Validation of BlueSky Smoke Prediction System Using Surface and Satellite Observations During Major Wildland Fire Events in Northern California

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Abstract—*The BlueSky Smoke Prediction System developed by the U.S. Department of Agriculture, Forest Service, AirFire Team under the National Fire Plan is a modeling framework that integrates tools, knowledge of fuels, moisture, combustion, emissions, plume dynamics, and weather to produce real-time predictions of the cumulative impacts of smoke from wildfires, prescribed fires, and agricultural burn activities. Currently, BlueSky smoke predictions are available daily across the contiguous United States. The output has been used by air regulators, burn bosses, and smoke managers as a guide to help make 'go' and 'no-go' decisions about prescribed fires and plan burn operations. It also helps track day-to-day emissions from wildland and prescribed fires. BlueSky is establishing its reputation as a one-stop shopping for regional smoke concentration and emissions tracking across all land ownership, and is being used by more and more users especially in the West. On the other hand, little is known about the accuracy of its predictions of smoke transport and dispersion under different meteorological conditions. This ongoing study aims at validating BlueSky predictions using in-situ and satellite observations. The study domain is northern California and southern Oregon during the last 2 weeks of August 2006 when several major wildland fires broke out in the region. The predicted smoke concentrations are evaluated by the $PM_{2.5}$ data at several stations, and the plume trajectories are compared with satellite images. Sensitivity tests are performed to identify potential sources in the smoke predictions so that improvements can be made to the BlueSky prediction system.*

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Introduction

BlueSky, developed by the U.S. Department of Agriculture, Forest Service, AirFire Team, is a smoke modeling framework that integrates consumption, emissions, meteorology, and dispersion models to predict smoke trajectories and concentrations of particulate matter. BlueSky smoke predictions are available daily across the contiguous United States and the output has been used by air regulators, burn bosses, and smoke managers as a guide to help make 'go' and 'no-go' decisions about prescribed fires, plan burn operations, and help track day-to-day emissions from wildland and prescribed fires. BlueSky is establishing its reputation as a one-stop shopping for regional smoke concentration and emissions tracking across all land ownership, and is being used by more and more users especially in the West, as this area is subject to higher risk of wildland fires than other parts of the country. Few studies have compared BlueSky predictions with actual observation. Validation efforts to date have been limited to isolated fire cases in the Northwest (Adkins and others 2003; Berg and others 2003; Larkin and others 2006).

As part of an effort to provide better information on fire weather and smoke dispersion/transport, the California and Nevada Smoke and Air Committee (CANSAC) has been running the coupled MM5 model and BlueSky smoke prediction system in real-time for California and Nevada. In this paper, we describe some preliminary results from an effort to validate the CANSAC BlueSky smoke predictions as part of a project funded by the Joint Fire Science Plan to develop tools for estimating contributions of wildland and prescribed fires to air quality in the Sierra Nevada.

Study Domain, Cases, Data

The study focuses on the area of northern California and southern Oregon during the last 2 weeks of August 2006 when a stream of major wildfires broke out in this area. These large fires provide a clear smoke signal on satellite imagery and surface PM monitors, creating an ideal environment for comparison efforts. Figure 1 shows the station locations where in-situ particulate matter and meteorological variables were collected. The predictions of BlueSky PM concentrations associated with these fires were produced by CANSAC at the Desert Research Institute. Four nested domains were used with the innermost domain of 4-km grid spacing covering California and Nevada. The meteorological input was provided by the MM5 forecast. Initial and boundary conditions for the MM5 forecasting were obtained from the

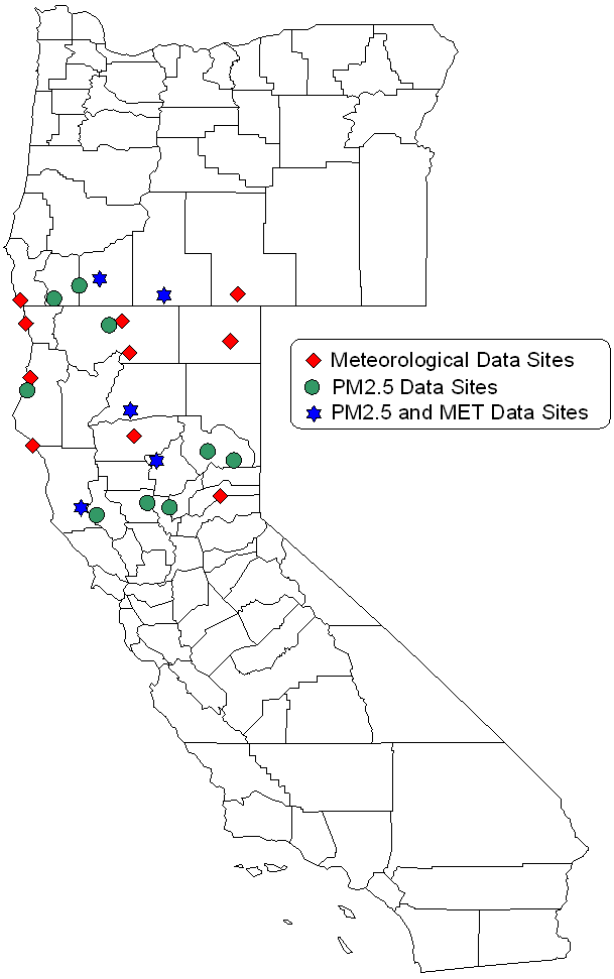

Figure 1–Locations of $PM_{2.5}$ monitoring sites and surface meteorological observation sites in the study domain.

6 hourly 40-km Eta forecasts from the National Center for Environmental Predictions. The details of BlueSky and MM5 configuration can be found at the CANSAC Web site at: http://www.cefa.dri.edu/COFF/.

$PM_{2.5}$ in-situ hourly measurements for approximately a dozen stations were obtained from both the Environmental Protection Agency (EPA) and Oregon's Department of Environmental Quality. Daily satellite images were downloaded from the National Geophysical Data Center's Satellite Fire Detections Web site (map.ngdc.noaa.gov/website/firedetects/viewer.htm). Hourly extracted $PM_{2.5}$ concentrations by station were compared with time series of observed measurements. An average of $PM_{2.5}$ concentrations taken from a fire free period during (July 16-24, 2006) was subtracted from the observed $PM_{2.5}$ value in an effort to view the fire induced effect on $PM_{2.5}$. Qualitative comparisons of smoke trajectories were done between the daily satellite images and the BlueSky output. Time series analysis of the MM5 model was necessary to be sure the meteorological variables being supplied to BlueSky were not causing inaccuracies in predicted smoke plume trajectories. In-situ hourly weather data were collected for 15 stations from the National Climatic Data Center Web site (www.ncdc.noaa.gov/oa/ncdc.html).

Results

Past studies concerning the accuracy of BlueSky have found that plume trajectories seem to agree well with satellite observations, but tend to underpredict $PM_{2.5}$ concentrations (Larkin and others 2006). Our investigation into BlueSky's accuracy concerning fires in northern California has produced similar results. As figure 2 shows, BlueSky has captured very well

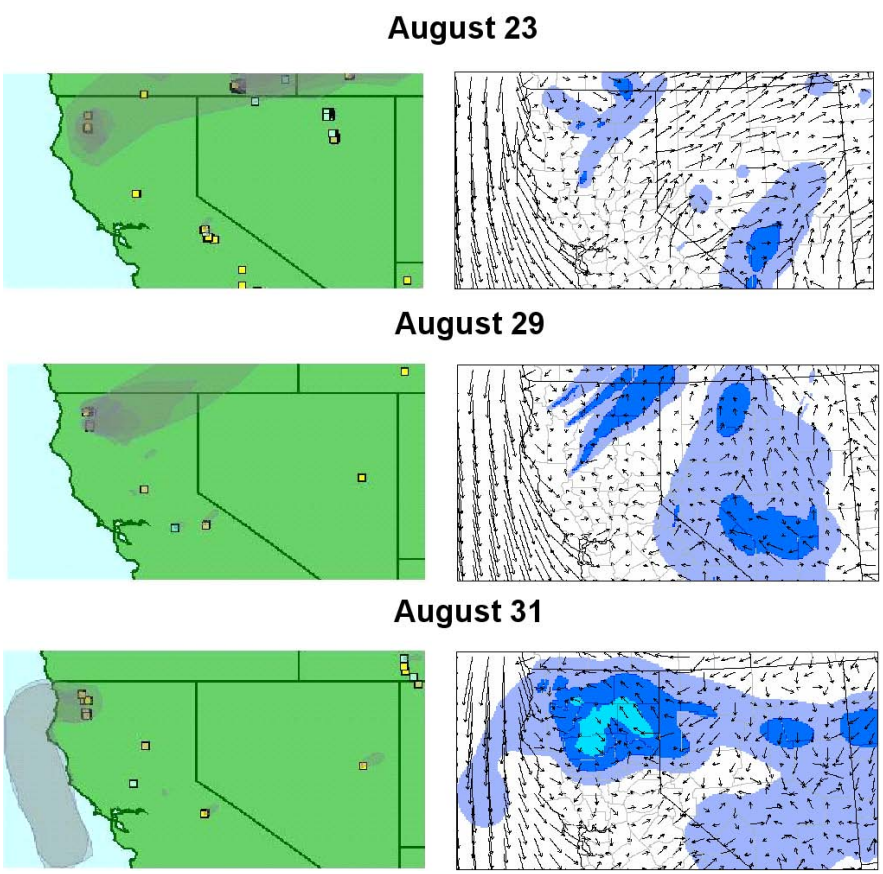

Figure 2–4km model domain used. The left panel shows the National Geophysical Data Center satellite images of smoke plume. The right panel shows the corresponding images from BlueSky output.

the trajectory and shape of the observed smoke plumes from the fires near the California and Oregon border. There are smoke plumes in Nevada in the BlueSky predictions that are absent from satellite images. The cause for this discrepancy is being investigated, and is likely due to inaccurate information on fire emissions.

Time series analysis of $PM_{2.5}$ concentrations at selected stations (fig. 3) shows increases of modeled values when observed values increase. The observed concentrations of $PM_{2.5}$ are a combination of emissions from fires and other emissions sources including primary and secondary sources. The only emission sources in BlueSky, however, are wildland and prescribed fires. To isolate the contributions to PM concentrations from fires, the hourly observed values during this period were subtracted from the mean hourly values from a fire-free period prior to the beginning of these fires. The negative values at a particular hour, therefore, imply that the observed value is less than the 'fire-free' mean value for that hour. Although these time series show relatively good agreement between BlueSky $PM_{2.5}$ concentrations and the observed measurements, BlueSky does not do well in capturing all of the smaller $PM_{2.5}$ fluctuations. Klamath Falls in Oregon is a good example. The model shows two large increases in PM concentration but fails to pick up the many smaller fluctuations. That said, the model in all cases has good quantitative agreement of $PM_{2.5}$ concentrations, which is different from previous studies where BlueSky was found to underpredict $PM_{2.5}$ concentrations (Larkin and others 2006).

The time series in figure 3 also shows small time lags between the model and observed concentrations. Figure 4 shows a sequence of meteorological time series at Klamath Falls. There tends to be a good agreement between the modeled and observed variables, but the model is underpredicting windspeed, which is probably the cause for the delay in the BlueSky predicted peak $PM_{2.5}$ value compared to the observed onset time of the peak. The time series of

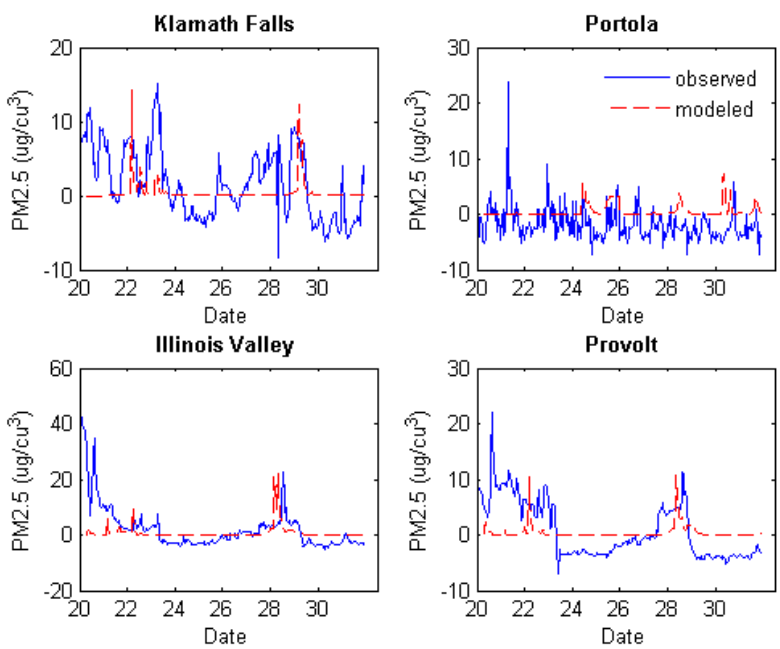

Figure 3–Time series of observed and modeled $PM_{2.5}$ concentrations at study sites. To isolate the contributions to PM from the fires, the hourly observations of $PM_{2.5}$ were subtracted by the hourly mean obtained using data from a fire-free period just before the study period.

the three remaining stations in figure 3: Portola, Illinois Valley, and Provolt, demonstrates the opposite situation, where the impact of $PM_{2.5}$ is sooner than observations show. Most likely, one could follow the same logic as above and assume the reason for this is due to overprediction of windspeeds, as figure 5 shows. However, in this study, the overprediction of MM5 windspeeds was not common in respect to how many times $PM_{2.5}$ impacts were predicted sooner than observed. One possibility is that MM5 overpredicts upper level winds. At the time of this writing, the predicted upper level meteorological conditions including windspeed, wind direction, stability, and boundary layer heights, are being compared with the twice daily rawinsonde soundings at Medford, OR. Other factors could also contribute to the disagreement between the modeled and predicted concentrations and sensitivity simulations will be performed to isolate these factors.

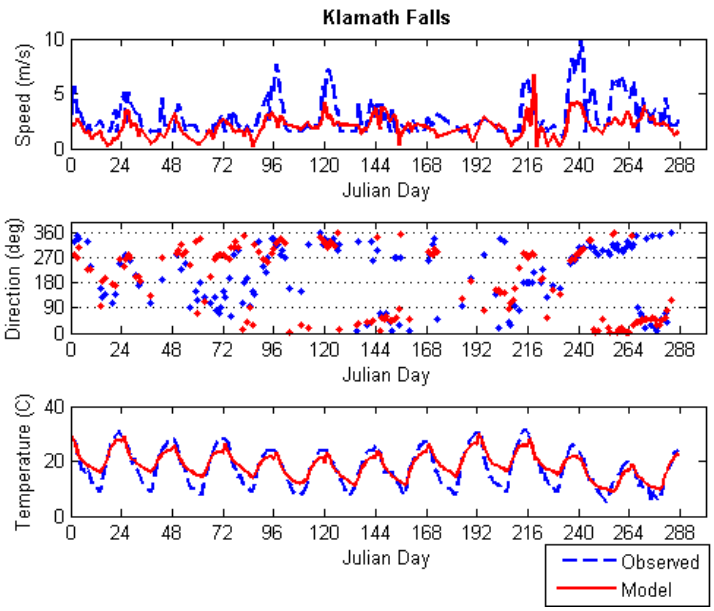

Figure 4–Time series of meteorological variables of Klamath Falls, OR. MM5 shows relatively good agreement with observations but slightly slower windspeeds, which was found to be normal in this study.

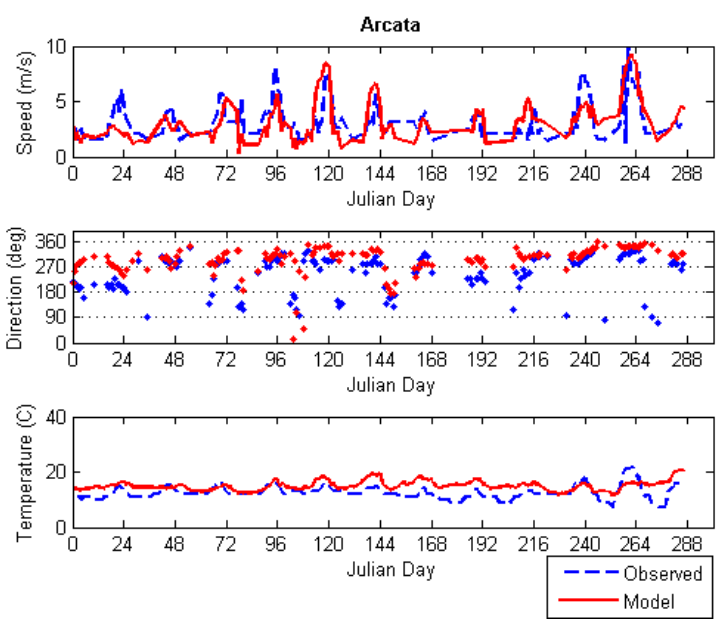

Figure 5–Same as figure 4, but for Arcata, CA.

Summary

In attempts to validate the accuracy of the BlueSky smoke model used by air regulators, burn bosses, and fire managers across the United States, a study over northern California during the last 2 weeks in August is being investigated. Preliminary results show good agreement between BlueSky smoke plume trajectories and satellite images. Although plume shape does not seem to be overly consistent between the two, BlueSky does do a reasonably good job in capturing accurate concentrations for large increases of $PM_{2.5}$ at surface stations. Meteorological analysis has also shown good agreement between observed and predicted values. Errors in MM5 windspeed predictions were evident, but alone those were not consistent enough to account for all inaccuracies within BlueSky.

Ongoing work includes more analysis of the meteorology supplied to BlueSky by the MM5 model. Specifically, upper air data will be reviewed to see if the plume trajectory behavior exhibited by BlueSky is in agreement with the MM5 model. Upper air data can also help to clarify discrepancies at the surface when predicted surface concentrations of $PM_{2.5}$ do not agree with the observed concentrations, but smoke plume trajectories do. More study into the actual smoke plumes predicted by BlueSky and the $PM_{2.5}$ concentrations within the plumes will be done by comparing them with aerosol optical depth data. Sensitivity studies will be done, forcing components of BlueSky to behave a certain way, in hopes to isolate which of those components of BlueSky—meteorological variables, emissions, plume dispersion, and so forth—are causing the major inconsistencies between BlueSky predictions and observations.

Acknowledgments

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