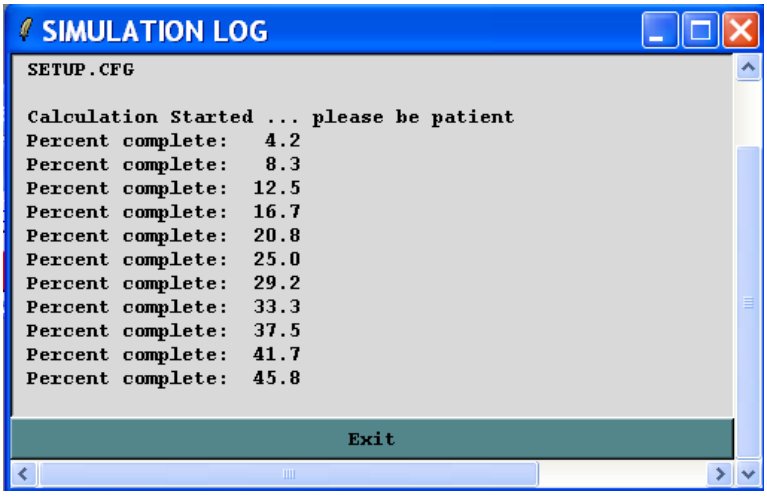
9. Run the HYSPLIT model to predict PM2.5 concentrations. Click on "Concentration, Run Model"



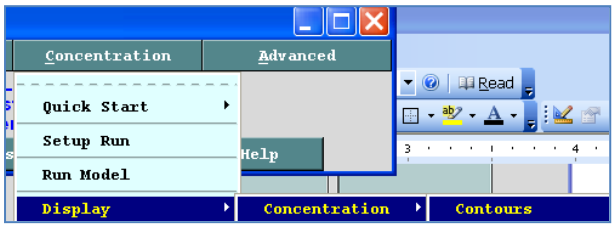
Select "Run Using Setup File" option. The following message may appear; if so, click "Run Using Setup File".



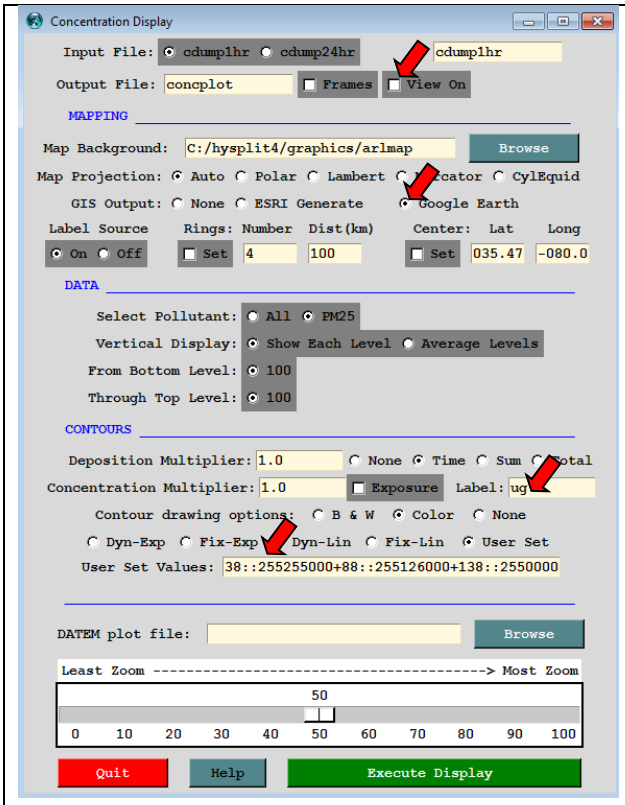
Progress of the modeling appears in the Simulation Log. When the run is complete, press Exit to move to the next step.



10. Display the concentration contours. Click on **Concentration → Display → Concentration → Contours.**



To display hourly results in Google Earth, set up the Concentration Display page as shown below. The UserSet values represent the upper limits of current hourly $PM_{2.5}$ AQI categories. To continue, press the Execute Display button. Do not be alarmed when windows on your screen flicker as the display executes – it just means that the display-writing software is working!



Enter the "UserSet" values in this order:
38::255255000+88::255126000+138::255000000+351::153000076

Copy the values from the "Values to Use in PC HYSPLIT" file to the "User Set" Box. Use the keyboard shortcuts of "ctrl c" to copy and "crtrl v" to paste.

This configuration allows the output to display in the PM2.5 Hourly Air Quality Index (AQI) color codes of yellow, orange, red and purple.

$PM_{2.5}$ Hourly Air Quality Index (AQI)[1]
Moderate
Unhealthy for Sensitive Groups
Unhealthy
Very Unhealthy

If you are interested in creating 24 hour concentrations to compare to the 24 hr $PM_{2.5}$ standard, select "cdump24hr" and enter **35:255126000** in the space after "User Set" (or, in place of the 34, you can enter the $PM_{2.5}$ level where it plus background = 35). All other settings are as shown for displaying hourly results.

[1]EPA has not set an hourly AQI for PM2.5. Values used in this example were taken from: Wildfire Smoke: A Guide for Public Health Officials, Revised July 2008. http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf.

11. To Display smoke plumes (color-coded by $PM_{2.5}$ concentration) in Google Earth:

    a. Start Google Earth.
    b. Open the HYSPLITconc.kmz file found in C:\hysplit4\working" directory. If you want to save the kmz file, then save it using a new file name before you execute another modeling run. Each time you run Hysplit and create a new display the program writes it to the same HYSPLITconc.kmz file name.
    c. The R8 Air Resource Team recommends that you rename the kmz file using the name of the fire, and save it to a separate folder, such as the folder that contains all other information for that particular burn.
    d. Remember that you can "play" the results with the time slider bar or advance through the images beginning at midnight and continuing until the end of the modeling simulation (48 hours or less).

Troubleshooting: If the program hangs up or stops responding, exit and start over.

Following the steps outlined above should provide not only the dispersion pattern but also a conservative projection of concentration levels in micrograms per cubic meter, the same parameter upon which that the $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) is based. Although the air quality standards for $PM_{2.5}$ are on a 24-hour and an annual basis, hourly $PM_{2.5}$ values are used to evaluate health risks using the Air Quality Index (AQI)[2/]. Below are the AQI levels.

PM2.5 Concentration (µg/m³)	***AQI Code***	***Description***
< 39	Green	Good
39 – 88	Yellow	Moderate
89-138	Orange	Unhealthy for Sensitive People
139 – 351	Red	Unhealthy
352 – 526	Purple	Very Unhealthy
> 527	Maroon	Hazardous

Note that Code Orange or higher values for just a few hours could potentially cause an exceedance of the 24-hour NAAQS, which is currently set at 35 µg/m^3. Therefore, R8 Air Resource Team recommends that FMOs pay attention to the downwind concentration levels if they exceed 88 µg/m^3 as they review the dispersion patterns.

Reminders for FEPS, VSMOKE, and HYSPLIT

- FEPS results are used as inputs to both VSMOKE and HYSPLIT Ready.
- VSMOKE is used during the fire planning process, and can be run multiple times using different meteorology to determine the potential downwind impacts under various weather conditions.
- HYSPLIT Ready is used the day before or day of a prescribed fire to assist in making final Go/No-Go decisions. It uses actual forecast meteorology data to calculate predicted downwind concentrations from the prescribed fire. At this time, R8 Air Resource Team does not recommended that HYSPLIT Ready be used.

- HYSPLIT PC provides more refined predictions of downwind concentrations.

If you have any questions about the use of these smoke modeling tools, please contact the Air Specialist assigned to your forest.

CITATIONS

[1/] Draxler, R.R. and Rolph, G.D., 2003. HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Laboratory, Silver Spring, MD.

Rolph, G.D., 2010. Real Time Environmental Applications and Display System (READY) website (http://ready.arl.noaa.gov). NOAA Air Resources Laboratory, Silver Spring, MD.

[2/] The 1-hour $PM_{2.5}$ AQI values are taken from "Wildfire Smoke: A Guide for Public Health Officials", July 2008 revision. http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf