Final Report for JFSP funded project entitled:

Modeling surface winds in complex terrain for wildland fire incident support

JFSP Project 03-2-1-04

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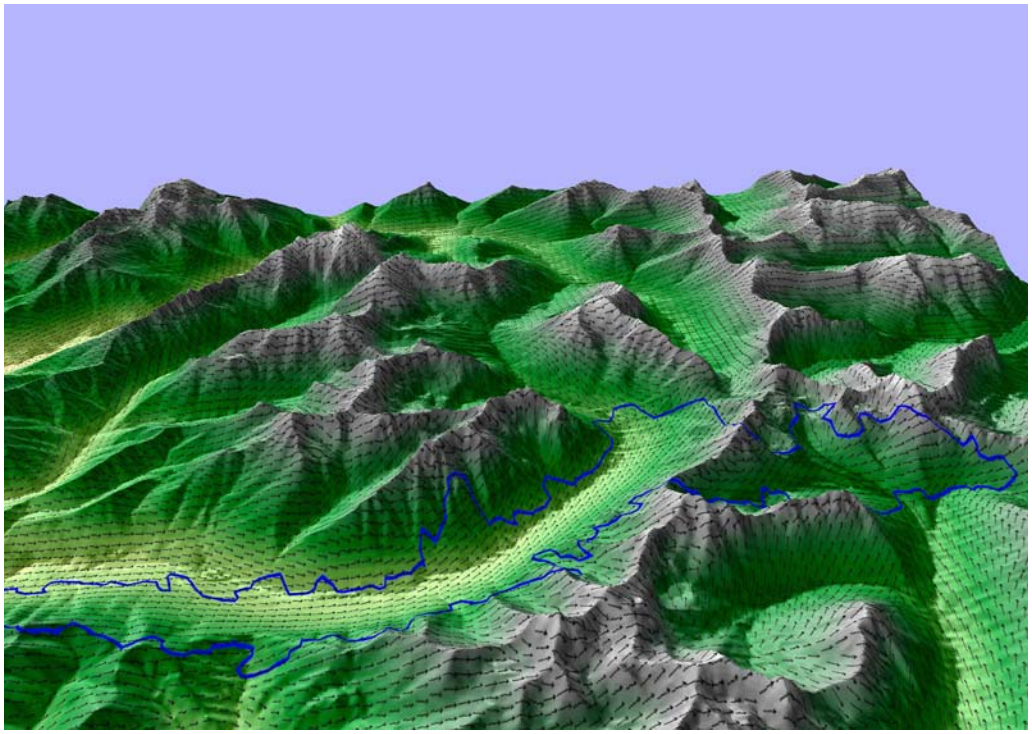

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Executive Summary

One major source of uncertainty in fire behavior predictions is the spatial variation in winds blowing over mountainous terrain. Fire managers have not had access to "real time" predictions of surface wind flow.

This project combines digital elevation map images with fluid dynamics predictive tools to simulate surface wind speed and direction at the 100m scale on the terrain surface (see figure 1). The project had three objectives:

1) Develop a methodology for producing high resolution surface wind maps.
2) Quantify the effect of high resolution surface wind data on fire behavior predictions.
3) Address the practical potential for modeling fire-induced changes to the wind fields.

With the generous support of the JFSP and additional funding from several USDA Forest Service sources a wind simulation tool has been developed and tested. It has been used to complete more than 1000 wind simulations on hundreds of fires across US over the last 3 years. It is being used to support research into smoke dispersion, flying insect pheromone dispersion and other applications. The tool is easily linked to the currently used fire growth simulation tools FARSITE, FlamMap and FSpro. Fire managers have found it to provide reliable, timely, and detailed information that has increased their capability to make informed decisions relative to firefighter and public safety and fire management. It has also provided valuable information about the conditions leading to firefighter entrapments.

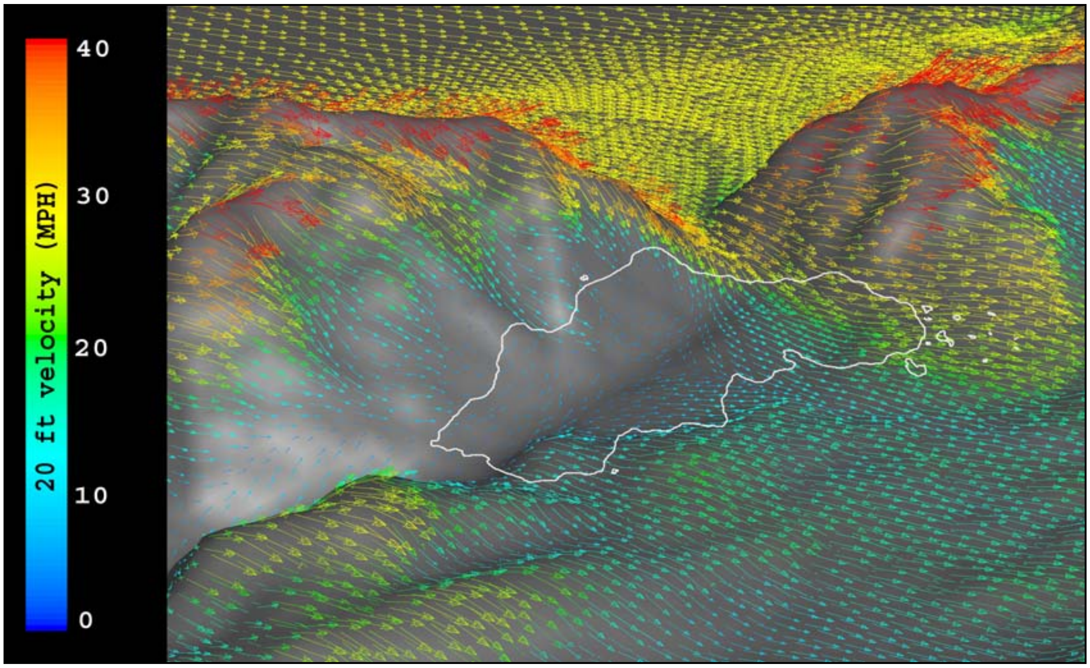

Figure 1 Wind vectors displayed on shaded relief surface image.

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Introduction

Spatial wind variability is a major factor in wildland fire behavior. The accuracy of short-range fire behavior predictions and meteorological forecasts (6-24 hrs) are limited by the lack of spatially resolved surface wind flow information. In most cases wind data are limited to only a few specific locations, none of which may be actually near the fire location. We know that wind speed and direction are needed for effective and accurate fire management decisions. No tools currently exist that have the capability for near "real time" surface wind flow predictions at the 100-300m scale to support fire management decisions. Consequently, until this project was completed, fire analysts, meteorologists and fire managers have been left to expert opinion and extrapolations from often distant weather stations for estimating the spatial variability in wind speed and direction at the 100m scale.

With JFSP funding a software tool was developed that provides high resolution (~100m scale) surface wind flow information. Outputs from the tool include raw data files of speed and direction, shape files to add to base maps of the fire area, and FARSITE and FlamMap input files of wind speed and direction. Users can run the simulations on a laptop computer and obtain results in a matter of an hour or two. The tool is currently being beta tested, with a final version 1.0 due out in early 2007.

Background

As computational and mathematical simulation capabilities have increased, methods for obtaining detailed wind information to support fire management efforts have been explored. Ferguson (2001) uses atmospheric scale models to assess the dispersion of smoke from natural and prescribed fires. Zeller and others (2003) are exploring the application of meso-scale atmospheric flow models for the prediction of surface winds. The National Weather Service (NWS) has recently provided public access to the National Digital Forecast Database (NDFD). Meso-scale forecast data are available for the entire United States on a daily basis at scales ranging from 4km to 36km resolution. The NDFD currently provides 5.0 (soon to be 2.5) km resolution, 8-day digital forecasts (and GIS support) for the conterminous U.S. These approaches include all the important physical processes but suffer from relatively coarse scale surface wind predictions (nominally greater than 2000 m scale) and large computational requirements. Meso-scale models and weather service forecast models are not easily configured for "what if" applications wherein a single user using a laptop computer can simulate multiple scenarios ahead of time and explore their impact on fire intensity and growth.

Others also have approached the problem from a fluid dynamics approach, for example Lopes and others (2002) and

Lopes (2003) describe a software system that calculates a surface wind field and includes topographical influences. However, their system remains a research tool; they have not provided a process through which their system can be used operationally by fire managers. Consequently the need still exists for a simple to run, computationally fast wind simulation tool.

Methods

We have commonly referred to our approach as gridded wind simulations. In the gridded wind approach, typically, the area of interest is about 30km by 30km (18.6 miles by 18.6 miles) square with the fire located approximately at the center (larger and smaller areas have also been simulated). The tool is based on the Fluent® and FloWizard® computational fluid dynamics software packages (http://www.fluent.com). These commercial software tools were selected primarily because of their computational speed, ease of use, and robust nature, they have been tested over many years and by thousands of users.

For the simulations, the atmosphere is assumed to be neutrally stable. The simulation assumes a constant temperature flow and turbulence is modeled using the rng κ-ε approach (Jones and Launder 1972; Yakhot and Orszag 1986).

The tool has been termed WindWizard. The simulation process followed by the WindWizard tool comprises the following general steps:

1) Acquire and import into WindWizard an ASCII raster digital elevation data file (DEM) for the area of interest, generally on the order of 30km by 30km (18.6 miles by 18.6 miles) in size.

2) Automatically build a computational domain over the area of interest and divide it into computational cells with dimensions on the order of 300m by 300m by 100m (900ft by 900 ft by 300ft) at the surface of the terrain. The result is 100,000 to 1,500,000 cells within the overall computational domain.

3) Compute a surface roughness parameter based on user input of the dominant plant species (forest, shrub, grass).

4) Solve the Navier-Stokes equations describing the wind flow over the earth's surface for up to 10 different wind scenarios based on **user input** of the ridge top or synoptic wind conditions. The user specified input wind is imposed as an inlet to the simulation domain.

5) Display and output the wind speed and direction 6m above the terrain surface at a resolution specified by the user.

The different wind scenarios are selected to match forecasted winds or are based on historical weather patterns. The gridded wind simulations are <u>not</u> forecasts; they are a snapshot at one point in time of what the local surface wind speed and direction would be for a given ridge top or synoptic wind scenario. WindWizard is a technique for determining the fine scale winds that result from a specific broader scale wind scenario.

Two methods have been utilized to quantify the accuracy and effectiveness of computational fluid dynamics (CFD) based wind simulations. The first compares simulated wind speed and direction against direct measurements. The second compares fire growth simulations with and without the high resolution wind.

In comparisons against measured wind data (fig. 2), generally the modeled wind speeds were within 9 percent of those measured except for the leeward upper slope of the hill where the simulated wind speed was nominally 32 percent greater than the measured value 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. Figure 3 indicates that simulated wind direction was within 13 degrees of the measured value for all locations (Butler and others 2006). The differences between the simulated wind direction and measured values were greatest near the base of the hill for both the upwind and leeward sides. These comparisons suggest that the CFD-based methodology for simulating surface wind flow over mountainous terrain can provide relatively accurate and useful information, but a valid evaluation requires comparison against additional data sets.

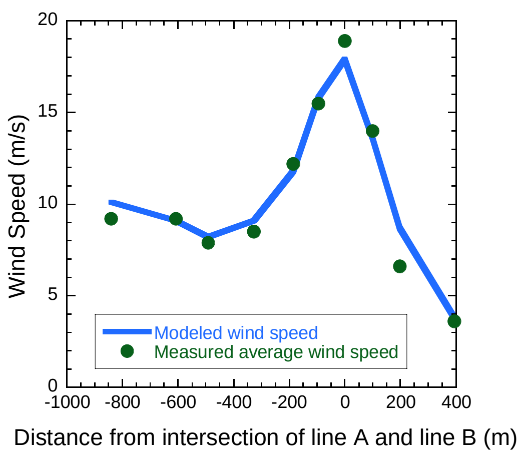

Figure 2—Comparison of measured and predicted wind speed.

Results and Discussion

WindWizard has been used to predict and reconstruct fire behavior during ongoing fire incidents and to support fire investigations [i.e. Price Canyon fire (Utah) -Thomas and Vergari (2002), Thirtymile fire (Washington) - USDA Forest Service (2001), Cramer Fire (Idaho) - USDA Forest Service (2004), Storm King Mountain Fire (Colorado) - Butler and others (1998), Cedar Fire (California) - California Dept. of Forestry and Fire Protection (2004)].

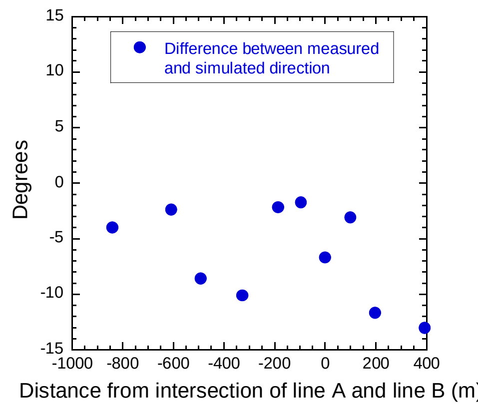

Figure 3—Comparison of measured and predicted wind direction.

Transfer of results from the wind simulations to fire managers and field personnel occurs in three forms: 1) Images consisting of wind vectors overlaid on a shaded relief surface image; 2) ArcView or ArcMap shape files of wind vectors and 3) files for use by the FlamMap and FARSITE (Finney 1998) programs. The images and files 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.

CFD based wind simulations have been used to provide wind input to FARSITE fire growth simulations of previous fire events. In all of the simulations the accuracy of short term (< one day) fire spread projections, as compared to actual fire spread histories, has markedly increased. For example, figures 4 and 5 present fire growth simulations of the South Canyon fire (Butler and others, 1998). The fire growth simulation developed from uniform wind direction (fig. 4) clearly does not match the actual fire perimeter. The fire growth simulation developed using the gridded wind (fig. 5) is a better fit to the actual perimeter. The South Canyon Fire comparison was chosen to point out that while the use of gridded wind increases fire growth simulation accuracy it does not guarantee perfect fit.

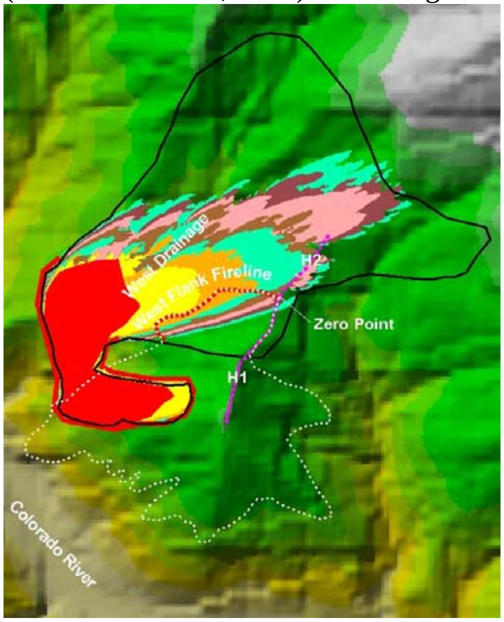

Figure 4—South Canyon fire growth simulation with uniform wind input.

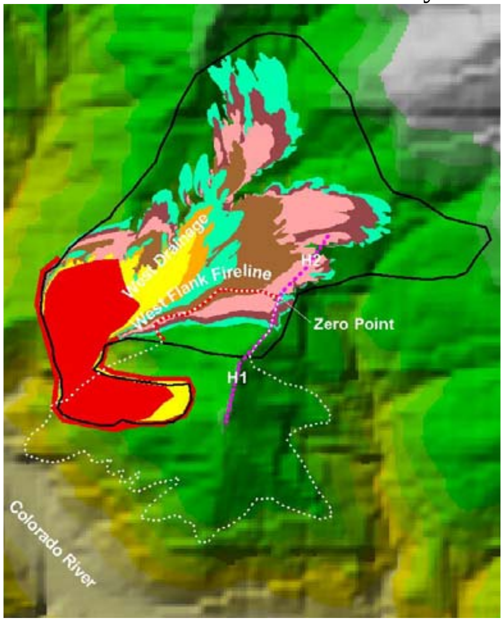

Figure 5—South Canyon fire growth simulation using gridded wind. Black line is actualfire perimeter. Sequential colored perimeters are fire growth simulations for the period during which the major fire growth occurred on July 6, 1994.

The discrepancy between actual and simulated fire perimeters can be attributed to input information used by the fire growth simulation such as inaccuracies in the vegetation map. It could also be attributed to the wind field. It is important to emphasize that the gridded wind simulations represents a "snapshot" of the flow field at one moment it time. In reality the wind field is varying in both time and space. The terrain present at the South Canyon Fire site would have induced strong turbulence in the surface wind. The eddies and transient flow created by that turbulence could significantly affect the fire growth.

Butler and others (2006) make a similar comparison for the Price Canyon Fire, the agreement between simulated and actual fire perimeters is very close when the gridded wind is included. The improvement in agreement between the fire growth simulations with the use of gridded wind indicates that the gridded wind is more representative of reality.

The CFD-based WindWizard tool represents a new technology not previously available to wildland fire teams and specialists. Consequently part of the research team's work during the past three fire seasons consisted of simply contacting the incident management teams to inform them of the new technology and supporting their fire management activities. Fire incident management teams (IMT) working in Montana, Colorado, Wyoming, California, Washington, Idaho, Arizona, Nevada and Utah have been supplied with custom wind simulations.

While it is subjective, one metric of the utility of the gridded wind as a fire management decision support tool is indicated by the responses from IMTs and fire specialists that are exposed to the technology. Generally, fire Behavior Analysts (FBANs), long term analysts (LTANs) and local fire specialists found the wind simulations to be highly useful for visualizing the channeling effect of terrain on the wind. The outputs from the WindWizard tool are being used in multiple ways: 1) to build shaded relief maps over which vectors representing wind speed and direction are placed. The maps could include fire perimeters. These maps proved useful in identifying synoptic wind conditions that might result in significant changes in fire intensity and spread. 2) Others have used the tools to identify areas that are sheltered from synoptic winds and therefore may not be at high risk for high intensity fire. 3) The FARSITE and FlamMap fire growth and potential fire behavior prediction accuracy are increased when gridded winds are included in the fire simulations. 4) Fire managers who have studied the gridded wind vectors displayed on maps have commented that the information presented would be useful in the appendices of fire management plans and could be useful for identifying potential fuel treatment areas. New and innovative applications continue to be discovered.

In all cases where it has been tested the WindWizard tool has provided wildland fire managers with an objective method for estimating local wind flows and the potential for changes in fire spread rate and intensity.

There has been some confusion regarding this tool versus a wind forecast. We have tried to emphasize that the wind simulation tool is not a forecast, but rather a simulation of surface wind flow given a forecast or imagined synoptic wind scenario.

The bottom line is that in all of the wind simulations completed so far, we have not observed any reason to believe that the simulated winds are not physically realistic representations of actual winds for similar free-air wind events. At the very least, the gridded wind tool represents a significant improvement over the previous method of applying a single wind speed and direction obtained from a point measurement such as a weather station or observer to a landscape.

Products

Deliverables specified for this project were:

-Beta version of WINDWIZARD template.

-WINDWIZARD wind simulation tool.

-Technical documentation.

A beta version of the surface wind simulation tool has been available for distribution for the last 8 months. During the 2006 fire season we estimate that it was used to develop surface wind information for more than 100 wind scenarios on more than 40 fires. The limitation seems to be getting the word out about the tool. Everyone that has either used it or been exposed to it immediately recognizes the utility of this information for making better fire management decisions. The tool is easy to use, runs on a laptop computer, and provides output in multiple formats.

Version 1.0 of the wind simulation tool will be available late 2006 or early 2007. It will be sold and maintained by the Fluent Corporation. One question that remains to address is how it will be purchased. There is some discussion as to purchasing a bulk license that will make it widely available to Forest Service Fire Management teams.

Technical documentation has been developed that details installation procedures, trouble shooting, how to use the tool and output data. A contact has been let for the completion of a User's Guide.

The gridded wind tool is really an interpolation system for producing high resolution surface wind flows from larger scale meso-scale weather models, synoptic wind forecasts, or historical weather patterns. Future efforts should focus on building a link between forecast models and the gridded wind tool to provide a physics based method for producing high resolution wind flow data from forecasts. This linkage would provide users with the initialization from meso-scale forecast models and the fine scale interpolation provided by the gridded wind tool.

Researchers also hope to work on methods for including the influence of the fire on the local flow field in future versions of the simulation tool.

Appendix A presents the product summary in a table format.

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Appendix 1. Deliverables Table:

	Deliverable	Delivered	Status
1	Beta version of WINDWIZARD template	A Beta version of the windwizard tool has been distributed to more than 50 users. Feedback from the users is being used to improve the tool.	Done
2	WINDWIZARD wind simulation tool	Based on feed back from users the windwizard tool continues to be improved. A version 1.0 is planned for release early in 2007.	Done
3	Technical documentation, user's guide, help tools and tutorials	Installation guidelines as well as instructions about how to display wind vectors in Arcview and Arcmap are included with the installation package. Instructions for accessing DEM data are also provided. A contract has been let for the completion of an online User's guide.	Done
4	**Technical Papers.**		Done
	Conference/Symposia/Work shop	B. Butler, M. Finney, L. Bradshaw, J. Forthofer, R. Stratton. 2005. THE USE OF COMPUTATIONAL FLUID DYNAMICS TO PROVIDE HIGH RESOLUTION WIND INFORMATION FOR USE IN FIRE GROWTH MODELING. in proceedings of the Eastfire Conference, 11-13 May, 2005, Fairfax, VA.	
	Conference/Symposia/Work shop	B. W. Butler, J.M. Forthofer, R.D. Stratton, M.A. Finney, and L.S. Bradshaw, and R.D. Stratton. 2005, High Resolution Wind Direction and Speed Information for Support of Fire Operations. presented at Wildfire 2005, 15-18 February, 2005 Albuquerque, NM. International Association of Fire Chiefs, Fairfax VA.	
	Conference/Symposia/Work shop	Jason M. Forthofer, B. W. Butler, K. S. Shannon, M. A. Finney, L. S. Bradshaw, 2003. PREDICTING SURFACE WINDS IN COMPLEX TERRAIN FOR USE IN FIRE GROWTH MODELS. Presented at 5th Symp. On Fire and Forest Meteorology, 16-20 Nov, 2003, Orlando, FL	
	Poster	B.W. Butler, J. Forthofer, and K.S. Shannon, 2003, High Resolution Wind Data for Fire Management Teams. Presented at Wildfire 2004. 2-5 March, 2004. Reno, NV.	

	Conference/Symposia/Workshop	B. W. Butler*, Jason M. Forthofer, K. S. Shannon, M. A. Finney, L.S. Bradshaw. 2004. HIGH RESOLUTION SURFACE WIND SIMULATIONS IN COMPLEX TERRAIN. Paper J2.6 presented at the 7th International Wildland Fire Safety Summit Toronto, Ontario, Canada, November 18-20, 2003, International Association of Wildland Fire, Hotsprings, SD.	
	Conference/Symposia/Workshop	Bret W. Butler, Mark Finney, Larry Bradshaw, Jason Forthofer, Chuck McHugh, Rick Stratton, Dan Jimenez. 2006. WindWizard: A New Tool for Fire Management Decision Support. In: Andrews, Patricia L., Butler, Bret W.; comps. 2006. Fuels Management—How to Measure Success: proceedings. 2006 March 29-30; Portland, OR. Proceedings RMRS-P-000. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.	
	Website	www.firelab.org	Done
	Unexpected Products		
	New understanding into the physics governing wind flow in mountainous terrain.	Simulations of fire/wind interaction on several past fires has assisted researchers in identifying new research needs and improving understanding of how wind interacts with terrain features and affects fire behavior and growth.	Done