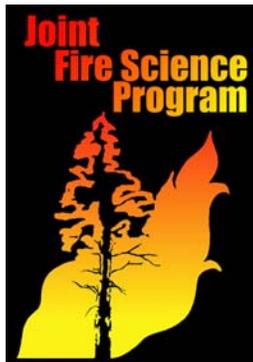


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Fire Effects on Regional Air Quality Including Visibility

Report by

**National Park Service
Air Resources Division
Joint Fire Sciences Project
01-1-5-01**



1 August 2006

**Cooperative Institute for Research in the Atmosphere
Colorado State University
Fort Collins, CO 80523-1375**



Report: Joint Fire Sciences Project 01-1-5-01
Fire Effects on Regional Air Quality including Visibility

JFSP Project Report

Project No.: 01-1-5-01

Project Title: Fire Effects on Regional Air Quality Including Visibility

Project Location: Fort Collins, Colorado

Principal Investigators: William C. Malm, NPS, & Douglas G. Fox, CIRA

Contact Information (Phone, e-mail): 970-491-8292; fox@cira.colostate.edu

Project Goal:

The goal of this research is to add the capacity to consider smoke from both natural (wildfire) and anthropogenic (prescribed and agricultural burning) into regional air quality models being developed for S/TIP regulatory programs.

Brief Project Description:

Forest burning contributes to regional haze in national parks and wilderness. The Clean-Air-Act-mandated Regional Haze Program establishes a complex regulatory framework requiring states to plan and enact programs that will eliminate the human-caused component of regional haze in the future. Fire also contributes to ozone and PM_{2.5}, which also have National Ambient Air Quality Standards, in turn requiring similar state-level plans to ensure compliance. Quantification of the relative contributions of wild fire, wildland-fire-use fire, prescribed fire, and other forms of open burning to regional haze and ambient pollutants is difficult. This research contributes to efforts by the air quality community to quantify impacts of these sources.

Ultimately, the objective of this research is to ensure that the data, modeling, and analysis tools needed for the appropriate representation of fire in the Regional Haze Program and future State (& Tribal) Implementation Plans are available for air quality planners. Fire managers will also need access to these tools so that they will be have appropriate information to help states and tribal governments develop accurate Smoke Management Plans.

Organization of This Report:

The table of deliverables at the end of this report follows the original proposal. In the course of conducting this work, we deviated sometimes significantly from the specific planned approach and use of the tools we had originally proposed because visibility research and modeling have progressed rapidly and the community has accomplished some of the activities we had proposed doing. Nevertheless, we have followed our original purpose and intent by providing results to accomplish our goal that data, modeling, and analysis tools for the appropriate representation of fire in the Regional Haze Program and future State (& Tribal) Implementation Plans are available for air quality planners.

For the purpose of this report, we will start with the last of the proposed deliverables, namely Task 5, disseminate appropriate information to analysts and others supporting the development of regional haze plans. Then we present results for the remaining four deliverables, Tasks 1–4, namely,

- 1) develop a fire smoke emissions inventory (Task 1);
- 2) process fire emissions for use in models (Task 2);
- 3) model simulations to study sensitivity of visibility to fire emissions (Task 3);
- 4) use IMPROVE monitoring with modeling to quantify impacts of fire on regional visibility (Task 4).

We are still working on publications from this work. However, all of the proposed activities have been accomplished by ourselves or collaboratively by the regional haze and air quality research community. Our research has been interactive with other groups since the Regional Haze Rule has provided added funding and compressed time schedules to produce emissions inventories, modeling, and analyses that inform our research.

Summary of Findings/Accomplishments to Date:

Task 5. Disseminate appropriate information to analysts and others supporting the development of regional haze plans.

Our proposal suggested we would conduct a workshop for air quality modelers to facilitate their application of our results and include fire emissions as they developed their analyses for State (and Tribal) Implementation Plans. However, the uptake of fire emissions estimations and their incorporation into modeling was done by Regional Planning Organizations that were established and funded under the regional haze regulations. Led by the Western Regional Air Partnership (WRAP—the western RPO), the RPOs all developed and applied fire emissions in their regional modeling. Since this activity generated many meetings we felt there was no need for a workshop. Rather, we decided that our objectives were better served by ensuring that fire emissions and modeling results were incorporated into the Regional Haze Rule technical sites that we are developing for the RPOs. In specific, the Technical Support System we are co-developing with other team members is delivering the fire emissions and fire modeling results for all state and tribal users developing plans in the western United States. The VIEWS site we have implemented nationally for all the RPOs allows state and other air quality analysts the opportunity to integrate IMPROVE data and display it with trajectories, compositional and trend information, as well as other monitoring results to help expose the potential for fire impacts on visibility.

5.1 The WRAP Technical Support System

(<http://vista.cira.colostate.edu/TSS>)

The Technical Support System (TSS) is being developed by the WRAP to

provide a single portal to technical data and analytical results prepared by WRAP forums and workgroups. CIRA has responsibility, as part of the TSS development team, to design and implement the web site and database integration. The data and results displayed on the TSS are intended to support the air quality planning needs of western states and tribes and will be maintained and updated to support both the implementation of regional haze plans and other western air quality analysis and management needs.

The primary initial and ongoing purpose of the TSS is to be the one-stop shop for access, visualization, analysis, and retrieval of the technical data and regional analytical results prepared by WRAP forums and workgroups in support of regional haze planning in the West. The TSS specifically summarizes results and consolidates information about air quality monitoring, meteorological and receptor modeling data analyses, emissions inventories and models, and gridded air quality/visibility regional modeling simulations. These copious and diverse data are integrated for application to air quality planning purposes by prioritizing and refining key information and results into explanatory tools. Finally, a major goal of the TSS is to make the standard and user-specified maps, charts, tables, and graphs easily available for export, while maintaining the original source data available for verification and subsequent analysis through the TSS.

For example, Figure 1, taken from TSS, shows (a) Crater Lake National Park and surrounding Class I areas in Oregon; (b) the gridded fire emissions inventory (for only one emissions component, NO_x) that is used in the WRAP regional air quality modeling; (c) a comparison of the IMPROVE monitoring results compared with the WRAP modeling results for the Crater Lakes site for 2002; and (d) a projection of the reductions needed in order to return visibility at Crater Lakes to its natural state by 2064, the time period of the regulations. It is clear that, at Crater Lakes, the greatest reduction needed is in organic aerosol (the green parameter). As the State of Oregon develops its Regional Haze Rule implementation plan to achieve this goal, fire sources will come under consideration, especially in order to distinguish prescribed burning impacts from wild and wildland fire use fire impacts.

Results in this report are presented in extinction units of inverse mega meters (Mm⁻¹), which are related to visual range and deciviews (the official Regional Haze Rule metric). To illustrate the visual significance of these numerical values, please see the IMPROVE (Interagency Monitoring of Protected Visual Environments) web site <http://vista.cira.colostate.edu/improve/>, which displays a photograph with a sliding scale of different extinction values and their associated reductions in visibility.

Presentation:

Ames, R. B., McClure, S. E., Fox, D. G., Schichtel, B. A., Moore, T. 2006. Examples of web-based reporting and analysis products from VIEWS and the WRAP TSS. Air & Waste Management Association Annual meeting in New Orleans, LA. June 2006. paper #524.

5.2 Visibility Information Exchange Web System

(<http://vista.cira.colostate.edu/VIEWS>)

The Visibility Information Exchange Web System (VIEWS) is an online exchange of air quality data, research, and ideas designed to understand the effects of air pollution on visibility and to support the Regional Haze Rule. In particular, VIEWS provides users the IMPROVE data and other relevant aerosol and chemical speciation data for the United States. It also provides so-called Regional Haze Rule metrics constructed from the data, which are required under the regulation to determine visibility degradation at Class I areas and just how much of it is attributed to which types of pollution.

For example, Figure 2 is taken from VIEWS outputs showing visibility trends and composition at a western (Crater Lake National Park), an eastern (Cape Cod Seashore), and a southern site. At Crater Lakes the role of organic carbon is likely associated with forest fire because of the timing of the impacts, and it is pronounced. At the northeast site, sulfate dominates impaired visibility, with organics playing a relatively minor role. The role of organics is a bit more important in the southeastern site, but again sulfate pollution dominates the impaired visibility.

Presentations/Papers:

Ames, R. B., McClure, S. E., Fox, D.G., Schichtel, B. A., Moore, T. 2006. Examples of web-based reporting and analysis products from VIEWS and the WRAP TSS. Air & Waste Management Association Annual meeting in New Orleans, LA. June 2006. paper #524.

Ames, R. B., McClure, S. E., Schichtel, B. A., Fox, D. G. 2005. The Visibility Information Exchange Web System (VIEWS), Air Toxics, and IMPROVE web sites: Database driven internet sites for access, inter-comparison, and on-line analysis of air quality data. Presented at the Air & Waste Management Association Specialty Conference in Oak Brook, IL, Apr. 2005.

Ames, R. B., McClure, S. E., Schichtel, B. A., Fox, D. G. 2004. The Visibility Information Exchange Web System (VIEWS): An update on available datasets and web-based tools for data analysis and visualization. Regional Haze Speciality Conference AWMA, Asheville. Oct. 2004.

Schichtel, B. A., Ames, R. B., McClure, S. E., Fox, D. G. 2003 Update on VIEWS. Invited presentation at the National Meeting of the Regional Planning Organizations, St. Louis, Nov. 2003.

Schichtel, B. A., Ames, R. B., McClure, S. E., Fox, D. G. 2002. Update on VIEWS. Invited presentation at the National Meeting of the Regional Planning Organizations, Dallas, TX. Dec. 2002.

Ames, R. B., Schichtel, B. A., Fox, D. G., Engle, M., Winchester, J., Malm, W.C. 2002. The IMPROVE and VIEWS web sites: Supporting better understanding and control of regional haze, 95th Annual AWMA Conference, Baltimore, MD, June 2002

Fox, D. G., Schichtel, B. A., Ames, R. B., McClure, S. E., Malm, W. C. 2002. VIEWS – A new national air resource. The IMPROVE Newsletter, Vol. 11/3. pp 4-6.

Task 1. Develop a fire smoke emissions inventory.

In order to quantify the contributions of fire to regional air quality, the first step is to develop an inventory of fire emissions. For retrospective analyses, fire activity over a specified period of time (for example, for a specific year) must be documented. For real-time analyses or forecasts, current fire activity data are required. In either case, a fire emissions inventory requires the fire activity (location, start and end time, and area burned), the nature of the fuels involved, and the type of fire (i.e., wildfire, prescribed burning). Emissions are calculated from the following equation:

$$\text{Emissions } _i = A \times B \times CE \times e_i$$

where Emissions $_i$ is the emission of chemical species i (in mass units), A is the area burned, B is the fuel loading (biomass per area), CE is the combustion efficiency, or fraction of biomass fuel burned, and e_i is an emission factor for species i (mass of species per mass of biomass burned)

1.1 Modeling Fire Emissions

When we began this Joint Fire Sciences research project, there was no tool available to make such a calculation. We developed, under additional support from the U.S. EPA, the *Community Smoke Emissions Model* (CSEM), which has the capability of converting fire activity anywhere in the contiguous United States into emissions. CSEM utilizes NFDR fuel model coverage (Bergen et al., 1998; Hardy et al., 1998), coupled with meteorological information from a mesoscale meteorological model such as MM5 (Grell et al., 1994) to drive a consumption model (CONSUME, Ottmar et al., 1993) and an emission model (EPM, Sandberg & Peterson, 1984) to generate smoke emissions.

Since its initial development, CSEM has been further refined and improved by the BlueSky development team and others (O'Neal et al., 2003). CSEM has not been developed any further as a standalone capability because the functionality it provided has been accommodated within the BlueSky framework.

Presentations/Papers:

Sestak, M., Fox, D. G. 2003. The Community Smoke Emissions Model. Draft Users Guide. 23pp. available from <ftp://ftp.cira.colostate.edu/Fox/>

Sestak, M., O'Neill, S., Ferguson, S., Chang, J., Fox, D. G. 2002. Integration of wildfire emissions into MODELS-3/CMAQ with the prototypes: Community Smoke Emissions Modeling system (CSEM) and BlueSky. Extended abstract presented at the First CMAS (Community Modeling and Analysis System) Models3 Workshop, Research Triangle Park, NC, October 21-22, 2002. (http://www.cmascenter.org/conference/2002/session5/fox_abstract.pdf)

Fox, D. G. 2002. The Community Smoke Estimation System. Presented at the WRAP Fire Emissions Joint Forum meeting, Jackson, WY, Dec. 9-12, 2002. http://www.wrapair.org/forums/fejf/documents/emissions/JFEFWRAP_CSEM.ppt

Barna, M., Fox, D. G. 2003, [Combining Wildfire Emissions From The Community Smoke Emissions Model \(CSEM\) With A Regional-Scale Air Quality Model](#). Proceedings, Fifth Symposium on Fire and Forest Meteorology, American Meteorological Society, Orlando, Florida. Nov. 16-20, 2003.

Barna, M. G., Fox D. G. 2003. CSEM: The Community Smoke Emissions Model. Presented at the NW-AIRQUEST Annual Meeting, Portland, OR.

References:

Burgan, R., Klaver, R. W., Klaver, J. M. 1998. Fuel models and fire potential from satellite and surface observations. *International Journal of Wildland Fire*.

Grell, G. A., Dudhia, J., Stauffer, D. R. 1994. A description of the fifth-generation Penn State/NCAR mesoscale model (MM5). NCAR Technical Note, NCAR/TN-398 + STR. Mesoscale and Microscale Meteorology Division, National Center for Atmospheric Research, Boulder, CO.

Hardy, C., Menakis, J. P., Long, D. G., Garner, J. L. 1998. FMI/WESTAR emissions inventory and spatial data for the Western United States. Missoula, Montana. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.

O'Neill, S.M., Ferguson, S. A., Peterson, J., Wilson, R. 2003. The BlueSky smoke modeling framework, Proceedings, Fifth Symposium on Fire and Forest Meteorology, American Meteorological Society, Orlando, Florida.

Ottmar, R.D., Burns, M. F., Hall, J. N., Hanson, A. D. 1993. CONSUME Users Guide. USDA Forest Service General Technical Report PNW-GTR-304. Pacific Northwest Research Station, Portland, OR.

Sandberg, D. V., Peterson, J. 1984. A source-strength model for prescribed fires in coniferous logging slash. In: Proceedings, 21st Annual Meeting of the Air Pollution Control Association, Pacific Northwest International Section. Pittsburgh, PA: Air Pollution Control Association.

1.2 Fire Smoke Emissions Inventories

It was never our intent under Task 1 to develop a wholly new fire smoke emissions inventory. Under support from the Regional Haze Program's Regional Planning Organizations (RPO), different groups have applied the CSEM and other tools to develop new fire smoke emissions inventories. Air Sciences, Inc., has recently developed a national emissions inventory for wildfire for 2002. It represents the best (from a quality control standpoint) and the most comprehensive wildfire emissions inventory yet developed. It is available for download from the Western Regional Air Partnership (WRAP): <http://www.wrapair.org/forums/feif/tasks/FEJFtask7InterRPO.html>

In addition to the national wildfire emissions inventory, WRAP has contracted with Air Sciences and others to generate detailed emissions inventories for wildland fire use, for prescribed fire, and for agricultural burning for 2002, as well as making projections for a "baseline" or average year and an anticipated future "average" year (2018). These are also available at

<http://www.wrapair.org/forums/fejf/tasks/FEJFtask7Phase11.html> for the 2002 inventory; and <http://www.wrapair.org/forums/fejf/tasks/FEJFtask7Phase3-4.html> for the baseline and 2018 projection data.

There have also been a number of efforts to develop emissions inventories using satellite observations. These are summarized in a recent paper by Wiedinmyer et al. (2006). These alternative estimates of emissions are very useful in that they help to bound uncertainties and provide confidence in fire emissions estimates.

References:

Wiedinmyer, C., Quayle, B., Geron, C., Belote, A., McKenzie, D., Zhang, X., O'Neill, S., Wynne, K. K. 2006. Estimating emissions from fires in North America for air quality modeling. *Atmospheric Environment* 40, 3419–3432.

[Inter-RPO National 2002 Wildfire Emissions Inventory, Final Work Plan](#)

Task 2. Process fire emissions for use in models.

2.1 Developing a Fire Emissions Processor

The *BlueSky* framework (AirFIRE team, 2006) incorporates a CSEM-like fire smoke emissions model as well as other approaches (e.g. FCCS, Sandberg et al., 2001) to simulate fire emissions. Recently, it has been reprogrammed by programmers at the University of North Carolina's Carolina Environmental Program to generate inputs for the SMOKE emissions processor (Pouliot et al., 2005; Seppanen 2005). It is now available for download and anyone to use via the UNC web site at: <http://www.cep.unc.edu/empd/products/smoke/bluesky/>. This computer code provides a capability to simulate future fire emissions given fire activity data and mesoscale meteorological data.

References:

AirFIRE team. 2006. *BlueSky and BlueSkyRAINS User's Guide and Operating Manual*, version 1.1, 64pp. http://marlin.airfire.org/BSUG_v1_1_020206.pdf

Pouliot, G., Pierce, T., Benjey, W., O'Neill, S. M., Ferguson, S. A. 2005. Wildfire emission modeling: Integrating BlueSky and SMOKE. Presentation at the 14th International Emission Inventory Conference, Transforming Emission Inventories Meeting Future Challenges Today, Las Vegas, NV, April 11-14, 2005.

Sandberg, D. V., Ottmar, R. D., Cushon, G.H. 2001. Characterizing fuels in the 21st Century. *International Journal of Wildland Fire*, 10, 381-387.

Seppanen, C. 2005. BlueSky/SMOKE integration. <http://www.cep.unc.edu/empd/products/smoke/bluesky/>

2.2 Processing Fire Emissions to Produce Model-Ready Inventories

The detailed fire emissions inventories that are mentioned above all have been processed using the SMOKE model to generate model ready emissions

inventories. Details are available at the WRAP fire emissions web site: <http://www.wrapair.org/forums/fejf/>. Results are detailed in two reports developed by Air Sciences, Inc. (Air Sciences, 2004; Air Sciences, 2005).

References:

Air Sciences. 2004. FINAL REPORT – 1996 Fire Emission Inventory for the WRAP Region – Methodology and Emission Estimates. Project 178-1, March 2004.
http://www.wrapair.org/forums/fejf/documents/emissions/FEJF1996EIReport_040325_final.pdf

Air Sciences. 2005. Integrated Assessment Update and 2018 Emissions Inventory for Prescribed Fire, Wildfire, and Agricultural Burning Report. Project 178-2. November 2005. Prepared for the Western Governor's Association/WRAP/Fire Emissions Forum.
<http://www.wrapair.org/forums/fejf/documents/emissions/WGA2018report20051123.pdf>

Task 3. Model simulations to study sensitivity of visibility to fire emissions.

We have simulated western regional visibility with and without fire emissions. At CIRA we have used two different models (REMSAD and CAMx) for this work. We have also coordinated with the WRAP Regional Modeling Center (RMC), which has done extensive modeling with a third model, CMAQ.

3.1 REMSAD

We initially worked with the regional air quality model REMSAD (Regional Modeling System for Aerosols and Deposition), which was designed to simulate gaseous and particulate pollutants over large domains (e.g., continental scale) and for extended periods (e.g., months to years in duration). REMSAD treats the physical and chemical processes that affect atmospheric pollutants and their precursors, including advection, diffusion, wet and dry deposition, and chemical transformation. A highly simplified treatment of organic species in the chemistry mechanism allows REMSAD to be computationally efficient.

Our application of REMSAD was in support of a field program known as BRAVO whose goal was to understand visibility degradation at Big Bend National Park in Texas. An outer domain of 36 km and an inner domain of 12 km centered on Texas were utilized. REMSAD's chemistry mechanism treats gas-phase, aqueous phase, and aerosol equilibrium processes (SAI, 2001). Wind fields, temperature fields, and other meteorological data for BRAVO were simulated by MM5 (Grell et al., 1994).

We used BRAVO as an opportunity to evaluate the ability of regional air quality modeling to simulate aerosol measurements and ascribe them to a regional emissions inventory. Progress is documented with series of papers.

However, we decided that REMSAD did not adequately treat all the elements of aerosol chemistry needed to simulate fire effects on visibility. Meanwhile, other

groups were developing regional fire simulations using the CMAQ model and the CAMx models, both of which perform better than REMSAD. Thus, we decided not to simulate fire emissions with REMSAD but to focus on CAMx. Below we briefly review fire simulations done by WRAP using the CMAQ model and ongoing work that CIRA is doing using CAMx.

Presentations/Papers:

Barna, M. G., Fox, D., Malm, W.C. 2002. Initial REMSAD simulation of sulfate aerosol for the BRAVO study. Presented at the 95th Annual Meeting of the Air & Waste Management Association, Baltimore, MD.

Barna, M. G., Gebhart, K. A., Schichtel, B. A., Malm, W. C. 2006. Modeling regional sulfate during the BRAVO study: Part 1. Base emissions simulation and performance evaluation. *Atmospheric Environment*, 40, 2436-2448.

Barna, M. G., Schichtel, B. A., Gebhart, K. A., Malm, W. C. 2006. Modeling regional sulfate during the BRAVO study: Part 2. Emission sensitivity simulations and source apportionment. *Atmospheric Environment*, 40, 2423-2435.

Barna, M. G., Schichtel, B. A., Gebhart, K. A., Rodriguez, M. A. 2005. Evaluating the linearity of sulfate formation in response to change in sulfur dioxide emissions within a regional air quality model. Presented at the NOAA/EPA Golden Jubilee Symposium on Air Quality Modeling and Its Applications, Durham NC.

Schichtel, B. A., Gebhart, K. A., Barna, M. G., Malm, W. C., Day, D. E., Kreidenweis, S. 2004. Big Bend Regional Aerosol and Visibility Observational (BRAVO) study results: Air quality data and source attribution analyses results from the National Park Service/Cooperative Institute for Research in the Atmosphere. CIRA, Colorado State University, Fort Collins, CO, ISSN 0737-5352-65.

References:

SAI. 2001. User's Guide to the Regional Modeling System for Aerosols and Deposition (REMSAD), version 6, Systems Applications International, Inc., San Francisco, CA.

Grell, G.A., Dudhia, J., Stauffer, D.R. 1994. A description of the fifth generation Penn State/NCAR Mesoscale Model (MM5). NCAR Technical Note (TN-398-STR), NCAR, Boulder, CO.

3.2 CMAQ

The Community Air Quality model known as CMAQ has been applied by WRAP and other RPOs (Southern and Central States RPOs) to simulate regional air quality including the effects of fire. Although we have not directly conducted these simulations, this work is relevant because much of the analysis needed for this project has been accomplished especially by the WRAP Regional Modeling Center. We see no point in doing again what has already been done.

The WRAP RMC conducted three model sensitivity runs considering fire impacts on the WRAP region (RMC, 2005). These runs used 2002 fire emissions that included prescribed, agricultural, and wild fire emissions in the region. The WRAP considers that wild fires, wildland fire use fires, and prescribed burning

used for resource management are natural, while agricultural burning and some prescribed burning are considered anthropogenic (for more information regarding the definitions of specific fire activities see

http://wrapair.org/forums/fejf/meetings/041208m/FEJF_N-A_EI_Approach_20040903.pdf and

<http://wrapair.org/forums/fejf/documents/nbtt/FirePolicy.pdf> and for results see <http://wrapair.org/forums/aoh/ars1/report.html>).

Figure 3a presents the 2002 modeled annual average contribution to light extinction by the full set of emissions, including all fire emissions. However, the extinction values plotted for each grid cell represent modeled extinction due to fire activity only, because the extinction due to other species has been subtracted out. Visibility impacts due to all fires are shown to have been generally less than 10 Mm^{-1} across WRAP, although some locations were impacted by as much as 25, 50, or $>100 \text{ Mm}^{-1}$. Geographically, the largest impacts due to fire occur in southern Oregon, much of California, and isolated locations in Utah, Arizona, and Colorado. Figure 3b presents the modeled annual average contribution to light extinction by all natural fires for 2002. This map is not significantly different from Figure 3a, indicating that natural fires contribute a large percentage of the impact of both fire categories combined. Figure 3c presents the modeled annual average contribution to light extinction by all anthropogenic fires for 2002. This map indicates that the most significant contributions by anthropogenic fires during 2002 occurred in the region around the panhandle of Idaho and California's Central Valley. The maximum modeled impact of anthropogenic fires is less than 5 Mm^{-1} (<http://wrapair.org/forums/aoh/ars1/report.html> and <http://wrapair.org/forums/aoh/ars1/report.html>).

Presentations/Papers:

Vukovich, J., Shankar, M., Aijun Xiu, U., Adel, H., Fox, D. G., McNulty, S. 2005. Preliminary assessment of the impact of climate change and variability on biomass and forest fires, the impact of forest fires on ozone and PM air quality, and the regional climate response to these changes in the southern United States. Presented at the EASTFire Conference, George Mason University, Fairfax, VA, May 11-13, 2005.

References:

Air Resources Specialists, Inc. 2005. Attribution of Haze Report (Phase I) Geographic Attribution for the Implementation of the Regional Haze Rule. WRAP report March 2005, 151pp:

<http://wrapair.org/forums/aoh/ars1/report.html>

RMC. 2005. Fire Sensitivity Simulations, <http://pah.cert.ucr.edu/aqm/308/cmaq.shtml#fire1>.

3.3 CAMx

CAMx is an Eulerian photochemical dispersion model that allows for integrated "one-atmosphere" assessments of gaseous and particulate air pollution over scales ranging from sub-urban to continental. It is designed to link all of the technical features required by "state-of-the-science" air quality models into a

single system that is computationally efficient, easy to use, and publicly available. <http://www.camx.com/>

Recently, the National Park Service visibility research group at CIRA has been applying CAMx to the United States using a 36-km grid resolution. Our CAMx application is driven by meteorological inputs from MM5 and emission inputs from the SMOKE emissions processor utilizing the 2002 RPO emissions inventory.

Although we are just getting started with this research, preliminary results are encouraging in that they seem to be reasonably well compared with IMPROVE observations. Figure 4 presents organic carbon aerosol simulation results compared with the IMPROVE monitoring results. More CIRA CAMx simulation results are presented under Task 4.2 below.

Presentations/Papers:

Rodriguez, M. A., Barna, M. G., Schichtel, B. 2006. Using CAMx to model the potential impacts of a proposed power plant in the Four Corners region. Presented at the 99th AWMA Annual Conference and Exhibition, New Orleans, LA, June20-23.

Task 4. Use IMPROVE monitoring with modeling to quantify impacts of fire on regional visibility.

The web sites referred to above provide a wide array of tools to allow quantification of fire's contributions to visibility. However, none of these is, by itself, completely satisfying. Figure 5 illustrates the results from the IMPROVE monitoring for 2002. It plots the relative contribution that each of the IMPROVE aerosol species makes to visibility on the 20% worst visibility days in 2002. Note that the locations where the pie charts are predominantly green are locations where one might expect fire to be a significant contributor to regional visibility degradation.

4.1 Statistically Apportioning Visibility Impacts to Fire

Among the inferential ways to consider fire's impact are statistical analyses of the IMPROVE and other aerosol data. If there were a unique tracer of fire's contribution, then simply measuring the amount of that unique tracer would be possible. However, there is no such unique tracer, although our research group, under the direction of Dr. Malm of the National Park Service, along with many others, continues to search for one. This is also the subject of ongoing JFSP research activities.

One approach that has been followed is to look at the ratio of organic carbon to black (or elemental) carbon in the measurements (Malm et al., 2004). Ames et al. present results of this and an alternative approach aimed at bracketing the influence of fire. The ratio of organic carbon to elemental carbon (OC/EC) can be

associated with significantly different forms of combustion. Combustion of fossil fuels (gasoline, diesel, etc.) is generally associated with an internal combustion engine characterized by a relatively efficient combustion. This combustion is enriched in elemental carbon such that the OC/EC ratio is on the order of 3. Urban fine particulate measurements often display ratios on this order. Open combustion is often less efficient, emitting a higher amount of OC relative to EC. Fine particulate measurements that can otherwise be related to wildland fire display OC/EC ratios on the order of 10 or more. Ames used this ratio to attempt to distinguish fire from urban sources in the IMPROVE measurements. However, there are sources of organic carbon not associated with elemental carbon at all, namely atmospheric chemical reactions of natural hydrocarbon emissions from vegetation, termed biogenic emissions, that generate so-called secondary organic aerosols (SOA). Wherever there is significant vegetative cover, there will be SOA formed. *Since this source of OC is not considered in the analysis, the OC/EC ratio will be biased high by the presence of this added OC; thus, this ratio is likely to overestimate the influence of fire on visibility.* To bracket this, Ames considered a second apportionment method, namely using a fire occurrence database (Brown et al., 2002) and then looking at back trajectories (Heffter, 1980) from each IMPROVE monitor for a period of time leading up to and through the measurement and apportioning the fire influence, based on the amount of time the air spent over fire locations. This approach has many potential errors, so many in fact, that the JFSP recently funded Bret Schichtel of our group to investigate this and related methodologies further. *However, due to the fact that the fire activity database used does not include all fire and the inadequacies of trajectories, this method is likely to underestimate the influence of fire on visibility.*

Table 1 and Table 2 summarize the results from these two receptor-based apportionment techniques, apportioning OC observed at IMPROVE monitoring locations to wildland fires and other carbon source types. OC concentrations at IMPROVE monitoring sites (2000-2002 OC/EC analysis) are approximately 1.0 $\mu\text{g}/\text{m}^3$ in the western United States and 1.7 $\mu\text{g}/\text{m}^3$ in the East. Over the same time period and monitoring sites, OC apportioned to fire and SOA using the OC/EC ratio approaches about 0.6 $\mu\text{g}/\text{m}^3$ in the West and 0.9 $\mu\text{g}/\text{m}^3$ in the East, or approximately 60% of observed OC in the West and 55% in the East. OC apportionments to U.S. wildland fires from the fire activity and trajectory method averaged about 0.3 $\mu\text{g}/\text{m}^3$ in the West and 0.4 $\mu\text{g}/\text{m}^3$ in the East, or approximately 30% of observed OC in the West and 20% in the East.

For reference, the regional haze regulations assume that natural visibility in the United States is characterized by an OC concentration of approximately 1.1 $\mu\text{g}/\text{m}^3$ in the eastern United States and 0.4 $\mu\text{g}/\text{m}^3$ in the West (EPA, 2003).

Recently, using a global air quality model, Park et al. (2003) have estimated OC values of approximately 0.7 to 1.1 $\mu\text{g}/\text{m}^3$ may be representative of natural conditions in the West and OC concentrations of approximately 0.9 $\mu\text{g}/\text{m}^3$ to be

characteristic of natural conditions in the eastern United States.

Presentations/Papers:

Ames, R. B., Malm, W. C., Schichtel, B. A., Fox, D.G. 2001. Apportionment of particle carbon to wildland fires, regional haze and global radiation balance – aerosol measurements and models: closure, reconciliation, and evaluation. Presented at the AWMA/AGU Regional Haze and Global Radiation Balance Conference, Bend, Oregon.

Ames, R. B., Hand, J. L., Schichtel, B. A., Malm, W. C., Fox, D. G. 2004. Preliminary apportionments of carbonaceous aerosols to wild fire smoke using long-term records from the IMPROVE network. Presented to the Electric Utilities Environmental Conference, Tucson.

Ames, R. B., Fox, D. G., Malm, W. C., Schichtel, B. A. 2004 Preliminary apportionments of carbonaceous aerosols to wild fire smoke using observations from the IMPROVE network Regional Haze paper # 76; AWMA 2004, Asheville, NC.

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Brown T. J., Hall B. L., Mohrle C. R. Reinbold H. J. 2002. Coarse Assessment of Federal Wildland Fire Occurrence Data, CEFA Report #02-04.

EPA. 2003. Guidance for Estimating Natural Visibility Conditions under the Regional Haze Rule, Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-454/B-03-005.

Heffter J. L. 1980. Air Resources Laboratories atmospheric transport dispersion model (ARL-ATAD). Technical Memo ERL ARL-81, NOAA, Rockville.

Malm, W. C., Schichtel, B. A., Pitchford, M. L., Ashbaugh, L. L., Eldred, R. A. 2004. Spatial and monthly trends in speciated fine particle concentration in the United States. *Journal of Geophysical Research*, 109, doi:10.1029/2003 JD003739.

Park, R.J., Jacob, D. J., Chin, M., Martin, R. V. 2003. Sources of carbonaceous aerosols over the United States and implications for natural visibility. *J. Geophys. Res.*, 108 (D12).

4.2 Compare Model Results to IMPROVE Monitoring

WRAP CMAQ results are compared directly with IMPROVE monitoring on the TSS web site as illustrated in Figure 1. Figure 6 is developed from the TSS, the WRAP preliminary 2002 fire simulations, and CIRA preliminary CAMx results. Here we present three of the more fire-influenced sites in the western United States. The IMPROVE monitoring result is presented in the top panel, the second panel presents WRAP CMAQ modeling results from the full emissions inventory, the third panel presents CAMx modeling results (along with IMPROVE results for the organic carbon component of the aerosol, the green bars in the IMPROVE and WRAP modeling results), and the fourth panel represents the fire-only contribution to the extinction as calculated by the WRAP RMC CMAQ simulations.

Results are presented for the Flathead Lake IMPROVE site in Montana (Figure 6a); Hells Canyon IMPROVE site in Oregon (Figure 6b); and Sequoia National Park IMPROVE site in California (Figure 6c).

It is clear from the results that the modeling exhibits some qualitative skill in simulating the impacts of fire on visibility. However, it is also clear that this represents only the beginning of what will be a continuing investigation into the influences of fire on regional haze.

At present, WRAP is engaged in an attribution of haze analysis that is being conducted utilizing the capabilities of the TSS (<http://wrapair.org/forums/aoh/index.html>). This project is scheduled for completion by the end of 2006. Figure 7 presents one preliminary result from this activity, for illustration purposes only since the data making it up are not yet cleared by the various WRAP quality assurance programs and appropriate review. The figure presents preliminary results illustrating the influences of different emissions types on visibility at one of the IMPROVE sites in Idaho. Specifically to organic carbon aerosol, this analysis involves combining source regions and the trajectories of air flows during the worst visibility conditions experienced in the 2000–2004 five-year baseline period. It shows that prescribed fire may have a potential impact. This is a preliminary result and should not be quoted or copied for any purpose. The actual site location has been removed so that it is not actually used.

Proposed Deliverable	Status and Accomplishment
<p>Task 1: Develop a fire smoke emissions inventory.</p> <ul style="list-style-type: none"> Selected periods and regions in support of regional air quality modeling and update the existing NEI emissions inventory to include smoke from fire. 	<ul style="list-style-type: none"> The CSEM model was developed and documented (Sestak & Fox, 2002; Sestak et al., 2003; Barna & Fox, 2003). Methodology was used to help develop comprehensive inventories for various types of fire that are now available from WRAP: http://www.wrapair.org/forums/fejf/.
<p>Task 2: Process fire emissions for use in models.</p>	<ul style="list-style-type: none"> CSEM and related smoke emissions tools have been bundled with the BlueSky framework and incorporated into an air quality model data processing tool known as SMOKE: http://www.cep.unc.edu/empd/products/smoke/bluesky/. SMOKE processed emissions inventories for various types of fire are now available from WRAP: http://www.wrapair.org/forums/fejf/.
<p>Task 3: Model simulations to study sensitivity of visibility to fire emissions.</p> <ul style="list-style-type: none"> REMSAD applied in support of the BRAVO study. CMAQ applied in support of WRAP. CAMx applied by the NPS at CIRA for visibility research. 	<ul style="list-style-type: none"> REMSAD evaluated as a regional model and determined not to be adequate for fire applications. CMAQ simulations with and without fire emissions for the western United States reported by the WRAP RMC at University of California, Riverside: http://pah.cert.ucr.edu/aqm/308/cmaq.shtml. CIRA CAMx simulations are just getting under way.
<p>Task 4: Use IMPROVE monitoring with modeling to quantify impacts of fire on regional visibility.</p> <ul style="list-style-type: none"> Statistically apportioning visibility impacts to fire. Compare modeling results to IMPROVE monitoring. 	<ul style="list-style-type: none"> Statistical apportionment has been done using OC/EC ratios and a trajectory based analysis including a fire inventory (Ames et al., 2004). Model results are presented on the TSS and the WRAP RMC web sites: http://vista.cira.colostate.edu/tss and http://pah.cert.ucr.edu/aqm/308/cmaq.shtml. CIRA CAMx model results to be published by August 2007.
<p>Task 5: Disseminate appropriate information to analysts and others supporting the development of regional haze plans.</p> <ul style="list-style-type: none"> Organize and conduct a workshop for fire and air quality modelers to review results and plan development of emissions modeling. 	<ul style="list-style-type: none"> Workshop was not conducted. In its place, two web sites are under development to disseminate the information: vista.cira.colostate.edu/tss and vista.cira.colostate.edu/views/. These sites are developed by and for the state and tribal regional haze planners.

Key Publications and Presentations

Ames, R. B., Fox, D. G., Malm, W. C., Schichtel, B. A. 2004 Preliminary apportionments of carbonaceous aerosols to wild fire smoke using observations from the IMPROVE network, Regional Haze paper # 76, AWMA, Asheville, NC.

Barna, M. G., Fox, D.G. 2003 Combining Wildfire Emissions From The Community Smoke Emissions Model (CSEM) With A Regional-Scale Air Quality Model. Proceedings, Fifth Symposium on Fire and Forest Meteorology, American Meteorological Society, Orlando, Florida. November 16-20, 2003.

Fox, D.G., Riebau, A., Lahm, P. 2005. A Review of Wildland Fire and Air Quality Management. Invited presentation at EASTFire Conference. George Mason University. Fairfax, VA. May 11-13, 2005. (Submitted for publication as a chapter in the conference book.)

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Sestak, M., Fox, D.G. 2003. The Community Smoke Emissions Model. Draft Users Guide. 23pp. available from <ftp://ftp.cira.colostate.edu/Fox/>.

Sestak, M., O'Neill, S, Ferguson, S., Chang, J., Fox, D.G. 2002. Integration of wildfire emissions into MODELS-3/CMAQ with the prototypes: Community Smoke Emissions Modeling system (CSEM) and BlueSky. Extended abstract presented at the First CMAS (Community Modeling and Analysis System) Models3 Workshop. October 21-22, 2002. Research Triangle Park, NC. .
http://www.cmascenter.org/conference/2002/session5/fox_abstract.pdf

Other Publications and Presentations

Ames, R. B., McClure, S. E., Schichtel, B. A., Fox, D.G. 2005. The Visibility Information Exchange Web System (VIEWS), Air Toxics, and IMPROVE Web Sites: database driven internet sites for access, inter-comparison, and on-line analysis of air quality data. Presented at the Air & Waste Management Association Specialty Conference in Oak Brook, IL, April 2005.

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Barna, M. G., Gebhart, K. A., Schichtel, B. A., Malm, W. C. 2006. Modeling regional sulfate

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Barna, M. G., Schichtel, B. A., Gebhart, K. A., Malm, W. C. 2006. Modeling regional sulfate during the BRAVO study: Part 2. Emission sensitivity simulations and source apportionment. Atmospheric Environment, 40, 2423-2435.

Barna, M. G., Schichtel, B. A., Gebhart, K. A., Rodriguez, M. A. 2005. Evaluating the linearity of sulfate formation in response to change in sulfur dioxide emissions within a regional air quality model. Presented at the NOAA/EPA Golden Jubilee Symposium on Air Quality Modeling

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Fox, D.G., Riebau A. 2005. Mountain air quality in the USA, with particular attention to contributions from wildfire. Proceedings International Open Science Conference on Global Change in Mountain Regions, Perth, Scotland, UK, October 2005

Fox, D.G., Riebau A., 2005. Emissions from wildfires and effects on air quality and human health. Invited Presentation, USGS

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Riebau, A., Fox, D. G. 2004. Damage assessment of agrometeorological relevance from natural disasters: economic and social consequences. Presentation at the Expert Group Meeting on Reducing the Impact of Natural Disasters and Mitigation of Extreme Events in Agriculture, Rangelands, Forestry and Fisheries, Beijing, February 2004.

Riebau, A. R., Fox, D. G. 2003a. Fire consortia for advanced modeling of meteorology and smoke – FCAMMS. Presented at the 3rd International Wildland Fire Conference and Exhibition, Sydney, Australia.

Riebau, A. R., Fox, D. G. 2003b. Fire Consortia for Advanced Modeling of Meteorology and Smoke – FCAMMS: A national paradigm for wildland fire and smoke management. Presented at the Fifth Symposium On Fire And Forest Meteorology, Orlando, FL.

Rodriguez, M. A., Barna, M. G., Schichtel, B. A. 2006. Using CAMx to model the potential impacts of a proposed power plant in the Four Corners region. Presented at the 99th AWMA Annual Conference and Exhibition, New Orleans, LA, June20-23.

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Schichtel, B. A., Ames, R. B., McClure, S. E., Fox, D. G. 2002. Update on VIEWS. Invited presentation at the National Meeting of the Regional Planning Organizations, Dallas, TX. Dec. 2002.

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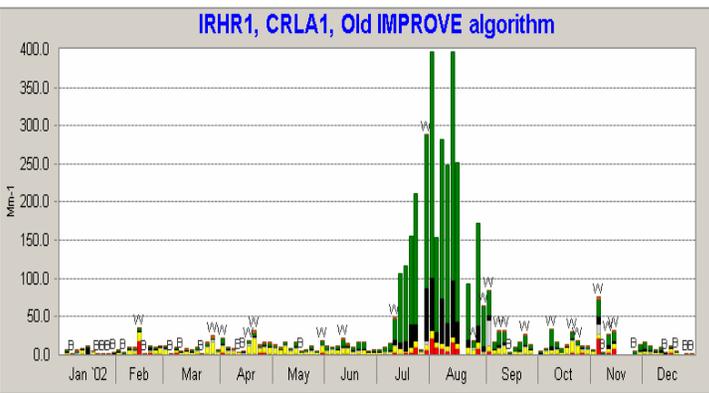
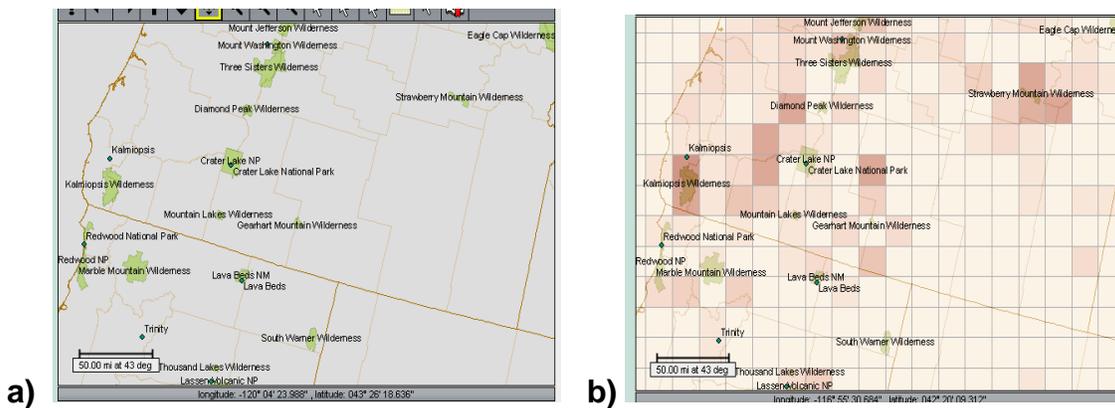


Figure 1. Title - Program: IRHR1, CRLA1, Old IMPROVE algorithm. Series - Parameter: ammNO3f_best, ammSO4f_best, CM_best, ECF_best, OMCf_best, SOILf_best. Metadata - Poc: 1, Aggregation: Not aggregated

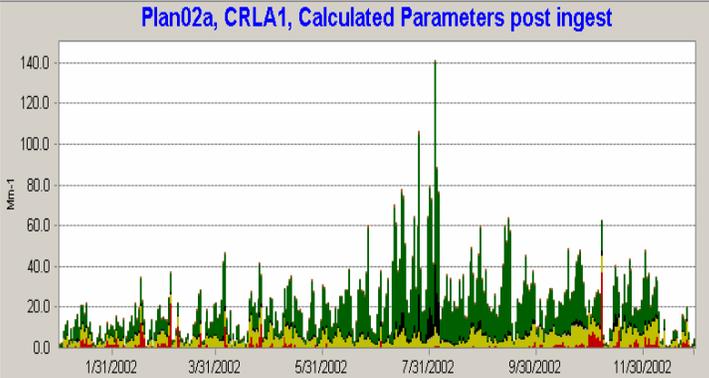


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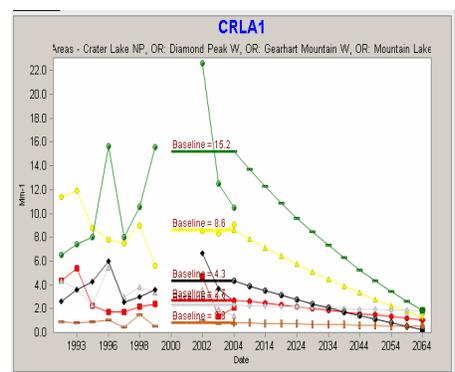


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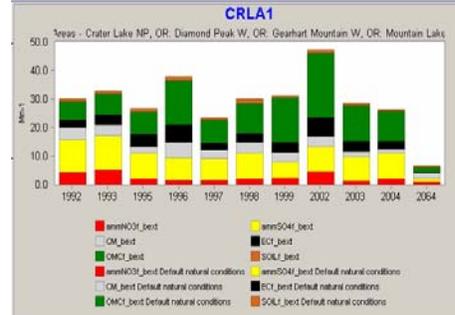


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Figure 1. This figure represents screen captures from the TSS on July 28, 2006. Starting at the top left panel: (a) presents a map of Crater Lake National Park and surrounding Class I areas in Oregon; (b) presents a map of the gridded fire emissions inventory (for only one emissions component, NO_x) used in the WRAP regional air quality modeling (discussed below); (c) shows a comparison of the IMPROVE monitoring (upper) results compared with the WRAP modeling (lower) results (discussed further below) for the Crater Lakes site for 2002; and (d) shows a projection of reductions needed to return visibility at Crater Lakes to its natural state by 2064, the time period of the regulations.

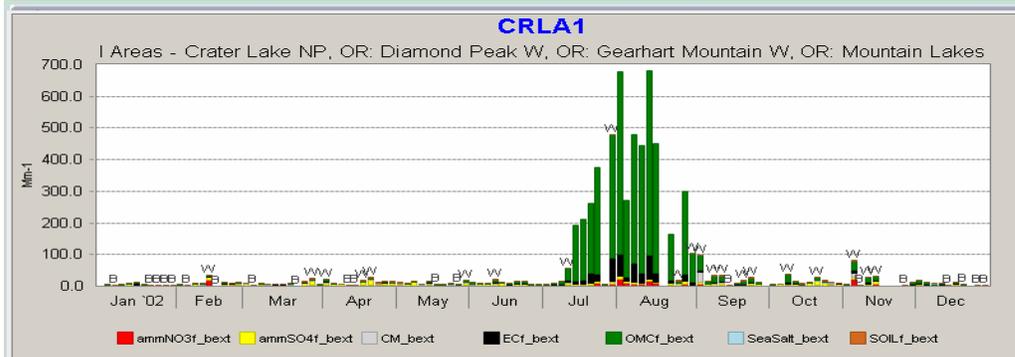
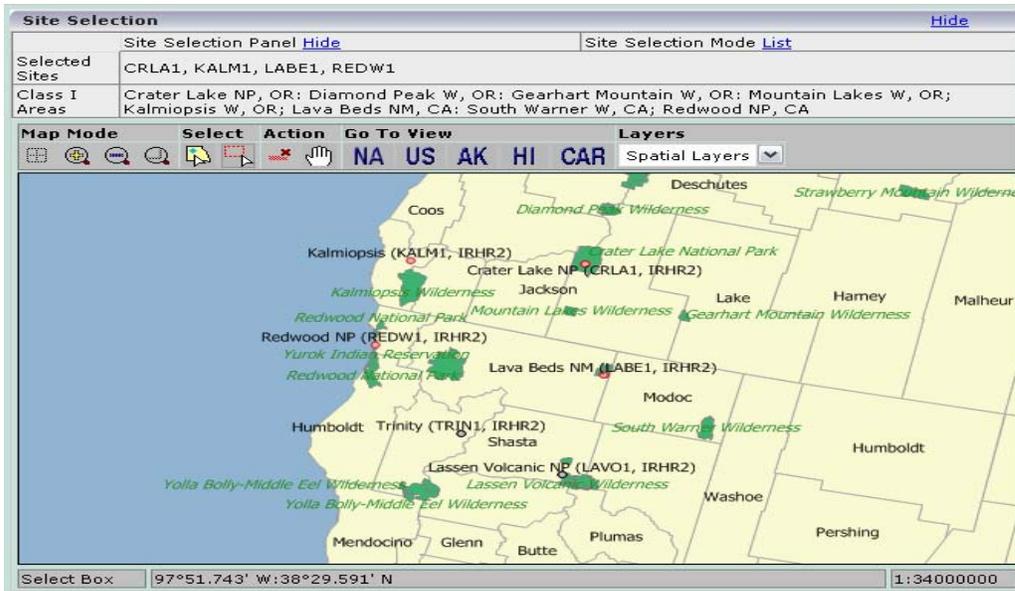


Figure 1. Title - Site: CRLA1. **Series** - Parameter: ammNO3f_bext, ammSO4f_bext, CM_bext, ECf_bext, OMCf_bext, SeaSalt_bext, SOILf_bext. **Metadata** - Program: IRHR2, Method: New IMPROVE algorithm, Poc: 1, Aggregation: Not aggregated

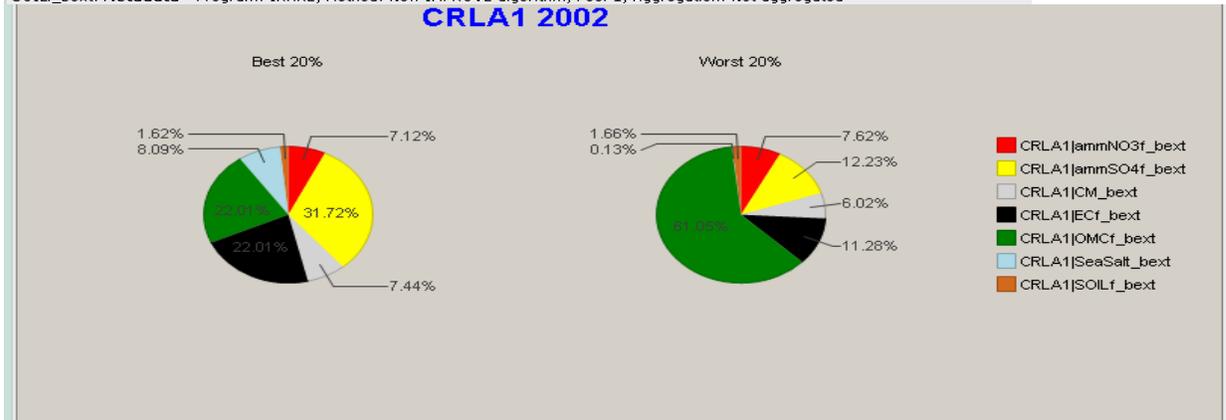


Figure 1. Title - Site: CRLA1. **Series** - Aggregation: Best 20%, Worst 20%. **Metadata** - Program: IRHR2, Poc: 1, Method: RHR aggregation

Figure 2a. This figure represents screen captures from VIEWS on July 28, 2006. Respectively (from top to bottom), it shows a map locating the Crater Lake National Park IMPROVE monitoring site along with surrounding Class I areas and IMPROVE monitors; 2002 individual measurements plotted as stacked bar charts for the primary visibility impairing components (ammonium sulfate & nitrate, coarse mass, organic carbon, elemental carbon, sea salt and soil) contributions to extinction; pie charts of the average component contributions to the best 20% and worst 20% visibility days (a regulation requirement).

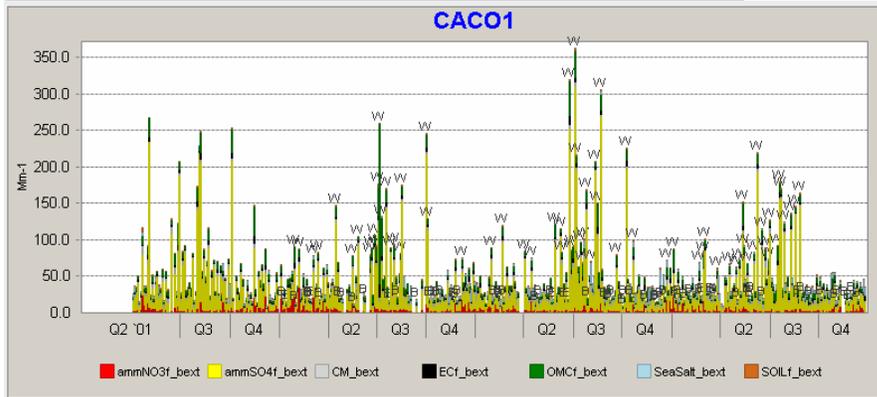
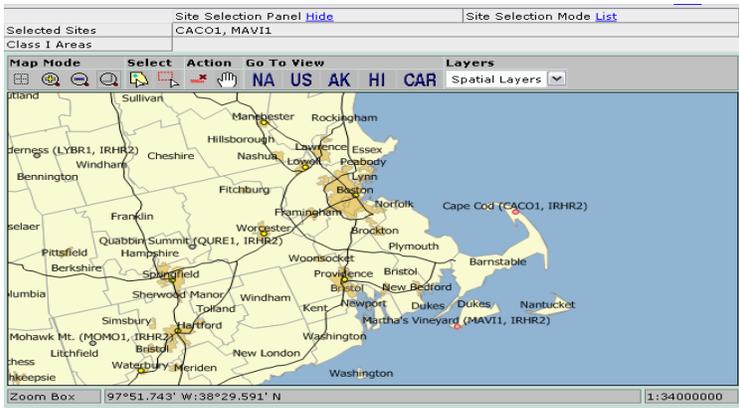


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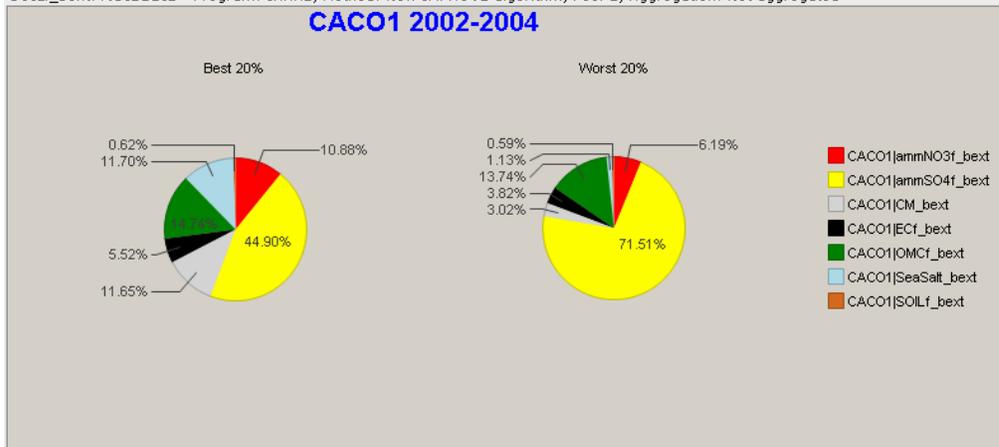


Figure 1. Title - Site: CACO1. **Series** - Aggregation: Best 20%, Worst 20%. **Metadata** - Program: IRHR2, Poc: 1, Method: RHR aggregation

Figure 2b. Similar to Figure 2a except it shows the Cape Cod National Seashore IMPROVE site and displays data from 2002 through 2004.

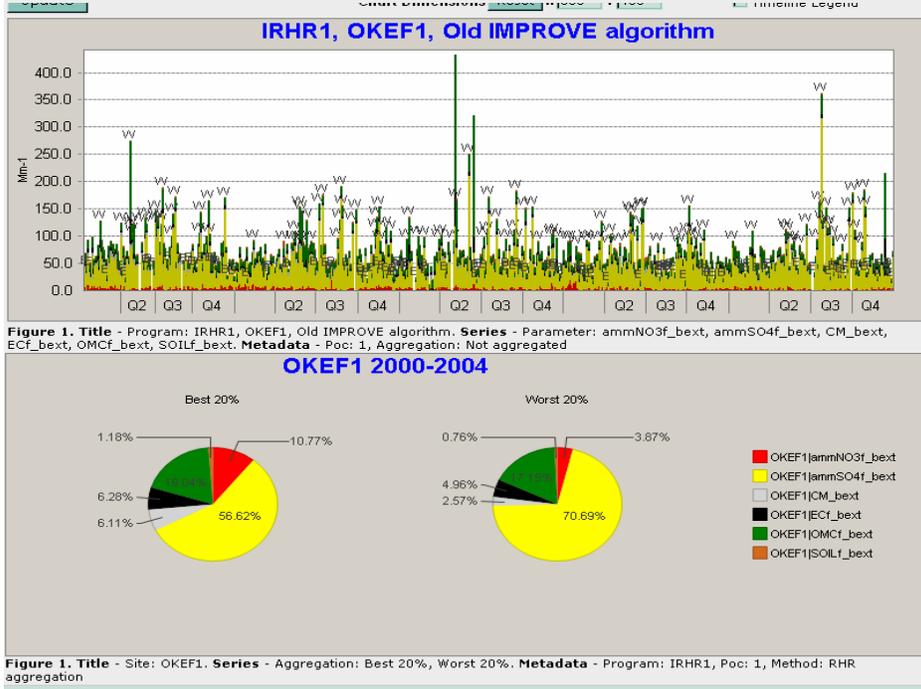
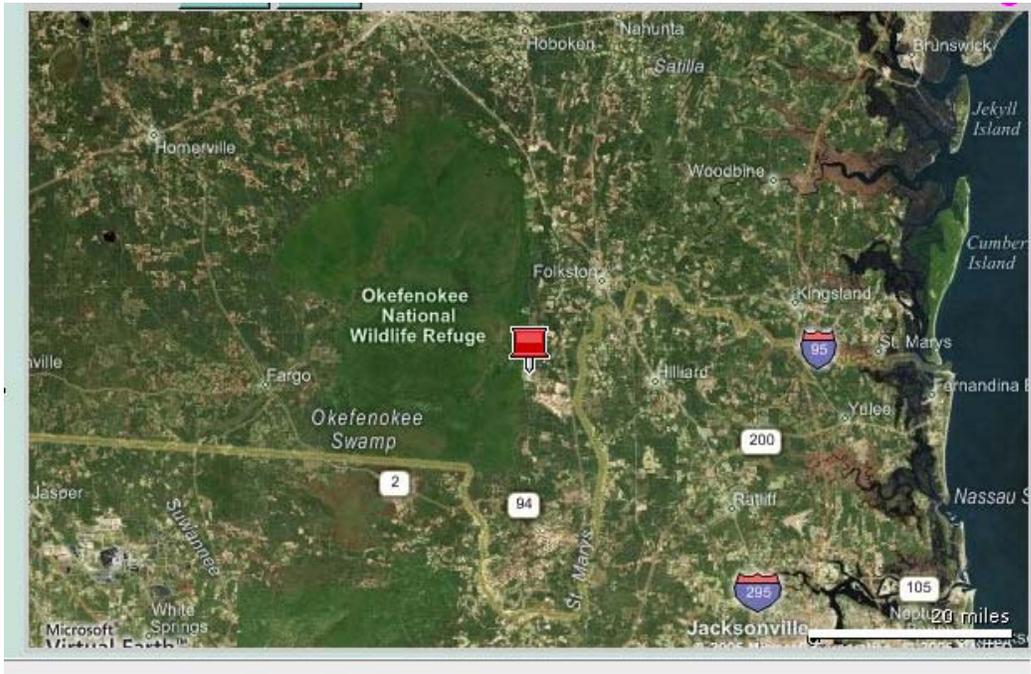


Figure 2c. Similar to Figure 2a except it shows Okefenokee national wildlife refuge IMPROVE site and displays data from 2000 through 2004. The site map comes from the TSS implementation of the Microsoft Visual earth application rather than VIEWS as in the other cases.

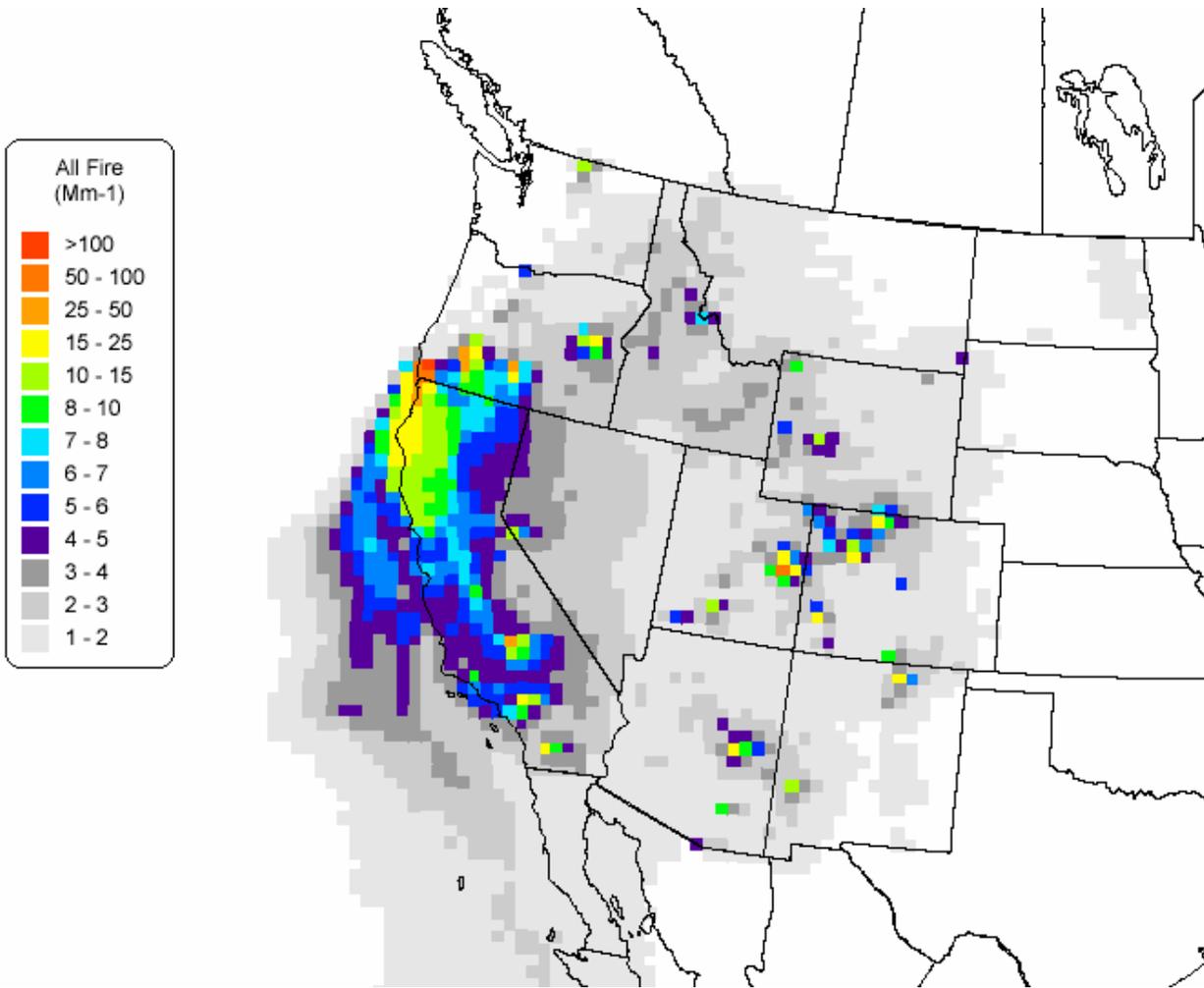


Figure 3a. CMAQ model results from a 36-km simulation of all 2002 emissions. However, only the extinction attributed to fire emissions (all fire emissions, wildfire, wildland fire use fire, prescribed fire and agricultural burning) is presented. From WRAP Attribution of Haze results: <http://wrapair.org/forums/aoh/ars1/report.html>.

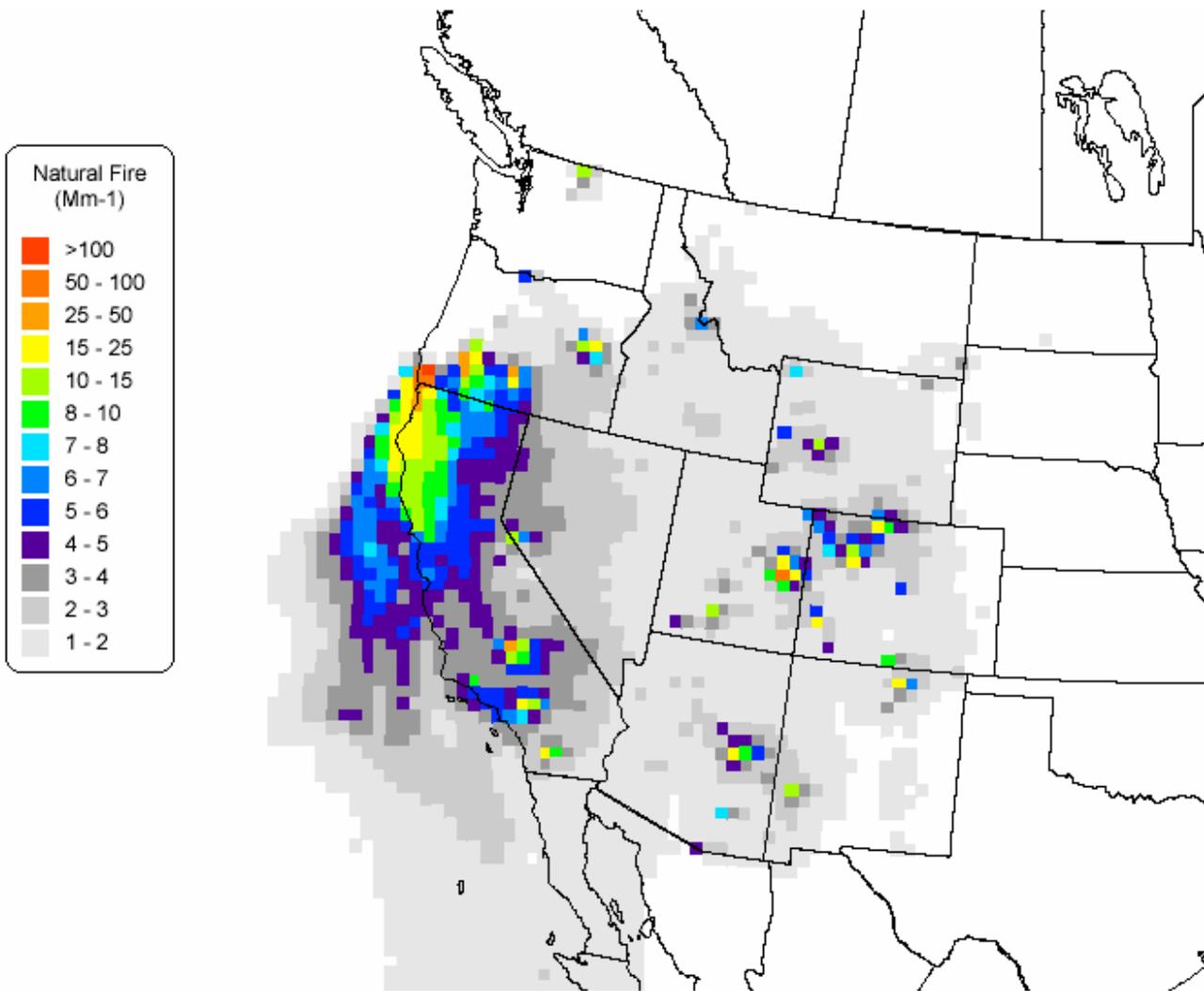


Figure 3b. CMAQ model results from a 36-km simulation of all 2002 emissions. However, only the extinction attributed to “natural” fire emissions (wildfire, wildland fire use fire, and prescribed fire for ecosystem management purposes) is presented. Note this figure is nearly identical to Figure 3a showing results of all fire emissions. From WRAP Attribution of Haze results: <http://wrapair.org/forums/aoh/ars1/report.html>.

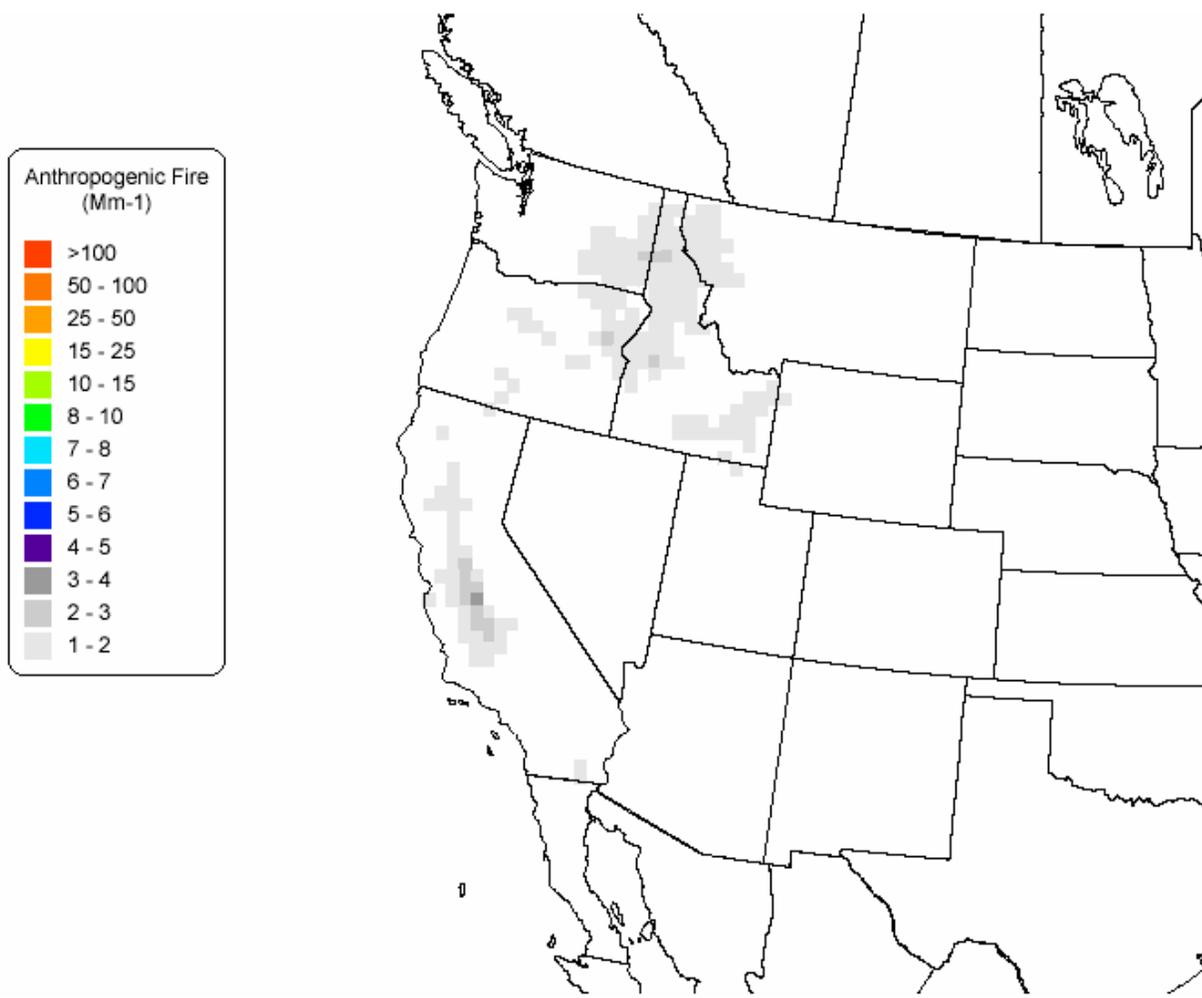


Figure 3c. CMAQ model results from a 36-km simulation of all 2002 emissions. However, only the extinction attributed to “anthropogenic” fire emissions (some prescribed fire and agricultural burning) is presented. Note this figure illustrates that in the western United States, the contribution of this anthropogenic fire to regional haze appears to be quite limited. From WRAP Attribution of Haze results: <http://wrapair.org/forums/aoh/ars1/report.html>.

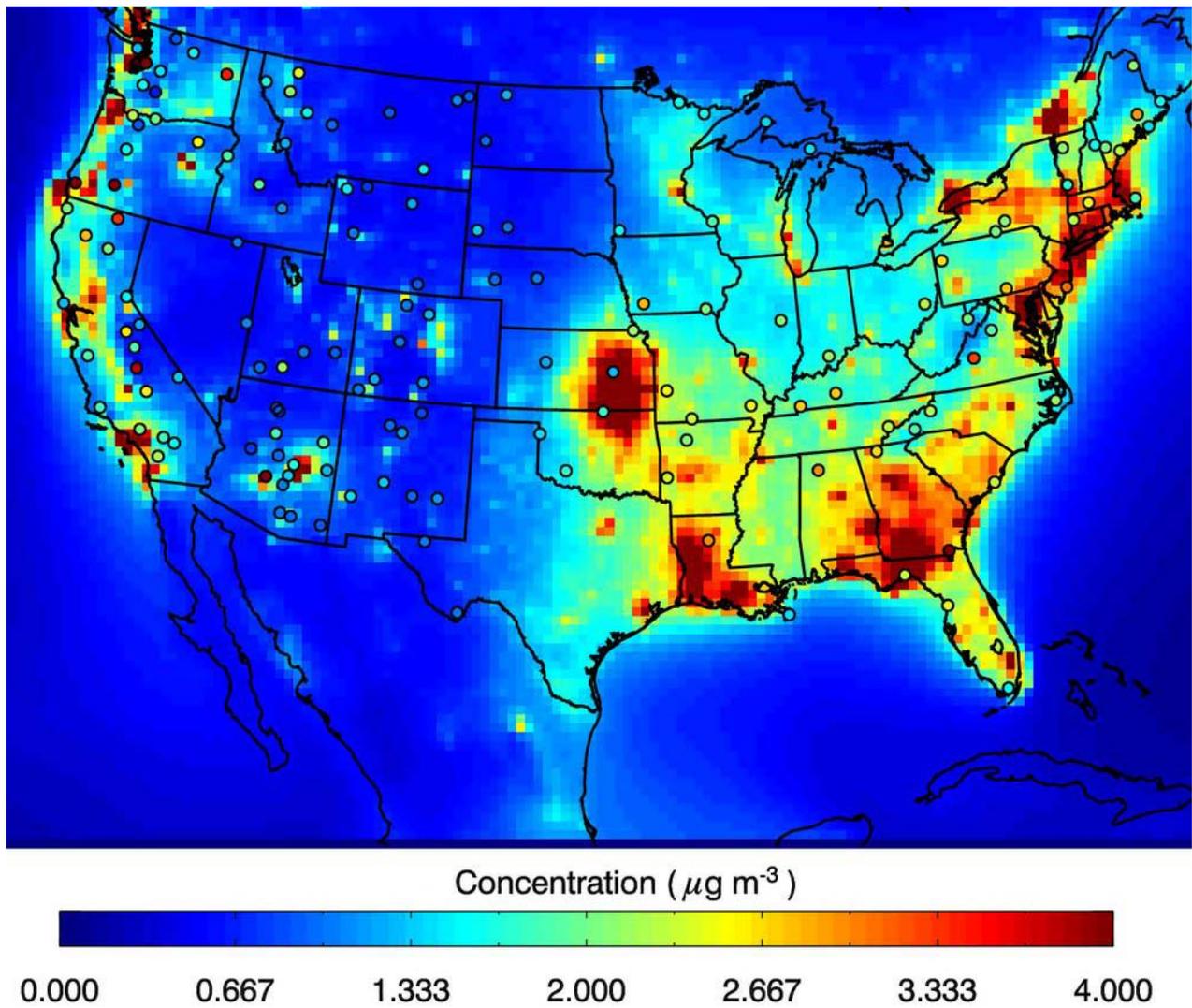


Figure 4. Comparison map of results from the CIRA CAMx 36-km grid simulation of 2002 annual average organic carbon aerosol compared against IMPROVE annual average values (in the small dots).

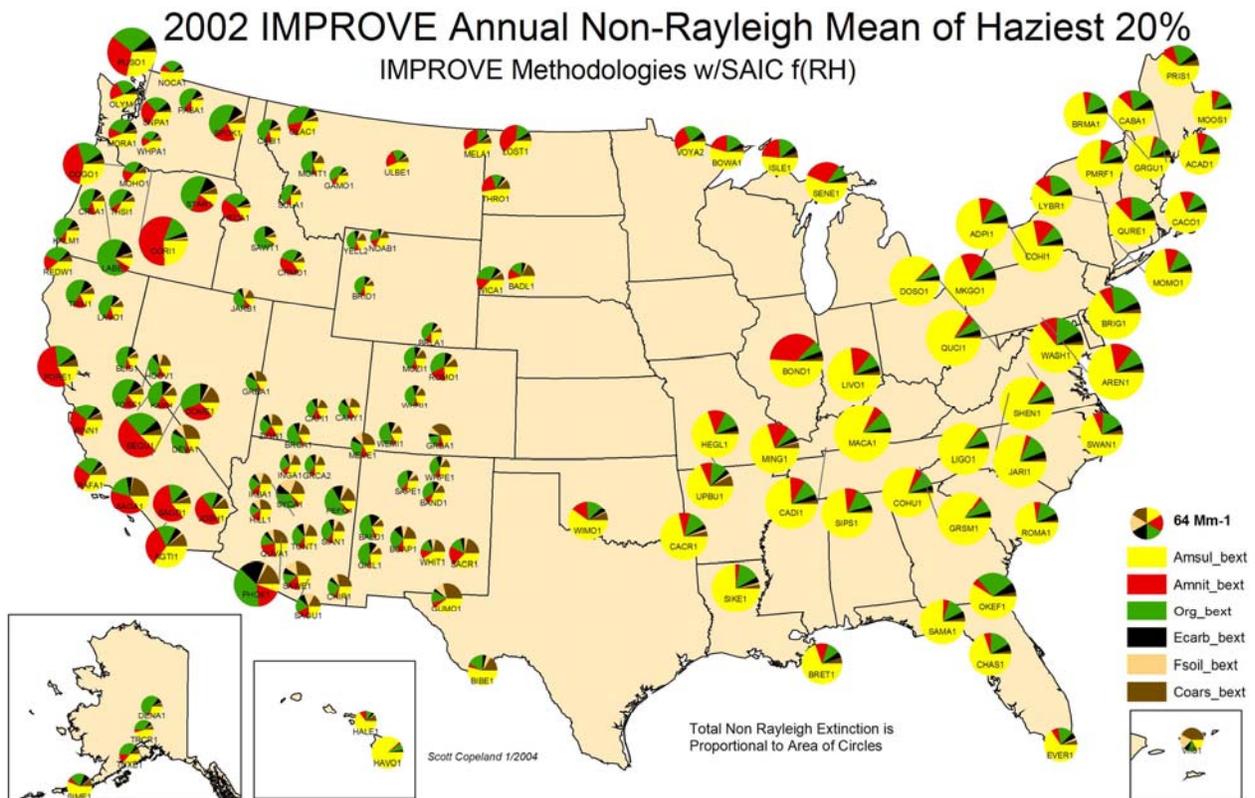


Figure 5. IMPROVE monitoring results from 2002 for the 20% worst visibility days. The pie charts illustrate the contribution that each of the IMPROVE aerosol components makes to the extinction. Note the distribution of values of organic carbon (green) suggests locations where fire may have a potentially significant impact on regional visibility.

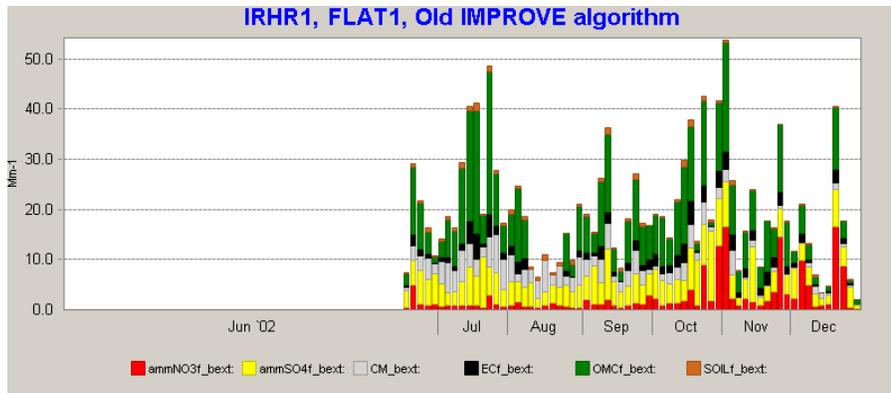


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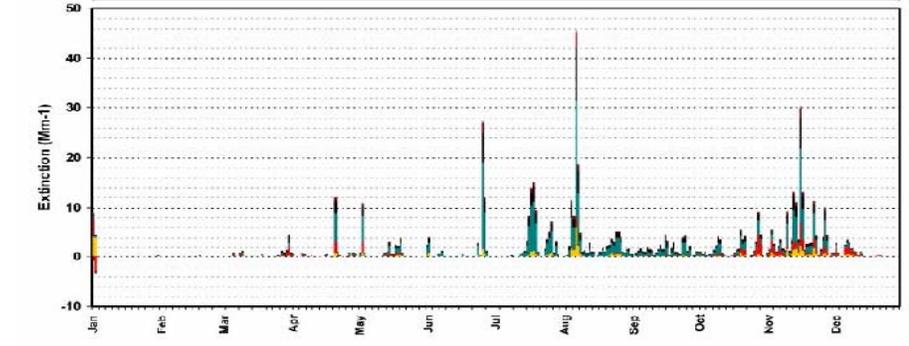
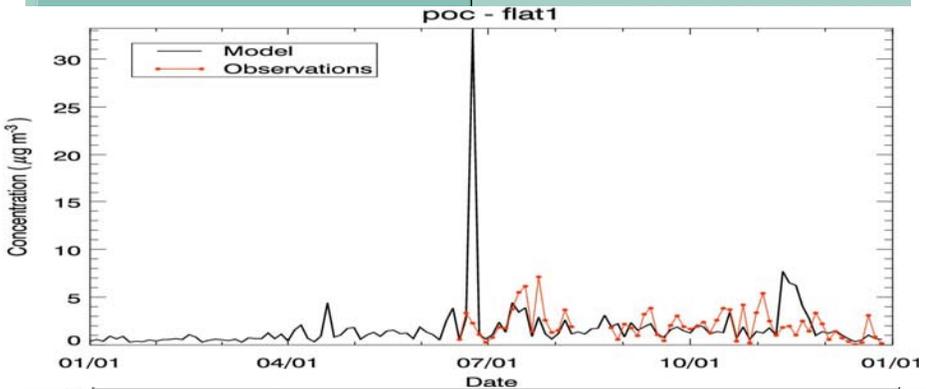
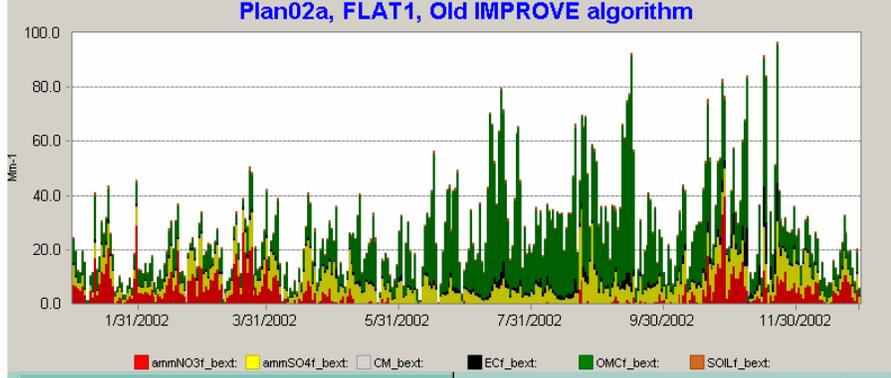


Figure 6a. Monitoring and modeling compared for Flathead Lake, MT, for 2002.

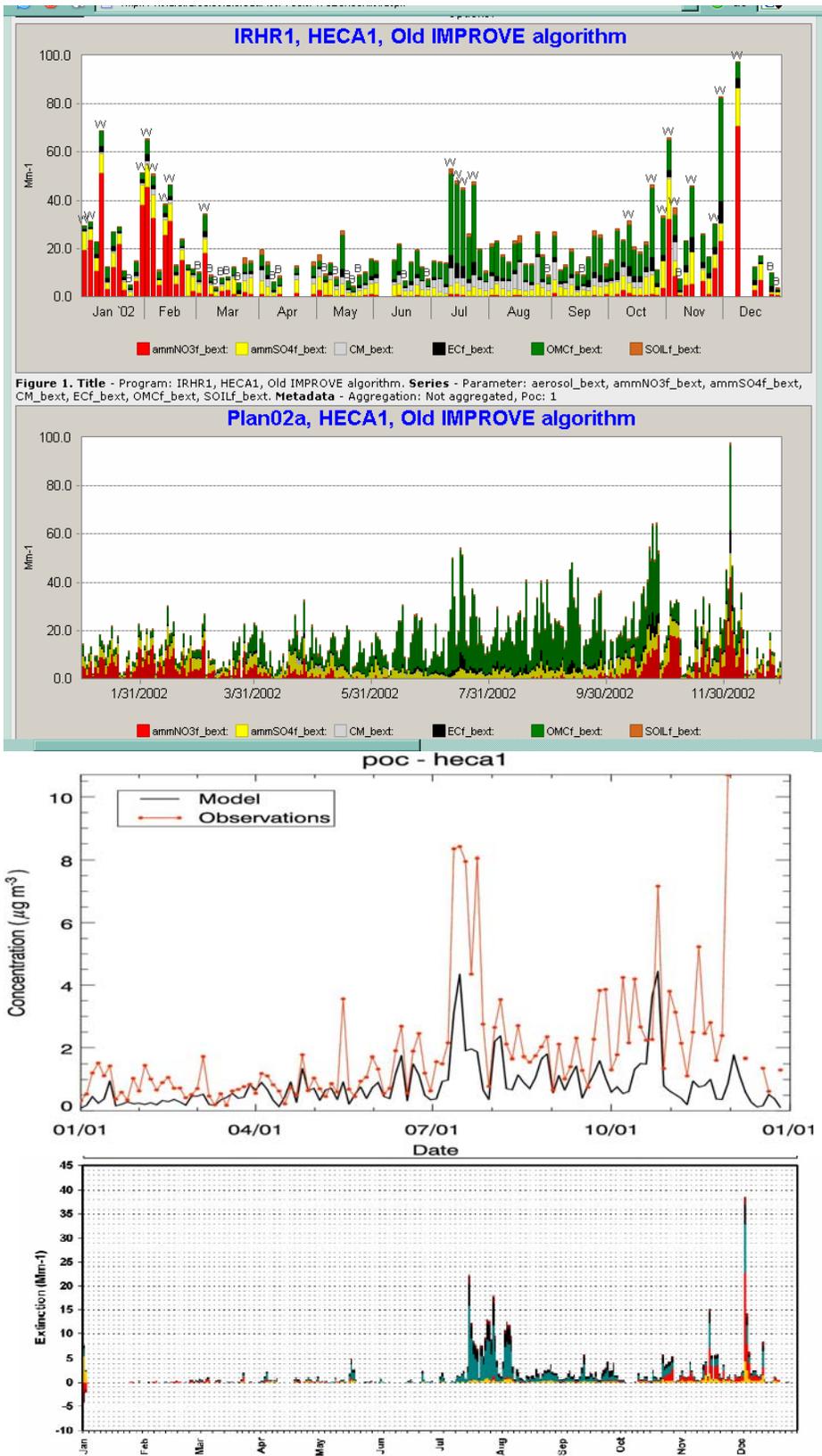


Figure 6b. Monitoring and modeling compared for Hells Canyon, OR, for 2002.

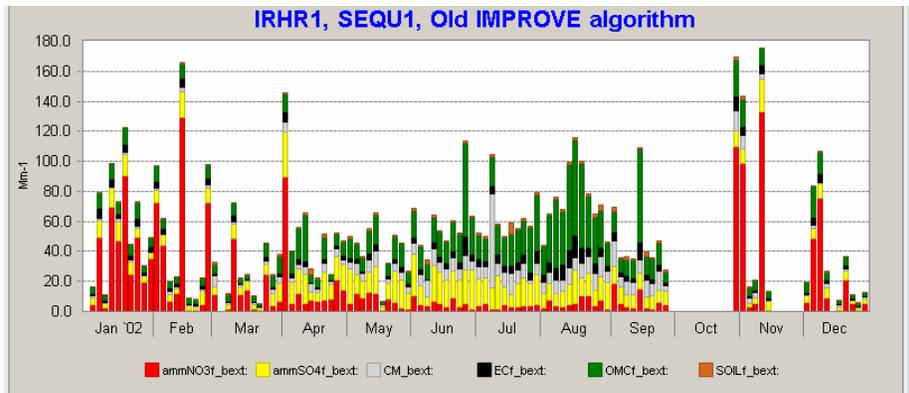
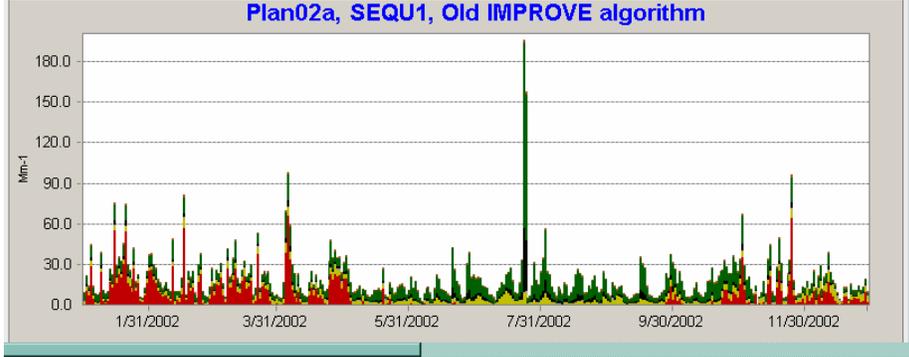


Figure 1. Title - Program: IRHR1, SEQU1, Old IMPROVE algorithm. Series - Parameter: aeroso_bext, amnNO3f_bext, amnSO4f_bext, CM_bext, ECf_bext, OMCf_bext, SOILf_bext. Metadata - Aggregation: Not aggregated, Poc: 1



poc - sequ1

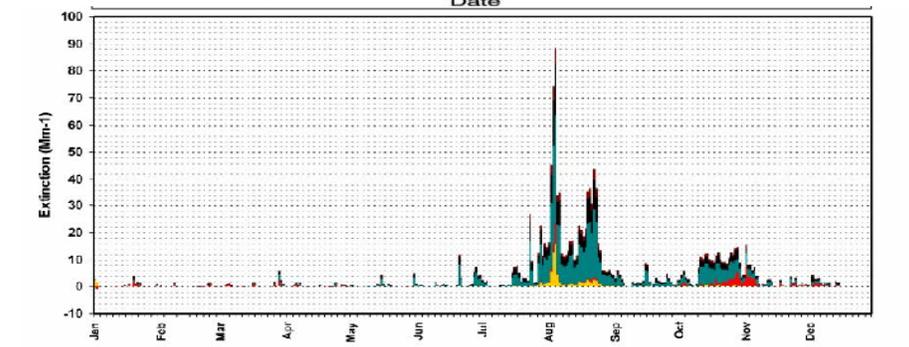
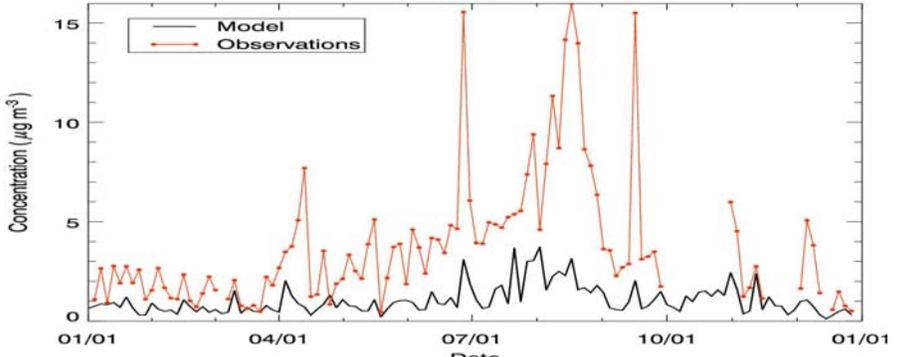


Figure 6c. Monitoring and modeling compared for Sequoia National Park, CA, for 2002.

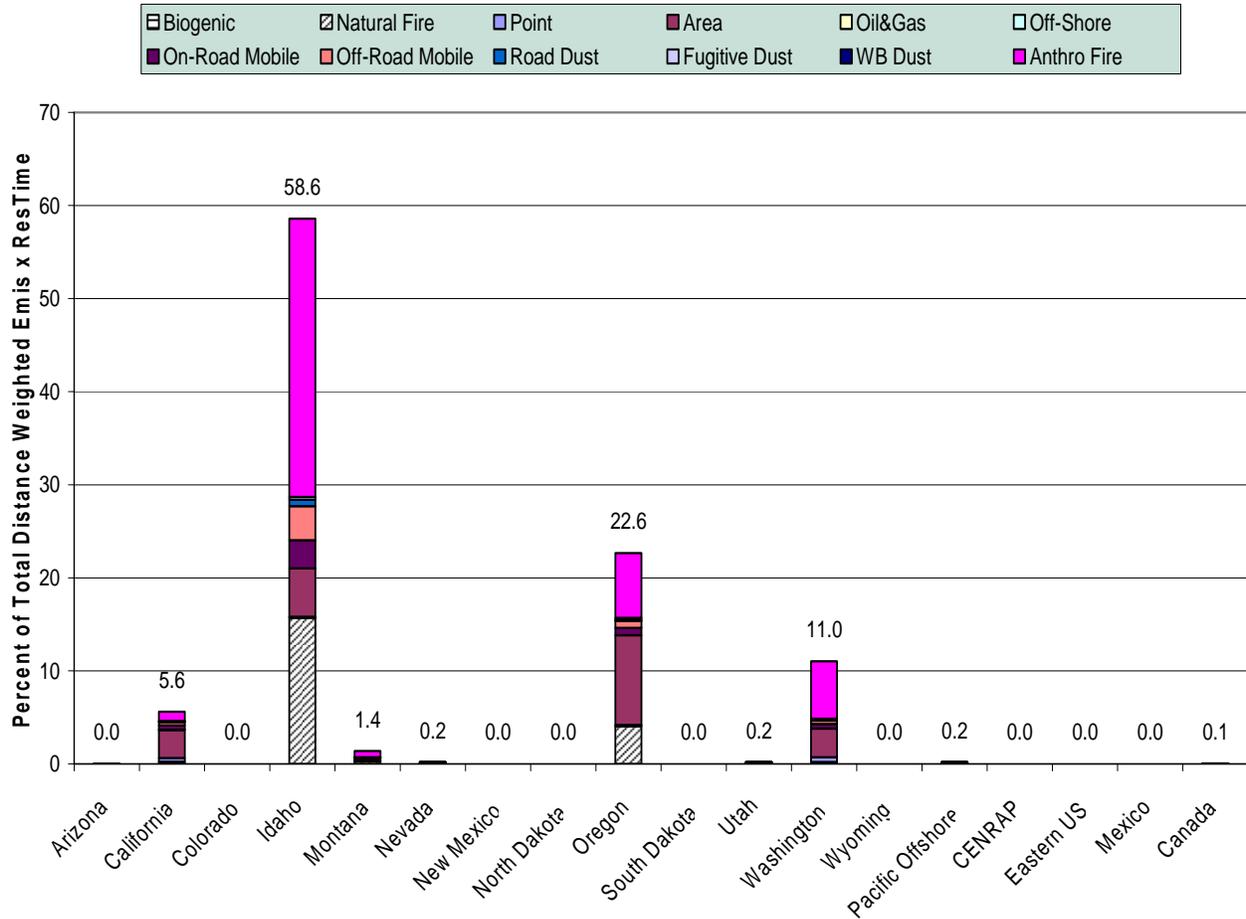


Figure 7. Preliminary results illustrating the influences of different emissions types on visibility at one of the IMPROVE sites in Idaho. Specifically to organic carbon aerosol, this analysis involves combining source regions and the trajectories of air flows during the worst visibility conditions experienced in the 2000–2004 five-year baseline period. It shows that at this site in Oregon, anthropogenic fire (the purple component of the bar) from Idaho, Oregon, and Washington may potentially impact degraded visibility during the worst 20% of the visibility days. This is a preliminary result and should not be quoted or copied for any purpose. It is presented to illustrate the type of analyses that will be used for regional haze plan development.

Table 1. Apportionment of organic carbon to fire and secondary organic aerosol and urban sources using OC/EC ratios. This is considered an overestimate of fire impacts on the regional visibility. The IMPROVE site at Crater Lake was omitted from the average at western sites due to possible impacts of residential wood burning during the winter months. From Ames et al. (2004).

		F,SOA OC (ug/m3)	F,SOA OC (%)	Urban OC (ug/m3)	Urban OC (%)	Observed OC (ug/m3)	Number of Sites
2000	EAST	.88	51	.85	49	1.73	20
	WEST	.67	59	.47	41	1.14	61
	NMtn	1.57	77	.47	23	2.03	7
	CA	.64	56	.50	44	1.13	13
2001	EAST	.82	54	.69	45	1.51	45
	WEST	.45	55	.37	45	.82	77
	NMtn	.62	69	.28	31	.90	13
	CA	.60	54	.51	45	1.11	15
2002	EAST	.90	57	.69	43	1.58	49
	WEST	.69	61	.44	39	1.12	91
	NMtn	.68	73	.25	27	.93	13
	CA	.99	65	.51	34	1.50	18

Table 2. Summary of trajectory mass balance wildland fire apportionment by region. This is considered an underestimate of fire impacts on the regional visibility. The IMPROVE site at Crater Lake is omitted from West due to potential influences from wood stove smoke during the winter. From Ames et al. (2004).

		Wildland Fire OC (ug/m3)	Wildland Fire OC (%)	Non- Wildland Fire OC (ug/m3)	Non- Wildland Fire OC (%)	Observed OC (ug/m3)	N Sites
2000	EAST	.43	21	1.59	79	2.02	7
	WEST	.41	36	.72	63	1.14	46
	NMtn	1.06	68	.51	32	1.57	8
	CA	.15	12	1.14	88	1.30	9
2001	EAST	.31	15	1.71	85	2.01	16
	WEST	.26	29	.65	71	0.91	51
	NMtn	.35	36	.63	64	.98	13
	CA	.37	25	1.14	75	1.51	8