FireBuster: A Tool for Fire Management[1]

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Abstract

We developed an experimental high-resolution fire weather forecast system called FireBuster to help fire management in California. This system streamlines and automates many processes required to deliver timely fire weather intelligence. FireBuster provides routine twice-daily 72-hour weather forecasts in real-time for California at a 5-km grid resolution. Authorized users can select part of the domain and request a 1-km resolution 72-hour forecast with only a few clicks. Forecast outputs include near surface values of temperature, relative humidity, wind speed and direction, precipitation, and several specialized variables. Each forecast run (5-km and 1-km resolution) takes from 1 to 2 hours to process on our in-house computing hardware.

FireBuster delivers information, as each 6-hour increment completes, via a web page which visually depicts the forecast over an interactive map. The user can view future weather conditions hour-by-hour over the entire domain. When available, weather data from the MesoWest observational network can be displayed for post-evaluation. Additional features are in development, such as a format of the gridded output that can be downloaded for input into FARSITE, a popular fire spread model.

The Southern California Geographic Area Coordination Center (GACC), which manages all regional fire-fighting resources, is the intended user of this system. Collaboration with the GACC's fire meteorologists has provided us ongoing feedback on how to best improve FireBuster. The next development phase of the system includes adding forecasted fire danger indices, observed fire perimeters and an economic data layer so that FireBuster can truly be part of an integrated fire management tool.

Also, we developed a related parallel system, called FireBusterSim, to examine the downscale simulation. FireBusterSim works similar to FireBuster, but produces downscaled weather given archived global analysis data. Both 5- and 1-km grid cell resolution model runs are made over the area of the fire. Increased spatial resolution is shown to indeed provide better accuracy in model data. Incorporating finer topographic details into the model improves weather prediction in complex terrain where fires often occur.

Keywords: Decision-making, fire weather, meteorology, high-resolution weather model, fire management.

Introduction

Weather is the most important factor in determining fire behavior, yet it remains the most elusive to predict, especially at high resolution over complex terrain. To forecast future weather conditions, a fire manager may extrapolate from current conditions, given just the observed weather or climatology. However, this method

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does not capture variations from the norm, or extreme weather events. It is often necessary to overcome this by relying on output from coarse weather models that still do not accurately represent the area where fire events are occurring. Additionally, such models may not forecast on a timescale that captures the daily variability of local weather patterns.

High-resolution weather models can provide a better picture of what is happening in complex terrain to fire managers and firefighters. Unfortunately, these models can be computationally expensive and require a large amount of time to produce usable output. Complex model output can also be difficult to interpret and require specialized personnel to process.

Fire managers can make use of a fire weather forecasting tool that is easy to use, readily available, and can provide fire weather information that is timely and detailed. This paper describes such a weather forecasting system that we have been developing called FireBuster, which can be used operationally by fire personnel.

Objectives

Although extensive research went into the development of FireBuster, its ultimate purpose it to be use in an operational setting. The main objectives of the FireBuster system are:

- To be easy to understand and use by fire management personnel, including incident meteorologists and firefighters.
- To be accessible to operational personnel.
- To provide timely, accurate, and detailed fire weather information.
- To allow interaction so that the user can extract specific information for a place or time.

The California Department of Forestry and Fire Protection (CAL FIRE)[3], U.S. Forest Service Region 5[4], and other California fire management agencies are currently the intended users.

Methodology

FireBuster uses the mesoscale spectral model (MSM, Juang 2000) from National Center for Environmental Prediction (NCEP). MSM is the non-hydrostatic version of the Regional Spectral Model (RSM, Juang and Kanamitsu 1994), which has been used in many of our previous regional modeling work (e.g. Chen et al. 1999; Chen et

[3] See http://www.fire.ca.gov .
[4] See http://www.fs.usda.gov/r5 .

al. 2008; Roads et al. 2010). Forecasts are computed for all of California at 5-km grid cell resolution. That is, forecasted values are produced for every five square kilometers over California. The domain grid measures 243 by 243 square cells. The MSM produces a set of weather variable grids for every hour out to 72 hours into the future. We initiate each forecast by downloading a portion of the daily output from NCEP's Global Forecast System (GFS), which has a resolution of 0.5˚ in latitude-longitude interval, and downscaling it using the MSM. The model can also be run at a 1-km cell size, but since it would take an unacceptably long time to process the area all of California at this resolution, we only perform these runs for the areas and the times, usually for fire events, specified by user. The domain for the 1-km run is also reduced to 96 by 96 cells. The 1-km forecast runs use the 5-km forecast for initial conditions, so these finer scale runs must be nested within the coarser, larger ones (Figure 1).

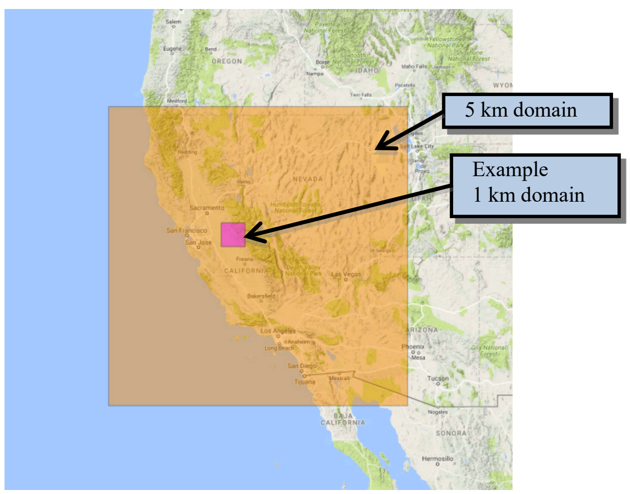


Figure 1: Mesoscale model domains used by FireBuster. The 5-km domain covers all of the state of California (and Nevada as well). Forecasts for the 5-km domain are run twice daily. The 1-km domain forecasts can be run when needed for specific areas.

The MSM forecasts several weather products, including temperature, relative humidity, precipitation, and wind direction and speed. A number of less common variables are also produced, such as convective available potential energy (CAPE) and planetary boundary layer (PBL) height that may be of interest to fire weather meteorologists.

To determine what forecasted information would be of use to fire managers, we worked with a fire weather meteorologist with the Predictive Services program at the Southern California Geographic Area Coordination Center (GACC). The 11 GACCs located around the U.S. are responsible for allocating Forest Service firefighting resources to fire incidents. Understanding future weather conditions is critical to their operations. The FireBuster system is designed with the GACCs' needs in mind.

We use in-house equipment, a Dell PowerEdge R820 server, to perform the downscaling and other related computational tasks (Figure 2). Forecasts for the 5-km domain are run twice each day for 12UTC and 00UTC – at local noon and midnight, respectively – out to 72 hours. The 5-km forecasts typically take about 2 hours to be completely processed. However, the forecast data is divided into files representing 6-hour increments, which are available to access once they are complete. Each increment file is produced every 8 to 15 minutes during a run. The 1-km forecast run takes roughly 1 hour to process a 72-hour forecast. All forecast data is archived for analysis purposes.

Figure 2: The FireBuster forecast model runs on a 40-core Dell PowerEdge R820 server. Mass storage systems are used for archived data. Another server (not shown) converts model output to web-displayable graphics.

Model output is saved in GRIB format, which is a data storage format commonly used in the meteorology community. This format stores weather data in three spatial dimensions as well as time. However, extracting data from GRIB is not easy without specialized software. We wrote code to automatically extract data from each model run's GRIB file into data layers representing individual hourly forecast of weather variables. These data layers are then converted to graphics (PNG images) that are viewable using a web browser or picture-viewing software. The code also creates a web page to display the images. The web page, images, and related files are saved to a web server that is accessible on the Internet. The images representing weather variables are displayed semi-transparently over an interactive Google Maps background. The map can be zoomed and panned similar to the regular Google Maps interface[5]. The user can control which forecasted hour and weather product are being viewed (Figure 3).

Authorized users can submit requests for high-resolution 1-km forecast runs through the FireBuster web page. This feature is intended to allow fire managers run detailed forecasts over areas where fire events are occurring. The web page is continuously updated while the model is producing forecast output; the user does not have to wait until the forecast has entirely finished to see output. Given a latitude and longitude, the user can view an hourly 1-km resolution weather forecast of an area with ease.

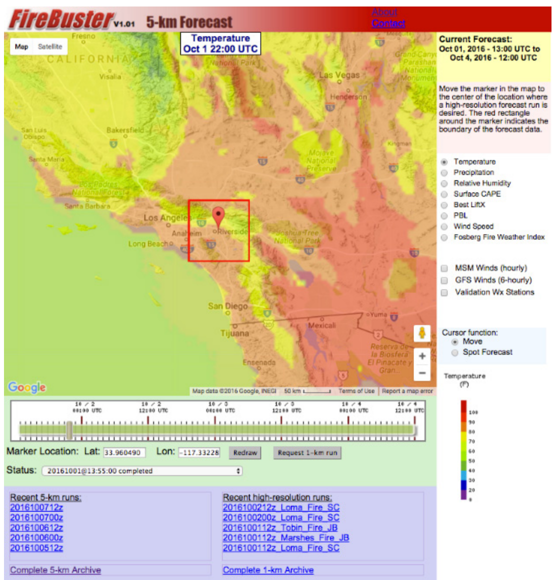


Figure 3: The FireBuster web page allows the user to see the output of the latest 5-km fire weather forecast run. Authorized users can also request special 1-km forecast runs. Past runs are archived and accessible for review.

Along with producing forecasts, we automated the collection of observed weather data from a large number of stations throughout California on a daily basis. The data comes from the Mesowest station network, and is available through online services (MesoWest & SynopticLabs 2016). We reviewed and selected high quality stations to display on the FireBuster web page. This data is reformatted for display on the page and can be used for model validation (Figure 4). The user can view station data by clicking a checkbox on the page. Displayed station data is hourly, like the forecasted data, and consists of temperature, relative humidity, and wind speed and direction values. This observed data can obviously only be plotted for past hours.

[5] http://maps.google.com .

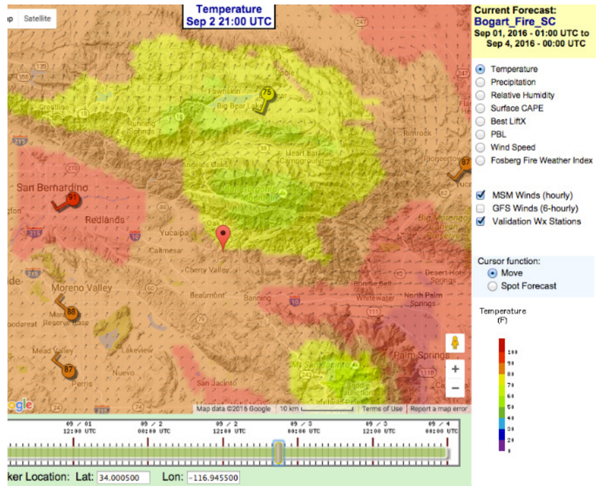


Figure 4: 1-km forecast for the area around an active wildfire, showing locations of nearby weather stations. Station icons indicate temperature, wind direction, and wind speed. More station data is available by clicking on the icons.

In addition to viewing weather values over an area by each hour, we added a feature to the web page to perform a 'spot forecast' for any location on the map that the user clicks on. This consists of time series plots of temperature and wind information for a single location (Figure 5). If available, observed data from the closest weather station is also plotted. This allows for validation of forecast values over time.

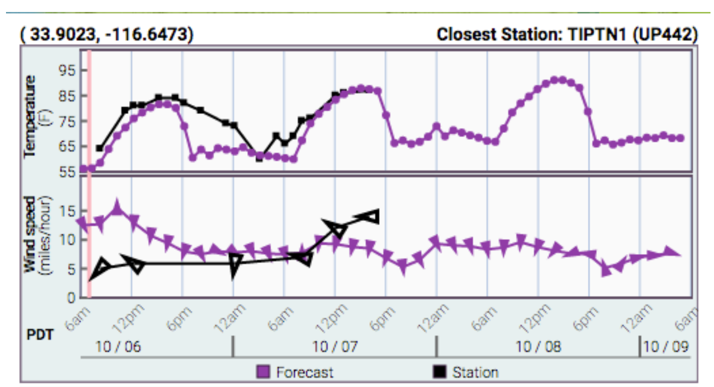


Figure 5: Spot forecast of a single location on the FireBuster web page. Plots of all 72 hours of forecasted temperature and wind values are shown (purple). Available observed data from the closest weather station is also shown (black).

There is often interest in examining past weather scenarios for higher resolution patterns. Along with the FireBuster fire weather forecasting system, we developed a similar product for analyzing past modeled weather data, called FireBusterSim. FireBusterSim provides downscaled *simulations* of weather fields rather than forecasts. The web page is very similar to the regular FireBuster page, but with some variations. FireBusterSim uses archived NCEP GDAS data to produce modeled weather downscaled to a higher resolution. This is useful for studying the added skill of the mesoscale model from the coarser model output. We can use FireBusterSim to learn more detail about near surface flow, and how having a 1-km cell resolution forecast would benefit over the 5-km resolution product.

Case Study: The Esperanza Fire

We looked at how high-resolution weather data like that produced by FireBuster and FireBusterSim might help on a fire incident. We investigated the Esperanza Fire of 2006, which occurred in the San Jacinto District of the San Bernardino National Forest in Southern California. Although this fire happened several years ago, an extensive amount of data has been collected on it due to an investigation on the deaths of five firefighters during its suppression. The fire started during Santa Ana conditions – a period of strong winds descending from the Great Basin accompanied by low humidities and warm temperatures that is common in autumn in Southern California. The accident investigation determined that the fire was primarily wind-driven, with wind speeds around 40 miles per hour (~64 km per hour), gusts around 60 miles per hour (~96 km per hour), and relative humidity below 10% (Esperanza Investigation Team 2007, p. 65). Aerial fire imaging (Riggan et al 2010, Coen and Riggan 2014) showed that it progressing in a southwesterly direction during the first several hours after being initially reported on October 26th, 2006 at 1:11am (Figure 6). Ultimately, the fire grew to 41,000 acres (~16,600 hectares).

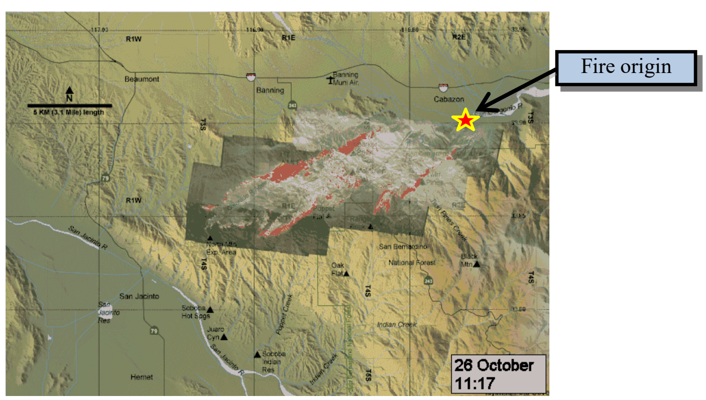


Figure 6: Image from FireMapper, an aerial thermal mapping system that can identify active sections of a fire perimeter. The Esperanza fire is shown burning predominantly southwest after the first several hours.

The Esperanza Fire occurred in steep, rugged terrain, with many hills and canyons. These terrain features would be undetectable to coarse weather models, yet these greatly contribute to fire behavior. For example, along with weather conditions, a narrow “unnamed creek drainage” contributed to the extreme fire behavior near the firefighter fatality site:

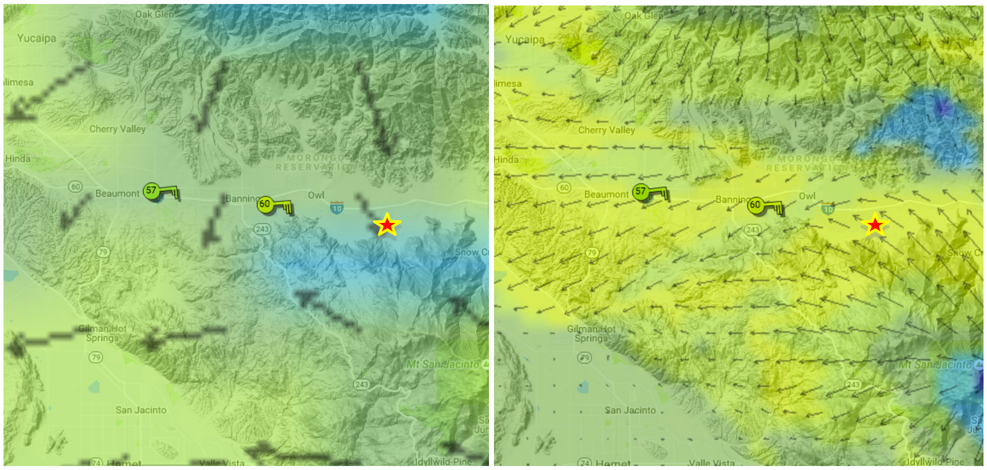
> *“Santa Ana winds came into alignment with the 'unnamed creek drainage' and the inversion was penetrated by the thermal uplifting from a fire run which contributed to extreme fire behavior and area ignition.”*
>
> (Esperanza Investigation Team 2007)

We accessed archived initial model data from NCEP to run the MSM for the time of the Esperanza Fire. FireBusterSim runs were performed at 5- and 1-km cell resolutions. As resolution increases, topography has greater influence on the mesoscale model output. The 1-km model data should thus produce more realistic wind and temperature values in complex terrain than the 5-km version. Both 5-km and 1-km FireBusterSim runs are expected to provide more accurate output than the archived data from NCEP Global Forecast Model, which establishes the initial conditions to the model runs. In a similar manner, FireBuster *forecasts* should demonstrate greater accuracy with increased resolution.

Results

We performed a 5-km FireBusterSim run initialized on October 25th, 2006 to capture the starting hours of the Esperanza Fire. At this resolution, general terrain features were taken into account. Over the rugged landscape at site of the fire, however, modeled wind speed and direction were only influenced by large-scale topography. The overall temperature field also appeared to only vary slightly during each hour.

We then modeled the area at a resolution of 1 km. In contrast to the 5-km run, topographic details seemed to have affected wind and temperature values (Figure 7). Likewise, more variation in relative humidity and other variables could be seen in the downscaled model data. The general wind direction and speed as well as temperature produced at 1-km resolution matched observations from two weather stations in the area. The winds from neither resolution seemed to explain the initial southwesterly spread of fire from the origin – the 5-km winds were predominantly southerly, and the 1-km ones were northwesterly during the first few hours. It is possible fuels (mainly dried sage, chamise, and grasses in this area) as well as the uphill slope drove the direction of fire spread during the early morning. The 1-km model output, however, did show winds blowing in a southwesterly direction several kilometers west of the fire's origin. Also, as the day of October 26th, 2006 progressed, the modeled wind did change from a northwesterly to a more westerly direction.



(*a*) **(*b*)**

Figure 7: 5-km (*a*) and 1-km (*b*) FireBusterSim model output for the Esperanza Fire area for October 26th, 2006 at 7am local time. The star marker indicates the approximate location of the fire origin. Two weather stations – Beaumont (left) and Banning (right) are shown. The 1-km run (*b*) shows wind vectors more closely align with weather stations and the fire progression (southwesterly) than in the 5-km run. More variation in temperature values can also be seen in the 1-km image. Note that only *every other* wind vector is shown in the images.

It was possible to compare variations in time for a random fixed location by using the 'spot forecast' feature in the FireBusterSim page. The comparison of model values for temperature, wind speed, and wind direction could be made with observed hourly data for the entire period of the run, since historical station data is archived along with past forecasts. The 5-km and 1-km values could be compared for the same location to examine accuracy over time (Figure 8). The 1-km temperature values seemed to more closely match observed station data[6] than those from the 5-km run. Likewise, wind speed and direction data from the 1-km model was a better fit to the station data than the coarser model data.

[6] From Beaumont weather station (RAWS Id: BNTC1), approximately 3.3 miles (5.4 kilometers) away.

(*a*)

(*b*)

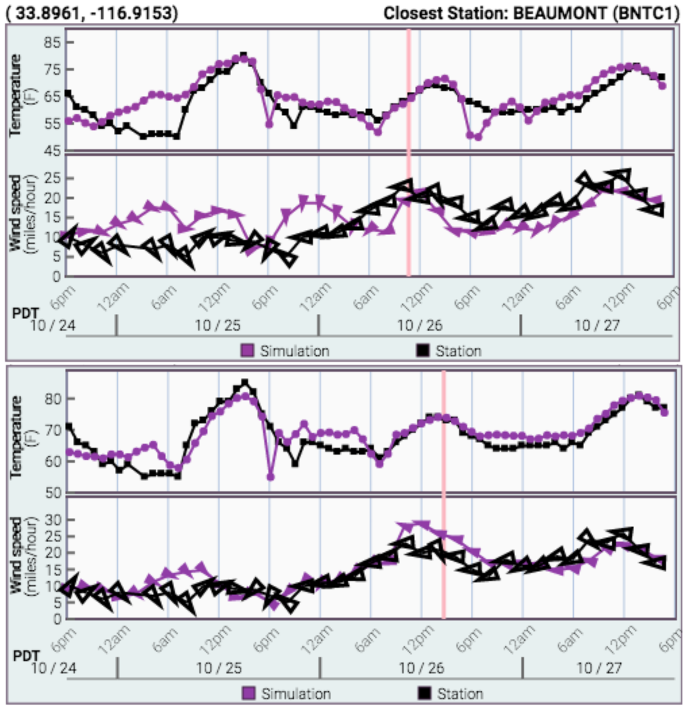


Figure 8: 'Spot forecast' (time series) of a single location. (*a*) shows FireBusterSim and observed values of temperature and winds using 5-km resolution; (*b*) shows 1-km resolution. Triangular wind markers point in the direction wind is going.

Discussion

Technological advances over recent years have allowed us to produce forecasts at the resolution of FireBuster's in a manner timely enough for use operationally. The increasing processing speeds of computer hardware, prevalence of weather data, and network accessibility have contributed to building better fire management tools. FireBuster has the specific goal of helping those who manage fire. It provides high-resolution fire weather forecasting for California, although the domain can likely be adapted to any geographic region globally. Having forecast values at 5- and 1-km spacing, for every hour out to 72 hours, provides a large improvement over coarser scale official forecasts. These higher resolution mesoscale spectral models incorporate finer topographic detail, allowing them to resolve wind, temperature, and other fire weather variables in rugged terrain where fires often need to be fought.

FireBuster may also be the groundwork for forecasting fire danger at high spatial and temporal resolution. The U.S. fire danger rating system relies on knowing weather conditions as well as topography and fuels information for calculating a set of indices that measure fire potential (Bradshaw et al 1984, Cohen and Deeming 1985, Deeming et al 1977). For fire danger computation, fuel moisture values would also need to tracked daily by FireBuster.

Adding an economic data layer to the system may allow users to assess the monetary impact of possible fire events (Benoit et al 2013). However, collecting such data on a state-wide basis is difficult, as it would consist of both market and nonmarket values. Real estate prices and recreational use fees, among other economic data, would need to be assembled into a data layer, which must be periodically updated. There has been discussion of including an economic data into FireBuster in the future – however, it will likely take a considerable amount of time to fully develop this addition.

Currently, FireBuster and FireBusterSim are being used primarily in a research and development setting. Periodic communication with fire management personnel provides suggestions on improvements to the system. Additional features are being developed and will be added soon. Because of the demand for it, the FireBuster system will provide weather data files in a format that can be read directly into FARSITE, a well-known fire spread model used in the U.S. (Finney 1998). Progressive fire perimeters of well-documented fires will be converted to a format that can be displayed on the FireBusterSim web page. A mobile version of the web page is in development, which will allow a smartphone or tablet computer user to view a spot forecast of their current location. This design is intended for fire personnel with Internet access to instantly view predicted fire weather in their area. An operational version of FireBuster should be available next year.

Acknowledgements

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