WindWizard: A New Tool for Fire Management Decision Support

Bret W. Butler[1], Mark Finney[1], Larry Bradshaw[1], Jason Forthofer[1], Chuck McHugh[1], Rick Stratton[2], and Dan Jimenez[1]

***Abstract**—A new software tool has been developed to simulate surface wind speed and direction at the 100m to 300 m scale. This tool is useful when trying to estimate fire behavior in mountainous terrain. It is based on widely used computational fluid dynamics technology and has been tested against measured wind flows. In recent years it has been used to support fire management decisions to improve firefighter and public safety, understand the environmental conditions associated with entrapment fires, improve prescribed fire prescriptions, and estimate fire potential. Outputs from this tool include tiff images, GIS shape files, and FARSITE wind input files.*

Introduction

Wind is one of the primary environmental variables influencing wildland fire spread and intensity (Rothermel 1972, Catchpole and others. 1998). Indeed, wind and its spatial variability in mountainous terrain is often a major influencing factor in the fire behavior associated with "blowup" fires (e.g., South Canyon Fire 1994, Thirtymile fire 2000, Price Canyon Fire 2002, and Cramer Fire 2003). The extent, elevation and orientation of mountains, valleys, ridges, and the fire itself, influence both the speed and direction of wind flows (figure 1). The lack of detailed wind speed and direction information is one major source of uncertainty in fire management decisions. Methods to obtain estimates of local wind speed and direction at the 100 to 300 m (300 to 900 ft) scale have not been readily available. In most cases, fire incident personnel estimate local winds based on weather forecasts and/or weather observations from a few specific locations, none of which may be actually near the fire. A computer based tool is described here that provides fire and land managers with the ability to determine local surface wind flows at the 100-300 m (300 to 900 ft) scale for a given synoptic wind condition. A brief discussion of how the tool's accuracy has been evaluated is presented followed by some examples of how this tool is being used in wildland fire management decisions.

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

In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management—How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

[1]USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. bwbutler@fs.fed.us

[2] Systems for Environmental Management, Missoula, MT.

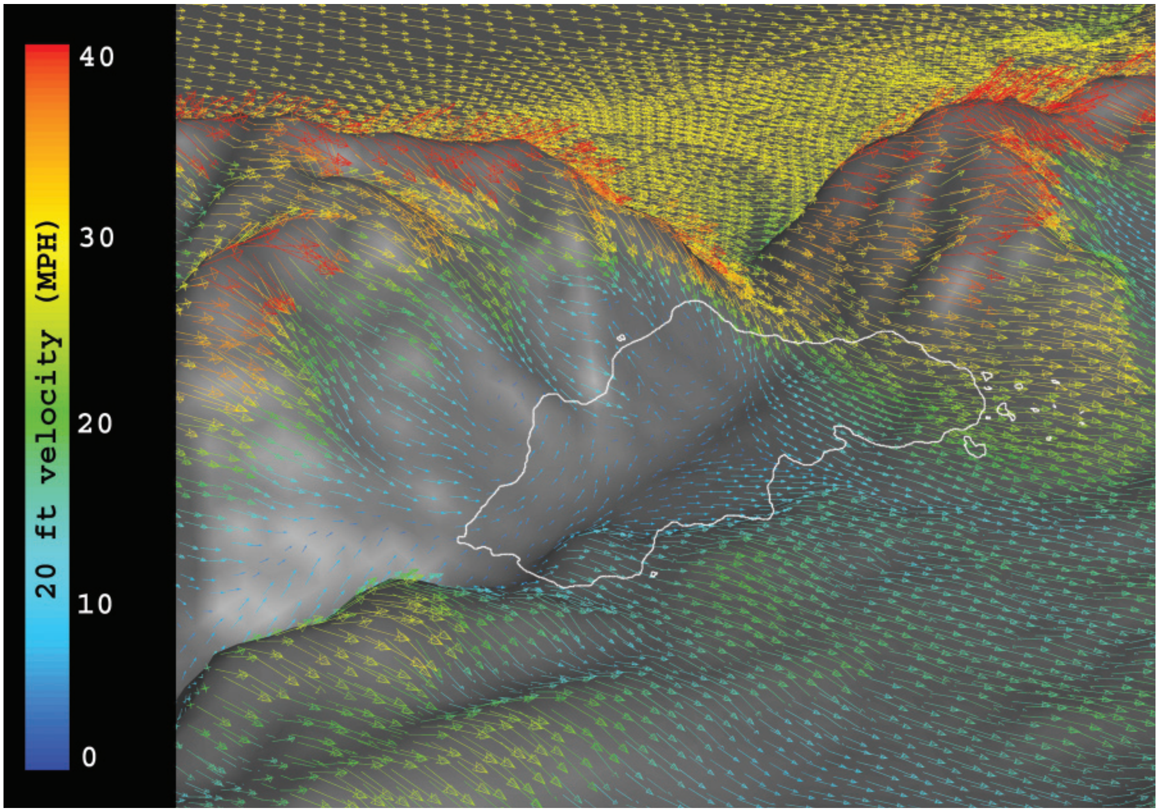

Figure 1—Example of a gridded wind simulation. The white line represents the fire perimeter. Wind speed and direction are indicated by the vectors, with length representative of relative speed and orientation representative of local wind direction. Vectors are also colored by wind speed.

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 4 km to 36 km 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 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.

We have commonly referred to our approach as gridded wind simulations. In the gridded wind approach, typically, the area of interest is 30 km by 30 km (18.6 miles by 18.6 miles) square with the fire located approximately at the center. The tool is based on the Fluent® and FloWizard® computational fluid dynamics software packages (http://www.fluent.com). 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 30 km by 30 km (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 300 m by 300 m by 100 m (900 ft by 900 ft by 300 ft) 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 and is uniform with height above the terrain surface.
5) Display and output the wind speed and direction 6m above the terrain surface at a resolution specified by the user.

Wind modeling for specific fires consists of simulating multiple combinations of free-air wind speed and direction. The different cases are selected to match forecasted scenarios or are based on historical weather patterns. The gridded wind simulation accounts for the influence of elevation, terrain, and vegetation on the general wind flow. We emphasize the gridded wind simulations are <u>not</u> forecasts but rather 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. 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)].

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 using a single wind speed and direction obtained from a point measurement such as a weather station or observer.

Methods

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 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 2004). 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.

Metrics for quantifying the impact of this technology on wildland fire management decision making can be defined through two methods: 1) the degree of interest in and use of the tool as the fire management community becomes aware of it and 2) the response from fire managers as to its utility. One major focus of this project has been to take advantage of opportunities to assist IMT's by proactively producing wind simulations for their area of interest.

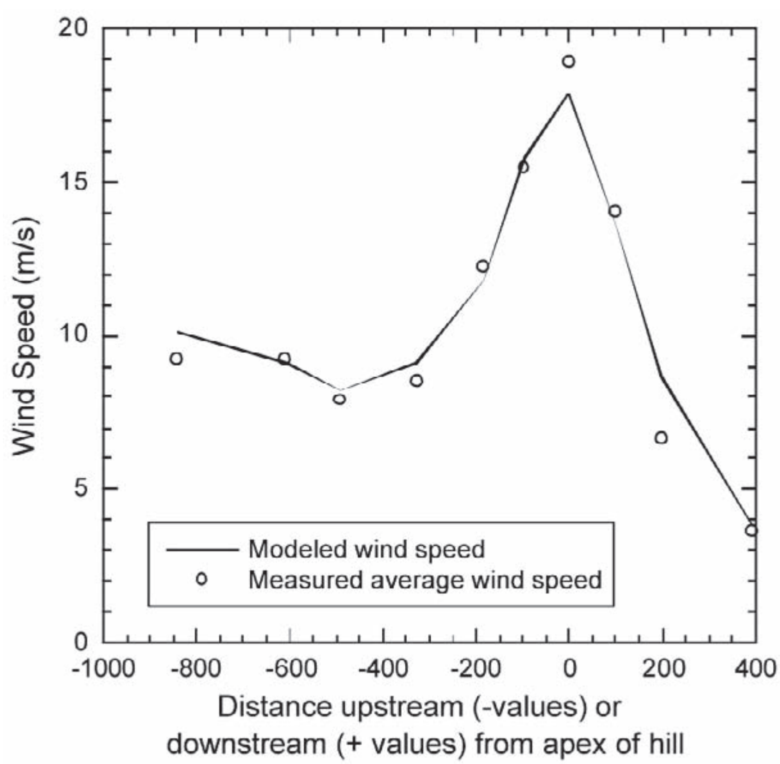

Figure 2—A comparison of measured and predicted wind speeds reported from the Askervein hill data set. Positive values represent distances downstream from apex and negative values represent upstream from apex.

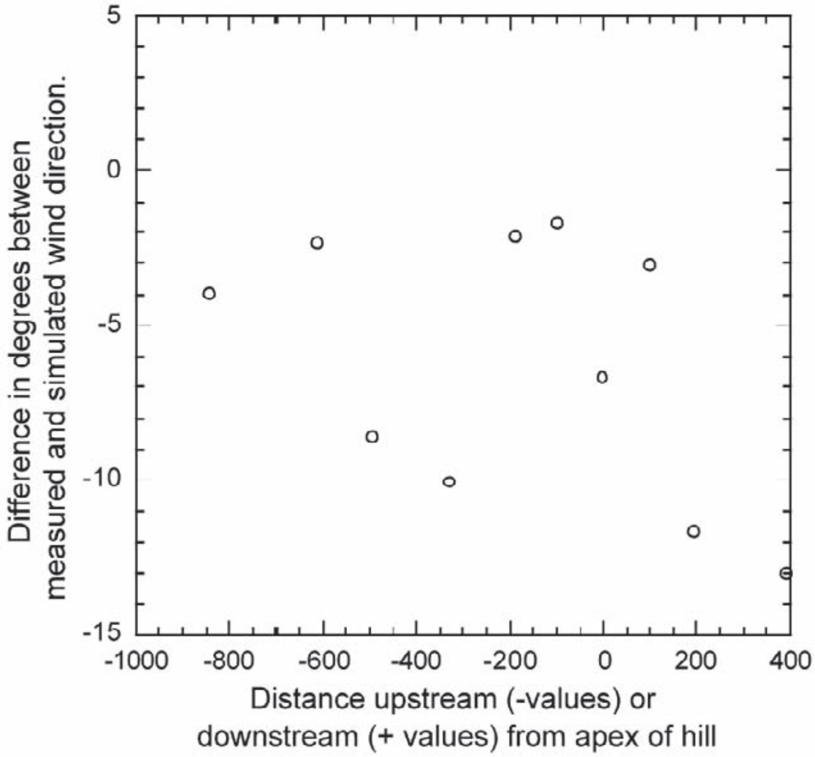

Figure 3—A comparison of the variation from the overall 210 degree flow direction for the measured and predicted winds from apex of Askervien hill. Positive values represent distances downstream from apex and negative values represent upstream from apex.

Discussion

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 a number of 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. 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

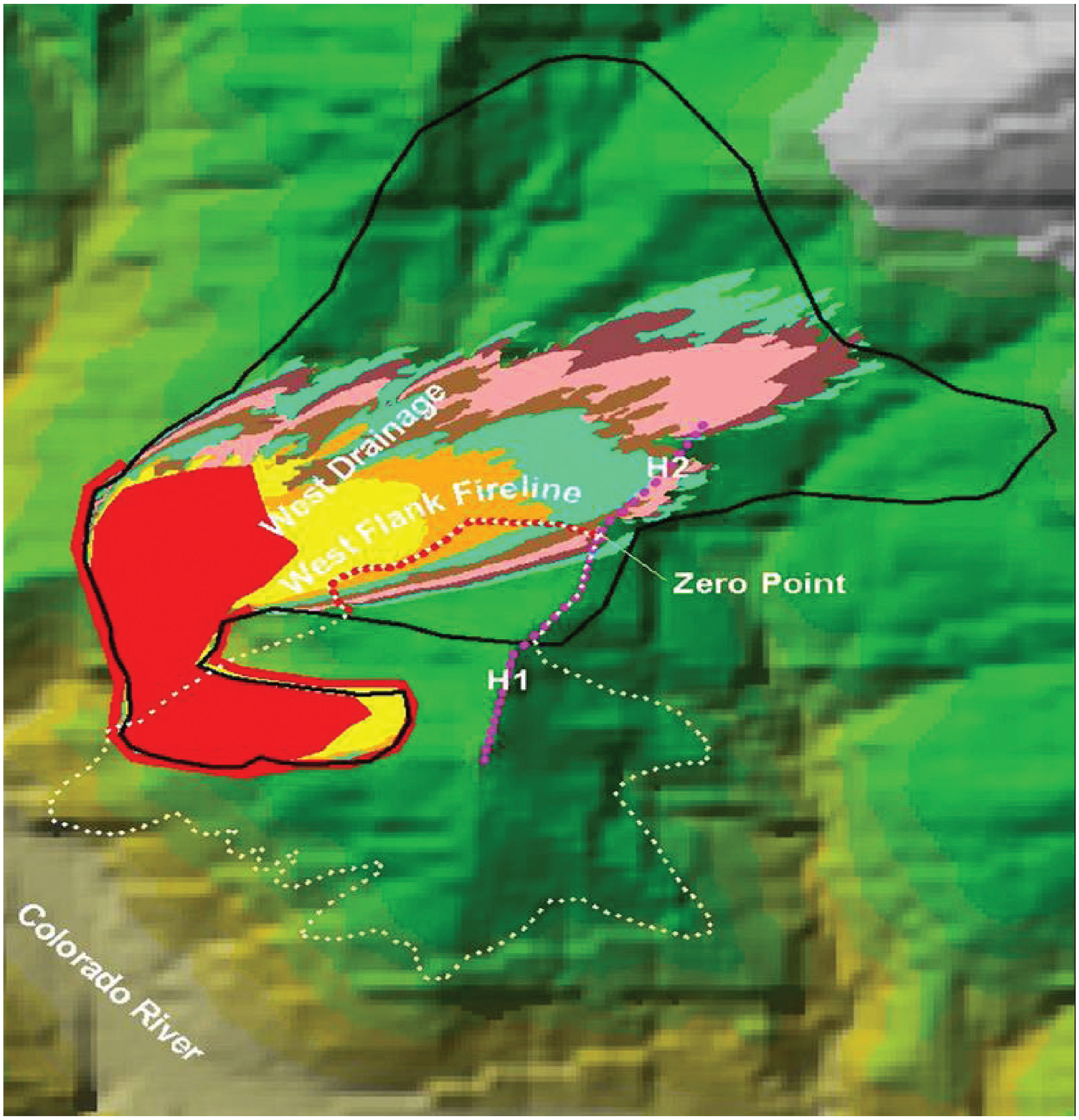

Figure 4—FARSITE simulation of the Storm King Mountain Fire assuming uniform wind speed and direction from the left to right (west winds). Black line represents actual fire perimeter at same point in time as last fire simulation. Fire growth simulations are shown as successive fire burned areas with color varying. Last perimeter is shown in light blue-green.

vegetation map. It could also be attributed to the wind field. It is important to emphasize that the gridded wind 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 (2004) 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

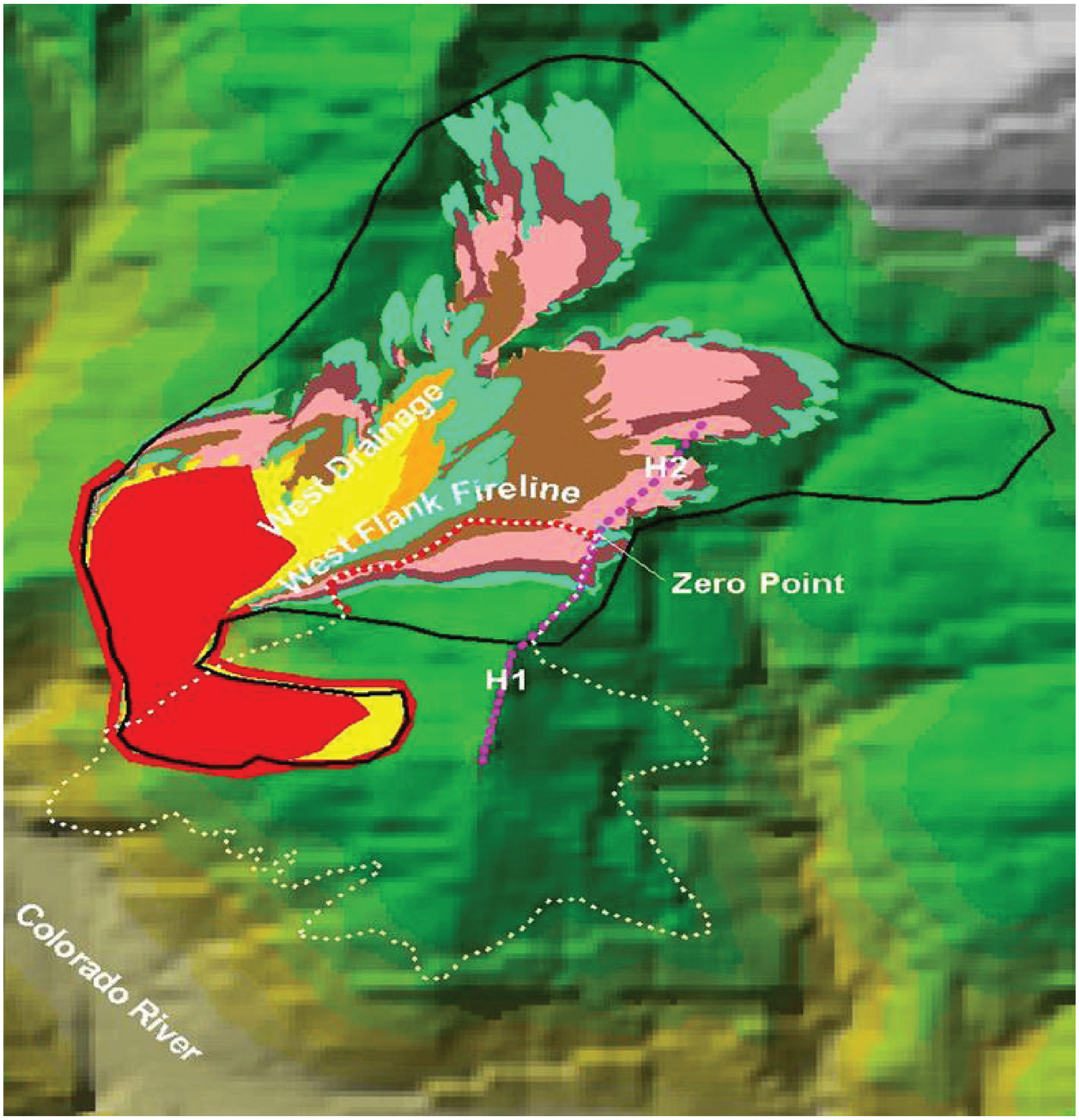

Figure 5—FARSITE simulation of the Storm King Mountain Fire using gridded wind data from CFD-based simulation. General wind flow input to CFD was aligned with the Colorado River gorge (west winds generally flowing diagonally from upper left to lower right). Black line represents actual fire perimeter at same point in time as last fire simulation. Fire growth simulations are shown as successive fire burned areas with color varying. Last perimeter is shown in light blue-green.

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. For example, given a particular wind scenario the WindWizard based wind simulations can be used to identify areas on or near the fire perimeter that might be exposed to high winds and thus potentially higher intensity fire behavior. 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. GIS shape files produced by the WindWizard tool can be easily used as another layer in addition to vegetation, terrain, resources, roads etc. in building images and analyzing relative fire risk on a spatial scale. 3) More recently, the FARSITE and FlamMap fire growth and potential fire behavior tools can easily ingest gridded wind data. In all cases, simulations of fire growth and potential have more closely matched observed and intuitively expected fire behavior with the use of gridded wind 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. As the technology is used further new and innovative applications are found for it.

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.

Conclusions

The research team has used this technology to support wildland fire management teams by completing more than 500 wind simulations for approximately 200 fire incidents located across the country. Additional uses for this tool are being found as more people become aware of and use the technology.

Because this technology is still new, many fire management teams are not aware of it or do not know how to access or use it. As stated previously the gridded wind simulations are not weather forecasts. While it is not a forecast, one of the real benefits of this approach is that it can be used in a “gaming” mode to explore the impact that various forecasted wind scenarios might have at the local scale on the fire, something not possible with meso-scale weather models.

Acknowledgments

Financial support for this project has been provided by the USDA Forest Service, The Joint Fire Science Program, John Szymoniak from the National Interagency Fire Center and Mike Hilbruner from the USDA Forest Service

Washington Office. Significant improvements have stemmed from suggestions and trials of the technology by many Interagency Fire Management Teams who have contributed time and effort as test cases for the gridded wind tool. Finally the contributions of individual FBANs and LTANs willing to take the time to explore this new technology have been invaluable to the development and improvement of WindWizard.

References

Butler, B.W.; Forthofer, J.M.; Finney, M.A.; Bradshaw, L.S.; and Stratton, R. 2004. High Resolution Wind Direction and Speed Information for Support of Fire Operations. In: Aguirre-Bravo, Celedonio, et al. Eds. 2004. Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere; 2004 September 20-24; Denver, CO. Proceedings RMRS-P-37CD. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Butler, B. W.; R. A. Bartlette; L. S. Bradshaw; J. D. Cohen; P. L. Andrews; T. Putnam and R. J. Mangan. 1998. Fire behavior associated with the 1994 South Canyon Fire on Storm King Mountain. USDA Forest Service RMRS Res. Pap. RP-9.

California Dept. of Forestry and Fire Protection (2004). Review report of Serious CDF Injuries, Accidents and Near-Miss Incidents. Engine Crew Entrapment, Fatality, and Burn Injuries, October 29, 2003 Cedar Fire. California Dept. of Forestry and Fire Protection Serious Accident Review Team Report March 10, 2004.

Castro, F. A.; Palma, J. M. L. M., and Lopes, A. S. 2003. Simulation of the askervein flow. part 1: Reynolds averaged navier-stokes equations (k-ε turbulence model). Boundary-Layer Meteorology 107:501-530.

Catchpole, W. R.; Catchpole, E. A.; Butler, B. W.; Rothermel, R. C.; Morris, G. A.; and Latham, D. J. 1998. Rate of spread of free-burning fires in woody fuels in a wind tunnel. Comb. Sci. Tech. 131:1-37.

Ferguson, S. A. 2001. Real-time mesoscale model forecasts for fire and smoke management: 2001. Fourth Symposium on Fire and Forest Meteorology, 13-15 November 2001, Reno, NV. American Meteorological Society. 162-167.

Finney, M. A. 1998. FARSITE: Fire Area Simulator-Model Development and Evaluation. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Jones, W. P. and B. E. Launder. 1972. The Prediction of Laminarisation with a Ywo-equation Turbulence Model. Int. J. Heat and Mass Transfer Vol. 15 p. 301

Lopes, A. M. G.; Cruz, M. G.; and Viegas, D. X. 2002. Firestation-an integrated software system for the numerical simulation of fire spread on complex topography. *Environmental Modelling & Software*. 2002(17):269-285.

Lopes, A. M. G. 2003. WindStation—a software for the simulation of atmospheric flows over complex topography. *Environmental Modelling & Software*. 2003(18)81-96.

Rothermel, R. C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Intermt. For. Range Exp. Stn. Ogden, Utah. Res. Pap. INT-115.

Thomas, D. and Vergari, G. 2002. Price Canyon Wildfire Staff Ride. USDA Forest Service, Region 4, Ogden, UT. 55p.

USDA Forest Service. 2004 www.fs.fed.us/r4/fire/cramer/ cramer_q&a_air_1_12_04.doc

USDA Forest Service 2001. Thirymile fire investigation. as amended on October 16, 2001. USDA Forest Service. Washington DC.

Yakhot, V. and Orszag, S.A. 1986. Renormalization group analysis of turbulence. I. Basic theory. J. Scientific Computations. 1:3-51.

Zeller, K; Nikolov, N; Snook, J; Finney, M; McGinley, J; Forthofer, J. 2003. Comparison of 2-D wind fields and simulated wildland fire growth. In proceedings of the Fifth Symposium on Fire and Forest Meteorology and Second Wildland Fire Ecology and Fire Management Congress, 16-20 November 2003, Orlando, FL. American Meteorological Society. Washington, DC.