Draft manuscript

Real-Time Numerical Forecasting of Wildfire Emissions and Perturbations to Regional Air Quality

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Introduction

During the summer of 2006, western forest fires engulfed more than 8 million acres of timber and rangeland and set records for acreage burned and biomass consumed. These fires are significant in terms of the areal coverage and also in terms of the extended period of the summer and fall during which continuous emissions of gas and particulate phase pollutants were released into the atmosphere. For example, the Tripod complex fires in north-central Washington, which eventually consumed approximately 175,000 acres of forest, began in mid-July and continued to burn through all of August and September. Similarly, the Columbia complex fires in southeastern Washington started due to a lightning strike in early August and continued burning into October. More than 109,000 acres were burned in this complex of fires. In cases like these, the wildfire emissions are estimated to equal or exceed regional anthropogenic pollutant emissions during the same period (Wiedinmyer et al., 2006). This raises the question of the short term impact of these emissions on regional atmospheric chemistry and air quality and the longer-term effects of perturbed regional chemistry upon global change. In 2006, for the first time, the impact of wildfire emissions were treated explicitly within the framework of a 'one atmosphere' numerical atmospheric chemistry/air quality forecast system called AIRPACT-3 (Vaughan et al., 2004). In this report, we describe the AIRPACT-3 forecast system and show results for the impact of wildfire emissions upon regional photochemistry and particulate loadings. These results put the impact of wildfires in perspective with respect to typical summertime air quality. In particular, the automated daily simulations provide a way to build a detailed long term record of wildfire impacts on regional air quality.

The AIRPACT-3 air quality forecast system runs daily to predict ozone, particulates, and other pollutants in the Pacific Northwest from both anthropogenic and biogenic sources. For the 2006 western US wildfire season, AIRPACT-3 was enhanced to ingest pollutant emission estimates for wildfires provided from the BlueSky smoke modeling system operated by the U.S. Forest Service (Larkin et al., 2006; O'Neill et al., 2005). Numerical meteorological fields are obtained each night from a daily MM5 (Mesoscale Meteorological model version 5; Grell et al., 1994) weather forecast system operated by Mass and colleagues at the University of Washington (Mass et al., 2003). Anthropogenic emissions are based on the US-EPA National Emissions Inventory 2002 and processed with the Sparse Matrix Operator Kernel Emissions (SMOKE) (Houyoux and Vukovich, 1999) model. Biogenic emissions are generated using the US-EPA Biogenic Emissions Inventory System (BEIS version 3) model with adjustments for forecast temperature and solar-radiation. The hourly meteorological and emissions data are used to drive the Community Multi-scale Air Quality (CMAQ) model (Byun and Schere, 2006) for a region that encompasses Idaho, Oregon, Washington, and bordering areas. Boundary conditions are derived from long-term global simulations using the MOZART-2 global chemical transport model (Horowitz et al., 2003), while initial conditions for each day are daisy-chained from the previous day forecast. The CMAQ system explicitly accounts for the detailed photochemistry of gas phase emissions, the formation and fate of aerosol phase species, and the deposition of both gas and aerosol species. The model utilizes uniform 12 km x 12 km grid cells with variable vertical layer spacing and outputs ambient pollutant concentrations and deposition rates on an hourly time step.

Wildfire emissions

For wildfires, the Forest Service BlueSky system automatically pinpoints the location (see Figure 1 and http://www.blueskyrains.org), updates sizes of wildfires, and uses this information to estimate pollutant emissions. Daily wildfire information with fire locations, size, and other information are downloaded through the federal Incident Command System (ICS)-209 reports collected by the National Interagency Fire Center. Currently, BlueSky utilizes these reports to estimate the next day's fire growth based on a simple apportioning scheme. An advanced system combining these ground reports with satellite fire detections is under development and will be operating for the 2007 fire season.

Wildfires emit a variety of trace gases and particulates. BlueSky exports fine and coarse particulate matter (PM2.5 and PM10 respectively), carbon monoxide (CO), oxides of nitrogen (NOx), heat released, and total organic gas emissions to AIRPACT-3. These emissions are calculated from the daily fire growth using mapped fuels by size class from the Fuel Characteristic Classification System (FCCS, McKenzie et al., 2006). The fuels data are input into a consumption model (EPM/CONSUME, Sandberg and Peterson, 1984) derived from empirical pre- and post- burn measurements. Such calculations contain uncertainties; recent work indicates that this system likely underestimates emissions of fine particulates (Larkin et al., 2006).

Within AIRPACT-3, the wildfire emissions data are processed using the SMOKE emissions processing system to prepare the inputs for the CMAQ photochemical model. Emissions for each fire are allocated by vertical layer by accounting for plume buoyancy from the fire heat flux (Pouliot et al., 2005). To better account for chemical interactions, emissions are speciated into model mechanism species. For example, 77% of total PM2.5 is assumed to be of primary organic aerosol, 16% is specified as elemental carbon, 5% as primary unspecific fine PM and 2% as fine sulfate aerosol.

Perturbations to Summertime Regional Air Quality

The daily forecast runs show the extent of wildfire plumes of PM2.5, CO and other species and also show how ozone is formed downwind of the fires to contribute to regional photochemical levels. Visibility reduction is also modeled. Extensive forecast results are presented on the web (http://www.airpact-3.wsu.edu). In addition, monthly accumulated statistics for ozone and PM2.5 are updated with results from each daily run to show maps of monthly maximum concentrations (shown in Figure 1). A recent satellite image showing the locations of a number of large fires in the Northwest is also shown in Figure 1.

The most significant impact on regional air quality is in terms of increases in PM2.5 concentrations and associated reductions in visibility. Maximum 24-hr average PM2.5

concentrations accumulated during August, 2006 are shown in Figure 1, and as shown in Figure 2, 24-hr averaged PM2.5 concentrations in Pullman, WA, located downwind from the Columbia fire complex, varied from 2 $\mu g/m^3$ immediately following the passage of fast moving cold fronts to more than 40 $\mu g/m^3$ when there appeared to be relatively direct impact of the plume from the fires. In this case, the maximum concentration exceeded the new National Ambient Air Quality Standard for PM2.5 of 35 $\mu g/m^3$. In the model simulations, these patterns were generally captured, although the model predicted one extreme plume impact which was not observed. In the model simulation, the composition of the PM2.5 predicted at Pullman, WA included primary organic aerosol plus contributions from aerosol elemental carbon and other unidentified aerosol. These results are consistent with the species profile assigned to wildfires within the BlueSky and SMOKE emissions processing systems and confirm that the model simulations reflected impact of wildfires at this site.

In terms of ozone, regional levels in central and eastern Washington and in northern Idaho during the summer typically stay in the range of 40 to 50 ppbv. The wildfires have a significant and widespread effect on ozone formation within the region. To demonstrate this, 8-hr daily maximum ozone contours are shown in Figure 3 for simulations with and without NOx emissions from wildfires. The results show that the various fires produce hotspots of ozone contributing more than 30 ppb above the case without wildfire NOx emissions and that there is widespread increment in ozone levels of 15 to 20 ppb that can be attributed to wildfire emissions.

The AIRPACT and BlueSky forecast systems, together, provide a dramatic and unique perspective of the impact of wildfires upon regional atmospheric chemistry and air quality. These effects are widespread and, because the wildfires burn for extended periods, the impact is long lasting.

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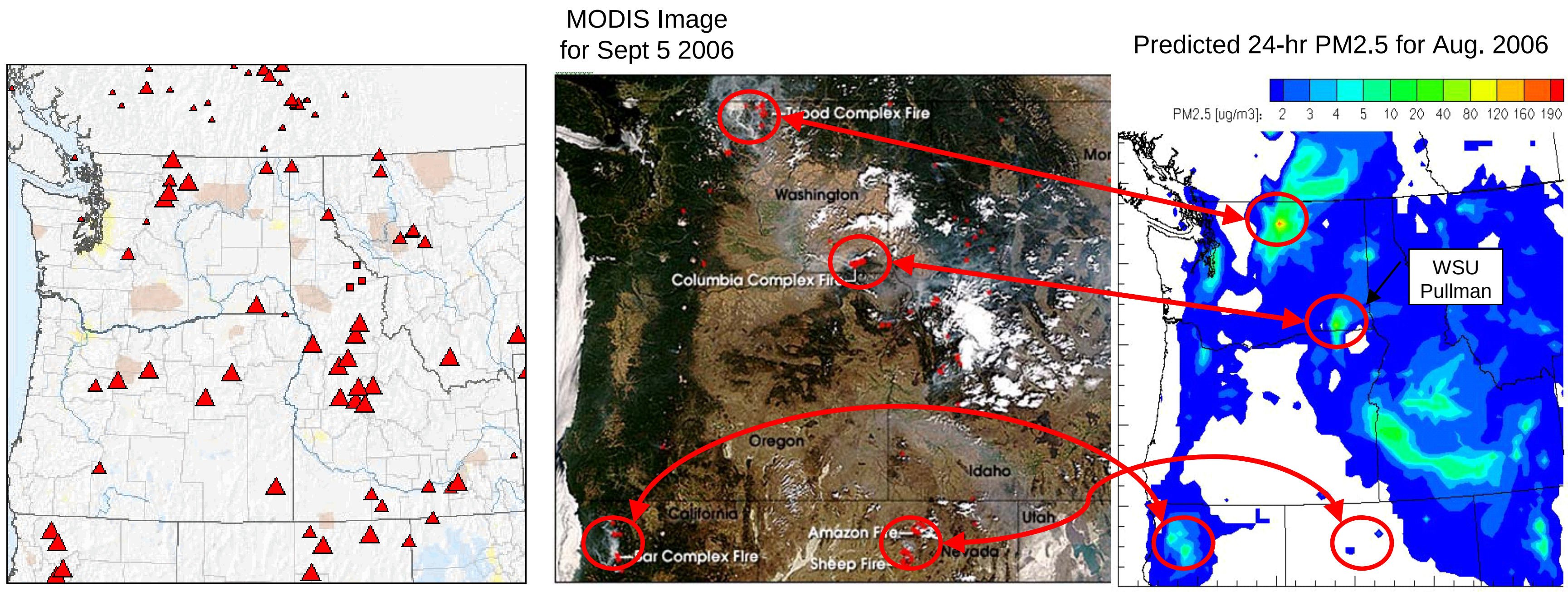

Figure 1. (Left panel) BlueSky wildfire map showing location and relative size of wildfires for September 5, 2006; (Center panel) MODIS image of wildfire locations and smoke plumes compared to accumulated monthly maximum PM2.5 surface concentrations forecast (right panel) with the AIRPACT-3 system.

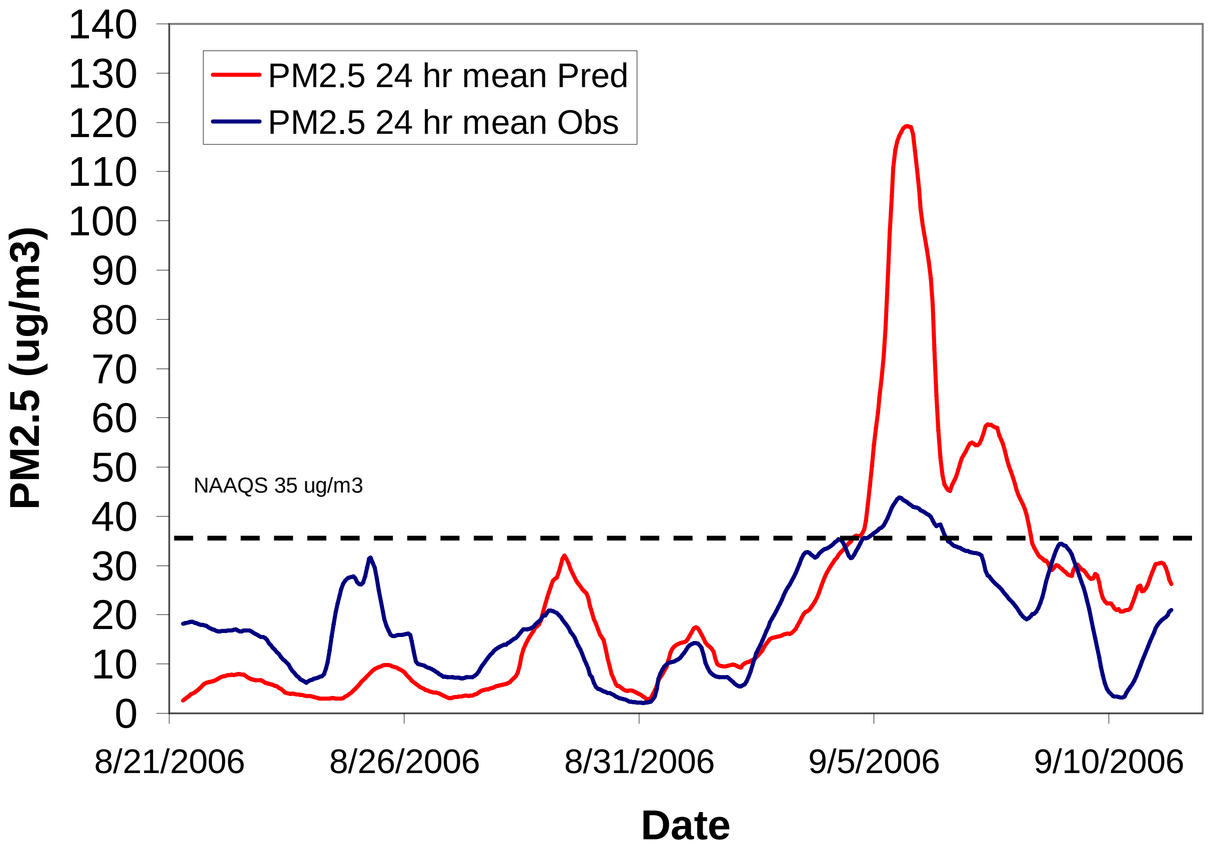

Figure 2. Observed and forecast 24 hr mean PM2.5 surface concentrations at Pullman, WA from August 18 through September 11, 2006

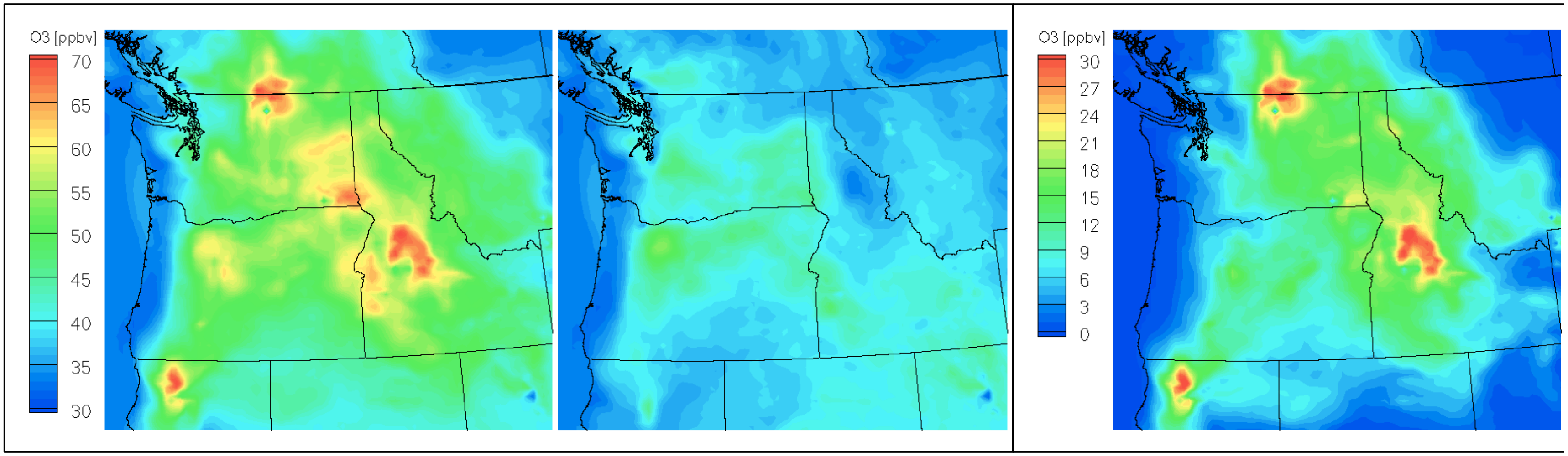

Figure 3. Daily maximum 8 hr surface ozone concentrations for the period September 2 through September 8, 2006. The map on the left shows ozone produced when NO2 from wildfire emissions are included in the simulation, while the map in the center shows the ozone formation when no NO2 emissions from wildfires are included. The map on the right is the difference between the left and center maps.