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TECHNICAL MEMORANDUM

# PLAN FOR MODEL SENSITIVITY RUNS FOR FIRE

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**PROJECT NO.:**

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This technical memo has been prepared Air Sciences for the Emissions Task Team (ETT) of the Fire Emissions Joint Forum (FEJF) of the Western Regional Air Partnership (WRAP). This memo is based on an initial "strawman memo" and a series of conference calls to discuss the objectives and strategies for the execution of dispersion modeling runs intended to determine the sensitivity of the model to varying parameters in the fire emissions inventory. The memo is intended to provide direction to the Regional Modeling Center (RMC) as the RMC prepares its workplan and cost estimate for performing the sensitivity model runs and analysis of the results.

The RMC has participated in the development of this memo. Part of the memo development included obtaining information from the RMC about many specific aspects of the CMAQ model and SMOKE emissions processing program. Information provided by the RMC is presented in blue in this memo.

## Summary of Current Knowledge of the Model - RMC.

At the request of the FEJF, the RMC has provided information that summarizes the current knowledge of the CMAQ model. This information has been based, at least in part, is based on the RMC's initial comparison of CMAQ to REMSAD, the CMAQ performance evaluation runs (using 1996 "base" emission inventories), and the preparation of the technical support documentation for CMAQ. Topics included in this summary are:

- CMAQ's treatment of area sources vs. stationary sources? Q – Has the decision to represent fires as stationary sources had an influence on predicted impacts of the model? Fire emissions can be treated in the model either as a point (aka stationary) source or as area source. Fire emissions are likely to be distributed over a larger area than traditional "smoke stack" point source emissions, however, in the CMAQ model, point source emissions are distributed throughout the grid cell in which the point source is located. Thus, with the current point source approach, fire emissions are being distributed over an area identical to the model grid resolution. In the case of the WRAP CMAQ 36 km modeling, fire emissions are averaged over a 36km x 36km grid cell. Depending on the size of the fire, this approach should provide an accurate representation of the area source nature of large fire emissions, while it may be too coarse to resolve the smaller fire emissions. When WRAP begins modeling on nested subdomains, the 12 km or 4 km resolution grids may provide a more accurate treatment of fire emissions for smaller fires. If a fire changes location over a period of days as the fire spreads, it will be important to update the location of the fire in the model domain for each day. Plume in grid (PinG) modeling is an option available in many models to resolve more accurately the location of point source emissions. Given that fire emissions are distributed horizontally more like an area source, it would not be recommended to use a PinG treatment on fire emissions.

- The extent to which the RMC can make post-SMOKE adjustments to fire emissions parameters? An important part of the study design is the efficiency with which the FEJF and RMC can make changes to the input files in order to test the sensitivity of the model. Q – Can the post-SMOKE input files be manipulated to adjust per-event emissions, state-wide emissions, diurnal distribution of emissions, plume characteristics, fumigation rates into the first vertical layer, other parameters? Most fire emissions parameters can be adjusted by reading in the fire SMOKE output files and writing algorithms to manipulate the fire emissions data. The effort required to accomplish depends on the complexity of the desired changes in the fire emissions. The RMC routinely performs simple sensitivity tests by manipulating these emissions files, for example, across the board reduction or increases in emissions take only a few hours effort to complete. More complex experiments, such as adjusting emissions in a particular state or county, or adjusting the layer into which emissions are injected would require more effort. We expect that most sensitivity cases would require no more than a day or a few days of effort. For each specific case we would assess the amount of effort needed to manipulate the SMOKE output file versus running SMOKE again with the new parameters, and we would recommend the most efficient approach.

- RMC's methods to distribute fire emissions to vertical layers. Q1 – Will the methods to distribute emissions to vertical layers be revised/refined for future modeling efforts? Q2 – Does the number and/or height of vertical layers (especially the first vertical layer) effect the modeling results? Q1. Model result can be very sensitive to the layer at which emissions are injected. This is especially true for point source emissions during the nighttime for which a stratified boundary layer and large wind speeds aloft can significantly effect the transport of trace species at different model levels. The fire emissions are likely to be less sensitive to these effects than traditional point source emissions because fire emissions occur primarily during the day, and there tends to be more rapid vertical mixing in the daytime PBL. However, the model predictions would be very sensitive to conditions in with a shallow inversion and boundary layer. The vertical distribution will also be very important for large fires for which emissions may be injected into the upper troposphere or lower stratosphere. We recommend performing model sensitivity experiments to evaluate the effect of different approaches for specifying the plume rise height of fire emissions. Q2: The height of the first model layer is important, especially for simulating species that are emitted during the nighttime. Because fires can have smoldering emissions during the nighttime this will be an important parameter to investigate. This would also be an important concern for winter conditions with shallow daytime PBLs. However, when fire emissions occur for unstable atmospheric conditions there will be rapid vertical mixing and the model should be relatively insensitive to the height of the surface layer.

- Construction of the three-dimensional grid. Q1 – Does the number of vertical layers into which emissions are distributed affect model results? Q2 – Does the distribution of mass of emissions across eligible vertical layers affect model results? Q1: there is still uncertainty regarding how many model layers are needed to accurately simulate air pollutants. The number of layers does affect model predictions, but more model sensitivity studies are needed to determine the optimal number of layers. The answer to this question is also affected by the number of layers needed to simulate accurately the meteorology and the approach used in reconciling the CMAQ layer structure with the MM5 layer structure if these are different. Q2: The distribution of mass of emissions across eligible vertical layers does affect model results. Injecting emissions into higher layers leads to lower surface concentration near the emissions area and to higher surface concentrations downwind of the source area. Correct representation of the vertical location of fire emissions is one of the more important research topics. It especially affects model performance for fires located close to monitoring sites.

- Air chemistry. Q - Are the model results sensitive to the air chemistry algorithms in the model? There are two major air chemistry processes: the gas phase chemistry and the aerosol dynamics and chemistry. For both of these there are a variety of science algorithms available. Gas phase chemistry can be represented by any one of several "condensed" chemical mechanisms including Carbon Bond Method version IV (CB4) , the Regional Atmospheric Chemistry Mechanism (RACM), the SAPRC99 chemistry, explicit mechanisms or other condensed mechanisms. Aerosol dynamics can be represented using sectional or model schemes and aerosol chemistry can be represented by a variety of thermodynamics and secondary organic aerosol formation schemes. The more comprehensive (and more computationally expensive) algorithms are generally likely to be more desirable from a science perspective, although it is not clear if this is always the case. Moreover, computational constraints may necessitate the selection of a more computationally efficient algorithm. The choices of chemistry and aerosol schemes can affect both the "baseline" model performance thereby affecting the concentration of species that interact with the fire plume, and it can affect the chemistry in the plume itself. The uncertainty in the chemistry is likely to be smaller than the uncertainty in the emissions and transport, and chemistry sensitivity experiments should be a lower priority.

- Pollutants. Q – What pollutants are important/unimportant in terms of contributing to regional haze as predicted by the model? All of the pollutants represented in the model can be important for visibility, either directly in their formation of PM or indirectly through their effect on the chemistry. The relative importance depends primarily on the magnitude of the emissions sources which varies depending on geographical emissions. Species that are particularly important include NOx, HNO3, SOx, NH3, VOC, O3, H2O2, soot, fugitive dust and water vapor. CO is less important than other species, though at high concentration it also affects O3 chemistry.

- Grid resolution. Q1 – Does the decision to use a 36 km grid make the model results less-sensitive to certain characteristics of individual emission sources (e.g., location, plume characteristics, source strength)? Q2 – Would the decision to move to a finer grid resolution (e.g., 9 or 16 km) for the sensitivity runs change the modeling results sufficiently to "mask" any effects caused by changes in fire emission inventory parameters. The coarse 36 km grid resolution may limit the ability of the model to accurately simulate the ambient monitoring data. It can cause under predictions by excessive dilution and it can cause over predictions due to rapid horizontal dispersion. This would be especially important for small fires for which the spatial extent is considerably less than the 36km x 36km grid cell. Sensitivity experiments would be performed both on the coarse grid and the fine grid, so it will be possible to determine and isolate the effects of grid resolution on the results of the sensitivity experiments.

# Objectives for the Sensitivity Runs.

Below is a list of some (but not necessarily all) of the objectives that the FEJF's envisions could be accomplished through a well-conceived and executed set of model sensitivity runs.

<u>Prioritize Data Collection Efforts.</u> The Regional Haze Rule (RHR) requires many forms of data collection pertaining to fire emissions. Examples include: emission inventories for modeling (as part of regional haze State Implementation Plans); emission tracking systems; tracking/quantifying "credit" for emission reduction techniques. The Sensitivity Run study should serve to prioritize data collection efforts. Examples of outcomes of the study could be: emissions from fires less than 50 acres in size are not likely to have an effect on model results; initial plume characteristics have a significant effect model results; day-to-day movement of fire activity is important for fires within 100 km of Class I areas).

<u>Prioritize Long-Term Research Needs.</u> The FEJF has acknowledged the uncertainty and imprecision of the information and tools available to estimate emissions from fire. The Sensitivity Run study should serve to prioritize research needs. Examples of outcomes of the study could be: ammonia emissions play the most significant role in predicted visibility degradation and improved ammonia emission factors for the major vegetation types should be developed; the amount of smoke from fire that is fumigated into the first vertical layer has a significant effect on extinction at receptors within 25 km of the fire event and more research on the topic of physical smoke plume characteristics dispersion into the first (lowest) atmospheric layer should be conducted.

<u>Improve Smoke Management Decisions.</u> Ultimately, States and Tribes will need to make real-time decisions with regard to issuing permits and requiring emission reduction and/or smoke management techniques. The study should serve to improve the ability of air quality

agencies to make prudent decisions pertaining to fire emissions. Examples of outcomes of the study could be: fewer, relatively larger fires tend to contribute less to visibility impacts than a larger number of smaller fires; an order-of-magnitude increase in agricultural burning (over predicted 2018 levels) is not likely to contribute significantly to visibility impacts; long range transport of emissions from distant fires are as likely to contribute to predicted visibility impairment as are local fires.

## Metric for the Sensitivity Runs.

Clint Bowman made the following suggestion (specifically pertaining to the addition of smaller fire sources to the fire emission inventory input files) in an email to the RMC list-server group. In many instances, this method of assessing model results could be effective in characterizing the sensitivity of the model to adjustments in specific parameters.

> *"A natural extension would then be to remove the spatial dependency by computing a histogram of the extinction using the values at every grid point for both the base case and the base+small sources case. These histograms may be compared in several ways to evaluate their differences – a qq plot comes to mind. A nice visual representation may be achieved by creating a pair of gray-scale (or color) plots where each grid is shaded by the value of the extinction. A difference plot can easily be composed. Indeed, difference plots for the "worst" and "best" days may be easily created."*

It is quite possible that a "one-size-fits-all" metric will not work in all cases. For example, if we're interested in the sensitivity of the model results to proximity of fire events, we may get a result like "concentration is inversely proportional to distance." If we're interested in plume characteristics, we might get, "75% of impact is due to emissions fumigated into the first vertical layer". In some cases, a review of the data (perhaps per C. Bowman's suggestion) could result in general rules-of-thumb to describe the sensitivity of the model to changes in specific parameters. For example, "fires less than 25 acres do not contribute significantly" or "fires greater than 1,000 acres in size may have a significant impact on Class I areas in a 500 km radius."

The FEJF places high importance on the development of protocols to direct the analysis and interpretation of the results of the model sensitivity study. These protocols should be developed as the study is being defined.

## Suggested Sensitivity Runs.

The following bullet list presents the FEJF's suggestions for sensitivity runs. The first four (4) suggestions should not require additional modeling runs, rather just an analysis of results from modeling runs already performed. The RMC has provided information as to how each sensitivity run would be executed and how the results would be analyzed and interpreted. All results will be analyzed by doing spatial animations of differences between the base case and sensitivity case. We will also perform scatter plots and time-series plots showing the base case and sensitivity case results at individual monitoring sites and Class I Areas. If needed, the RMC will also complete a model performance evaluation for the sensitivity case, i.e., comparing it with the ambient data.

- Quantify / characterize the contribution to extinction due to each type of fire source (agricultural burning, prescribed burning, and wildfire). Suggest use of the 2018 base inventory for this assessment.
- Quantify / characterize the effect of Optimal Smoke Management (OSM) on extinction levels. Suggest comparing results of 2018 OSM to 2018 Base model runs. Attempt to use model results to characterize predicted benefits to regional haze with less aggressive OSM reductions.
- Quantify / Characterize the effect on extinction due to the changes in spatial distribution between the revised 2018 Base Agricultural Burning inventory and the original 2018 Base Agricultural Burning. Evaluate the effect of changes in temporal and spatial distribution with no change in emissions.
- Quantify / characterize the effects of the current (revised) 2018 OSM and the original 2018 OSM (with extra 450 tons PM2.5) for prescribed fire. Evaluate the effect of increased emissions with no changes to the temporal and spatial distribution of the fire events.
- Quantify / characterize the contribution to extinction due to smaller fire events (between 10 acres and 100 acres). Subsets (representing only fires larger than specified size cut points) of the 2002 wildfire emission inventory or any one of the 2018 base inventories (prescribed fire or agricultural burning) would be provided by the FEJF to the RMC. Air Sciences will provide a proposed methodology and cost estimate for preparing emission inventory at various size cut-points.[1] This can be accomplished easily by adding a filter to remove emissions from fire in all grid cells for which the emissions exceed a certain cut point.
- Quantify / characterize the effect on extinction levels of the diurnal fire emission profiles provided to the RMC by the FEJF and used to distribute daily emissions to each hour of the day. Use 1996 wildfire emission inventory. FEJF to provide modified diurnal profiles to RMC. This can be accomplished by modifying the SMOKE fire output file to change the diurnal profile. Changes in emissions in night, early morning or late evening would be expected to have the largest effect.

    1. Twenty-four hour diurnal profiles were provided by the FEJF to the RMC to distribute daily emissions to each hour of the day. One representative profile

[1] Several notes are included in this footnote to document several strategies suggested for the sensitivity model runs pertaining to the contribution of smaller fire events to extinction.

- Use the 1996 wildfire emissions inventory for the entire modeling domain but for only the high-wildfire portion of the year (to be determined but likely June through September)) Prepare emission inventory(ies) of 1996 wildfires larger than some cut point for just a portion of the year. Considered to be more cost effective than developing new inventories for the entire year.
- Consider more / different cut-points in order to evaluate potential de minimis fire sizes for prescribed fire and agricultural burning.
- Consider merits of using 2018 base agricultural burning emission inventory.

was assigned to all wildfire and prescribed fire events. The FEJF has agreed that diurnal distribution of fire emissions varies more across all fire events than originally presumed (due to fire size, cover type, fuel loading, and fire type). The FEJF will provide the RMC with an alternative diurnal profile to test the sensitivity of the CMAQ model results to changes in hourly emissions from fire.

- Quantify / characterize the effect on extinction levels of physical plume characteristics provided for each fire event. Use 1996 wildfire emission inventory. FEJF to provide modified plume profile data to RMC. This can be accomplished by modifying the SMOKE fire output file to change the vertical profile. Alternatively, if a new plume rise algorithm is proposed, it would be better to run SMOKE again with the new algorithm.

  The FEJF has determined that two adjustments need to be made to the calculation methods used to distribute fire emissions into the vertical layers. The FEJF believes that these adjustments will improve/refine the plume distribution methods. These two adjustments are described below. For the purpose of the sensitivity analyses, results of post-adjustment runs could be compared to pre-adjustment model results.

  1. Adjust percentage fumigated into the first layer (LAY1F) based on revised empirical assumptions and basing LAY1F percentage height of first layer (91.5 m initially assumed, 38 m used in CMAQ model). In general, percentage of the plume fumigated into the first layer will be approximately one-half of amount initially assumed. Balance will go into second vertical layer.

  2. Adjust the assigned height for the bottom of the plume (PBOT). Empirical observation suggests that for large fires, the PBOT is up to three times greater than initially estimated (4,800 m vs. 1,600 m). The FEJF will provide a table of new PBOT values for each fire class size.

# Other Issues.

<u>Spatial extent of the sensitivity runs.</u> The FEJF prefers to perform sensitivity runs over the entire modeling domain. Depending on the nature of the runs and the protocols developed to analyze and interpret the data, smaller geographic areas of sources or a limited number of receptors in Class I area may become the focus of sensitivity run.

<u>Temporal extent of the sensitivity runs.</u> For runs made with the 2002 wildfire inventory, limiting the model runs to a three- or four-month period of high wildfire incidence (June – September, for example) should be adequate. For interpreting the results from modeling runs already performed, analyzing the entire year's of data is preferred.

<u>Performance Evaluation Runs for Complete 1996 Fire Emission Inventory.</u> During the conference call on September 15, 2003, the CMAQ performance evaluation runs were discussed. The 1996 performance runs included only the 1996 wildfire emissions inventory. The group on the call discussed the preference (although not a unanimous preference) to

have a performance evaluation run that included the 1996 emissions inventory for prescribed fire and the representative agricultural burning emissions inventory.

Emissions from Other Sources Included in the Fire Sensitivity Runs. During the September 24 – 25, 2003, meeting of the FEJF, the following questions (paraphrased) were asked: Will emissions from other sources be included in the sensitivity model runs for fire emissions? If so, which emission sources will be included and at what level ("Base" or some level of control (e.g., "optimal")). In interpreting the results of the modeling runs for fire, will the model results be sensitive to the presence of emissions from other sources? (Presumption: If emissions from other sources are not included, then small changes in fire emissions may result in significant changes in modeled visibility conditions.) Input / information from the RMC is needed to establish the emission levels of non-fire sources that will be included in the sensitivity runs.

Suggestion to Use Alternative Modeling Framework to Determine the Best Physical Representation of Fire. As a follow up the conference call on September 10, 2003, members of the Atmospheric and Fire Interactions Research and Engineering group of USDA – FS Pacific Wildland Fire Sciences Laboratory asked the FEJF – ETT to consider using an alternative modeling framework (specifically, BlueSky or CSEM) to determine the best physical representation of fire, given modeling constraints. The companion suggestion is to limit the CMAQ modeling to runs intended to determine the sensitivity of the model to changes in the physical environment.