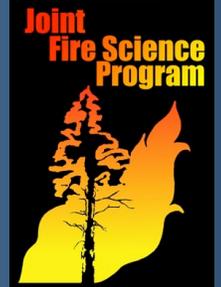


# Rapid response field observations to calibrate the BlueSky smoke prediction model



## FINAL REPORT TO THE JOINT FIRE SCIENCE PROGRAM September 30, 2009

Project #: **06-1-1-12**  
Website: **<http://airfire.org/projects/bluesky/rapid-response-obs>**

PI: **Dr. Narasimhan K. Larkin**  
**U.S. Forest Service AirFire Team**  
**Pacific Northwest Research Station**  
**400 N. 34<sup>th</sup> St Suite 201**  
**Seattle, Washington USA 98103**  
**206.732.7849 (W) 206-732.7801 (F) [larkin@fs.fed.us](mailto:larkin@fs.fed.us) (E)**

Co-PI(s): **Dr. Robert Solomon, U.S. Forest Service AirFire Team**  
**Dr. Tara Strand, U.S. Forest Service AirFire Team**

Co-authors: **Candace Krull, U.S. Forest Service AirFire Team,**  
**Miriam Rorig, U.S. Forest Service AirFire Team**



This project was funded through a grant from the Joint Fire Sciences Program (<http://firescience.gov>).

## Abstract

The BlueSky smoke modeling framework, developed with support from the National Fire Plan and recently reworked through a grant from NASA, is used to enable a variety of real-time predictions of surface smoke concentrations from prescribed fires, wildfires, and agricultural burns. These predictions form the basis of several decision support systems and are used by air quality regulators and land managers to assess the impacts from planned and ongoing fires. Field observations are needed to assess these predictions, change parameters and model path choices, and improve the accuracy of the resulting smoke predictions.

This project collected fine particulate matter observations in smoke plumes during 3 field deployments. Observations were made during: the Tripod Fire of 2006; the Montana/Idaho fires of 2007; and the California fires of 2008. The observed data were collected on a rapid-response basis and the monitors were deployed in a coordinated effort with other groups and organizations in order to maximize their effectiveness. During the Tripod 2006 campaign it was discovered that fine-tuning of the dispersion model (i.e. CALPUFF) would not adequately account for the differences between predicted and observed smoke concentrations. Major path changes through the Framework needed to be changed or adjusted. Several novel improvements to BlueSky were implemented, including major systems overhauls and a new fire information system.

The field work done through this project and the real-time fine particulate matter observations helped form the basis of a new U.S. Forest Service Emergency Smoke Forecast System prototype developed at the behest of the USFS Fire and Aviation Management. The observed data collected by this project have been included in after action reports for the California fires and they have been submitted to the Smoke and Emissions Model Intercomparison Project (SEMIP) for use in its database.

## 1. Background

Simulating smoke emissions, transport, and internal plume chemistry is a complex process. A series of sequentially linked modeling steps is required to determine fire location and information, fuel loading, and consumption before the emissions from the fire can be calculated. Once the emissions are calculated plume rise, transport and chemistry can be simulated through various models. The BlueSky Smoke Modeling Framework (BlueSky Framework) is a modular framework designed to link models and datasets into a unified structure. The BlueSky Framework can assist with answering the following questions (Larkin et al., 2009):

- 1) Where and how big are the fires?
- 2) What is the fuel available to be burned?
- 3) How much fuel is consumed?
- 4) What emissions are produced?
- 5) Where do the emissions go?

Note that the answer to each question is required input for the following question. The BlueSky Framework is not a model but a structure in which models and datasets are used to answer the

above questions and provide input for the next step in the process. Because the BlueSky Framework incorporates a number of models to answer each question, numerous model combination pathways are available. Smoke impact predictions can vary both by choice of modeling pathway and by choices of parameters used by each model.

Historically, the original BlueSky Framework was developed to provide smoke impacts information to forest managers investigating the possibility of a prescribed burn. The flexibility of the framework allowed for later use in many predictive applications and in a variety of research studies. Currently, BlueSky Framework based wildfire smoke predictions across the contiguous US are available daily from the U.S. Forest Service (USFS)-based Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS, [fcamms.org](http://fcamms.org)). The U.S. National Weather Service's operational smoke forecast products (Rolph et al., 2009) use BlueSky Framework emissions calculations to help produce their daily air quality forecasts. The framework has also been used to assist in calculations of U.S. and global emissions inventories for modeling studies (Chen et al., 2008; McKenzie et al., 2006; Wiedinmyer et al., 2006).

This study was designed to provide ground truth data that could be used to benefit BlueSky in general, thereby affecting a variety of uses for BlueSky-enabled smoke calculations, but primarily aimed at improving the accuracy of real-time smoke predictions.

Past analyses of BlueSky, notably as part of the 2005 BlueSkyRAINS-West demonstration project (Riebau et al, 2006) found that BlueSky-enabled predictions typically tracked overall plume shape well, but under-predicted ground concentrations. Observational data used in these studies were typically from fine particulate matter (PM<sub>2.5</sub>) sensors. Because smoke plumes contain large quantities of PM<sub>2.5</sub>, observation data of PM<sub>2.5</sub> serves as a good surrogate for smoke.

The BlueSkyRAINS-West demonstration project also included a rapid response field observation campaign where smoke (PM<sub>2.5</sub>) monitors were placed downwind of the Frank Church Wildland Fire Use Fire in the Salmon-Selway National Forest (Summer 2005). These observations were later deemed to be considerably more useful in evaluating BlueSky-enabled output than the established monitoring network due to the ability to closely cluster the rapid response monitors in areas of interest. Even more utility was derived by combining both the rapid response and existing monitoring network data. This project directly follows from the experience of the BlueSkyRAINS-West project and is designed to gain additional data with which to evaluate BlueSky-enabled predictions under various conditions.

## 2. Description

Observed PM<sub>2.5</sub> concentration data were collected in wildfire smoke plumes during the summers of 2006-2008. The observation instruments were deployed for 12 to 77 days. This number of days ensured that background or 'zero-plume' concentrations were measured during instrument deployment. At several sites the meandering of the smoke plumes across the instrumentation were observed. The fires were located in Washington, Idaho and California; they ranged from a single fire event to multiple fires in a region. The Tripod complex fire (Fig. 1), located in

Washington, was targeted for smoke plume data collection in 2006. In 2007 and 2008 in northern Idaho (Fig. 2) and California (Fig. 3), respectively, there were so many fires in the region that instrument location could not target a single fire complex, but instead targeted regional smoke transport and concentrations from the collective plumes.

Instruments were purposely deployed in the field on a spatial scale useful for evaluation of smoke modeling predictions (Fig. A1), such as those produced by the BlueSky Framework (Larkin et al., 2009). They were deployed approximately every 12 km to 36 km, which allowed for no more than a single observation point per modeling grid cell. The instruments were deployed along multiple parallel or perpendicular transects cutting through urban and rural centers.

The type of instruments deployed varied with each field campaign (Table 1, Fig. 5,6,7). In 2006

**Table 1.** Observation instruments deployed to the field, and their numbers during fire seasons 2006 (Tripod, WA), 2007 (Regional outbreak, ID and western MT), and 2008 (northern CA lightning event).

Instrument Type	2006	2007	2008
	Number Deployed		
<b>E-BAM; Met One Instruments, Grants Pass OR</b>	3	5	7
<b>E-Sampler; Met One Instruments, Grants Pass OR</b>	1	2	.
<b>Data Ram 4 and 2000; Thermo Scientific, Waltham, MA</b>	8	4	.
<b>Dust Trak</b>	.	1	.
<b>Total Instruments Deployed</b>	12	12	7

the predominant instrument type was the DataRam (4 and 2000; Thermo Scientific, Waltham, MA), however, by 2008 the Environmental Proof Beta Attenuation Monitor (EBAM; Met One Instruments, Grants Pass OR) was the only instrument type deployed. The DataRam uses a nephelometer to measure the scattering of light from particles and an equation to convert the scattering to a mass per volume unit and the EBAM uses beta-attenuation to measure the amount of mass collected on filter-tape. The EBAM systems require power for long-term use but they are robust for the field, can withstand transport, and can handle high concentrations of PM<sub>2.5</sub> without shutting down. This is important for PM<sub>2.5</sub> monitoring in wildfire smoke plumes because the concentrations in smoke plumes can peak at >400 µg/m<sup>3</sup> (Fig. A2). Additionally, EBAM systems are often used by other agencies (e.g. EPA) and in established monitoring networks.

## 2006: Tripod Complex

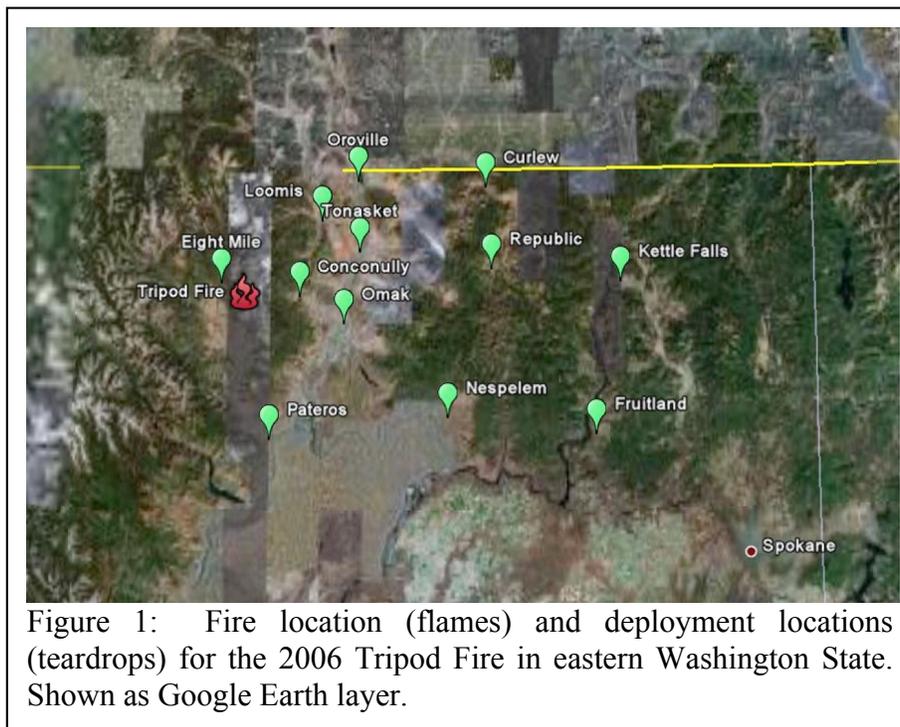


Figure 1: Fire location (flames) and deployment locations (teardrops) for the 2006 Tripod Fire in eastern Washington State. Shown as Google Earth layer.

Ignited by two lightning strikes on July 24, 2006 in the Okanogan-Wenatchee National Forest, near Winthrop Washington, the Tripod fire complex burned approximately 175,000 acres before fall rains and snow eventually extinguished the fire. The fire was located in complex terrain with slope drainage flows funneling the smoke down the valleys into the urban communities located on the eastern slopes of the Cascade Mountains. The fire burned through various fuel types ranging from heavy timber, to old growth timber, to fuel-managed timbers (both mechanical and under-burned).

To monitor  $PM_{2.5}$  in the eastern part of Washington State, twelve instruments (8 DataRams, 1 E-Sampler, and 3 E-BAMs) were deployed (Table 1) along the north-south highway 97 and parallel to the west at sites on the Sinlahekin Rd. Two perpendicular transects going east-west were created by placing instruments along highway 20 in the towns of Republic and Kettle Falls, and in central Washington in the towns of Nespelem and Fruitland (Fig. 1). The monitors were deployed into the field on August 1, 2006 and were retrieved October 10, 2006 (Fig. 4). Visits were made to the sites for maintenance throughout deployment. Although some monitors shutdown due to power failure, seven of the twelve monitors ran for a month or longer.

## 2007: Regional fire outbreak in Idaho

In August 2007, lightning strikes sparked several fires in central Idaho and western Montana. Most of these fires were located in complex mountainous terrain or narrow river canyons. The smoke generated from this regional wildfire event heavily impacted the communities of western Montana.

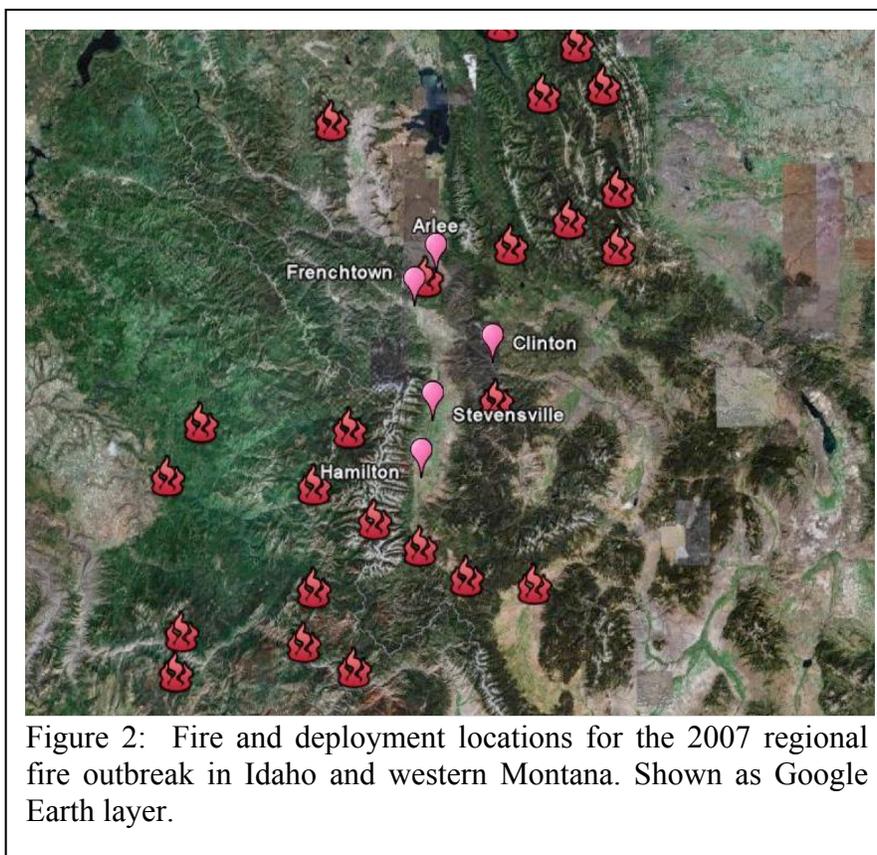
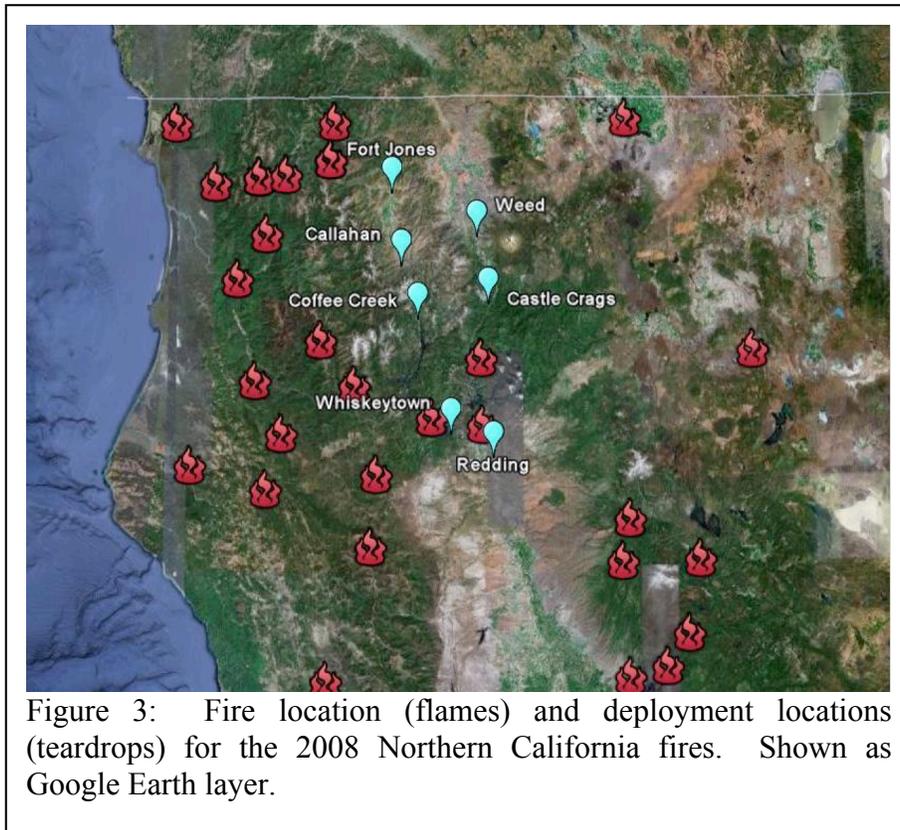


Figure 2: Fire and deployment locations for the 2007 regional fire outbreak in Idaho and western Montana. Shown as Google Earth layer.

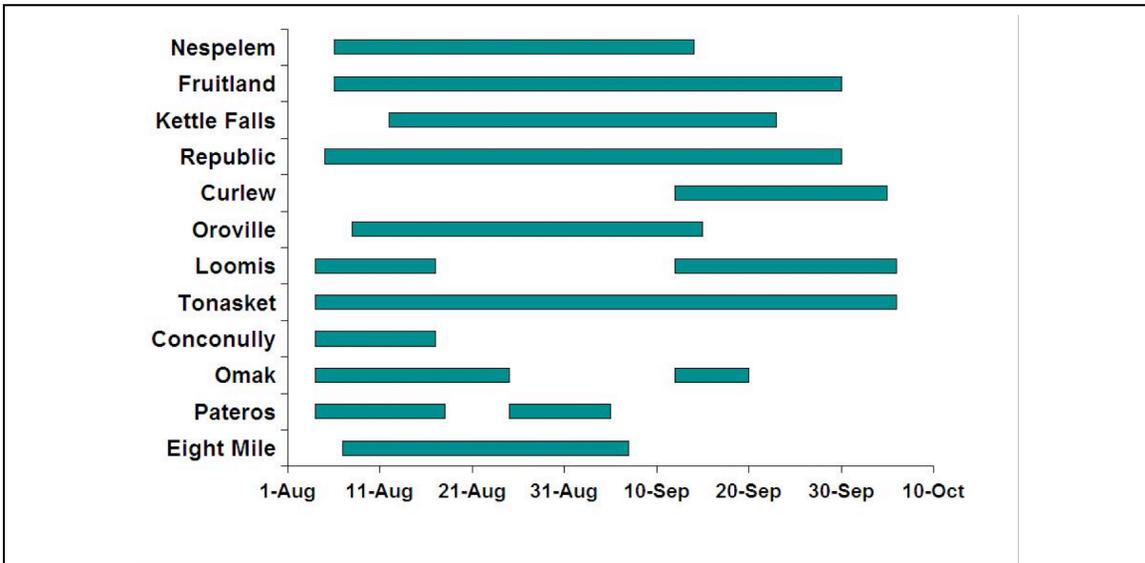
Twelve monitors (Table 1) were deployed in western Montana (Fig. 2). 3 monitoring sites were placed along a north-south transect in towns on highway 93 with Arlee as the northern most site and Hamilton as the southern most site. A perpendicular east-west transect was set up with 2 sites along the I90 freeway ranging from Frenchtown as the western most site and Clinton as the eastern site. At the monitoring sites, two or three monitors were placed together and  $PM_{2.5}$  concentration data were collected side-by-side (Fig. 5). This was done to help give us an expected relative range of variability from instrument type to instrument type. The monitors were deployed for one month, starting August 28 and operating until September 25. Most of the monitors functioned for ten or more days and several operated for more than twenty days.

### 2008: Regional fire outbreak in California

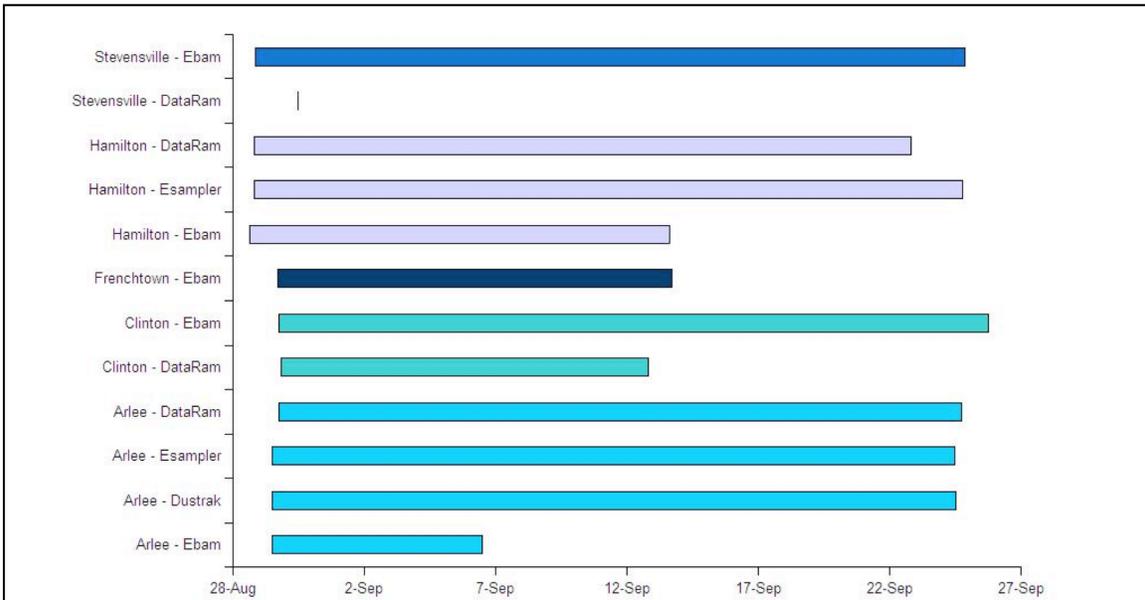
An unprecedented lightning strike event occurred in northern California on June 20, 2008 sparking thousands of small fires in the region that turned into several large fire complexes. The fires were in generally remote locations and in terrain consisting of narrow valleys with steep valley walls. These valleys were conducive to deep inversions that broke late in the afternoon due to heavy smoke near the valley floor. Although the fires were largely in remote locations, the size and number resulted in large amounts of smoke throughout the region and both rural and urban communities were impacted.



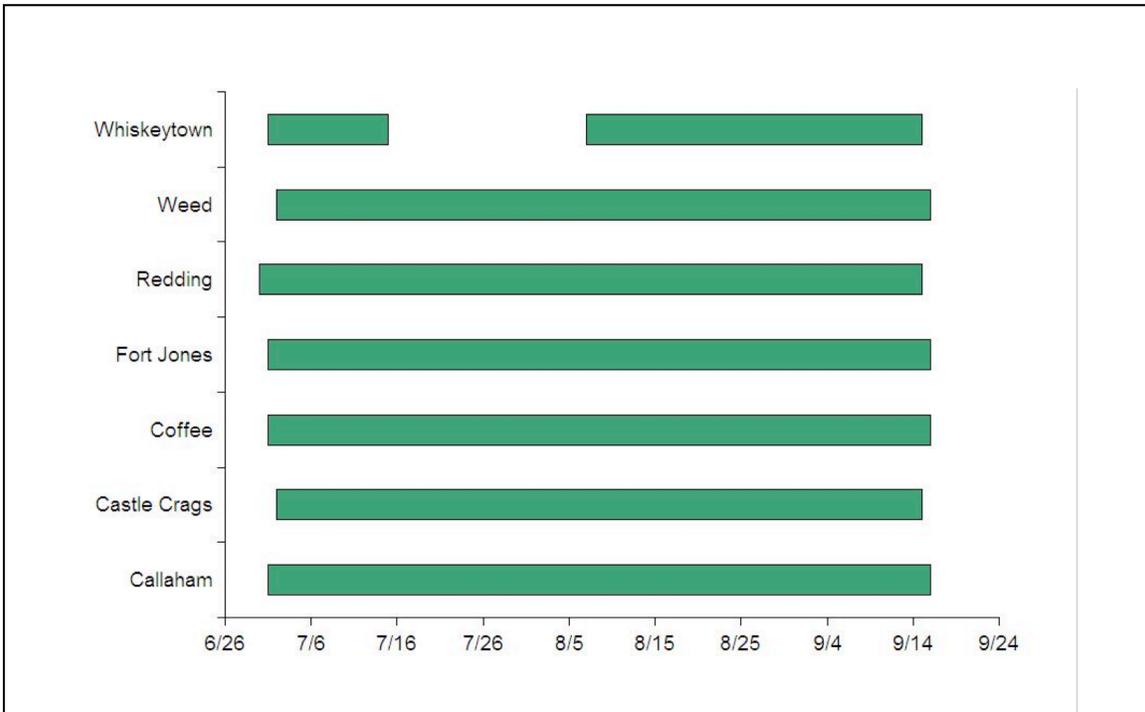
To observe regional smoke concentrations, seven monitors (Fig. 3) were deployed along two parallel north-south transects ranging from Redding, CA in the south, along freeway I5, to Weed, CA in the north. The second, parallel transect started in the south in Whiskeytown, CA and ran along highway 3 to Fort Jones in the north. The monitors were deployed on June 30 and were removed on September 16 (Fig. 6). All deployed monitors were EBAMS (Table 1) and majority of the monitors ran for the entirety of the deployment period.



**Figure 4:** Location sites of the PM<sub>2.5</sub> observation monitors during the 2006 Tripod rapid response in Washington. The bars indicate the duration the monitors collected data. The gaps are times due to maintenance and power failures.



**Figure 5:** Location sites of the PM<sub>2.5</sub> observation monitors during the 2007 rapid response in Montana. In 2007 multiple monitors of different types were deployed to the same site location (bars of the same color represent the same site, but different monitor type). The bars indicate the duration the monitors collected data.



**Figure 6:** Location sites of the PM<sub>2.5</sub> observation monitors during the Northern California rapid response. The bars indicate the duration the monitors collected data. The gaps are times due to maintenance and power failures.

## Calibration of BlueSky

Throughout the period of the study, comparisons were made between the rapid response observations and the BlueSky-enabled smoke predictions. At the time of the study, BlueSky used a particular pathway (Table 2, 2006 column). The BlueSkyRAINS-West project had found that the simulated plume footprint showed good agreement with overall plume shape as measured by satellites, but that the ground concentrations had underpredicted the observed values. At the time this was believed to be due to the resolution of the model combined with the very narrow canyons in Idaho and Montana where the monitors were located. The focus at this point was on generating finer scale predictions and tuning model parameters to better fit the BlueSky output to the observations.

**Table 2.** The differences in pathways through the BlueSky Framework as implemented in the FCAMMS smoke prediction systems in 2006 and 2009

<b>Modeling Step</b>	<b>2006</b>	<b>2009</b>
BlueSky Version	2.5	3.0
Fire Information data feed	ISC209	SMARTFIRE
Number of cores/fire	1	1 to many
Consumption	EPM	CONSUME3.0
Emissions	EPM	FEPS
Plume Rise	embedded calculation	new modeling step
Meteorology model	MM5	WRF / NAM / GFS / MM5
Dispersion model	CALPUFF	CMAQ / HYSPLIT / CALPUFF

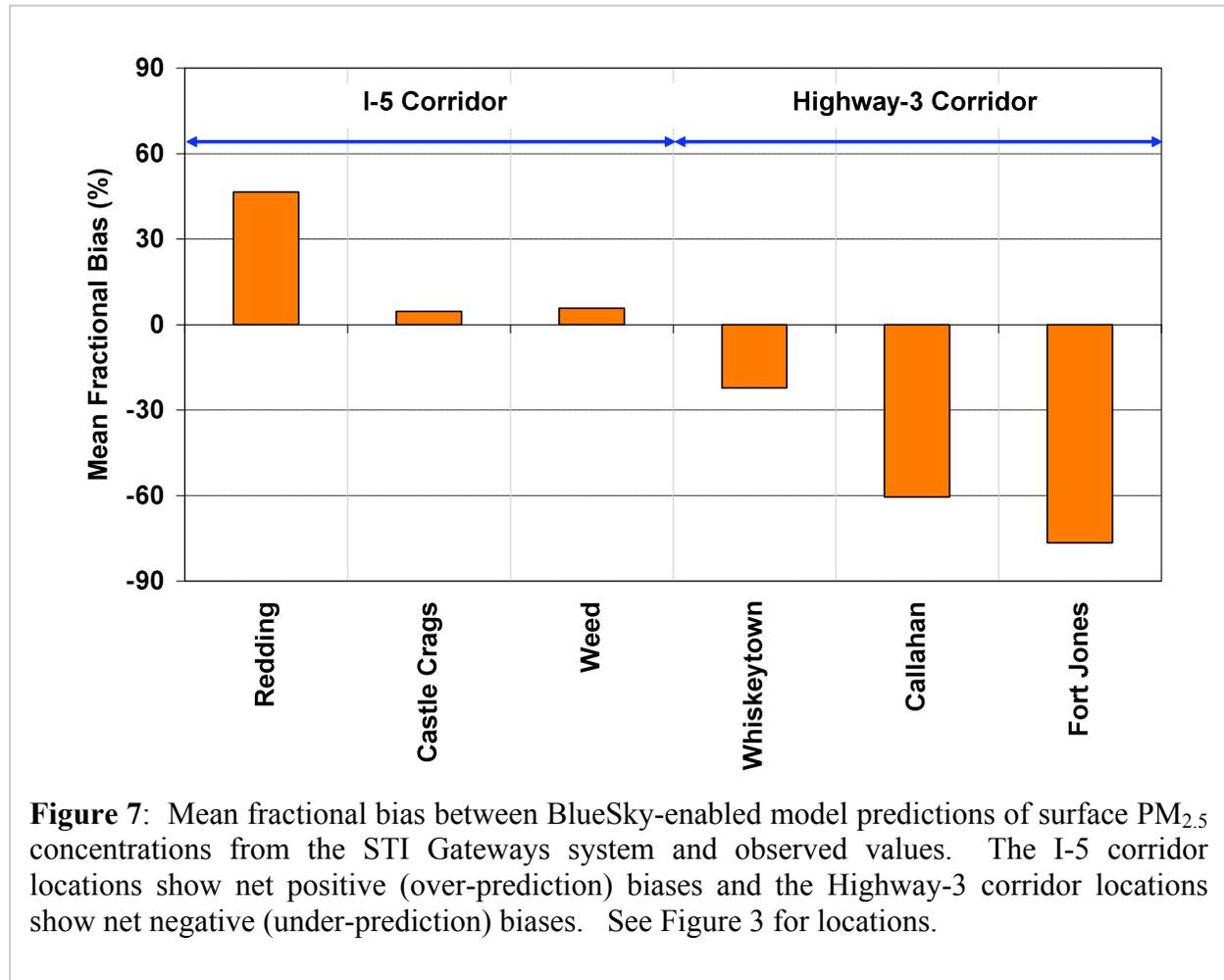
During the 2006 Tripod fire, monitors were placed in relatively flatter terrain, and higher resolution meteorological output were available. The results still did not significantly improve model – observation comparisons. The model output was found to be significantly (5x – 10x) lower than the observed predictions. These results pointed out larger structural issues within current smoke modeling that needed to be addressed. Since BlueSky is simply a collection of existing models, these issues could not be addressed through simple dispersion model tuning. Model tuning could raise ground concentrations somewhat, but not enough; a larger fix was needed. This was a major change of focus for this project – instead of performing multiple calibration runs, the focus became on finding the largest issues in predicting ground concentrations.

Specific issues were identified through simple experiments (hard coding of the model to behave in different ways). Fire information was determined to be questionable at best, including the daily fire growth. The existing BlueSky used ICS-209 reports for fire information; both the geo-referencing of these reports and their reporting of daily fire growth were at issue – on some days cumulative fire size was found to shrink from day to day. The lack of smoldering in the emissions calculations of BlueSky were called into question as potential source of reduced ground concentrations, particularly near the fire. But perhaps the biggest uncertainty identified was in the plume rise scheme. BlueSky used CALPUFF which has a built in plume rise schema. Because of the reliance on ICS-209 information the entirety of the fire was being considered as a single plume and run through the built-in schema which was developed through smokestack observations. Simple experiments (Larkin et al, 2009) showed that mild assumptions that broke the fire into several plumes (sometimes called “cores”) had dramatic impact on ground concentrations and could be a major source of the observed model error.

Based on this analysis, major changes to BlueSky were undertaken. These changes were too large to be part of this project but instead involved modifying a NASA ROSES grant (2005-2009) that was designed to make BlueSky more operational. While numerous changes to BlueSky were made under the NASA project, specific ones important here are: the separation of plume rise into its own modeling step (instead of relying on the embedded plume rise schemas

within the dispersion models); making fuel loadings and consumption models fully modular, including the rewriting of aspects of the FEPS and CONSUME3 code to make this work; and the creation of the SMARTFIRE fire information system that combines ground report data from the ICS-209 system with satellite information in order to gain better geo-referencing and spatial distribution of the fire information. None of these changes were explicitly part of the original NASA proposal, but were incorporated due to issues identified through the resulting rapid response observations (this JFSP project).

These structural changes to BlueSky were only recently completed (2009) and the new predictive setup is listed in Table 2 (2009 column). Use of SMARTFIRE data not only allows for better geo-referencing but also for multiple fire plumes from a single fire as SMARTFIRE is capable of detecting when a “fire” is made up of separate burning cores. Use of the FCCS-CONSUME3 pathway allows for smoldering to be explicitly calculated and input into the dispersion model separately (in the lowest layer). Creation of the plume rise modeling step allows for better and newer plume algorithms to be adopted regardless of the dispersion model’s internal plume rise algorithm. This last improvement has been realized for both HYSPLIT and CMAQ, but due to the structure of CALPUFF only CALPUFF’s internal schema can be used when it is selected as the dispersion model choice. This is part of the rationale why the newer FCAMMS and other predictive modeling setups enabled by BlueSky no longer use CALPUFF.



Analyses of the Northern California rapid response monitors shows that, for the first time, the smoke model predictions are now both under- and over- estimating the observed ground concentrations (Fig. 3), indicating that the changes identified by this project and made to BlueSky have allowed for significant improvements in smoke predictions. These results are due to changes done on the modeling pathway, new fire information systems, and large structural changes to the Framework itself. Additional work is still needed to investigate all of the Framework pathways and other model parameter choices that are now available in the new BlueSky system (version 3.1). Some of this work has now be carried out and is continuing to be carried out through through the Smoke and Emissions Model Intercomparison Project (SEMIP) where the data gathered here forms the basis for 2 test case scenarios.

## Key Findings

### Monitor placement best practices

#### **Twice the modeling grid scale is the finest scale for monitor deployment**

Observation monitors placed far enough apart so that no two are in the same modeling grid cell (12 km to 24 km apart) nor in adjacent cells are an efficient way to provide data that can be used to evaluate gridded predictions. Closer placement results in numeric issues with the modeled predictions (based on spatial NyQuist frequency). Monitors can also be placed within one grid cell for model grid cell/point observation scale mismatch analysis, but this is less useful for large scale transport validation.

#### **Monitors should be left on to monitor non-fire periods**

To register plume drift at the observation location background values must be measured sometime during deployment.

#### **Monitors should be used to supplement existing networks**

This increases the effective pool of monitors but also adds needed non-fire period information from the existing network. Ideally in combination the existing and rapid response monitors should be placed in transects that run perpendicular and/or parallel to each other.

#### **Length of deployment is critical**

To capture smoke plume drift and meander it is best to deploy instruments when the single or multiple fire event remains uncontained for ten or more days.

#### **Different monitor types show good agreement, but uniformity is better**

In 2007 several monitors were co-located to give an expected range of variability between observation data due to the monitors themselves (Fig. A3). For most of the deployment the instruments tracked reasonably well with each other. The DustTrak (at the Arlee site) performed poorly, however, due to mechanical difficulties. These agreements were better than expected, but analysis was still easier when a uniform set of monitors were used.

## Real-time broadcast of the observed values is critical

### **It assists decision makers during the fire events**

The observed PM<sub>2.5</sub> concentrations were broadcasted in real-time to the web via satellite. Decision makers and the general public found the real-time data a useful tool for monitoring the air quality conditions. Local air quality managers expressed gratitude for the extra monitors and the real-time reporting of the data.

### **It makes deployment easier**

Real-time broadcast of data also interested parties that otherwise would not have participated and/or would have objected to monitoring being done in their area.

### **It saves money**

By being able to remotely check the status of the monitor, less travel time is needed and it ensures that monitors are not incorrectly placed or that bad data are being recorded.

### **Observational data can fix a bad forecast**

Often forecasts go bad by being spatially or spatiotemporally ‘off’ rather than completely wrong. Real-time data allows the forecaster to better interpret the model prediction – for example by realizing that the smoke plume is hitting 50 miles to the south of where it was predicted to hit.

### **High hourly observational data peaks can compromise a monitor**

The observational data show that PM<sub>2.5</sub> concentrations can peak at very high values during the life of the fire(s). For the regional fire events the concentrations remained elevated for long periods of time (Fig. A2), in some cases exceeding the National Ambient Air Quality Standards for PM<sub>2.5</sub>. The observations show that a plume can drift quickly over a site or remain over a location for multiple days (Fig. A2). In addition to monitors typically having correspondence issues at high concentrations, such high concentrations can easily clog filters and cause other problems. Several monitor issues were due to high smoke values, and these problems were also seen in the in-situ monitoring networks.

## Observational datasets are in high demand

The data from the field campaigns were highly sought after in real-time by local fire officials and public health entities. In addition, some citizens took to actively monitoring their location, in one case using the data to be able to stay longer than they would have otherwise felt comfortable.

After the fires, the data have been sought for after action reports and data almanacs. Additionally the SEMIP project is using the data for test case validations. Data from all three campaigns can be seen and downloaded at the project website (<http://airfire.org/projects/jfsp/rapid-response-obs>).

## BlueSky is much improved

### **Classical model calibration was not sufficient to address the needs of smoke prediction**

Model-observation differences were analyzed during the Tripod Fire of 2006 and found to be too large to be addressed using classical model calibration techniques that involve simple model parameter tweaks. Gross scale underprediction of ground concentrations were found not to be addressable either by changing existing model pathway settings or by model resolution improvements. Further, and more extensive changes to the fire information ingested, the models used, and the development of new schemas for plume rise were found to be necessary. We note that even course scale resolution predictions now outperform previous predictions that we done on finer grid resolutions.

### **Data used to adjust BlueSky modeling pathway used for smoke predictions**

The fuel consumption model was changed from EPM to CONSUME3, which was linked to the FEPS emissions model. Plume rise was determined to be a major factor in underprediction and adjustments were made to enable multi-core plumes for fires with spatially disaggregated fire detects. SMARTFIRE was added as the fire-information feed. SMARTFIRE is the fire information system that merges ICS-209 information reports with satellite hot spot detects from NOAA's HMS; this data contains fire location and size and is used as input feed in BlueSky. Together these improvements have greatly improved BlueSky accuracy.

### **CALPUFF is not amenable to necessary plume rise changes**

Significant development was done to create a separate modeling step for plume rise, removing it from the dispersion model. The Framework now outputs files that can be used by the CMAQ system and now is enabled to run HYSPLIT, thereby allowing easy modifications and testing of different plume rise schemes. CALPUFF proved to be difficult to separate from its plume rise scheme. Modifying the plume rise scheme for CALPUFF requires making changes to the CALPUFF code itself, because CALPUFF is a privately developed code this would require working with the CALPUFF programmers. In part because of this difficulty, most BlueSky-enabled smoke prediction systems do not use CALPUFF.

### **There is still much to improve**

Despite these improvements, analyses of BlueSky-enabled predictions during the California fires of 2008 still show error, in some cases significant error. Smoke predictions are now found to both under- and over-predict smoke observations. Early analyses who BlueSky-enabled predictions grossly underpredicting the observations. Analysis of the predicted concentrations for the California fires shows general over-prediction of ground smoke concentrations. Yet during peak concentration periods underprediction occurred. This indicates a spatiotemporal misrepresentation within the modeling pathway. The source of this misrepresentation could come from the simulated meteorology (i.e. wind speeds, atmospheric stability) and/ or rate of consumption of fuels. This issue is still a source of active research.

## **New scheme for probabilistic interpretations based on proven model/observation correspondence**

Models are merely approximations to the real world. To be useful they need interpretation from model-space to observed-space. Ideally the correspondence is exact and the interpretation is easy, this is rarely the case for complex process modeling (i.e. weather and smoke). By comparing the simulated PM<sub>2.5</sub> data to the observed data we have generate a way to probabilistically interpret the model forecast into a real-world prediction based on past performance. The result is a forecast more in line with weather forecasts (e.g. ‘30% chance of showers’) and details the likelihood that the location will experience mild, moderate, or severe smoke based on the model prediction. The basis for this approach is threshold analysis with a variable threshold using an equation of the form:

$$Model_{VALUE} > Model_{THRESHOLD} = \text{probability}( Obs_{VALUE} > Obs_{THRESHOLD} )$$

This type of threshold analysis can be used as a baseline for improvement of the modeled data in future applications (i.e. through SEMIP; see <http://semip.org> for more information).

## **Management Implications**

### **Real-time observations extremely useful**

During the 2006, 2007, and 2008 fire events air quality managers and incident command (2008) used the real-time access to the observed data. The Wenatchee and Okanogan health representatives (Tripod, 2006) and California Air Resources Board (CARB, 2008) expressed gratitude for having additional PM<sub>2.5</sub> monitors in the northern part of the state during the fire event. Each field deployment was marked by managers exploring methods of obtaining similar real-time observations during future fire events.

### **Real-time observations can help fix model forecasts**

During the 2008 regional fire event the real-time data were called upon by professional air quality forecasters to determine if the model simulated surface concentrations within reason. The real-time data allowed forecasters to fine tune their understanding of the predictions before submitting their forecast to managers and the public.

### **This worked served as base for the Emergency Smoke Response System (ESRS) prototype**

The success of the real-time observations used on the Tripod Fire helped to create the ESRS prototype that was invoked in Southern California in 2007 and Northern California in 2008 – the first time that enhanced smoke and fire weather predictions and observations were funded by fire suppression. Work is underway to determine whether increased smoke monitoring and forecasting can become a management resource that can be routinely called up for future events.

### **Probabilistic smoke forecasts are likely the best we can do**

While not generally preferred by managers (per personal communication), the real-time observations indicate that smoke predictions of a specific value are likely to be misleading. Similar to weather forecasts, smoke prediction systems are simply too complex not to contain uncertainty and error. The best way to combat such error is to directly address it through tools

such as probabilistic forecasting. Qualitative assessment of the predictions can be made by viewing smoke concentration predictions from multiple pathways through the BlueSky Framework. This was implemented in summer 2009 for the Northwest Coordination Center (NWCC), with funding from the National Forest System and the Bureau of Land Management. Smoke predictions from five different pathways can be viewed by the NWCC.

## Related Work

### ESRS

Based on the extremely positive review of having real-time PM<sub>2.5</sub> monitors broadcasting data to a webpage during the Tripod Fire, the ESRS prototype was developed and implemented during the southern California Santa Ana fires of fall 2007. Modifications were made and the ESRS prototype was again launched during the regional lightening fire event in northern California. Currently, ESRS has four components: fine scale meteorological predictions, fine scale simulated smoke impacts, daily forecasts by a forecaster, and real-time monitoring of PM<sub>2.5</sub> with web access to the data.

### SEMIP

The datasets compiled during this project are valuable because the data were collected to assist with model analyses and evaluation. The data have been submitted to SEMIP where they will continue to be useful for BlueSky Framework pathway evaluation and other smoke modeling output analyses. In part because of enhanced data availability, the 2006 Tripod fire complex and the 2008 northern California regional fire event were selected as two of the initial SEMIP test cases. These data will be used in those test cases. The selected test cases can be found at [www.semip.org](http://www.semip.org).

### Data Almanac for 2008 California Fires

The data collected during the 2008 field campaign were submitted and used in a regional report for USFS Region 5. This report compiles all of the PM<sub>2.5</sub> data collected in the region from the monitors that were deployed in rapid response. The EBAMS deployed through this project were a part of a larger network that was used by the land managers, air quality regulators, and daily smoke forecasters.

### BlueSky Framework development

The BlueSky Framework has changed significantly from 2006 to 2009 (Table 2). For the Tripod fire (2006) version 2.5 (Larkin et al., 2009) was in use by the FCAMMS. For the regional fire events in Idaho and Montana (2007) and California (2008) BlueSky Framework version 3.0 was in use and produced output results closer to the observations.

The data collected during this project will be used to evaluate future upgrades to the BlueSky Framework. A test case that will accompany the distribution of the framework will include data from the northern California field campaign. BlueSky Framework information can be found at [www.blueskyframework.org](http://www.blueskyframework.org).

## Future Work Needed

### Enhanced cache of monitors with real-time uplink capability

Observation monitors are expensive and several are required in the field to produce enough data points to make the dataset valid for model performance evaluation. An enhanced cache of real-time monitors that are deployed by researchers and/or at request through ESRS will supplement the existing observation networks and existing instrument supply. While some EBAMS caches do exist, they are typically fully or near-fully booked making them unavailable during large fire events. Some monitors in the cache do not have satellite uplink capability making their data not available in real-time. Since these instruments are delicate and shipping over long distances can cause damage, having several regionally based cache sites will prolong the lifetime of the instruments. The observation monitors need regular maintenance and calibration before going into the field. Ideally, a knowledgeable technician would be stationed at each cache site and would maintain, calibrate, and prepare the instruments for the field.

### Designated deployment sites, monitor setup training, and contact list

Finding sites appropriate for monitor deployment is difficult, particularly in rural and remote locations. The monitoring sites must be secure, have a power source, and be located away from non-smoke sources. For example, fugitive dust sources (i.e. dirt roads, construction sites) would influence PM<sub>2.5</sub> concentrations giving a false positive for smoke presence. Usually, the best sites are federal ranger stations, offices, state and county parks, and city halls, museums, schools, etc. These sites are trustworthy and usually have one or more personnel interested in the ongoing study who are willing to keep an eye on the instrument.

There are regions of the country that are prone to smoke impacts (i.e. California, western Montana, etc.), creating an inter-agency, across federal, state, tribal, county, city network of known deployment sites would assist with rapid response and ESRS deployment of monitors. This list would contain site location, contact, power location, and any other important information. The paperwork required to place monitors at that site (i.e. Forest Service placing a monitor on Parks land) would be ready to put in place and the personnel at the site location would be aware that they are apart of this network. Establishing this network ahead of time will assist with faster deployment times.

### Mechanism for enabling enhanced monitoring and modeling (e.g. ESRS) as a fire suppression utility

Designation of a team of modelers and field personnel into a fire suppression resource would speed deployment of monitors and modeling data to regions with active regional fire events. Even during the prototype ESRS deployment, administrative hurdles slowed the process down. Mechanisms to make such activations easier would benefit both managers and researchers.

### Observation network for predicted comparison during smoke events

Placing the monitors in a pattern designed with the model grid(s) in mind proved extremely useful for model result analyses. The observed data were used both in real-time to modify daily forecasts and in historical analyses to evaluate the performance of the modeling pathway through the BlueSky Framework. The value of using the data in this manner would have been much lower had the observation monitors been deployed close together such that more than one

monitor was within a single model grid cell. Deploying monitors on a grid that matches the modeling grid for the region will assist both with daily smoke forecasts and historical analyses.

### Standard database for aggregating both in-situ monitoring networks and mobile monitors

The data collected were most useful when used in conjunction with existing monitoring networks. Yet no unified dataset exists that captures all of the established monitoring network data as well as mobile monitor data. Some efforts are being made to do this in real-time using the EPA’s AirNow database, but this is far from uniform at present. The lack of a coherent data structure for capturing such data means that observations or the meta-data needed to understand the observations becomes lost over time resulting in reduced efficiency of monitoring efforts.

## Deliverables Crosswalk Table

Deliverable	Description	Delivery Dates
OBSERVATIONS AND IMPROVEMENTS		
Datasets of observations taken	As each smoke monitoring effort is completed, data will be gathered and compiled with documentation and explanation. This data will then be made available to federal, state, and local agencies, as well as the public for general use.	COMPLETE
Model improvements	Analysis will be on-going, and any model improvements will be incorporated into daily prediction systems used by clients as quickly as possible. After all of the observational data is collected a more intensive period of analysis will commence yielding a collection of finalized model improvements.	COMPLETE
PRESENTATIONS		
Presentations at user training sessions	This work will be discussed with users by incorporating it into on-going training efforts. These occur at least 2x /year.	COMPLETE
Presentations at annual meeting	This work to be discussed with users and researchers through a dedicated presentation and discussion at the BlueSky annual meetings	COMPLETE*
Presentation at scientific conferences	We will publicize this work at scientific meetings	18 COMPLETE/ MORE COMING**
Presentation at JFSP meeting	We will present this at the JFSP annual meeting as appropriate.	NOVEMBER 2009***

REPORTS		
Journal Articles	We will publish 2 journal articles on this work.	FORTHCOMING****
Conference Proceedings	We will publish conference proceedings for the scientific conference presentations.	COMPLETE/ CONTINUING**
Technical Report	We will publish a technical report on this work.	FORTHCOMING****
Final report	A final report will be prepared for the JFSP.	COMPLETE

Notes:

\* The 2007 BlueSky Stakeholder’s meeting in Winthrop, Washington was dedicated to the experiences of the Tripod Fire and gathered managers, legislators, and scientists to discuss lessons learned.

\*\*This work has been discussed at various scientific conferences (see below), and more presentations are scheduled for this fall at various meetings. We have published conference abstracts and short descriptions at various meeting and conferences. More are scheduled with upcoming talks.

\*\*\*Several journal articles covering this work in conjunction with improvements to BlueSky and other related work are in progress and expected to be completed in FY2010.

## Presentations

The 2007 BlueSky Stakeholders Meeting was held in Winthrop, Washington near the site of the Tripod Fire, and a special session including local forest managers, air quality regulators, public health officials, and congressional staffers was held.

Brown T., Larkin N.K., Sullivan D., Podnar D., Reinbold H., Abatzoglou J., Raffuse S., Solomon R., Strand T.M., Procter T. 2008. Historic California wildfires leads to Emergency Smoke Response System. Pacific Coast Fire Conference: Changing Fire Regimes, Goals and Ecosystems, San Diego, California, December 1-4.

Chinkin L.R., Strand T.M., Brown T., Goodrick S., Larkin N.K., Raffuse S. M., Solomon R., Sullivan D.C., Lahm P. 2009. Development and applications of systems for modeling emissions and smoke from fires: the BlueSky smoke modeling framework, SMARTFIRE, and associated systems. National Air Quality Conferences, Dallas, Texas, March 2-5.

Krull C., Rorig M., Larkin N.K., Moore M., Strand T.M., Potter B. 2008. AirFire BlueSky Field Experiments. 2008. 2008 BlueSky Modeling Stakeholders Meeting, Boise, Idaho, May 20-22.

Krull C., Rorig M., Larkin N.K., Solomon R. 2007. Rapid response field observations in support of improving BlueSky smoke predictions. 7th Fire and Forest Meteorology Conference (AMS), Bar Harbor, Maine, October 22-26.

Krull C., Rorig M., Larkin N.K., Solomon R., Mickler R., Bailey A. 2007. Field observations in support of improving smoke predictions. 2nd Fuels Management and Fire Behavior Conference, San Destin, Florida, March 26-30.

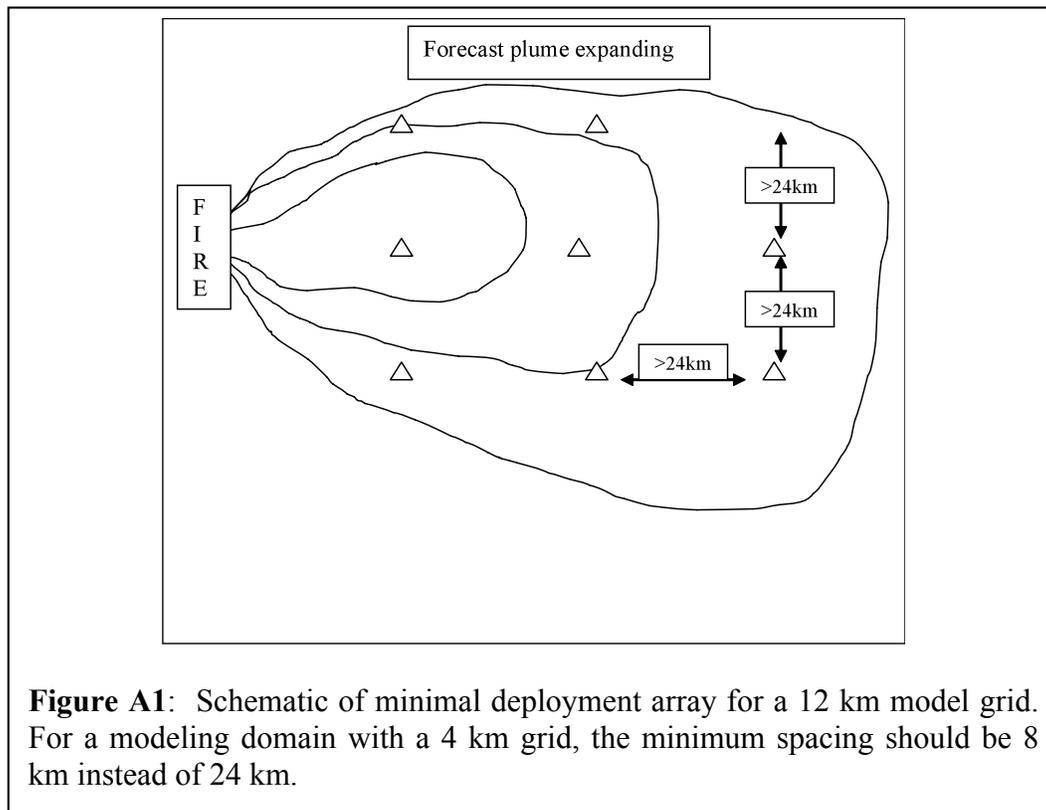
- Larkin N.K., Strand T.M., Solomon R., Raffuse S., Sullivan D., Chinkin L., Lahm P., Acheson A., Brown T., Friedl L. 2008. BlueSky, SMARTFIRE, SEMIP and associated efforts. NASA Biomass Burning Coordination Meeting, University of Maryland, College Park, MD.
- Larkin N.K., Lahm P., Sullivan D., Strand T.M., Solomon R., Krull C., Rorig M., Potter B., Wheeler N., Raffuse S., Pryden D., Chinkin L. 2008. The state of smoke tools. California Air Response Planning Alliance, Air Quality in Emergency Response: Monitoring, Modeling, Messaging, and Media, Sacramento, California October 15-16.
- Larkin N.K., Strand T.M., Solomon R., Rorig M., Krull C., Sullivan D., Raffuse S., Pryden D., Ovard C., Chinkin L., O'Neill S., Friedl L., Knighton R. 2008. Prototyping the Emergency Smoke Response System (ESRS). WESTAR Fall Business Meeting. Seattle, Washington, October 1-3.
- Larkin N.K., Raffuse S., Solomon R., Sullivan D.C., Chinkin L. 2007. BlueSky: the next generation. BlueSky Annual Meeting, Winthrop, Washington, May 22-24.
- Larkin N.K., Sullivan D.C., Raffuse S., Solomon S., Pryden D., Chinkin L., Friedl L. March 2007. Current operations and ongoing development of the BlueSky system of smoke impact predictions. 2nd Fuels Management and Fire Behavior Conference, San Destin, Florida, March 26-30.
- Solomon R., Strand T.M., Brown T., Larkin N.K., Raffuse S., Sullivan D., Craig K., Wheeler N. 2008. Evaluation of wildfire smoke forecasts in the southern California land-sea breeze environment. AGU Fall Meeting, San Francisco, California, December 15-19.
- Solomon R., Larkin N.K., O'Neill S., Vaughan J. October 2007. Evaluation of the BlueSky smoke modeling framework using AirNow monitors. 7th Fire and Forest Meteorology Conference (AMS), Bar Harbor, Maine, October 22-26.
- Strand T.M., Larkin N.K., Solomon R., Raffuse S., Sullivan D., Craig K., Pryden D., Wheeler N., Chinkin L., Brown T. 2009. The BlueSky Framework. Biomass Co-op Meeting, Monterey, California, June 25-26.
- Strand T.M., Larkin N.K., Solomon R., Raffuse S., Sullivan D., Craig K., Pryden D., Wheeler N., Chinkin L., Brown T., Procter T. 2008. New tools for fire and smoke and their application to the 2008 California wildfires. Pacific Coast Fire Conference: Changing Fire Regimes, Goals and Ecosystems, San Diego, California, December 1-4.
- Strand T.M., Potter B.P., Larkin N.K., Solomon R., Rorig M., Krull C. October 2008. AirFire Smoke Research. PNW Research Station Science Summit, Hood River, Oregon, October 29-31.
- Sullivan D.C., Chan A., Knoderer C., Brown T., Larkin N.K., Raffuse S., Solomon R., Strand T., Wheeler N., Craig K., Krull C., Moore M., Rorig M., Procter T. December 2008. Emergency Smoke Response Systems: Air quality forecasts and monitoring during the 2008 California wildfires. Pacific Coast Fire Conference: Changing Fire Regimes, Goals and Ecosystems, San Diego, California, December 1-4.
- Sullivan D.C., Raffuse S.M., Wheeler J.M.W., and Craig K.J. (2008) Emergency smoke response systems. California Air Response Planning Alliance, Air Quality in Emergency

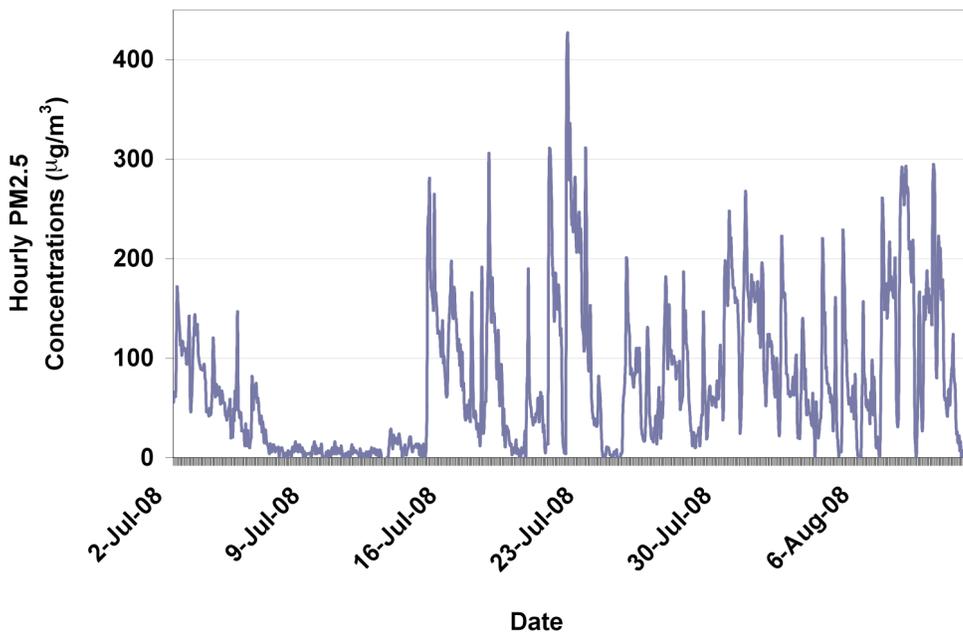
## References

- Chen J, Avise J, Lamb B, Salathé E, Mass C, Guenther A, Wiedinmyer C, Lamarque J-F, O'Neill S, McKenzie D, Larkin N (2008) The effects of global changes upon regional ozone pollution in the United States. *Atmospheric Chemistry and Physics*. **8**, 15165-15205.
- Larkin NK, O'Neill SM, Solomon R, Raffuse S, Strand T., Sullivan DC, Krull C., Rorig M, Peterson J, Ferguson SA (2009) The BlueSky smoke modeling framework. *International Journal of Wildland Fire (IAWF)*, in press.
- McKenzie D, O'Neill SM, Larkin NK, Norheim RA (2006) Integrating models to predict regional haze from wildland fire. *Ecological Modeling* **199**, 278-288.
- Riebau A., Larkin NK, Pace T, Lahm P, Haddow D, Allen T, Spells C (2006) The 2005 BlueSkyRAINS-West demonstration project: final report. USFS PNW Research Station, Portland, OR. pp.38.
- Rolph GD, Draxler RR, Stein AF, Taylor A, Ruminski MG, Kondragunta S, Zeng J, Huang H-C, Manikin G, McQueen JT, Davidson PM (2009) Description and verification of the NOAA smoke forecasting system: the 2007 fire season. *Weather and Forecasting* **24**, 361-378.
- Wiedinmyer C, Quayle B, Geron C, Belote A, McKenzie D, Zhang X, O'Neill SM, Wynne KK (2006) Estimating Emissions from Fires in North America for Air Quality Modeling. *Atmospheric Environment* **40**, 3419-3432.

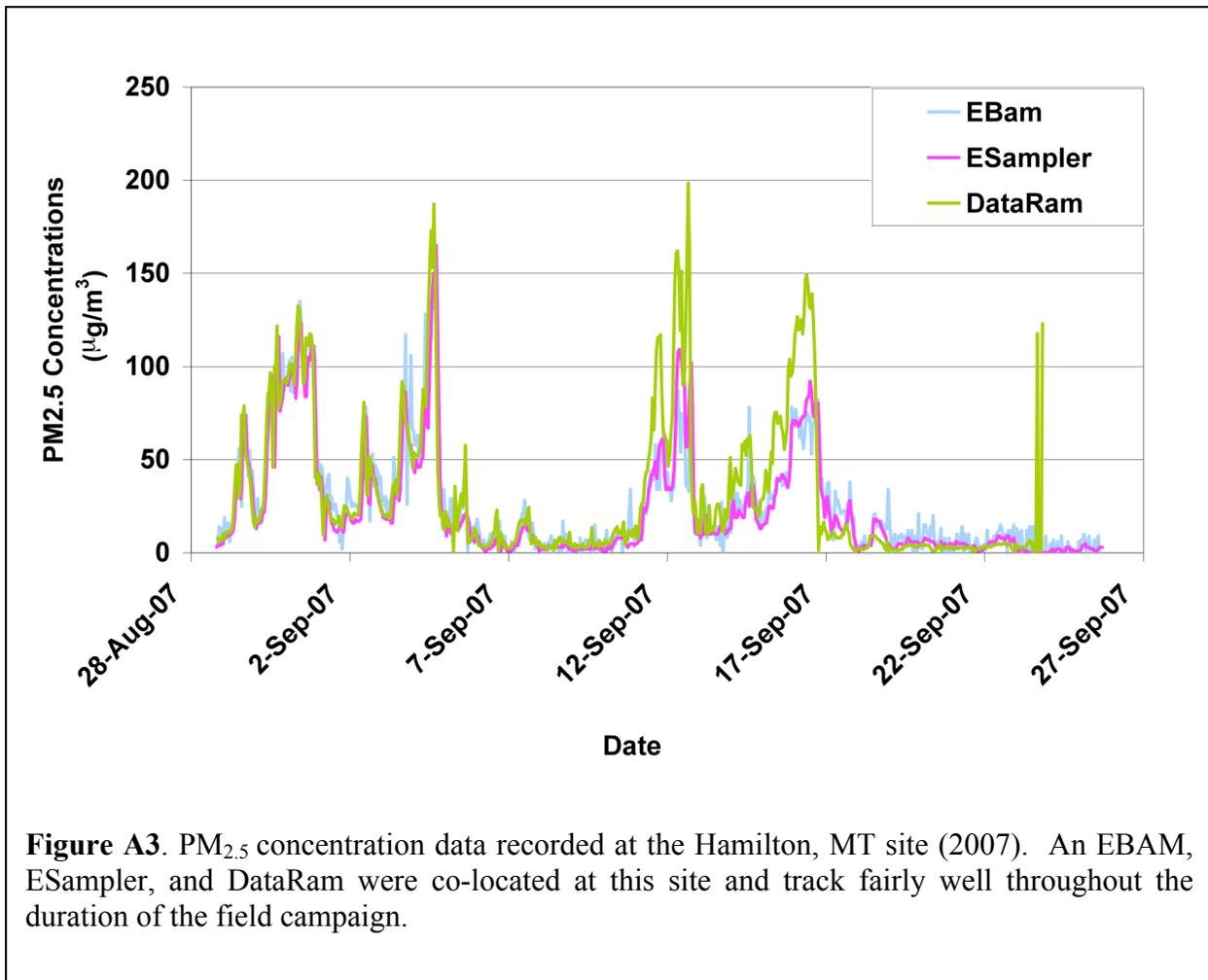
## Appendix: Additional Figures

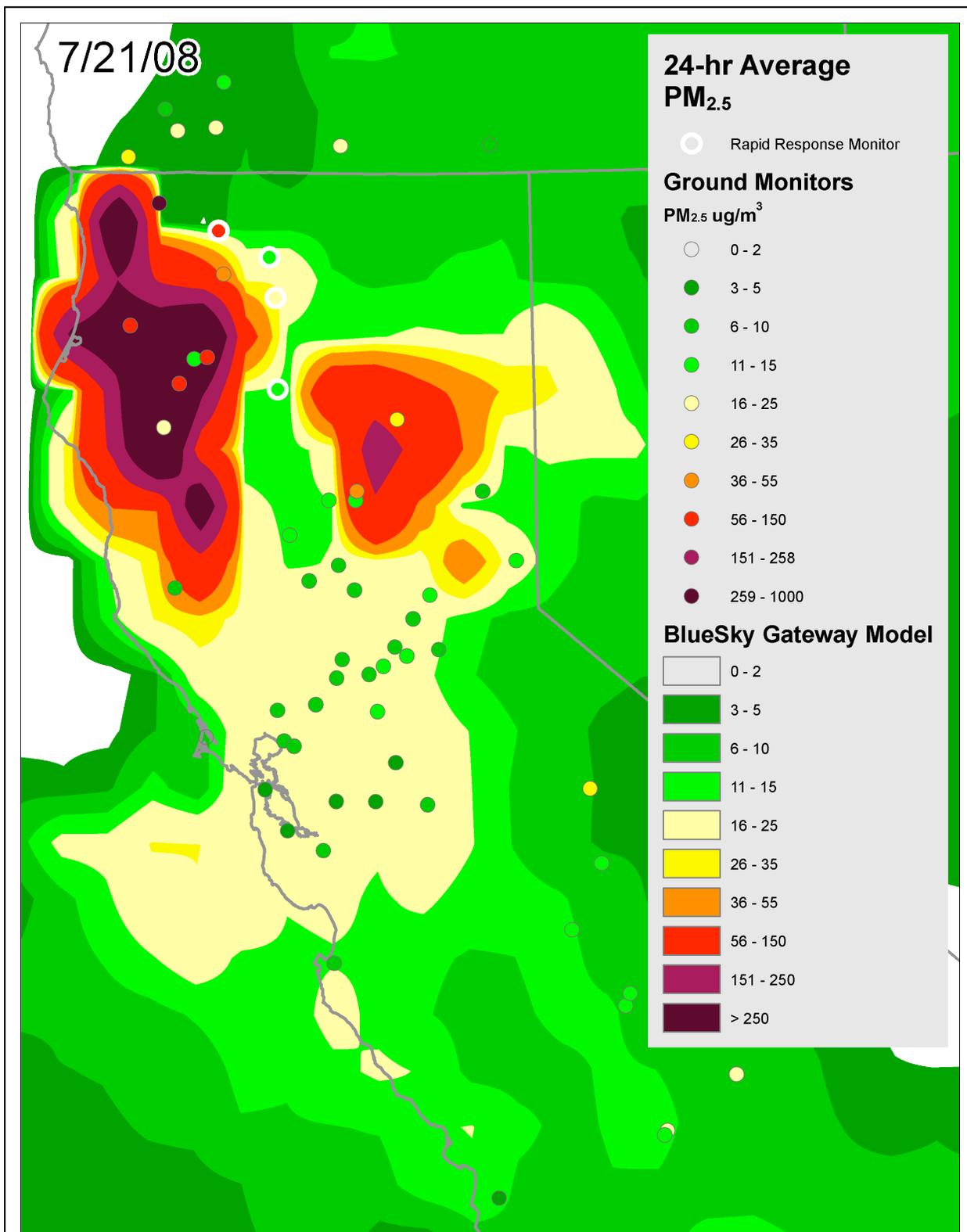
This appendix presents some additional figures referenced in the report. Even more data graphs and model comparison figures are available through links on the project website (<http://airfire.org/projects/bluesky/rapid-response-obs>).





**Figure A2.** Hourly PM<sub>2.5</sub> concentrations recorded at the Fort Jones site, during the northern California regional fire event (2008).





**Figure A4.** Northern California daily average (24-hr) PM<sub>2.5</sub> concentrations from the STI Gateway system enabled by BlueSky compared with ground observation data. Data shown are for the date 7/21/2008. Despite the course scale resolution of the STI Gateway system (36-km grid resolution), these predictions were found to outperform (Figure 7) finer scale predictions done previously using the older BlueSky setup (see Table 2).