Detailed wind information and at its application to improved firefighter safety

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Abstract

Fire intensity and rate of spread are strongly linked to the local wind flow. Forecasts and estimates of projected fire behavior provide vital information when planning tactics and strategies relative to wildland fire. Firefighter safety is enhanced when planning is based on accurate fire behavior estimates. One major source of uncertainty in fire behavior estimates and predictions is the lack of methods for estimating the local terrain effects on winds at the 100 ft and smaller scale. In most cases wind data available to firefighters are limited to a few measurements from weather stations, which may not even be near the fire location, or to broad scale meteorological forecasts. Consequently, fire managers and firefighter teams rely on personal observations, guesswork and past experience to estimate spatial wind variability and its effect on fire behavior. These methods provide rough estimates but are subject to local knowledge and the skill level of the analyst. The study described by this poster has three objectives: 1) develop a methodology for simulating surface wind flow at the 100ft and smaller scale; 2) identify methods of using this information; and 3) develop a tool that can be easily used on an operational basis to obtain this information. We describe the methodology, present evidence of the impact of this information on fire growth modeling, and describe how this information can improve firefighter safety.

Introduction

Firefighter safety is increased when tactics and strategies are based on accurate fire behavior forecasts. It is commonly recognized that wind is one of the primary environmental variables influencing wildland fire spread and intensity (Rothermel 1972, Catchpole and others 1998). However, methods for obtaining local wind information available are limited to that available from weather forecasts and/or weather observations from a few specific locations, none of which may be actually near the fire. Mountainsides, valleys, ridges, and the fire itself, influence both the speed and direction of wind flows. A major source of uncertainty in fire behavior predictions is the lack of detailed wind speed and direction information for use in the fire behavior calculations. Wind and its spatial variability in mountainous terrain has been a major influencing factor in the fire incidents that resulted in firefighter entrapments and/or fatalities [e.g. Mann Gulch, (Rothermel 1994), South Canyon Fire 1994 (Butler and others 1998), Thirtymile fire (USDA Forest Service 2001), and Price Canyon Fire (Thomas and Vergari 2002) and many others]. Researchers at the USDA Forest Service's Rocky Mountain Research Station, Fire Sciences Laboratory in Missoula, Montana over the last three years have developed a method that will provide prescribed fire planners and firefighters with a straightforward tool for simulating surface wind flow.

Discussion

Forthofer and others (2003) and Butler et al (2004) describe the wind simulation process in detail. Wind modeling for a specific fire typically consists of simulating several different combinations of wind speed and direction. The simulations are selected to match a forecasted scenario or are based on historical weather patterns. The simulation accounts for the influence of elevation, terrain, and vegetation on the general wind flow. Output files are geo-referenced

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so that they can be incorporated into standard GIS information systems. This is significant as it permits planners and fire management teams to overlay wind field on custom maps (fig. 1).

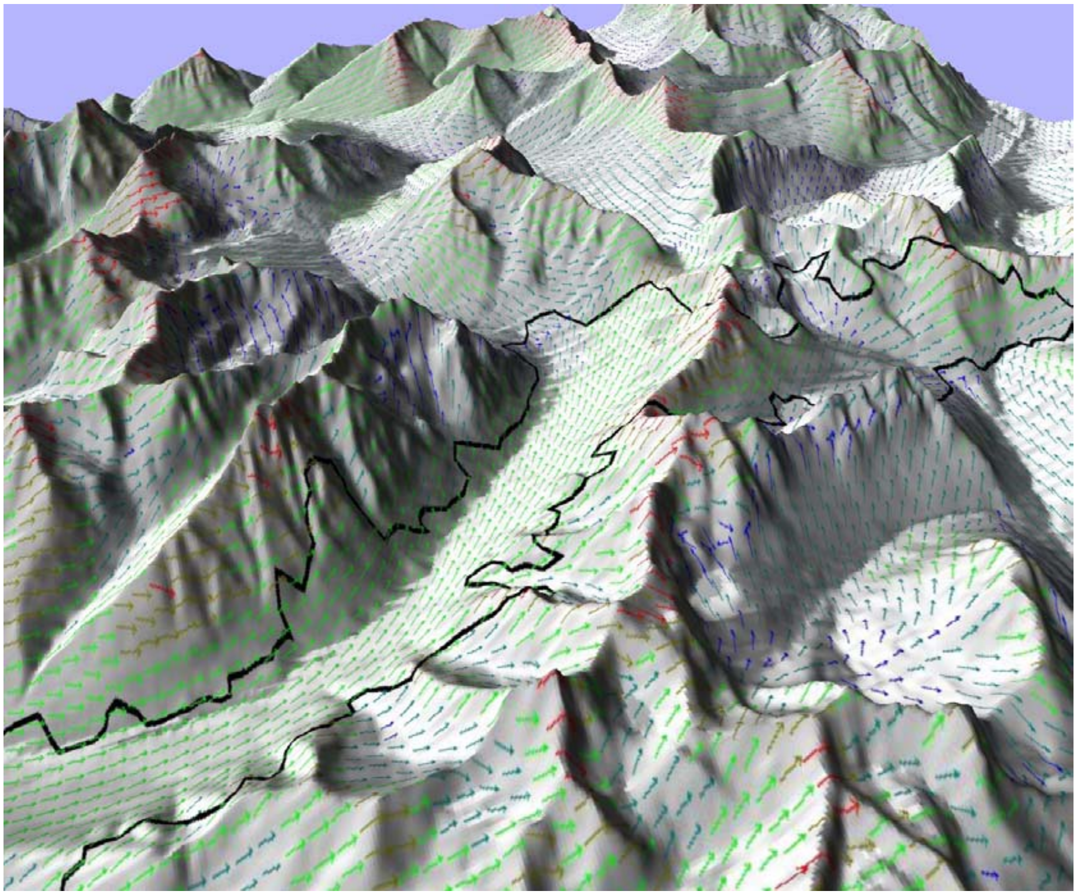

Figure 1—Example of wind field overlayed on 3-D shaded surface with fire perimeter shown (i.e. black line). Wind speed and direction is represented by orientation, length, and color of vectors.

Transfer of results from the wind simulations to fire managers and field personnel can occur in three different forms: 1) Images consisting of wind vectors overlaid on a shaded relief surface image. The fire perimeter and marked prominent landmarks can be added to orient the viewer (fig. 1). These images display the spatial variation of the wind speed and direction and can be used to identify high and/or low wind speed areas along the fire perimeter caused by the channeling and sheltering effects of the topography. 2) ARCView or ARCMap shape files of wind vectors. These vectors can be incorporated into a GIS database and custom maps/images developed. Some useful combinations are wind vectors over fuels maps, IR based fire perimeters, and 7.5 minute quad maps with contour lines, roads, and trails. The process can also produce input files for use by the FLAMMAP and FARSITE programs (Finney 1998). Naturally, the accuracy of fire growth projections are limited by the accuracy of the weather and wind forecasts used to develop the gridded winds. This implies that the uncertainty associated with both wind and fire growth projections will increase as the simulation progresses forward in time. Gridded wind simulations have been used to provide wind input to a small number of FARSITE fire growth simulations, in all of the simulations completed so far (less than 5) the accuracy of short term (< one day) fire spread projections, as compared to actual fire spread histories, has increased.

This methodology assumes a neutrally stable atmosphere and therefore does not account for density driven flows (diurnal winds and fire induced winds). Naturally this introduces some error (especially at low wind speeds) into the simulation; however as the upper air wind speed increases the relative magnitude of this error decreases.

The accuracy of these simulations has been verified by two methods: 1) comparison of modeled wind speed and direction against direct measurements, 2) comparison of predicted versus actual fire growth simulations with and without the high resolution wind information.

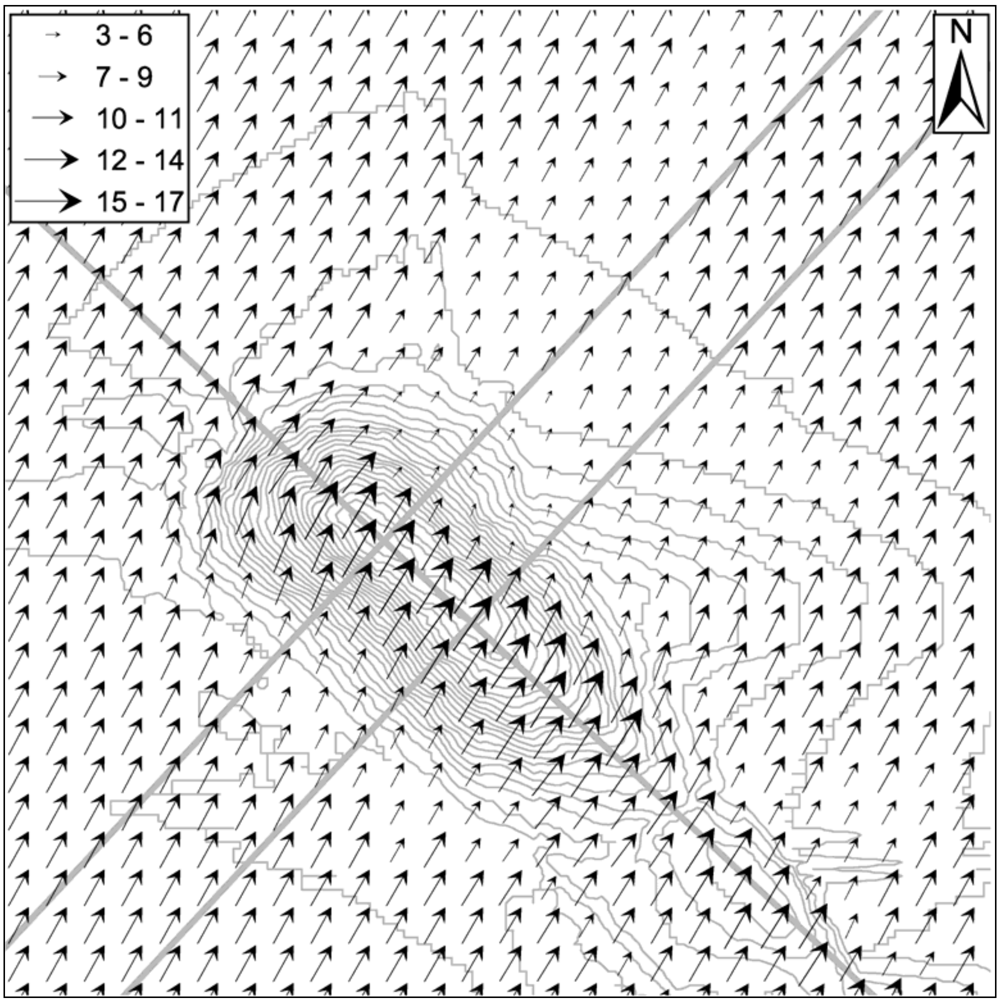

Figure 2-- Gridded wind simulation results for general input flow of 10 m/s from an angle of 210 degrees. Solid lines represent transects along which instruments were deployed.

A set of measurements were collected specifically for the purpose of characterizing surface wind simulations (Taylor and Teunissen 1987). The site was a 116 m high hill located on the west coast of the island of South Uist in the Outer Hebrides of Scotland. Vegetation was relatively uniform and consisted primarily of heather and grass. Winds were measured using over 50 10 m tall towers instrumented with cup anemometers. The towers were deployed along three lines (see fig. 2). Ten minute mean wind speed and direction measured 10 m above ground level were recorded during the 3 hour experiment. The overall mean direction and speed were 210 degrees and 8.9 m/s respectively. Using an input flow speed and direction of 10 m/s from 210 degrees a CFD-based simulation was completed. The simulated wind speeds along line A were compared against measured wind speeds (fig. 4). Generally the modeled wind speeds were within 9 percent of those measured except for the location

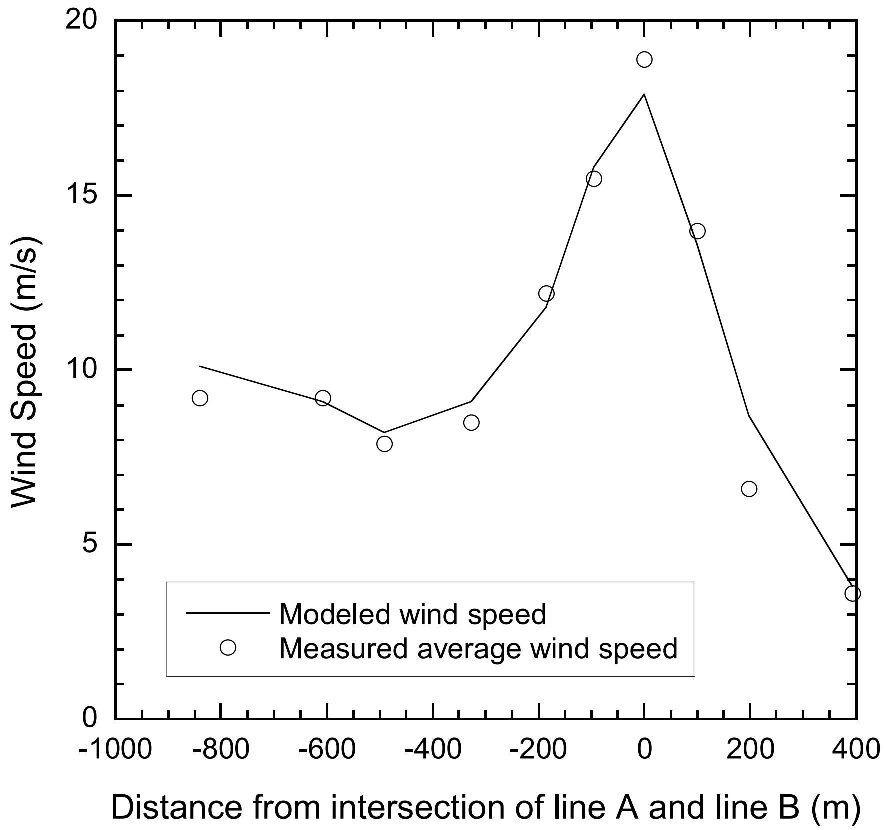

Figure 3 -- A comparison of measured and predicted wind speeds along line A.

approximately 198 m downwind from the intersection of the A and B lines were the simulated wind speed was 32 percent greater than the measured value. This location is approximately midslope on the leeward side of the hill and is likely related to differences between the steady state calculations produced by the CFD-based model and the transient nature of turbulent eddies forming on the leeward side of the hill (Castro and others 2003). This result suggests that the CFD-based methodology may not capture the transient nature of the flow. Simulated wind direction was also compared against measured values (fig. 5). As shown the agreement is not as good as that of the speed comparison but is still less than 13 degrees for all locations. The largest difference between the simulated wind direction and measured values were greatest near the base of the hill for both the upwind and leeward sides.

While the Askervein hill is topographically relatively simple, the comparison between simulated and measured winds suggests that the CFD-based methodology for simulating surface wind flow over mountainous terrain can provide relatively accurate information. Similar results have been obtained when wind simulations are compared to field measurements of wind speed and velocity on Waterworks Hill located north of Missoula, MT.

As noted previously, a second method for evaluating the accuracy and impact of this technology is to compare fire growth simulations against those demonstrated by actual fires. Simulations have been performed for several fires. In all cases the accuracy of the fire growth predictions increases with the use of high resolution winds (see Butler et al, 2004).

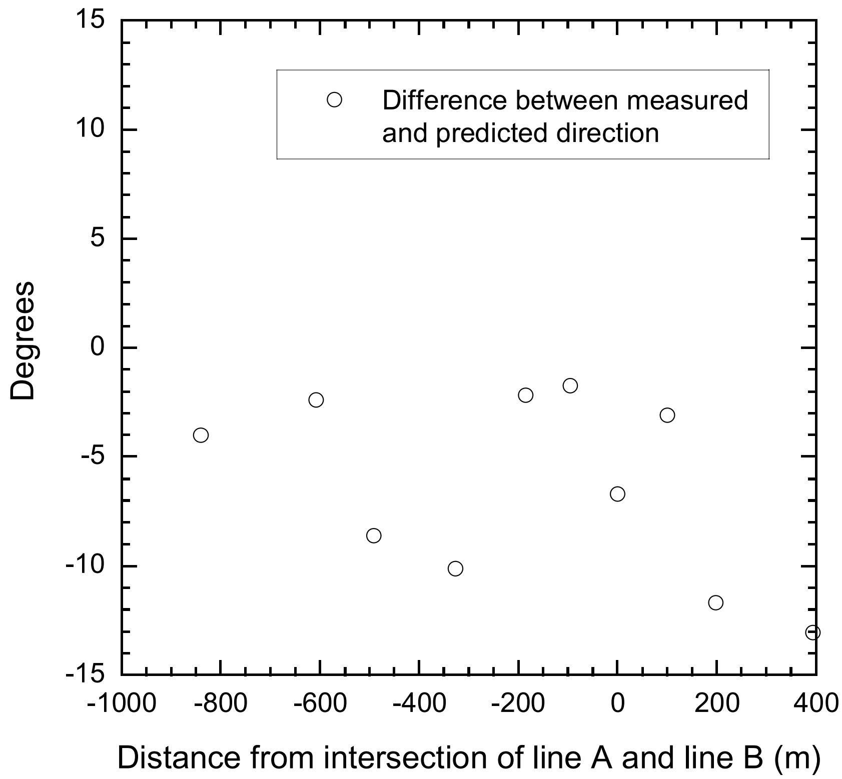

Figure 4 – Comparison of measured and simulated wind direction for Askervein Hill.

More recently the high resolution wind simulations have been used in the FlamMap model to characterize the potential for fire growth across a landscape (fig. 5). The high resolution wind information provides an added value in that fire growth potential now can include the primary influence of wind.

Conclusions

The CFD-based methodology for simulating the influence of terrain on surface wind flow represents a new technology, at least from a fire management perspective. Research efforts over the past two years have demonstrated that this technology, termed gridded wind, can provide highly detailed wind speed and direction information in time frames suitable for use by fire incident management teams (Price Canyon Fire-Thomas and Vergari 2002; Hayman Fire- Graham 2002). Although computationally intensive, the process has been refined so that a typical solution (10 to 100 m resolution wind speed and direction) on a grid measuring 40 by 40 kilometers can be completed in a matter of two to three hours using a laptop computer.

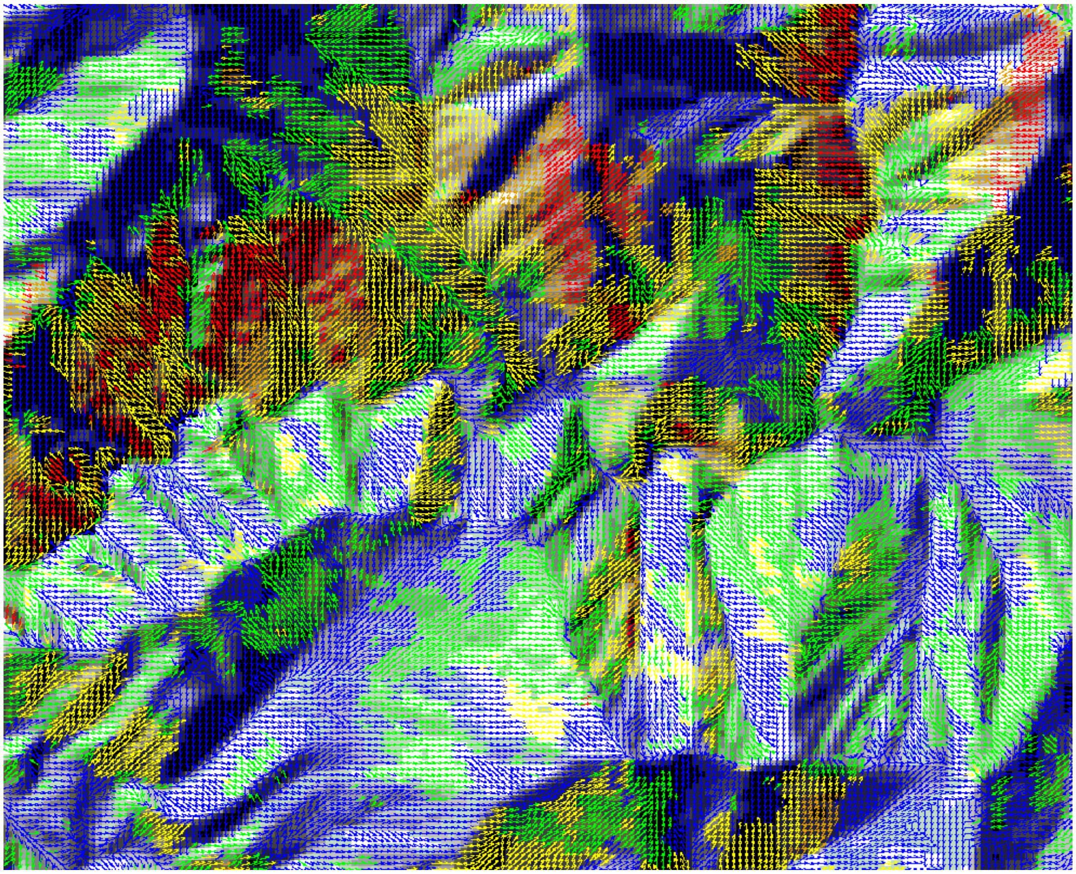

Figure 5 – Fire potential map based on the FlamMap model. The vectors represent simulated wind direction and speed. The colors represent fire growth potential based on combination of wind, terrain and fuels at each location.

The accuracy of the wind simulations has been evaluated by comparing simulated winds against measured wind averages at discrete points. The results indicate general agreement and that the simulated wind speeds and directions are most accurate for pressure gradients such as cold fronts, Foehn (Santa Ana), onshore/offshore winds and are less accurate for the low speed density driven flows such as those associated with diurnal heating and cooling of the earth's surface.

The winds developed from this tool are simulations and should be confused with wind or weather forecasts. They are simulations of what the wind flow would be under different general (synoptic) wind scenarios. Wind information derived using this method has been used to identify areas and/or conditions that may produce high fire intensity and spread rates and for identifying locations where fire spotting might occur. Comparison of fire growth simulations using the FARSITE fire growth simulator with and without high resolution wind information have demonstrated that the accuracy of short range (< one day) fire growth predictions is significantly higher using this wind information than without it.

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