# Improving meteorological data and forecasts for prescribed fire burn day decisions in the Lake Tahoe Basin

Final Report
December 2013

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This research was supported through an agreement with the USDA Forest Service Pacific Northwest Research Station, using funds provided by the Bureau of Land Management through the sale of public lands as authorized by the Southern Nevada Public Land Management Act (Round 10). The contributions of the Project Team are greatly appreciated, and without their efforts, this project could not have been undertaken.

# Executive Summary

This project addressed SNPLMA Round 10 Subtheme 3c – Understanding basin meteorology, and the issue of developing and/or improving meteorological data and monitoring tools for use in forecasting and making burn day decisions for prescribed fires. The products and deliverables from this project for the Lake Tahoe Basin included: 1) a 300-m gridded climatology of surface wind; 2) a 4-km mixing height climatology with associated transport wind; 3) 400-m resolution gridded operational forecasts of surface wind; 4) new weather station observations during the project period for an elevation transect within the Tahoe Basin; and 5) a customized smoke prediction website tool. These deliverables were developed from a suite of existing tools including the operational CANSAC forecast system at the Desert Research Institute, the Bluesky smoke prediction framework, WindNinja and field weather instruments. The project was developed in response to identified needs of improved meteorological information for burn day decisions after consultation with Lake Tahoe Basin Management Unit, California Air Resources Board, and USFS Predictive Services personnel.

## 1. Background and problem statement

Prescribed burning in the Tahoe Basin is a critical component of hazardous fuels reduction. In fact, prescribed fire has been identified as one of the most cost-effective forest management activities available for fuels treatments in Sierra Nevada forests (USFS 2007), as well as a critical component to maintaining ecological integrity. Currently, the multi-jurisdictional plan for fuel reduction and wildland fire prevention in the Lake Tahoe Basin identifies over 68,000 acres of fuels treatments that will be carried out over the next decade, either through first-entry or maintenance efforts (USFS 2007). Smoke management over the past decade has become a key factor in the ability to use prescribed fire for fuels treatments and hazardous fuels reduction (Kolden and Brown 2008). While air quality is a concern nearly everywhere prescribed fire is utilized, smoke impacts associated with prescribed fire are of particular concern in the Lake Tahoe Basin, where topography produces regular inversions that can exacerbate smoke impacts in the basin. While tools are available to assess smoke impacts, such as the Bluesky Smoke Modeling Framework (BlueSky Framework; Larkin *et al.* 2009), improvements to these tools and forecasts, and developing new support data is desired.

This project supports information needs based on recent conversations with and identified by the Lake Tahoe Basin Management Unit (LTBMU) Fire Management Officer and Fuels Officer, California Air Resources Board (CARB; provides burn permissions from air quality perspective in the LTBMU) and Predictive Services at North Ops in Redding, California (provides spot forecasts for prescribed burns in the LTBMU).

## 2. Objectives

The overall goal of the project is to provide the decision-makers (LTBMU Fire Management Officer and staff, CARB and Predictive Services) with improved meteorological forecasts and data for use in prescribed fire operational planning.

The specific objectives were:

1) Create a hi-resolution (100-m) gridded climatology of surface and upper level winds in the Basin
2) Produce a 4-km gridded climatology of mixing height
3) Develop operational forecasts of 100-m surface winds
4) Implement a transect of weather stations for wind forecast and inversion verification
5) Implement a customized smoke prediction website tool

## 3. Approach and methodology

### 3a. Approach

The California and Nevada Smoke and Air Committee (CANSAC) operational forecast system and data serve as the foundation for the project. CANSAC is a consortium of multi-agency fire weather and air quality decision-makers, managers, meteorologists and scientists in partnership to provide operational meteorological support for wildland fire and smoke management, and advance the scientific understanding of atmosphere and fire interactions for California and Nevada (Brown and Koracin 2007). The operational component of CANSAC is implemented at the Desert Research Institute (DRI) program for Climate, Ecosystem and Fire Applications (CEFA) in Reno, Nevada in collaboration with the CANSAC partners. CEFA consists of a team of scientists and technical experts whose purpose is climate and ecosystem studies and product development for wildland fire and resource management. The current partner members are comprised of agency representatives of directors, managers, researchers and operational personnel from USFS Region 5, USFS Pacific Southwest Research Station, National Park Service, Bureau of Land Management, US Fish and Wildlife Service, CARB, and the San Joaquin Air Pollution and Control District. CEFA manages and maintains the computing infrastructure used to produce the CANSAC products. Predictive Services and CARB utilize CANSAC products in the Tahoe Basin for spot forecasts, and prescribed fire declarations and allocations, respectively. LTBMU personnel use the information provided by Predictive Services and CARB as input for burn decisions.

The project tasks were stated as follows:

1) Twice daily forecast data from historical 4-km MM5 runs will be extracted from archive for the 5-year period May 2005 – May 2010. The extracted variables will include surface and upper level wind speed and direction, and the height of the planetary boundary layer (PBL). The PBL approximates the top of the mixing height. Hourly forecasts up to 12-hours starting with 00 and 12 UTC will be used to create a 4-km climatology of wind and PBL for each month Jan-Dec. The surface wind climatology will be used in conjunction with surface observations as input to generate a set of hi-resolution wind climatology described below. The 4-km model data will serve as the PBL climatology. Mean transport wind speed and direction associated with the PBL will also be calculated. Gridded model output is recommended for this analysis since there are insufficient surface observations to compute the wind climatology, and no observations exist to compute the mixing height climatology. Since the model short-term forecasts are recognized to have generally high forecast skill, it is suggested here that the wind climatology can be sufficiently computed from the model output.
2) The MM5 model output and available surface wind observations will be used as input into WindNinja (see below) to compute a 100-m gridded surface wind climatology for the Tahoe Basin. The hourly climatology will provide a hi-resolution look at the diurnal cycle of surface wind flow patterns across the Basin.

3) The MM5 model output will be used as input to the CALMET model (see below), which is currently utilized within the Bluesky Framework (see below) in operation at CANSAC, to create a 100-m gridded surface and upper level wind climatology for the Tahoe Basin. With increasing height from the surface, the wind field should become more aligned as friction decreases, but it is of interest to view the low-level climatological patterns given the need to disperse smoke from low intensity burns. The surface wind climatology from CALMET will be compared to WindNinja, as there are reasons to potentially combine them into a single climatology (see discussion below in section 5b).
4) The CANSAC forecast system will be enhanced by implementing a new 2-km Weather Forecasting and Research (WRF) model domain for the area, resulting in higher resolution wind and smoke particulate predictions. The WRF is not a significant change from MM5 in terms of basic output, and thus there should not be a concern of producing a MM5 based climatology and WRF forecasts in the project. Switching to WRF is primarily driven by available support for WRF (MM5 is no longer officially supported), the model runs faster than MM5 and has a capacity to incorporate a number of different analysis modules such as atmospheric chemistry, which will be used in future CANSAC related work.
5) WindNinja will be integrated into the CANSAC-WRF system to produce operational forecasts of 100-m gridded surface winds across the Tahoe Basin. Similarly, CALMET will be set up to produce forecasts at 100-m gridded resolution. It is known that WindNinja can produce output in a short amount of time, while CALMET is much more computationally intensive. Some timing tests will be required to determine the suitability of CALMET for hi-resolution operational forecasts, but given its current use at 4-km, and the acquisition of new computing hardware for CANSAC-WRF, we believe that CALMET can be run in reasonable computational time. See discussion in Section 5b below for comparison of WindNinja and CALMET.
6) Forecast verification of the hi-resolution winds during the project period will be undertaken by the combination of analyzing surface point observations (e.g. RAWS) and by deploying four to eight weather stations in a transect from near the lakeshore to the ridgeline. This is further described in section 5b below.
7) An enhanced user customized smoke prediction website tool for the Tahoe basin will be implemented that: a) allows users more options for input of data than currently exists, and b) provides faster smoke predictions based on input data. This tool will take advantage of the CANSAC-WRF operational system. This tool is further described in section 5b below.

## 3b. Methodology

### *WindNinja*

A numerical, mass-conserving model has been developed for simulation of surface winds in complex terrain for wildland fire behavior prediction. The model, called WindNinja, is limited to neutral atmospheric stability. WindNinja minimizes the change from an initial wind field while strictly conserving mass. The governing elliptic partial differential equation is solved numerically. A finite element discretization technique is used in conjunction with a simple hexahedral cell mesh. A Jacobi preconditioned conjugate gradient solver is used to solve the set of linear, algebraic equations. Wind simulations take approximately 1-15 minutes to reach convergence on a modern, single processor computer. A full description is given in (Forthofer 2007).

Typically, simulations are initialized using one wind speed and direction at a specified height above the ground; however, a new version is in development that allows initialization of the solution using gridded output from meso-scale models. Typically the domain is filled vertically assuming a neutral stable logarithmic wind profile and a roughness height for the dominant vegetation in the area (Wierenga 1993). The modeling domain is generally 40% larger than the fire area to reduce boundary effects.

This type of model appears to have certain advantages that align well with wildland fire applications. Computational cost is the major issue; WindNinja wind fields can be computed in seconds to a few minutes. The trade-off may be loss of some accuracy, especially in the wake region of a terrain feature as compared to models that include more physics (i.e. computational fluid dynamics (CFD) models that solve the momentum equation). Lopes (2003) investigated both a CFD model and a mass-consistent model for wildland fire application and found that on the lee side of an isolated hill, the CFD model more closely matched measurements. In his other simulations of complex mountainous terrain, however, the CFD results did not show any improvement over the mass-consistent model. This was attributed to a poor description of the approach flow, and/or local terrain features and roughness not accurately described in the complex mountainous terrain simulations. Another reason the mass conserving models like WindNinja may work well for fire applications is that they can be used in conjunction with large-scale prognostic weather models easily. Interpolation can be used to obtain an initial wind field for the mass-consistent model from the coarse grid weather model data. Such a combination would account for both the mesoscale meteorology (through the mesoscale model) and the local terrain effects (through the fine scale surface wind simulation model) (Petersen *et al.* 1997).

### *MM5, WRF and Bluesky*

CANSAC operational meteorological forecasts were originally generated using the Fifth Generation Penn State/NCAR Mesoscale Model (MM5; Grell *et al.* 1995) and the Bluesky Framework on a three-nested domain covering a large area of the Western US, and focusing on California and Nevada at the highest resolution (4-km) (see Figure 1). The MM5 model is initialized twice daily with the North American Meso (NAM) model 00 and 12 UTC forecast outputs. Hourly forecasts are made out to 72-hours. The physics options used in the model are given in Brown and Koracin (2007), and on the CANSAC website (http://cefa.dri.edu/COFF/coffframe.php), where the operational data may be viewed. It is relevant to note that all of the products are developed and designed with input from CANSAC's Operational Applications Group comprised of users within the CANSAC community. Figure 2 provides an example 4-km forecast wind product for the Lake Tahoe area. Figure 3 shows an example output map of forecast mixing height and transport wind for the Lake Tahoe area.

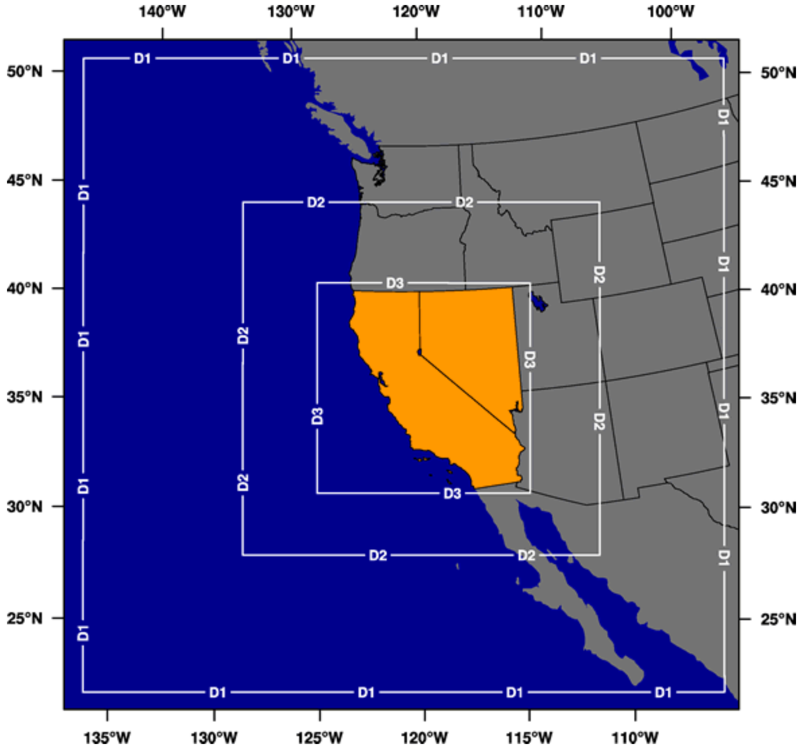


Figure 1. Domains (36-, 12- and 4-km) of the CANSAC MM5 forecast system.

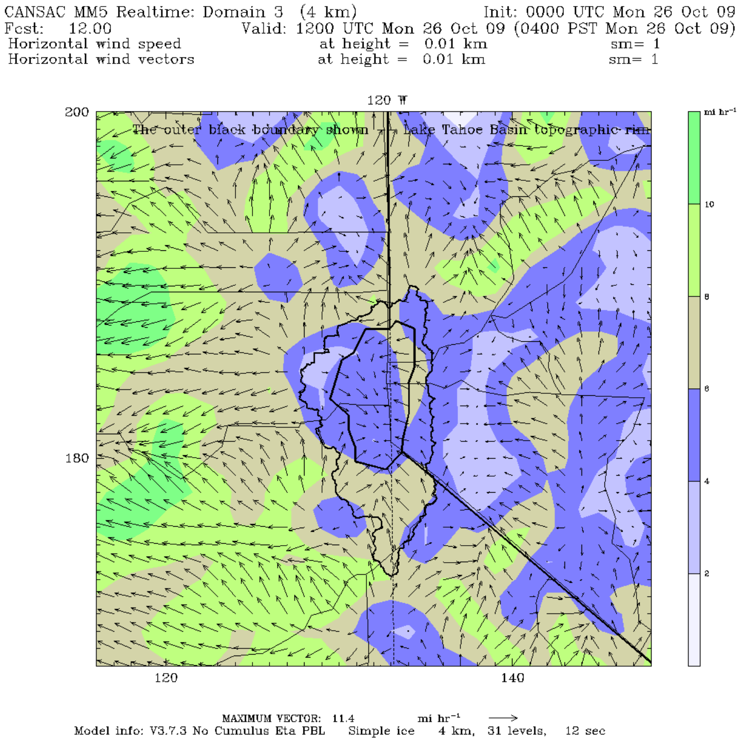


Figure 2. Example map of CANSAC forecast 4-km surface winds for the Lake Tahoe area. Wind speed is color shaded in mph, and direction by wind vectors. The lake and basin area are given by the respective polygons.

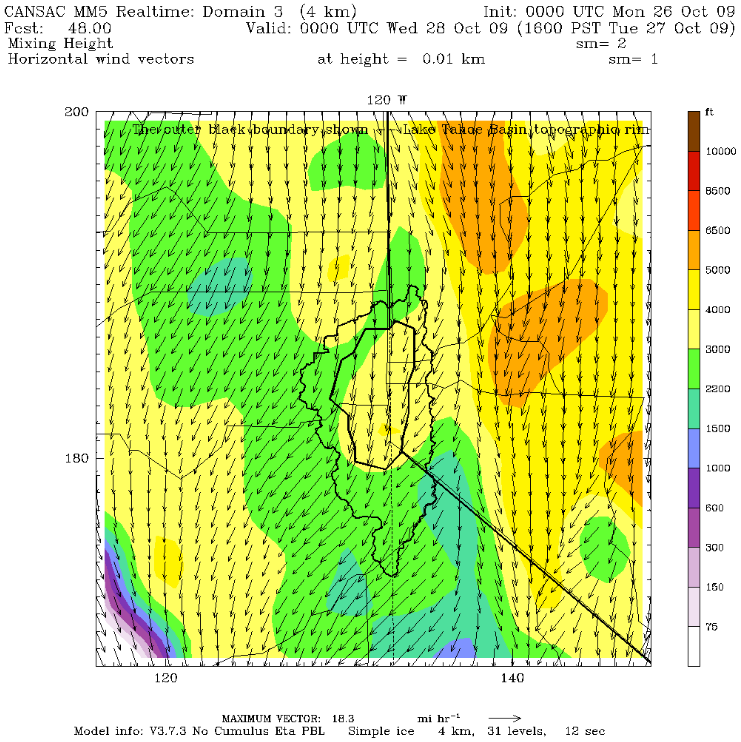


Figure 3. Example map of CANSAC forecast 4-km mixing height and transport wind. Height is color shaded in feet, and transport wind vectors denote direction and speed. The lake and basin area are given by the respective polygons.

In May 2010, an improved mesoscale modeling system was implemented utilizing the Weather Research and Forecast (WRF) model. While the MM5 model is still run, archived output was no longer kept as primary emphasis is given to WRF for CANSAC operations. The WRF model (http://www.wrf-model.org/index.php) employs the Lambert Conformal map projection centered at 38°N, 121°W and consists of three nested grids. The outermost grid (18-km horizontal resolution; 186x186x31 grid cells) covers the western U.S., parts of Mexico/Canada, and the eastern Pacific. The nested grid (6-km horizontal resolution; 310x310x31 grid cells) encompasses California, Nevada, Oregon, Utah, and parts of Idaho, Arizona, Wyoming, and Montana. The innermost grid (2-km horizontal resolution; 487x535x31 grid cells) encapsulates the entire California and Nevada boundaries. Output maps and products are the same as for MM5 (e.g., Figures 2 and 3), except for the higher resolutions. Meteorologists using the CANSAC WRF products have noted improved forecasts over MM5, primarily due to the addition of a land surface model and the higher resolution grids.

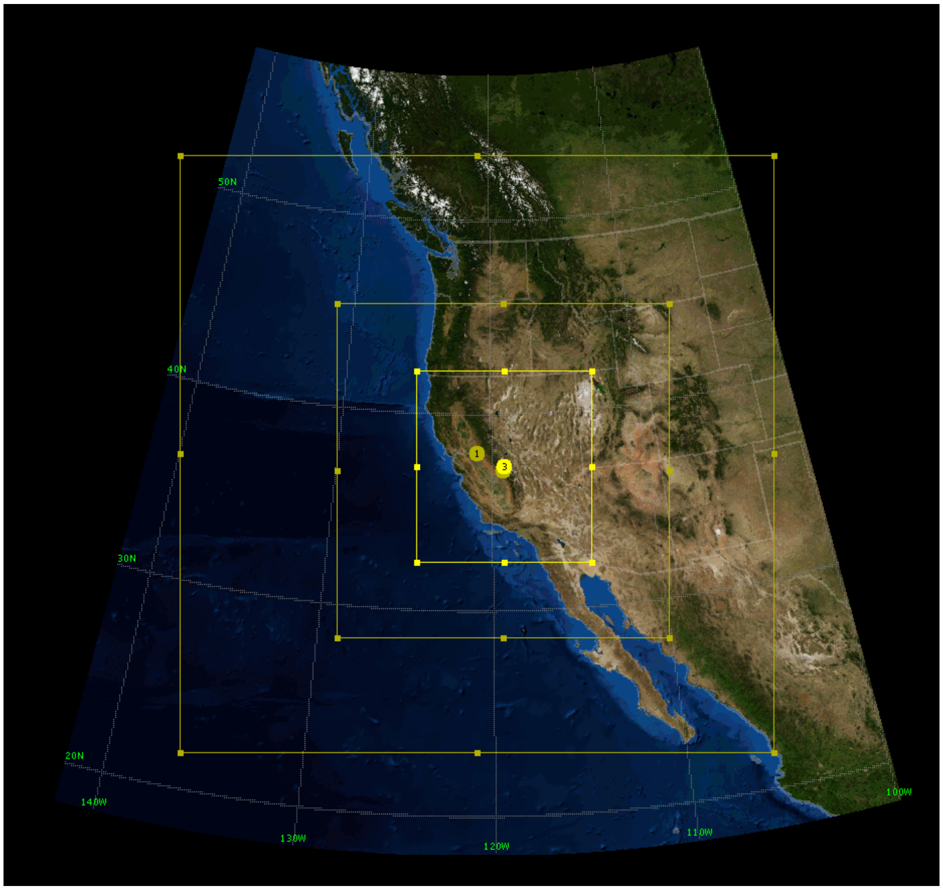


Figure 4. Domains (18-, 6- and 2-km) of the CANSAC WRF forecast system.

The BlueSky Framework is designed to predict smoke ($PM_{2.5}$ concentration) impacts from wildland, agricultural and prescribed burns, and is used to produce smoke forecasts. Bluesky produces emissions using standard emission factors, and predicts $PM_{2.5}$ surface concentrations by applying CALPUFF, an EPA approved dispersion model. CALMET is the diagnostic meteorological module of the modeling system that generates three-dimensional meteorological input fields and other micrometeorological parameters necessary for CALPUFF (Scire *et al.* 2000b). Fire information is input into the Framework through the use of the SMARTFIRE reconciled fire information system that relies on ICS-209 reports and NOAA Hazard Mapping System aggregated satellite fire detections. Prescribed fire information can also be input into BlueSky via a web-based form to indicate date, location, size and emission parameters including fuel type and fuel amount. Figure 5 is an example output map of forecast surface $PM_{2.5}$ concentration for the Lake Tahoe area.

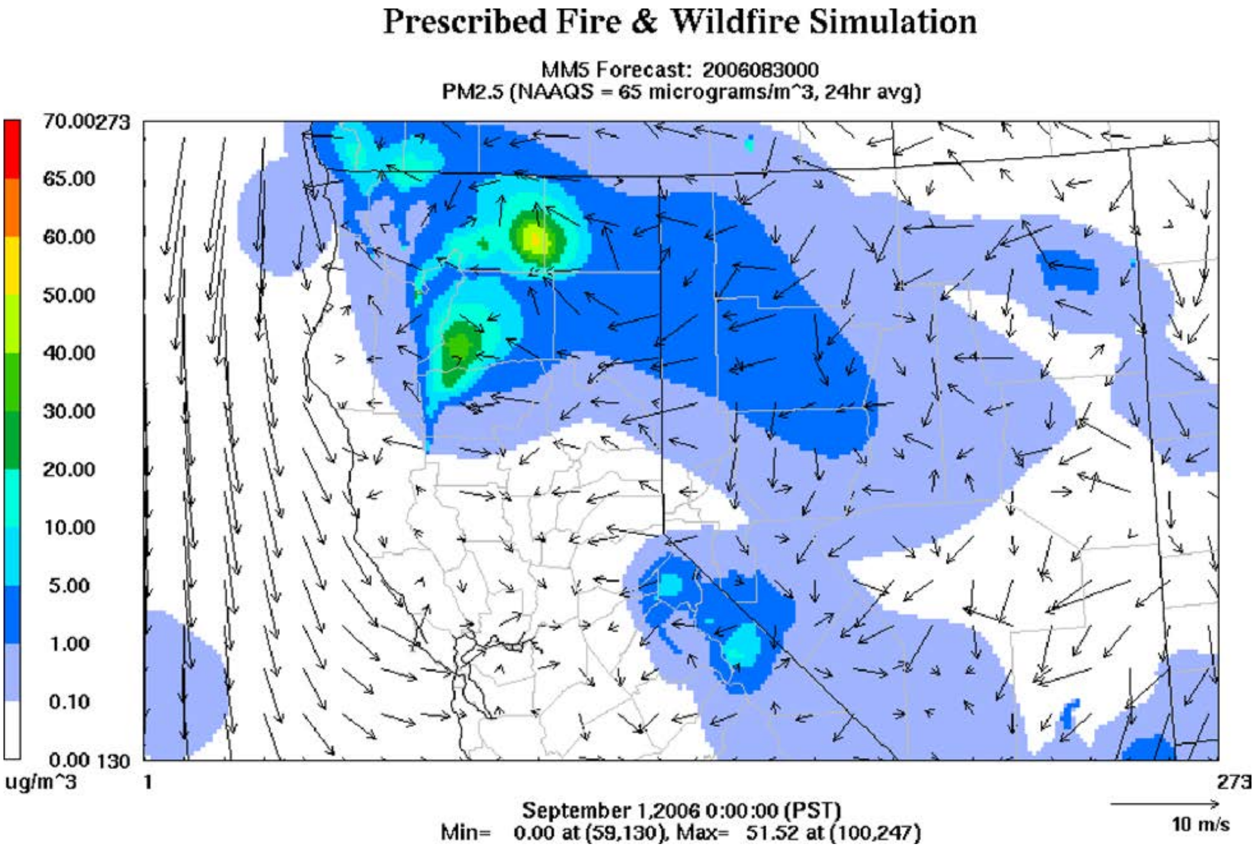


Figure 5. Example map of Bluesky forecast surface PM concentrations from MM5.

*Details of measurement system for forecast verification*

The US Forest Service PNW AirFire team deployed eight weather stations in two transects ranging from near the shoreline to the ridgeline of the basin. The stations were placed in the field in mid to late June (a late snowpack prevented access to the higher elevations), and continued to operate until mid October. The weather stations were instrumented with temperature, relative humidity, and wind speed and direction probes, with two stations including PM2.5 monitors. The continuous data collected allows for the characterization of smoke and inversion layers over the course of the burn season. The data are also used to compare with model output, for evaluation and improvement of the models.

Between 15 June and 14 July 2010, AirFire deployed six weather stations in two separate transects of three stations representing low, middle and high elevation, and two particulate monitors (E-BAM) near the lake (Figure 6). The southern, or “Angora transect” consists of an E-BAM in South Lake Tahoe, CA, and three weather stations along the road to Angora Lookout. The western, or “Blackwood transect” consists of an E-BAM near Tahoma, CA, and three weather stations along the Blackwood Creek road. The stations were set up in elevational transects in order to measure temperature inversions within the Tahoe Basin.

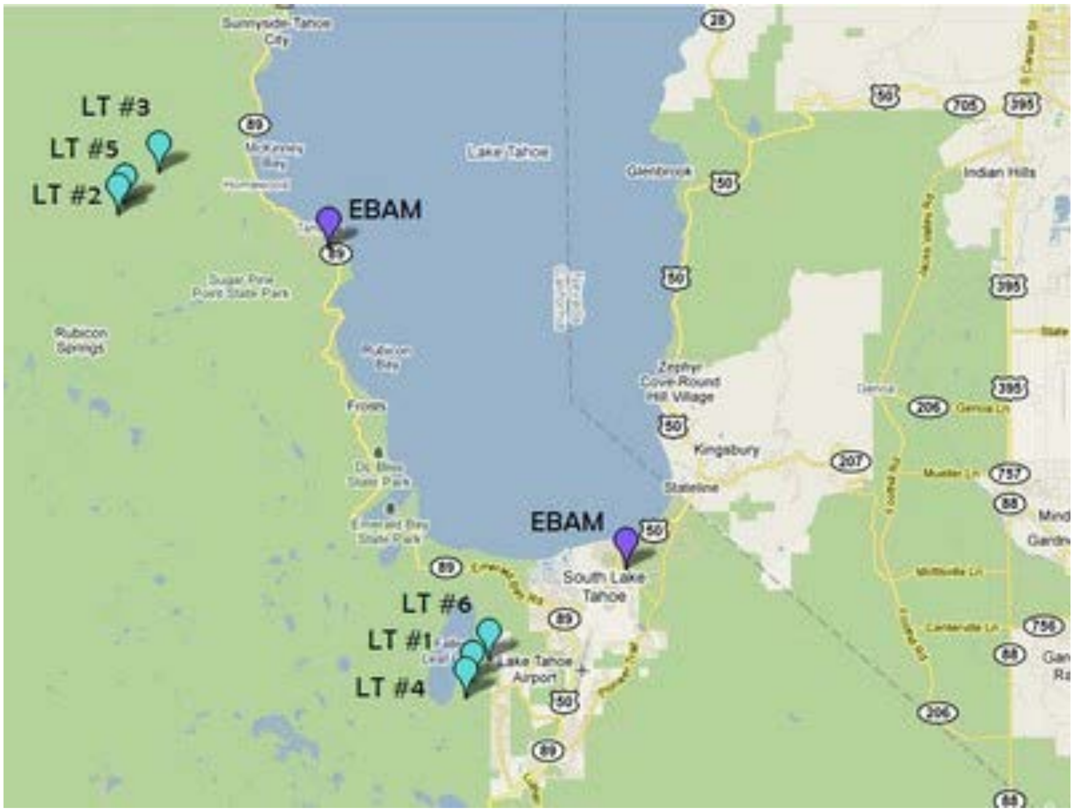


Figure 6. Locations of particulate monitors and portable weather stations in the Lake Tahoe Basin.

The monitors were deployed over a period of about one month. Table 1 lists the locations and elevations, dates of operation, sensor types, and notes for all the monitors. The first monitors to be set up in mid-June were two Met One E-BAM particulate samplers, with accompanying temperature, relative humidity, wind speed, and wind direction sensors. Data were averaged and collected hourly. The E-BAMs were deployed near the lake level of the Tahoe Basin, with one (SLT E-BAM) located in South Lake Tahoe, at the Lake Tahoe Basin Management Unit Supervisors Office, and the other (SPP E-BAM) at the Sugar Pine Point State Park office near Tahoma, CA. Both E-BAMs were equipped with satellite modems that provided real-time access to the data. The portable weather stations had no such communication devices, and therefore access to the data was by manual download only. All the collected data can be accessed at http://www.airfire.org/tools/wx-station/tahoe-deployment-2010.

Table 1: List of monitors deployed during the summer of 2010.

| Station Name | Location & Elevation | Start Date & End Date | Sensors | Notes |
|---|---|---|---|---|
| **SLT E-BAM** | Lat: 38.9328<br>Lon: -119.9739<br>Elev: 6330 ft | Start: 6/15/2010<br>End: 10/12/2010 | Temp, RH, WS, WD, $PM_{2.5}$ | Equipped with satellite modem; $PM_{2.5}$ stopped working 9/16/2010 |
| **LT6** | Lat: 38. 8969<br>Lon: -120.0425<br>Elev: 6590 ft | Start: 7/8/2010<br>End: 10/13/2010 | Temp, RH, WS, WD | Removed WS/WD 7/14/2010; replaced 7/26/2010 |
| **LT1** | Lat: 38. 8886<br>Lon: -119. 0508<br>Elev: 6970 ft | Start: 7/14/2010<br>End: 10/13/2010 | Temp, RH, WS, WD | |
| **LT4** | Lat: 38.8818<br>Lon: -120.0548<br>Elev: 7270 ft | Start: 7/8/2010<br>End: 10/13/2010 | Temp, RH, WS, WD | |
| **SPP E-BAM** | Lat: 39.0586<br>Lon: -120.1241<br>Elev: 6375 ft | Start: 6/15/2010<br>End: 10/13/2010 | Temp, RH, WS, WD, $PM_{2.5}$ | Equipped with satellite modem |
| **LT3** | Lat: 39.0882<br>Lon: -120.2099<br>Elev: 6765 ft | Start: 7/8/2010<br>End: 10/13/2010 | Temp, RH, WS, WD | WS&WD offline until 7/15/2010 |
| **LT5** | Lat: 39.0758<br>Lon: -120.2266<br>Elev: 7195 ft | Start: 7/8/2010<br>End: 10/13/2010 | Temp, RH, WS, WD | WS&WD offline until 7/14/2010 |
| **LT2** | Lat: 39.0719<br>Lon: -120.2306<br>Elev: 7720 ft | Start: 7/8/2010<br>End: 10/13/2010 | Temp, RH, WS, WD | WS&WD offline until 7/14/2010 |

In the first part of July, six portable weather stations were deployed in two elevational transects “uphill” from the two E-BAMs. Because of various equipment problems, the periods of record were not the same for all stations. Table 1 lists the starting and ending dates for each station. The portable weather stations consisted of temperature and relative humidity sensors, and wind speed and direction sensors, connect to Campbell CR10 or CR10X datalogger. The sensors were sampled every 60 seconds, and data were averaged and written to the dataloggers every 15 minutes.

*Customized smoke prediction website tool*

Recent work (e.g. Larkin *et al*. 2009) has shown that a significant portion of smoke model prediction error can be traced to uncertainties in fuels and fire information. The proposed customized system will provide the local burners a login-secured website for quick and easy entering of known prescribed burning activity in a manner that is designed in consultation with local LTBMU officials. This will help reduce errors in the smoke predictions caused by incorrect fuel loadings, size of the burn unit, ignition time, etc. Further, due to recent advances in the BlueSky framework that include a new web-service technology based capability, it is now possible to provide immediate smoke predictions by running the smoke model in real-time, returning the smoke dispersion results within minutes. To accomplish this, the BlueSky Framework web-services technology will be installed at CANSAC/DRI with the help of the AirFire Team. Additionally, because the resulting system can function more interactively, a “scenario-building” or “planning-mode” website will be provided where users can enter potential or considered burn scenarios, and observe the effects without the results being made public. These websites leverage the work done to create the BlueSky Playground (http://playground.blueskyframework.org) tool that was recently completed under a grant from the Joint Fire Science Program, but enhance and modify this tool for application to the Tahoe Basin.

## 4. Deliverables

### 4a. Gridded wind climatology

Both CALMET and WindNinja were examined for producing a higher resolution climatology. CALMET results did not appear to add significant value in creating a gridded climatology compared to using MM5 directly. Thus, hourly MM5 wind output was used as input for WindNinja to produce a 300-m surface wind climatology for the Tahoe basin. The climatology period is from May 2004 through April 2010. Though the MM5 outputs are forecasts, two factors are assumed that allows for the development of an acceptable climatology based product. First, the model was run twice daily, so no more than 12 hours of forecasts were used, and at 4-km resolution, the model forecast skill of wind is considered good. This is shown further in section 4c below. Second, six years of output, though short by climatology standards, still allows for 186 total maximum possible days (in a 31 day month) to create a diurnal climatology of wind speed and direction by hour.

Figure 7 shows the average WindNinja 10-m wind speed and direction at 300-m resolution for 0200 and 1400LT January (upper left and right, respectively) and July (lower left and right, respectively) as contrasting seasonal examples. Speed (mph) is indicated in color bar, and direction by vector arrows. The two different times represent a typical nighttime and daytime wind. January nighttime wind direction appears more uniform than during the day, where for example, a clockwise flow pattern is visible in the southeast corner, and some wind convergence along the eastern lakeshore. The speed is notably higher at ridge tops, and there is not substantial difference between the night and day speed patterns. In July, the speed is noticeably less during the night, while stronger during the afternoon, especially over the eastern basin ridgeline. This is the well-known summer pattern given higher pressure off of the coast and thermal lower pressure in the Great Basin. Both months show canyon and ridge details, made more visible by the varying speed colors.

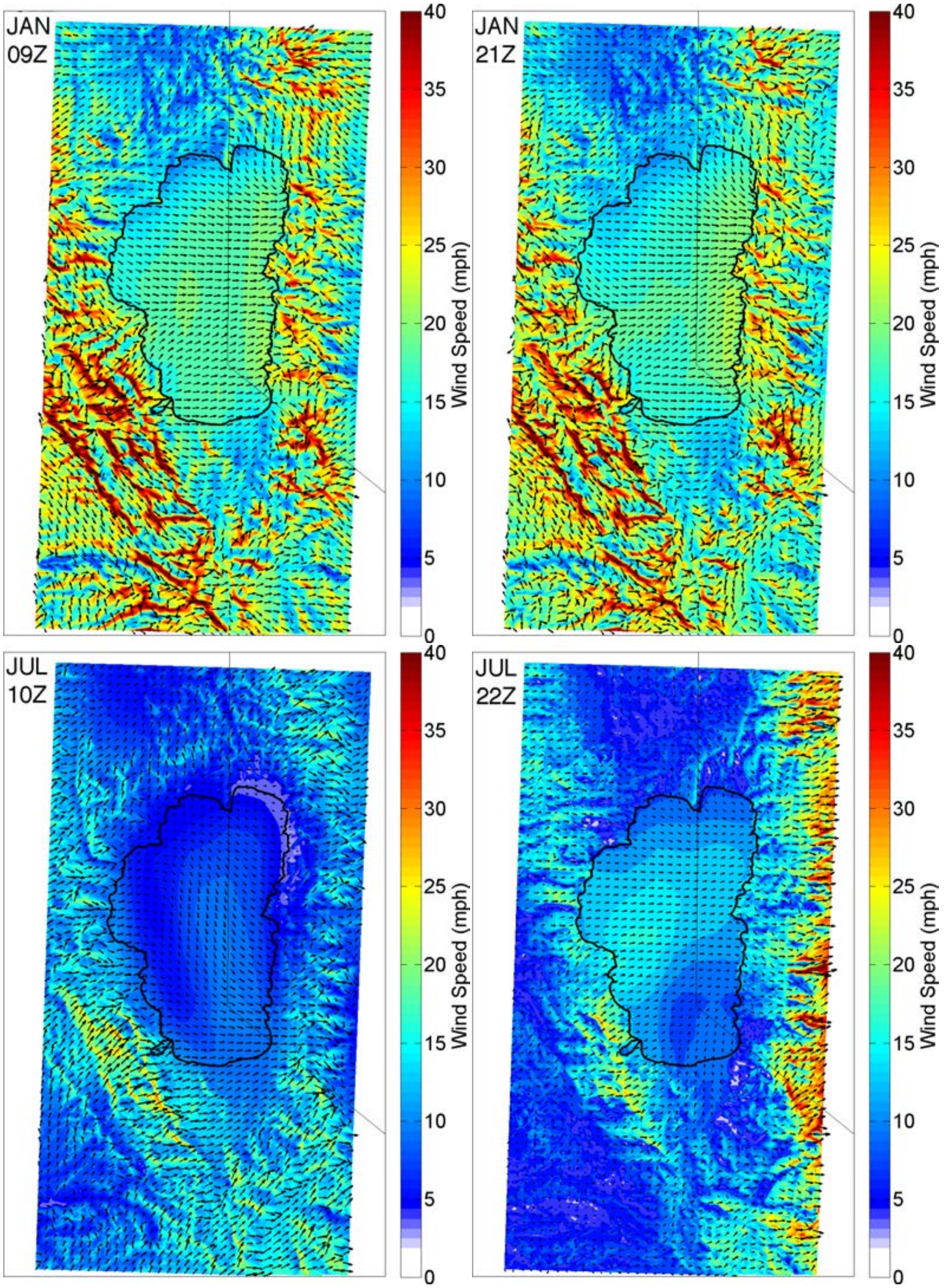


Figure 7. Average wind speed and direction from MM5 and WindNinja at 300-m resolution for 0200 and 1400LT January (upper left and right, respectively) and July (lower left and right, respectively). Speed (mph) indicated in color bar, and direction by vector arrows.

## 4b. Mixing height climatology

The mixing height in this analysis is defined as the planetary boundary layer (PBL) as produced by the WRF model. The mixing height is typically lowest during nighttime hours, and highest during the afternoon when solar heating creates increased convective mixing. Originally, MM5 was planned for producing the mixing height climatology. This was tested, but found not to produce satisfactory results, likely due to a lack of a land surface model (LSM) used in the MM5 runs. The WRF model does incorporate a LSM, and this parameterization strongly affects PBL calculations. But because of the limited WRF runtime beginning in May 2010, the mixing height climatology presented here is limited to two years. Figure 8 shows January and July nighttime and daytime example seasonal and diurnal maps.

Transport wind is defined as the mean wind speed of the levels between the surface and the top of the mixing height. Figure 9 shows mean transport wind maps corresponding the mixing height maps in Figure 8.

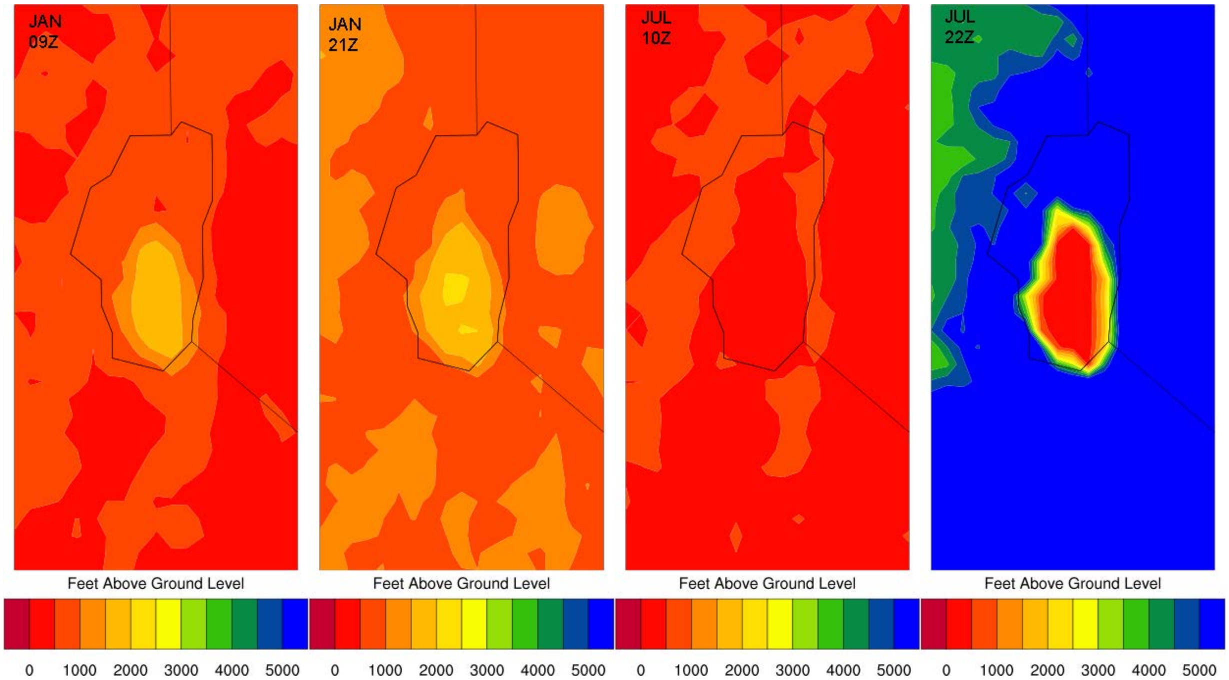


Figure 8. Example WRF produced mixing height climatology for January nighttime and daytime (09Z and 21Z, respectively) in the left maps, and July nighttime and daytime (10Z and 22Z, respectively) in the right maps.

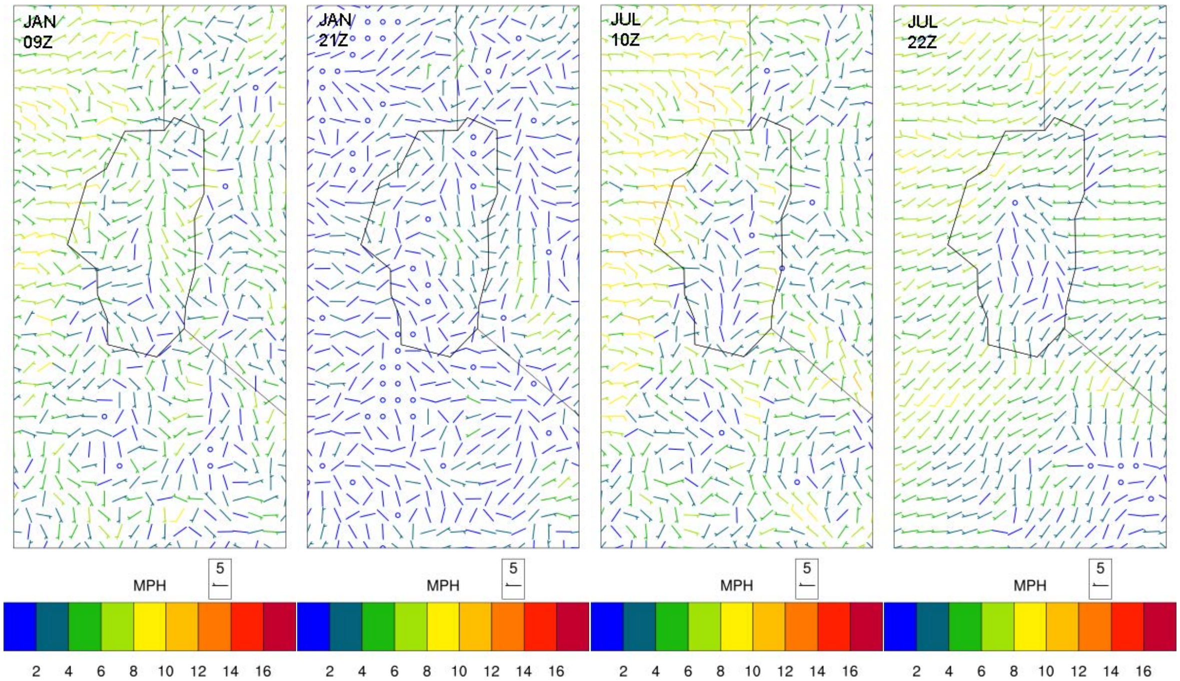


Figure 9. Example WRF produced transport wind climatology for January nighttime and daytime (09Z and 21Z, respectively) in the left maps, and July nighttime and daytime (10Z and 22Z, respectively) in the right maps.

### 4c. Operational wind forecasts

To assess the WindNinja climatology and potential skill of WindNinja forecasts from WRF, site observations were compared to the corresponding WindNinja grid point for a period in 2010. The eight USFS monitoring stations along with four additional stations recording hourly wind in the Basin were used in the analysis. The map in Figure 10 shows the 12 station locations.

Figure 11 shows boxplots of observations from the 12 hourly wind sites and the corresponding WindNinja 300-m and WRF 2-km grid points, respectively. Stations labeled “M” are the summer 2010 monitoring sites and “O” are the permanent sites; “N” represents WindNinja, and “W” represents WRF. Recall from section 3b that the MM5 archive was terminated in May 2010, at which point the WRF archive begins. Thus, for this analysis, WRF was used for the WindNinja input. The boxplots include all of the hourly observations for the monitoring station period given in Table 1. The box shows the 25th to 75th percentile range (interquartile range) and the median. The dashed lines indicate up to 1.5 times the interquartile range, and individual points are outliers. Ideally, the boxplots would overlap given similar distributions. Generally for WindNinja and WRF, the boxplots do overlap, which is good since WRF was the primary input for analysis. For the permanent “O” stations, there is also general overlap with WindNinja and WRF. However, for the summer monitoring stations “M”, there is unfortunately little agreement. This is due to two factors. First the station exposures were well within the canopy, which reduced wind speed. Second, was a difference in anemometer heights;

the anemometers on the summer monitoring stations were about 2 meters AGL, while the heights on the permanent stations were closer to 6 meters. Therefore, the wind speeds are considerably reduced compared to the more exposed sites. However, we can conclude from the other stations that the WindNinja speeds are a good representation of those observations. While observed within-canopy winds will likely not match model output, these lower speeds may be more representative for use when considering smoke dispersion from low-intensity, sub-canopy burns.

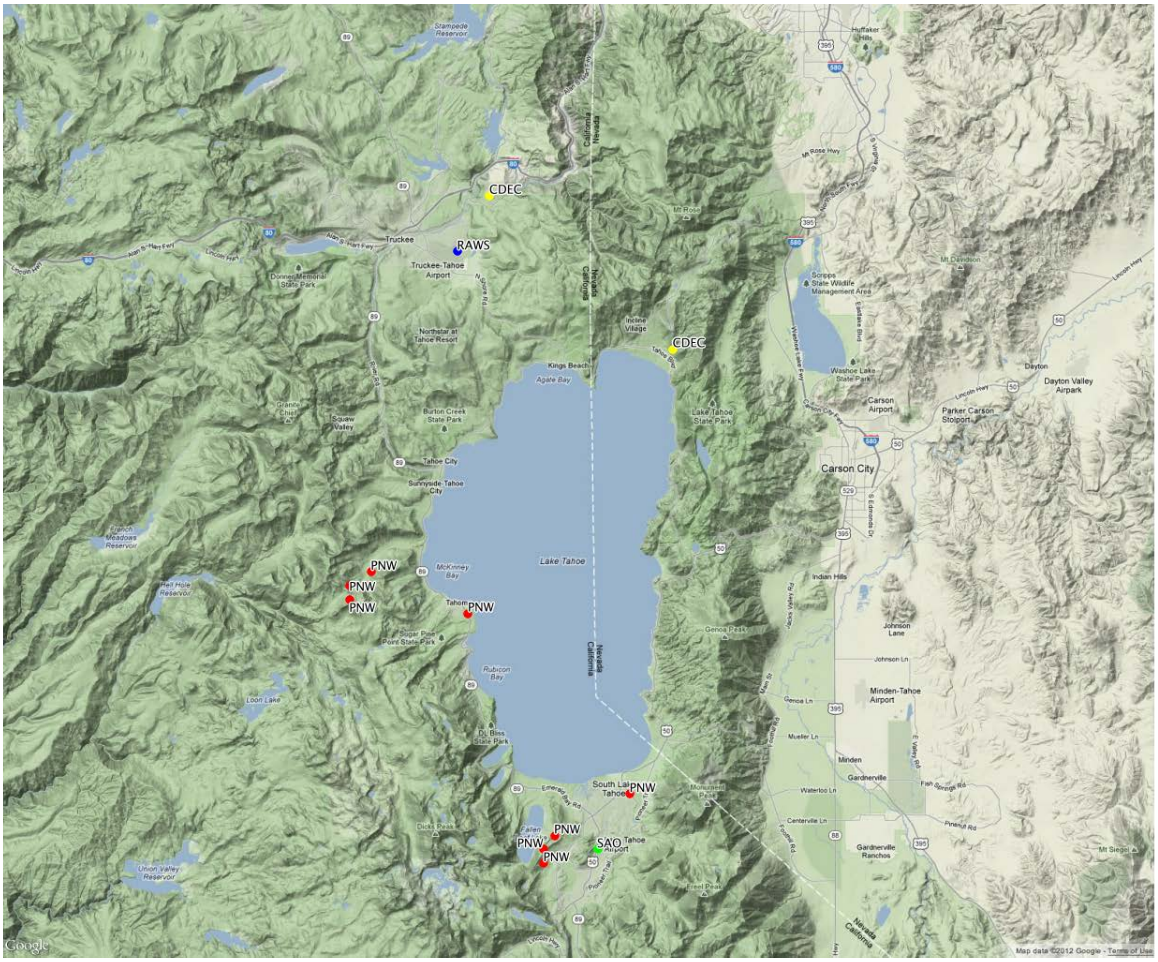


Figure 10. Map of station locations providing hourly wind data for the WindNinja assessment. Red points indicate the USFS monitoring sites for summer 2010.

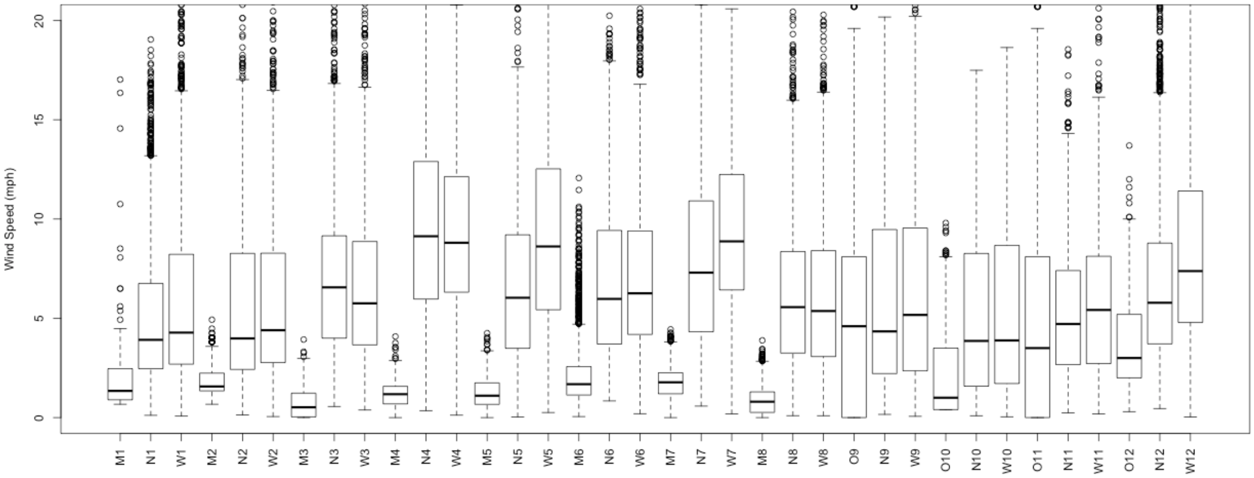


Figure 11. Boxplots of hourly wind speed observations from the 12 wind sites, and the corresponding WindNinja 300-m and WRF 2-km grid points, respectively. Stations labeled "M" are the summer 2010 monitoring sites and "O" are the permanent sites; "N" represents WindNinja, and "W" represents WRF.

To further assess station wind data detail with WindNinja and WRF, an analysis was done for the PNW LT4 station (Table 1; Figure 6). Of interest is how a single station and the WRF grid influence the WindNinja output. Figures 12a;b show the LT4 station wind speed and wind direction time series, respectively, for the 24-hour local time period on 17 August 2010. The black line is the station observed hourly values, and the purple line the WRF 2-km grid point value associated with the station. The wind speed lines show considerable difference between LT4 and WRF, highlighting the station's observations within the lower canopy versus a non-canopy influenced WRF speed. Next, only the stations in Figure 10 were used to generate a WindNinja grid (no WRF input). The yellow and blue lines are WindNinja values for the LT4 station associated 300-m grid point with the station included and removed, respectively. These two curves are very similar for wind speed and direction, showing that WindNinja did a good job replicating the hourly wind for the removed station. The final test only used WRF (no stations). The red curve shows WindNinja at 300-m resolution (the final climatological grid), and the green curve at 2-km resolution (the WRF resolution size), both for the associated grid point of LT4. Except for the lowest wind speeds at 0800 and 0900, the values do not correspond well, though the overall trend is similar. The 300-m WindNinja speed is greater than observed, but less than 2-km WRF grid value. Overall, the 2-km WindNinja speed is closer to the observed station values. Except for prior to 0900, the wind direction (Figure 12b) for all curves is generally consistent.

This particular test case suggests that WindNinja does perform well in depicting wind speed and direction. The WindNinja wind speed was underestimated compared to WRF, but likely more realistic of the general environment than the observed station values because of the canopy siting issue for the PNW LT locations.

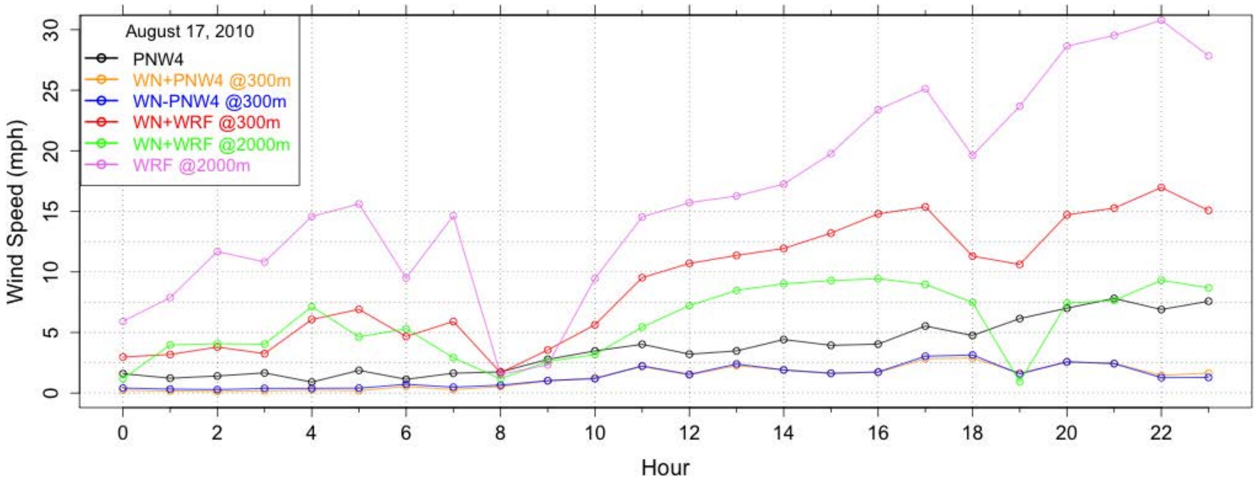


Figure 12a. Wind speed for 24-hour period for 17 August 2010 for the LT4 (PNW4) station and associated WindNinja and WRF grid points. Observed station values (black line), WindNinja 300-m estimate station input only including LT4 (yellow line), WindNinja 300-m estimate station input only removing LT4 (blue line), WindNinja 300-m estimate WRF input only (red line), WindNinja 2-km estimate WRF input only (green line), WRF 2-km grid point values (purple line).

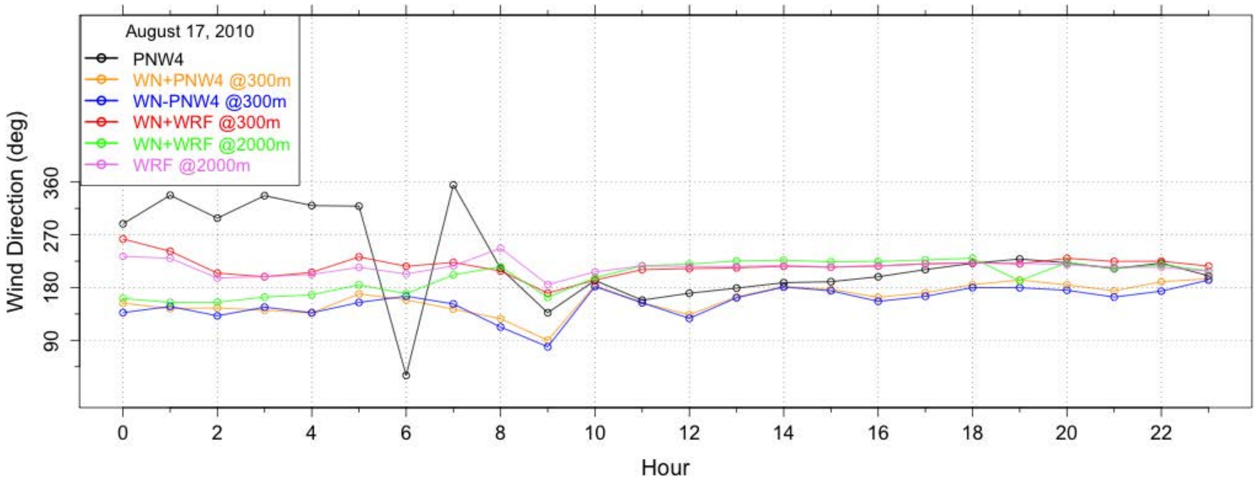
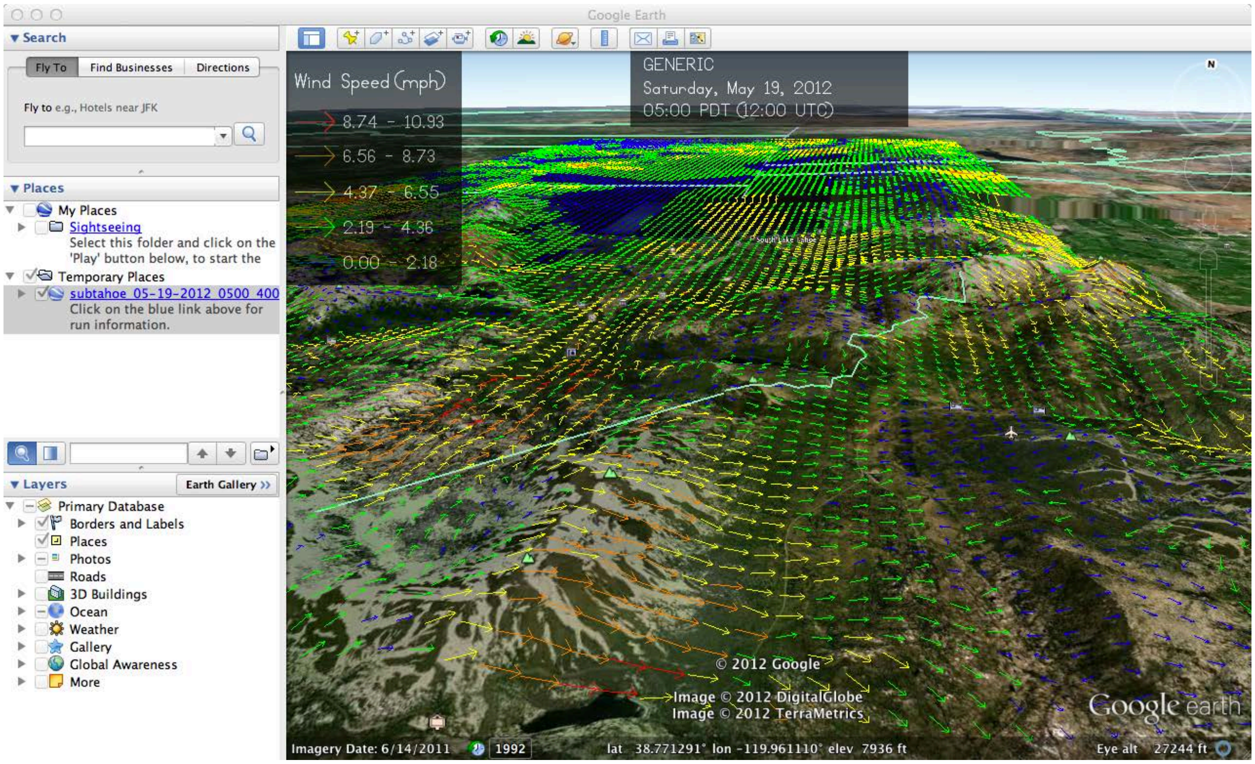


Figure 12b. Same as for 12a except for wind direction.

WindNinja is now an operational component of CANSAC WRF for the Tahoe Basin. Hourly forecasts at 400-m resolution are provided hourly out to 72 hours, and are available in kmz formatted files. Figure 13 shows an example forecast output map from May 2012.



Select this folder and click on the 'Play' button below, to start the

Click on the blue link above for run information.

Figure 13. Example WindNinja 400-m wind map based on an hourly WRF forecast in May 2012.

### 4d. Field measurements

Temperatures – Time series of temperatures from both the Angora transect and the Blackwood transect show diurnal nighttime inversions are common in the Tahoe Basin. On most nights along the Angora transect, the lowest minimum temperature occurs at the lowest station (E-BAM), while the highest minimum temperature occurs at the highest elevation station (Figure 14), which indicates the presence of a temperature inversion. The same is true for the Blackwood transect (Figure 15). The presence of a nighttime inversion is also evident from the diurnally averaged temperatures from the Angora and Blackwood transects (Figures 16 and 17). Nighttime temperatures increase with height at the Angora transect, with the highest temperatures at Angora high and the lowest temperatures at the EBAM site located in South Lake Tahoe. A slightly different pattern is seen at the Blackwood transect, with the EBAM at Sugar Pine Point State Park (the lowest elevation site) having the lowest nighttime temperatures, while the Blackwood Mid station has the highest temperatures. This suggests the top of the inversion layer may be below the upper Blackwood station, which is the highest of all the stations.

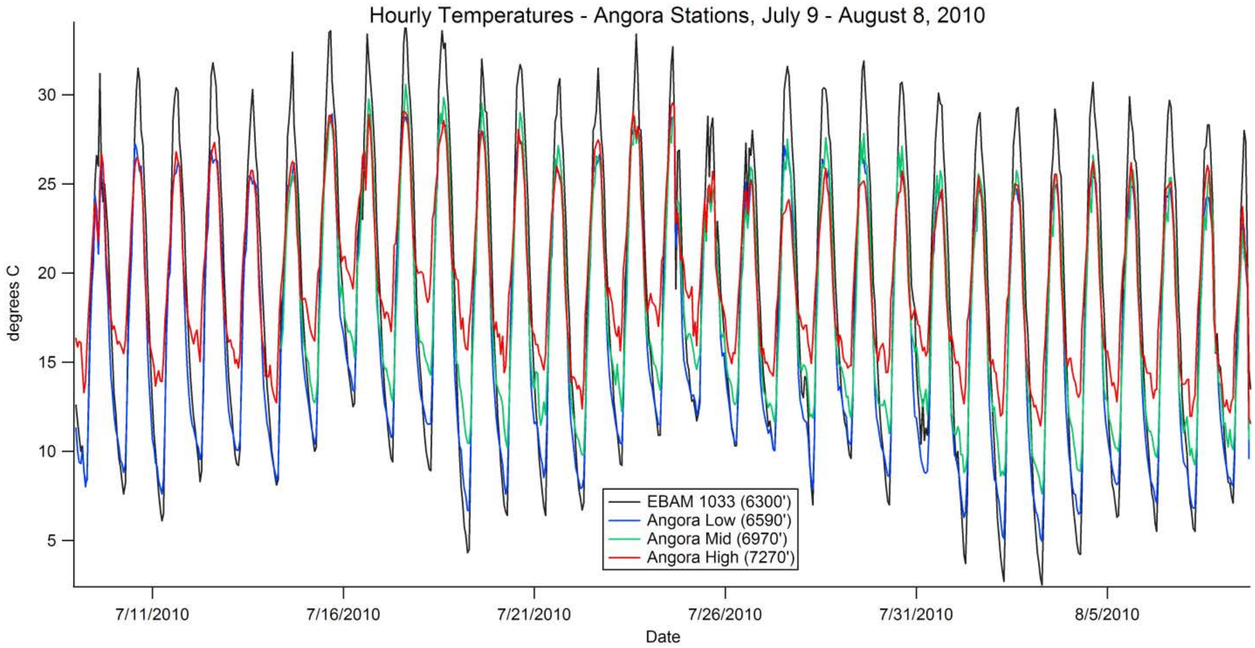


Figure 14. Hourly temperatures from stations along the Angora transect, 9 July – 8 August 2010.

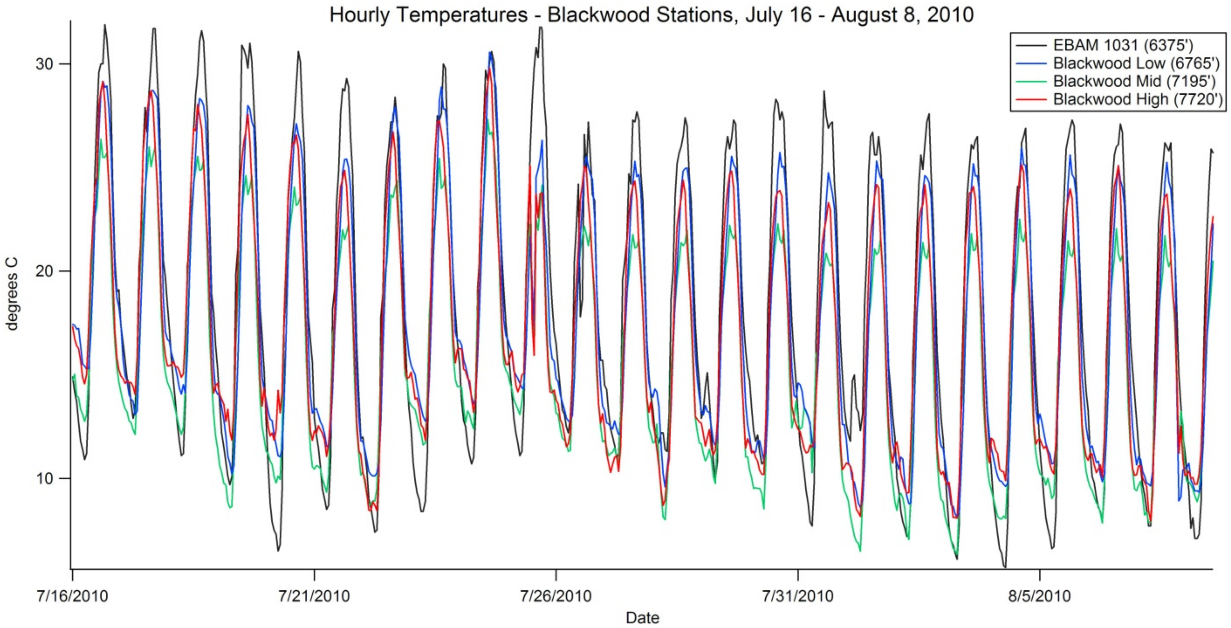


Figure 15. Hourly temperatures from stations along the Blackwood transect, 16 July – 8 August 2010.

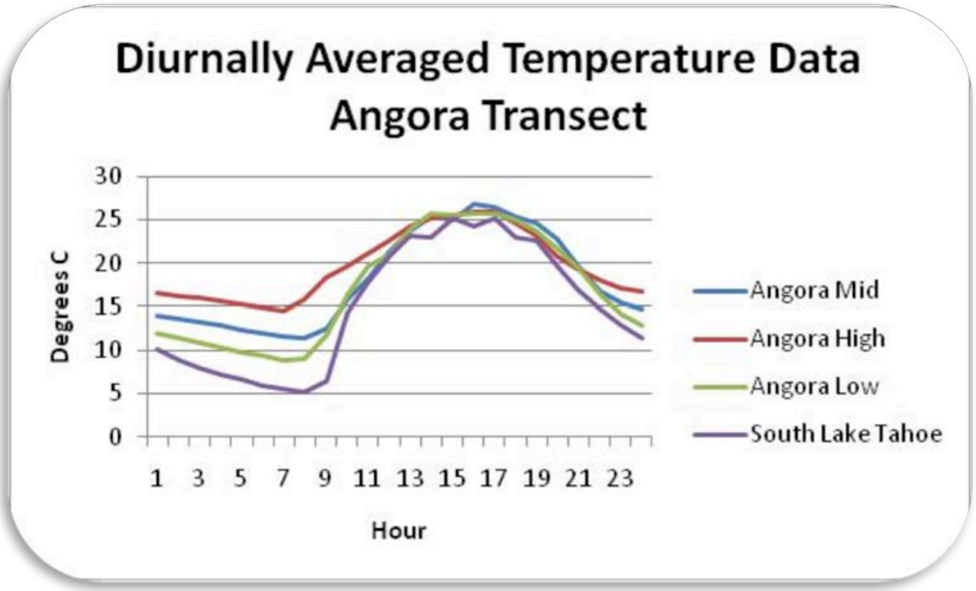


Figure 16. Diurnally averaged temperatures at the Angora stations, 8 July 8 – 13 October 2010.

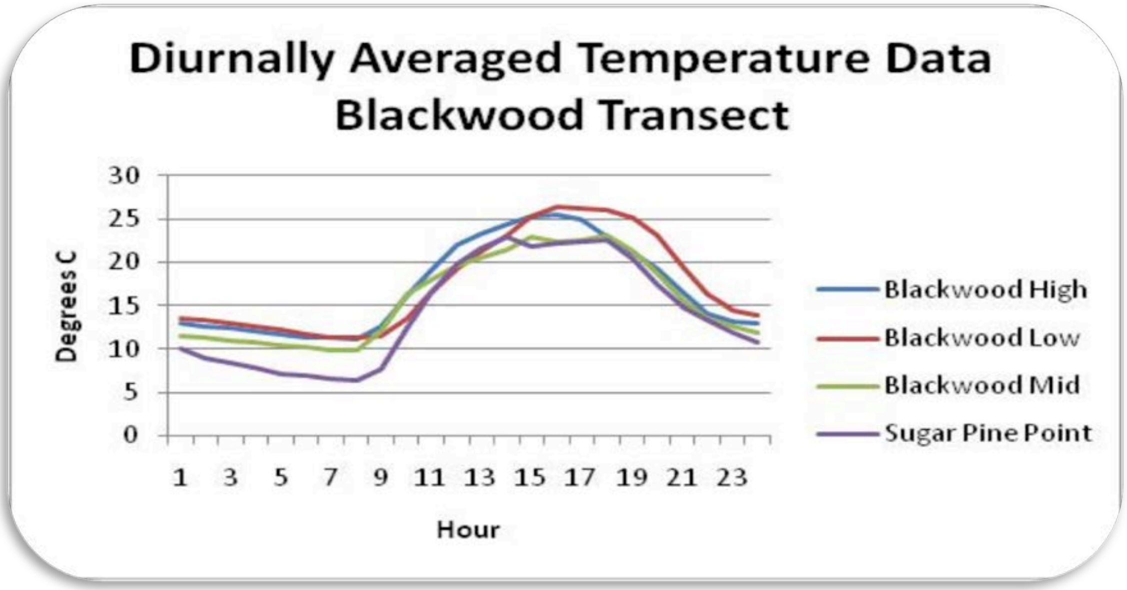


Figure 17. Diurnally averaged temperatures at the Blackwood stations, 14 July 14 – 13 October 2010.

Winds - With the exception of the Angora High station, all the weather stations were located within the forest canopy. Consequently, wind speeds were very light (typically ranging from calm to 2 m/s), with the highest winds speeds at the Angora High station. The wind directions show shifts between afternoon and nighttime winds at all the stations, with the nighttime wind directions being less variable than during the daytime hours (Figures 18 – 23).

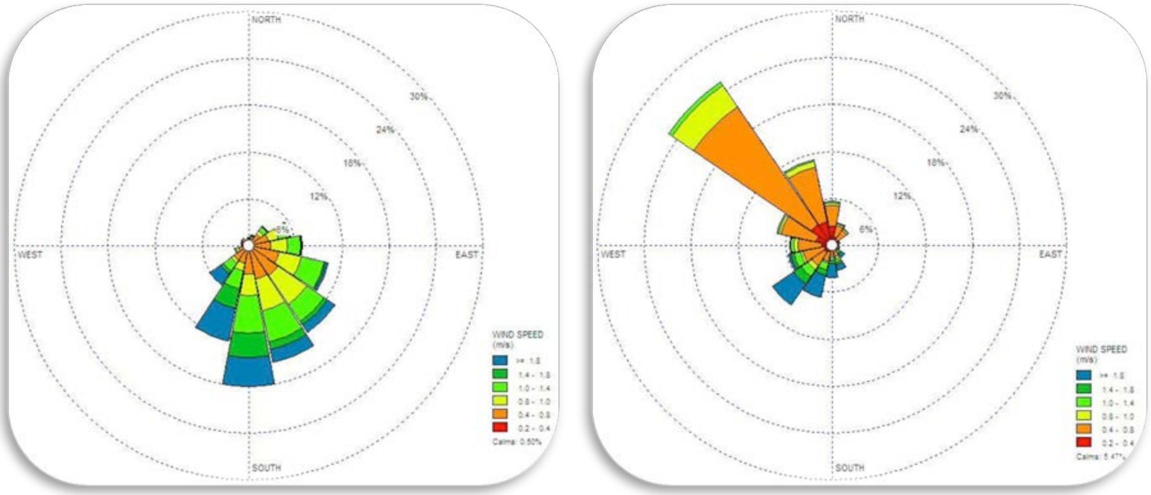


Figure 18. Afternoon (left) and nighttime (right) averaged winds, Angora High station.

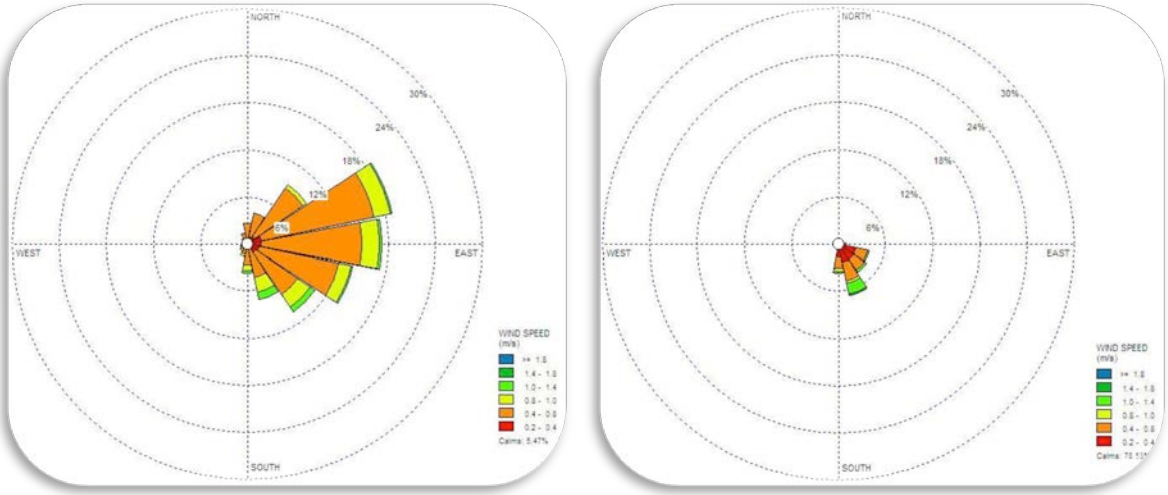


Figure 19. Afternoon (left) and nighttime (right) averaged winds, Angora Mid station.

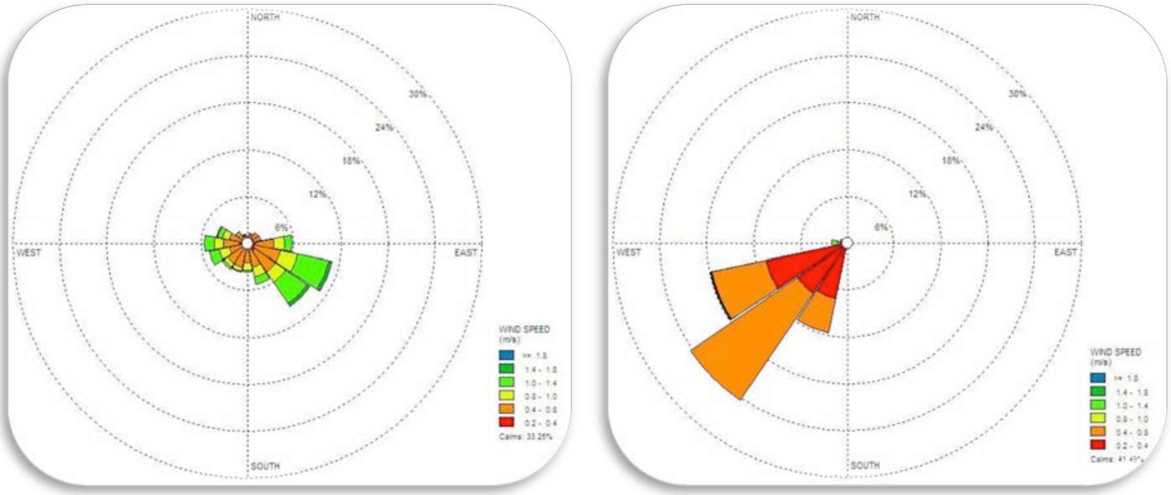


Figure 20. Afternoon (left) and nighttime (right) averaged winds, Angora Low station.

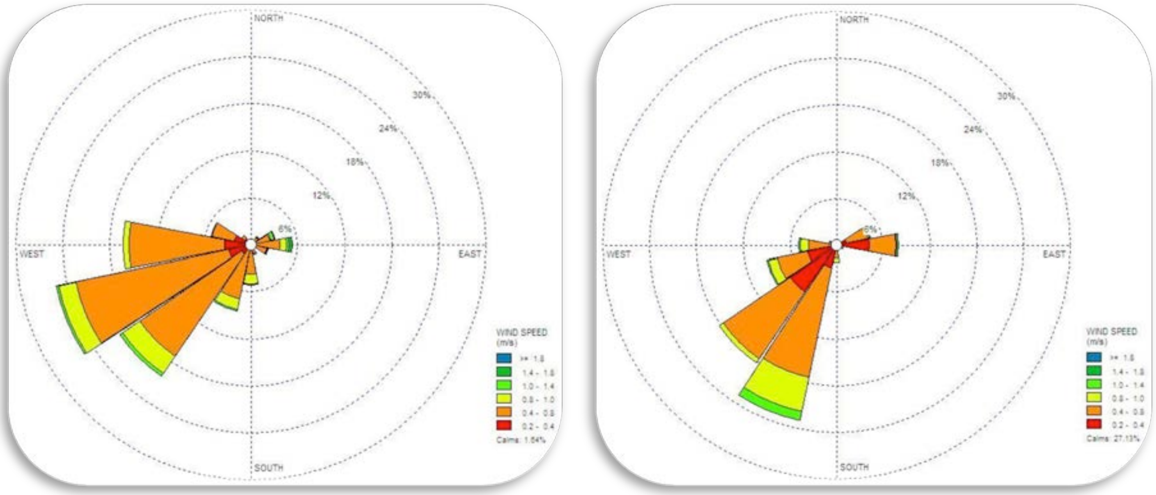


Figure 21. Afternoon (left) and nighttime (right) averaged winds, Blackwood High station.

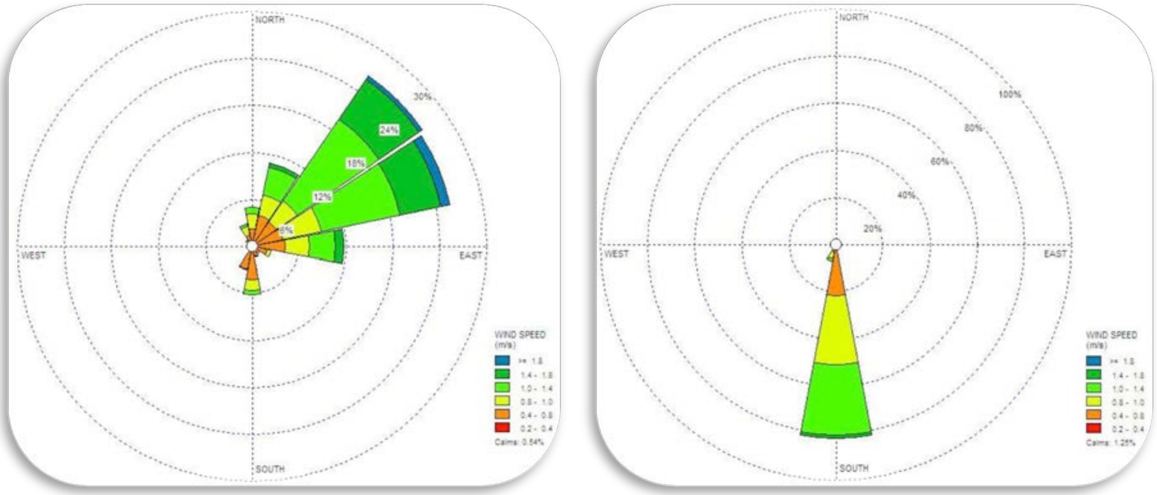


Figure 22. Afternoon (left) and nighttime (right) averaged winds, Blackwood Mid station.

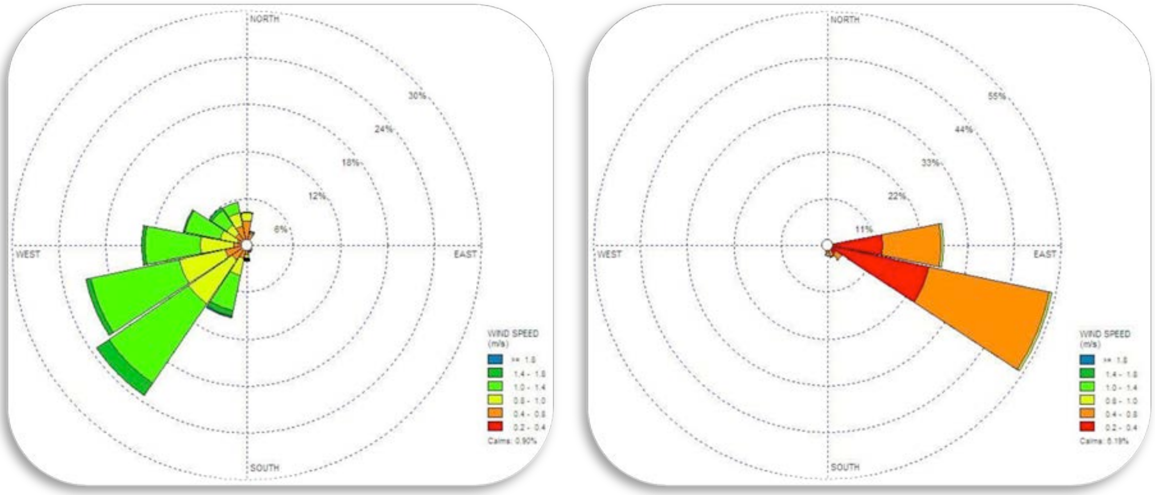


Figure 23. Afternoon (left) and nighttime (right) averaged winds, Blackwood Low station.

Particulates – Two Environmental Beta Attenuation Monitors (E-BAMs) were deployed near the bottom of the basin, one in South Lake Tahoe and one at Sugar Pine Point State Park. There were no large fires in the Tahoe Basin, therefore the $PM_{2.5}$ data show mostly random day-to-day variability (Figures 24 and 25). There were no strong diurnal signals in the $PM_{2.5}$ data. Because there was no fire-generated $PM_{2.5}$, these continuously running particulate monitors provide an indication of typical background levels of fine particulates in the basin. $PM_{2.5}$ concentrations were generally below 20 µg/m3, with a maximum of 31 µg/m3 at South Lake Tahoe, and a maximum of 52 µg/m3 at Sugar Pine Point. There were more values above 20 µg/m3 at Sugar Pine Point than South Lake Tahoe, and this could have been the result of campfires at the park in the vicinity of the E-BAM.

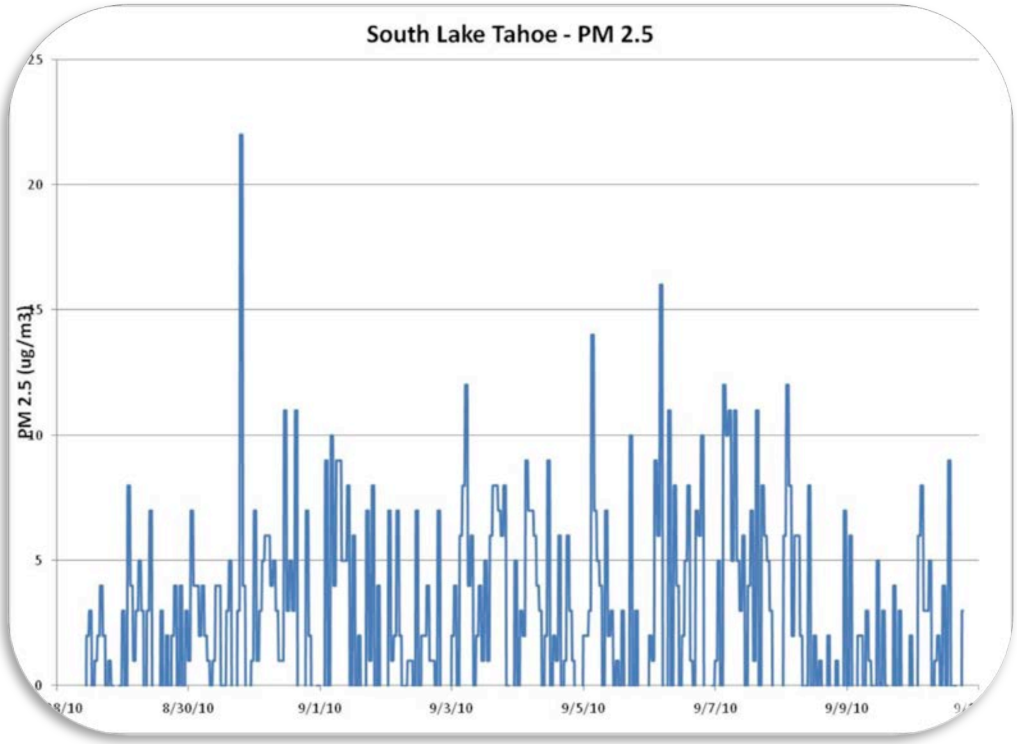


Figure 24. Time series of $PM_{2.5}$ from SLT E-BAM, South Lake Tahoe, 18 August 18 – 14 September 2010.

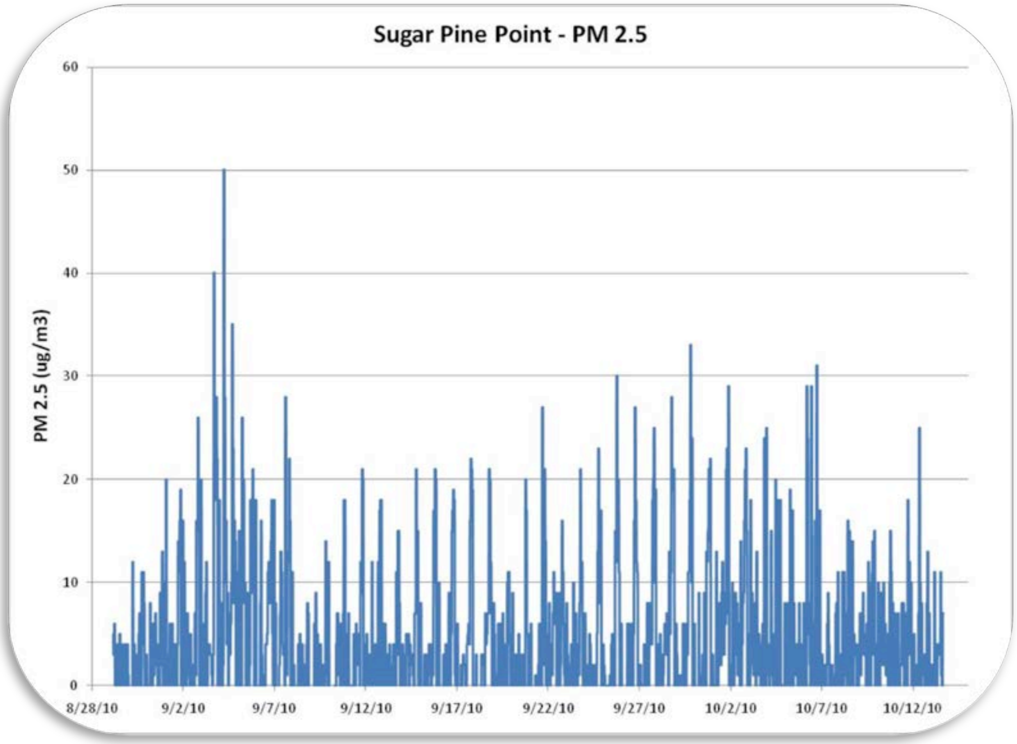


Figure 25. Time series of $PM_{2.5}$ from SPP E-BAM, South Lake Tahoe, 28 August 28 – 12 October 2010.

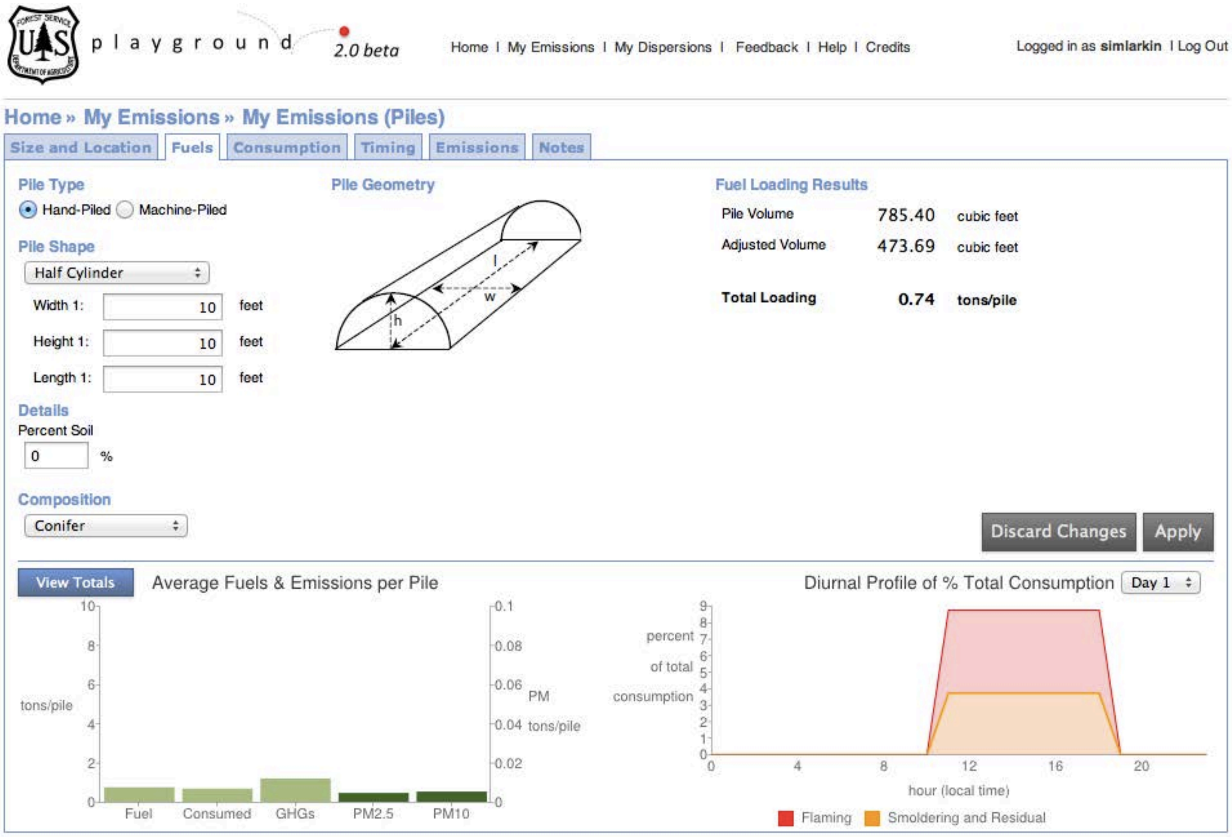
## 4e. Customized smoke prediction website tool

Based on the needs of the Tahoe Basin, specific, custom changes were made to the BlueSky Playground website tool. BlueSky Playground is a web-based system that allows a user to develop fire emissions and smoke dispersion model output for based on user specified fire information. Users can enter a fire's size and location and, proceeding through a series of steps, retrieve fuel information from mapped fuel layers, run consumption and emissions models, perform dispersion model runs, and visualize the resulting smoke impact maps. Because the system is web-based and interaction is done entirely within any standard internet browser, users are not required to download any software, nor have access to large datasets like the meteorological forecast model output required to run dispersion forecasts. A number of models are available for each modeling step, and users can adjust the model output before proceeding to the next step in order to further customize the run based on known information (e.g. observations of available fuels).

Prior to this project, BlueSky Playground did not incorporate an emissions model for pile burning, a major source of emissions within the basin. Additionally, BlueSky Playground relied on relatively coarse meteorological grids (at best 12-km) over the Tahoe Basin, which meant that the complex meteorological flows within the basin were not resolved. For these reasons, the utility of the system was limited. To address these issues, specific changes were made to BlueSky Playground, improving its utility Playground for the Tahoe basin area. The changes made were:

- To incorporate the pile burning emissions calculator from CONSUME;
- To allow for advanced setup of broadcast burns, including multiple plots with complex timing;
- To include a very high resolution (2-km) meteorological model grid for dispersion modeling over the Tahoe Basin; and
- To allow users to model dispersion from multiple fires within a single dispersion run.

These changes were identified and rolled into a larger tool redesign and restructuring, resulting in version 2 of BlueSky Playground in late summer 2012. Included in these changes were improved usability of the webpages, making the system function on most tablets, eliminating the need for users to wait while the dispersion model is running, and creating the ability for users to share emissions and dispersion scenarios. Training and testing of Playground v2 in the fall and winter of 2012 has resulted in better stability and operational performance, and feedback from users has been positive. Figure 26 shows a screenshot of the BlueSky Playground pile calculator.



**Pile Type**
● Hand-Piled ○ Machine-Piled

**Pile Shape**
Half Cylinder
Width 1: 10 feet
Height 1: 10 feet
Length 1: 10 feet

**Details**
Percent Soil
0 %

**Composition**
Conifer

**Fuel Loading Results**

| | | |
|---|---|---|
| Pile Volume | 785.40 | cubic feet |
| Adjusted Volume | 473.69 | cubic feet |
| **Total Loading** | **0.74** | **tons/pile** |

Figure 26. Screenshot of pile calculator interface for BlueSky Playground v2 website tool.

## 5. Deliverables

Project deliverables include:

1) Monthly diurnal climatology 300-m maps of WindNinja surface (10-m) wind
2) Monthly diurnal climatology maps of mixing height and transport wind
3) 400-m WindNinja wind forecasts
4) Data collected from the field observations
5) Customized smoke prediction tool

Mixing height and wind climatologies are available at: http://cefa.dri.edu/Cefa_Products/LakeTahoe/.

The WindNinja forecasts can be found in the air quality section at: http://www.cefa.dri.edu/COFF/cansac_output.php?model=wrf.

BlueSky Playground v2 is available at http://playground.airfire.org.

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