Title:	**Improving meteorological data and forecasts for prescribed fire burn day decisions for the Lake Tahoe Basin**
Theme Subtheme	Air Quality and Meteorology 3c: Understanding basin meteorology
Principal Investigator and Receiving Institution	**Dr. Timothy Brown** Desert Research Institute 2215 Raggio Parkway, Reno, NV 89512 Phone: 775-674-7090 Fax: 775-674-7016 Email: tim.brown@dri.edu
Co-Principal Investigator	**Dr. Narasimhan 'Sim' Larkin** USFS Pacific Northwest (PNW) Research Station 400 N. 34th Street, Suite 201, Seattle, WA 98103 Phone: 206-321-2013 Email: larkin@fs.fed.us
Agency Collaborator	**Kit Bailey** LTBMU Supervisors Office 35 College Drive, South Lake Tahoe, CA 96150 Phone: 530.543.2631 Email: kbailey@fs.fed.us
Agency Collaborator	**Bret Butler** US Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory 5775 Hwy 10 W, Missoula, MT 59808 Phone: 406-329-4801 Email: bwbutler@fs.fed.us
Grants Contact Person	**Lycia Ronchetti** Desert Research Institute 2215 Raggio Parkway, Reno, NV 89512 Phone: 775-673-7411 Fax: 775-674-7016 Email: lycia.ronchetti@dri.edu
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Total cost share (value of financial and in-kind contributions):	$32,272.80 (DRI $19,455) (PNW $10,117.80) (Missoula Fire Science Lab $2,700)

1. Abstract

This proposal responds to 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 will include for the Lake Tahoe Basin: 1) a 100-m gridded climatology of surface wind; 2) a 4-km mixing height climatology with associated transport wind; 3) a 100-m surface and upper level climatology; 4) 100-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 are 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.

2. Justification statement

This proposal addresses Subtheme 3c: Understanding basin meteorology. It specifically responds to the second issue: "Develop and/or improve meteorological data and monitoring tools for use in forecasting and making burn day decisions for prescribed fires…" Specifically, the project deliverables would provide improved meteorological data including smoke related climatology information for mixing height and wind, and higher resolution operational forecasts of wind and mixing height for short-term prescribed burn planning.

3. 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 proposal responds to 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 (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).

4. Goals, objectives and hypotheses to be tested

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

The specific objectives are:

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

In this project, there are no specific scientific hypotheses to be examined, but rather use and improve the existing tools and data to better inform decision-makers in operational planning.

5. Approach, methodology and location of research

5a. Approach

The California and Nevada Smoke and Air Committee (CANSAC) operational forecast system and data will 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 constituents. 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 consortium 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, California Air Resources Board and 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 are 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 indicates 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.

5b. 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 discretisation 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. Output files of velocity and direction are written for use in FARSITE and GIS.

This type of model appears to have certain advantages that align well with wildland fire application. 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).

CALMET

CALMET (Scire et al 2000) is a meteorological model that inputs observational data and/or gridded model output (such as that from MM5 or WRF), and generates three-dimensional fields of hourly winds and temperatures. CALMET generates the 3-dimensional wind field in a two-step process. First, an initial-guess wind field is adjusted for kinematic effects of terrain, slope flows and terrain blocking effects. Next the observations and/or modeled winds are introduced, and an objective analysis procedure is applied to the adjusted wind field to produce a solution that converges to a final wind field. In this way CALMET provides a physically mass consistent wind field at finer resolutions than can be generated by mesoscale models such as MM5. The wind field is influenced by the underlying terrain on a three-dimensional basis. Although CALMET is a diagnostic model, it can be used in a "prognostic" mode by inputting forecast modeled wind fields without using observational data.

Comparison of WindNinja and CALMET

Potter and Butler (2009) recently discussed wind models, including those proposed here, in relation to fire management activities. It is known that WindNinja gives good estimates of winds on the upwind sides and tops of hills, but degrades on the lee-side due to lack of turbulence inclusion in the model. Further, WindNinja has been shown to simulate wind in stable and neutral atmospheric conditions well, in a qualitative sense. On the other hand, CALMET was originally developed for air pollution studies and includes effects of turbulence, slope flows and flow over land and water surfaces. Hence, its incorporation into the Bluesky Framework and other modeling systems. Because the two models can yield different results under varying atmospheric conditions and topography (e.g. stability, upslope), it is desirable to utilize both models. In developing the climatology, it may be of value to merge the outputs of the two models. For the operational forecasts, it may be best for the meteorologists and end users to determine for specific days and times which model is performing best. This is not unlike meteorologists utilizing several different prognostic models in operational forecasting, and knowing which ones tend to perform better given certain conditions.

MM5 and Bluesky

CANSAC operational meteorological forecasts are 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 of an already existing 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.

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 4 is an example output map of forecast surface $PM_{2.5}$ concentration for the Lake Tahoe area.

Details of measurement system for forecast verification

The USFS AirFire Team will deploy between four and eight weather stations in a transect ranging from near shoreline to the ridgeline. Ideally, the transect will run a bisect of the lake basin to provide a cross section of wind speed and temperature and inversion height. The weather stations will be instrumented with temperature, relative humidity, and wind speed and direction probes. Some locations will also have instrumentation to measure $PM_{2.5}$. The location will be picked in conjunction with local expertise from the LTBMU to best characterize smoke and inversion layers. The monitors will be deployed immediately upon project start (May 2010) until winter snows interfere with the operation of the weather stations (approximately November 2010) to match expected period of hi-resolution wind forecasts, and to capture some prescribed fire events. AirFire and DRI will collaborate in using the data obtained to evaluate the forecasted hi-resolution winds. Several (at least two and possibly up to five) of the weather stations will telemeter data in real-time, allowing interested parties to access the collected data and model/observation comparison online.

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.

5c. Location of research

The area of research for all developed products is the Tahoe Basin.

6. Relationship of the research to previous and current relevant research, monitoring and/or environmental improvement efforts

The products and decision-support tools proposed are heavily based on existing data and on-going projects. Wind data for the development of the hi-resolution climatology is currently in-house based on both CANSAC model output gridded fields, and point observations archived at the Western Regional Climate Center, of which the PI is Director. The same model output will allow for the development of the mixing height and transport wind climatology. The existing CANSAC forecast system will be used to produce the hi-resolution wind forecasts based on the existing model technologies of WindNinja and CALMET. The USFS AirFire Team will provide the weather stations for the verification analysis, only requiring some modest funds to cover costs of new batteries and solar cells. The customized smoke prediction website tool is an addition to the existing Bluesky framework.

The project collaborators are the lead developers for the existing tools described in this project. The USFS AirFire Team is part of the USFS Pacific Northwest Research Station, and has led the development of the BlueSky Smoke Modeling Framework, which is in use as the enabling technology in smoke predictions around the country, including CANSAC. Additionally, AirFire has a long history of field research, most recently doing rapid response deployments of smoke and weather stations in response to the 2008 California fires as well as monitoring prescribed burning in North Carolina. AirFire and CEFA/DRI have a long history of close collaboration. The WindNinja development effort is done within the USFS Missoula Fire Sciences Laboratory.

7. Strategy for engaging with managers and obtaining permits

Though several individuals were contacted during proposal development, LTBMU, CARB and Predictive Services staff will be notified upon project initiation, and asked to provide input at the beginning and during stages of the project after being informed of the project plan. In particular, it is critical that LTBMU personnel assist in locating the weather stations planned for forecast verification. It is also important that users assist in designing the interface for the customized smoke prediction website tool. Hands-on training for the final products and deliverables will be provided for LTBMU, CARB and Predictive Services staff.

No permits will be required specifically for this project.

8. Description of deliverables/products and plan for how data and products will be reviewed and made available to end-users

Potential users of the deliverables from LTBMU, CARB and Predictive Services will be asked to review the final products prior to or as part of hands-on training. Feedback will be solicited as to content and usability, and changes made to the deliverable as relevant. Specific accessibility of the deliverables are as follows:

1) Climatology maps will be made available as web-based maps hosted on the CANSAC web site. If managers desire an additional media, such a CD of the maps, those will also be provided.
2) The hi-resolution wind forecasts will be made available on the existing CANSAC web site.
3) The real-time weather data used for verification will be posted on the CANSAC web site.
4) Weather data not collected in real-time will archived at both AirFire and DRI sites, and available for interested managers or researchers on request.
5) The customized smoke prediction tool will be based on the existing CANSAC web site.

Schedule of major milestones/deliverables

Milestone/Deliverables	Start Date	End Date	Description
Climatology maps	May 2010	Jan 2011	Development of the hi-res surface and upper level wind and mixing height climatology maps
Hi-res wind forecasts	May 2010	Apr 2011	Implementation of hi-res wind forecasts into CANSAC system
Weather station implementation	May 2010	Nov 2010	Implementation of weather stations for verification analysis
Verification analysis	Dec 2010	Feb 2011	Perform verification analysis of hi-res wind forecasts with observations
Customized smoke prediction web tool	May 2010	Jun 2011	Develop and implement the customized smoke prediction web tool into the CANSAC system
Prepare progress reports	Jun 2010 Sep 2010 Dec 2011 Mar 2011	Jun 2010 Sep 2010 Dec 2011 Mar 2011	Submit brief progress report to Tahoe Science Program coordinator by the 1st of July, October, January and April. Prepare summary of annual accomplishments in January.
Prepare final report	Apr 2011	Apr 2011	Submit final report to Tahoe Science Program coordinator

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Figures

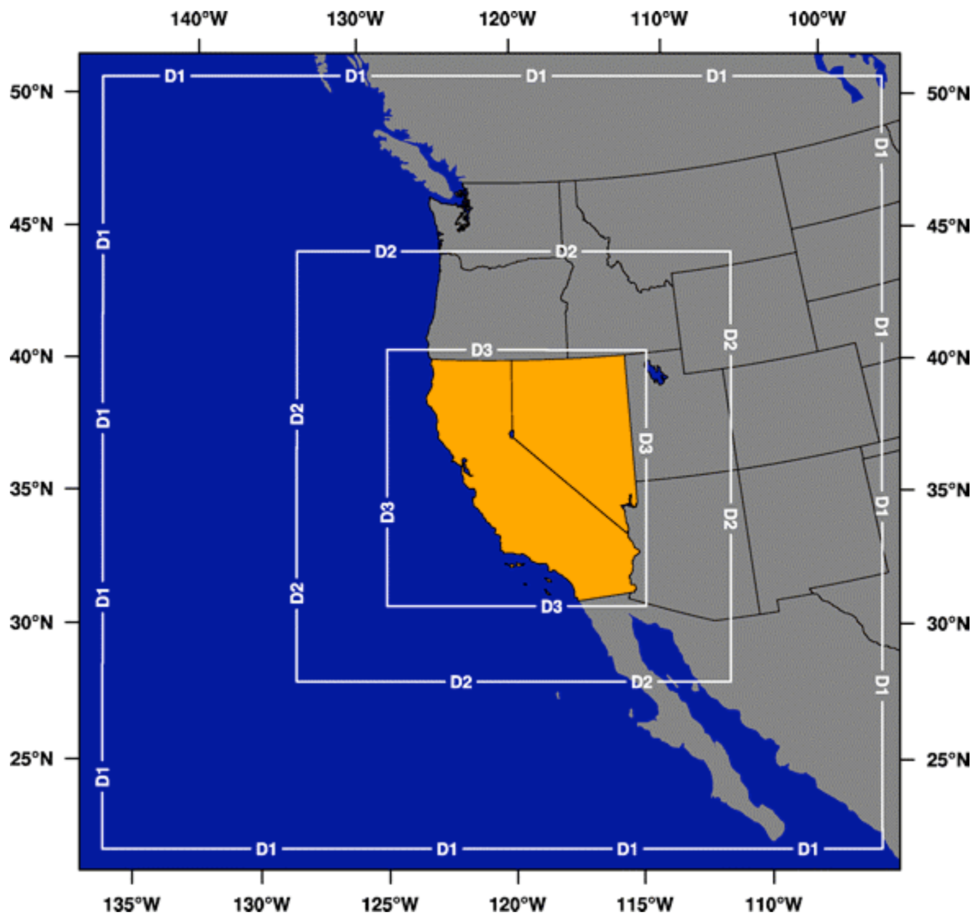

Figure 1. Domain for the existing CANSAC MM5 forecast system. With the new WRF forecast system, the inner domain will become 2-km.

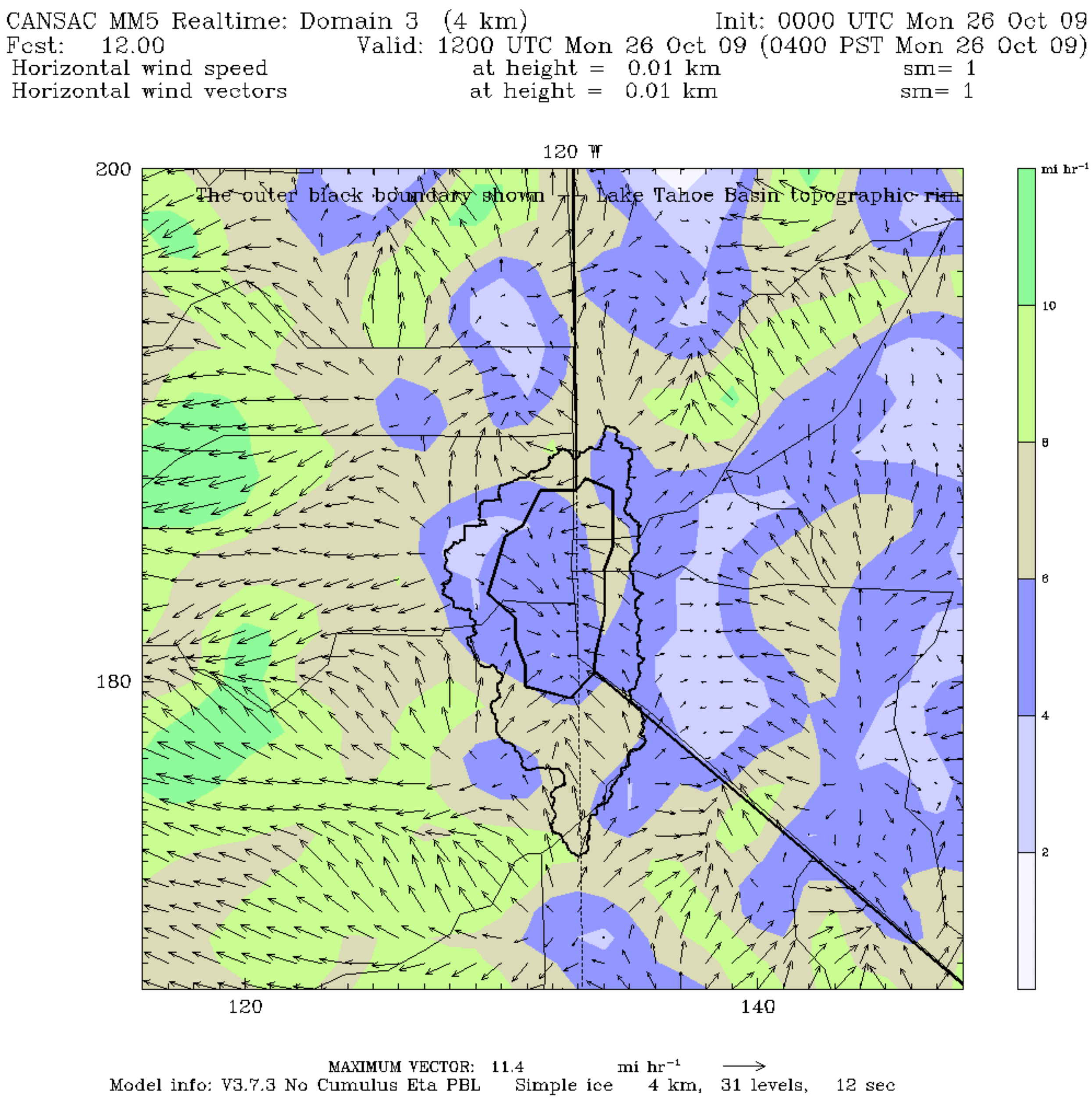

Figure 2. Example map of CANSAC forecast 4-km surface winds for the Lake Tahoe area. Wind speed is color shaded in mph, and direction by wind vectors. The lake and basin area are given by the respective polygons.

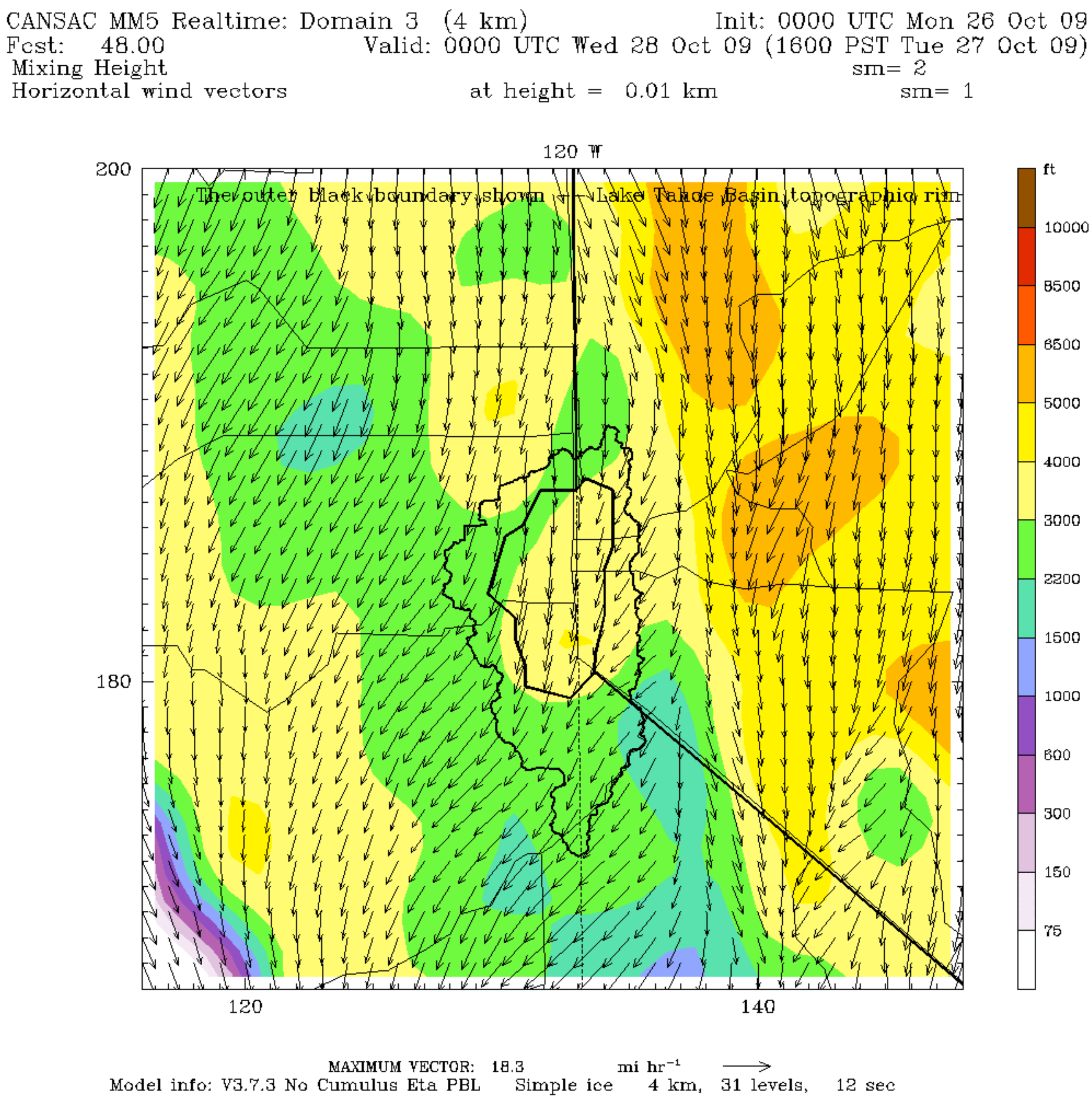

Figure 3. Example map of CANSAC forecast 4-km mixing height and transport wind. Height is color shaded in feet, and transport wind vectors denote direction and speed. The lake and basin area are given by the respective polygons.

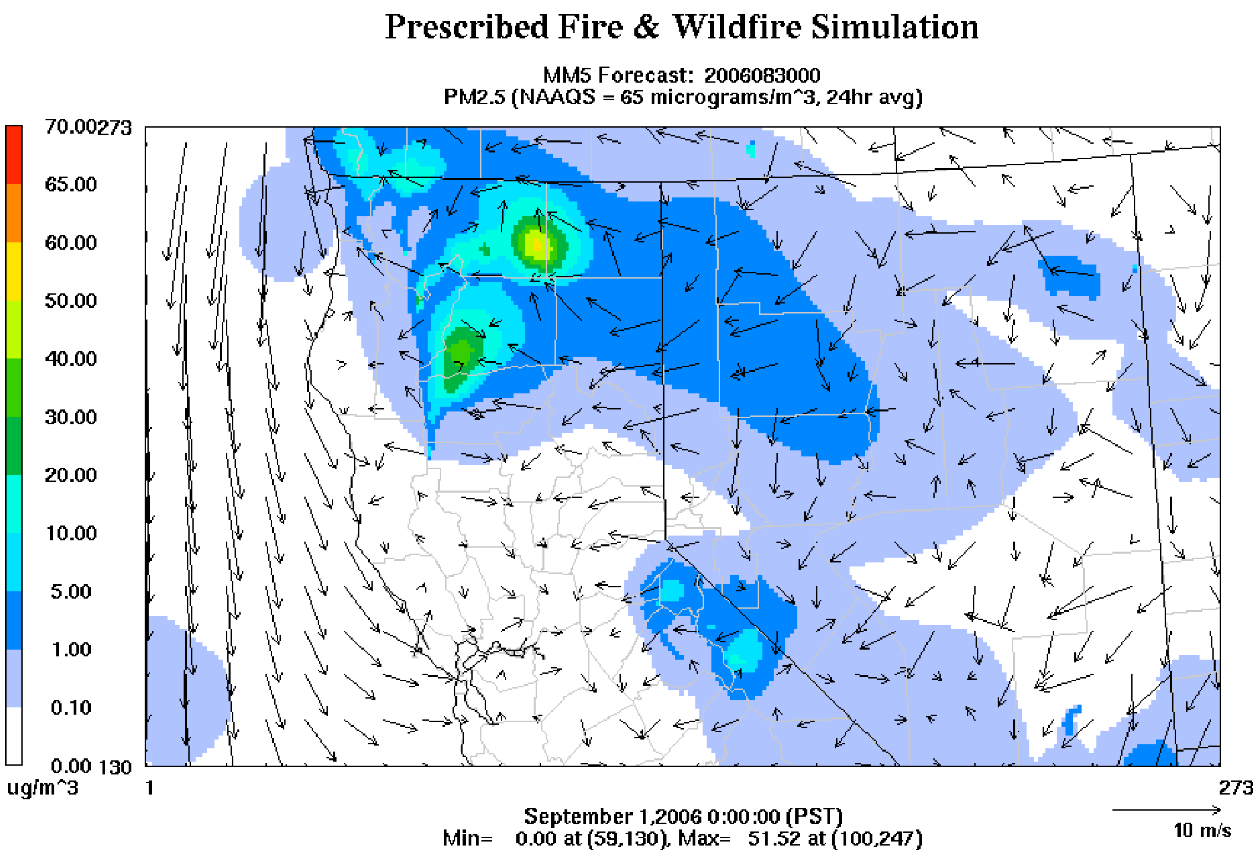

Figure 4. Example map of Bluesky forecast surface PM concentrations.