J2.6

PREDICTING SURFACE WINDS IN COMPLEX TERRAIN FOR USE IN FIRE SPREAD MODELS

Jason M. Forthofer ,* B. W. Butler, K. S. Shannon, M. A. Finney, L.S. Bradshaw
USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana

R. Stratton
Systems for Environmental Management, Missoula, MT

1. INTRODUCTION

It is generally accepted that wind speed and direction can be the dominant factor influencing fire spread and intensity; however, very few operational tools exist for obtaining such information. Spatial wind variability was a major factor in the fire behavior associated with recent fire incidents that resulted in firefighter entrapments and/or fatalities: South Canyon Fire 1994 (Butler et al, 1998), Thirtymile fire (2001), and Price Canyon Fire (2002).

Fire behavior predictions and forecasts are vital to tactical planning on wildland firefighting incidents. One major source of uncertainty in fire behavior predictions is spatial variation in the wind fields used in the fire models. In most cases wind data are limited to only a few specific locations, none of which may be actually near the fire location. Mountainsides, valleys, ridges, atmospheric stability, and the fire itself, influence both the speed and direction of wind flows. Fire analysts, meteorologists and fire managers are left to general forecast information, guesswork and expert opinion for estimating spatial wind variability. These methods provide rough estimates of wind speed and direction at ridges and to a lesser extent in the valleys, but are subject to local knowledge and the skill level of the analyst.

Short-range meteorological forecasts and fire behavior calculations (e.g. 6-12 hrs) on large fires could greatly benefit from information on local winds over the entire terrain, at resolutions of 10 to 100 meters. The study described herein has three objectives: 1) develop a methodology for using commercially available computational fluid dynamics (CFD) software to produce high resolution surface wind maps and 2) quantify the effect of high resolution surface wind data on fire behavior predictions, and 3) address the fundamental science question of the practical potential for modeling fire-induced changes to the wind fields. This paper describes preliminary results of the modeling process applied to fire incidents in the Northern Rockies during the 2003 fire season.

While methods for resolving spatial variability in turbulent air-flows with associated heat source effects are well established in the engineering disciplines (Launder and Spaulding, 1974; Patankar, 1980; Barman, 2001), application of this technology to wildland fires has been limited. Lopes et al (2002) and Lopes (2003) describe a software system that combines high-resolution wind simulation with fire spread modeling. Two methods of producing wind fields are implemented: a linear model called NUATMOS and a Navier-Stokes solver called CANYON. They indicate models like NUATMOS can not accurately predict non-linear flows in steep terrain such as recirculation on the lee side of ridges. Their analysis showed this application to be best suited for qualitative studies of wind flow rather than quantitative. They did not compare fire spread predictions from the FARSITE fire growth simulator with and without high resolution wind information.

This study combines digital elevation model data with general wind information using commercial CFD software to simulate surface wind speed and direction at discrete points on the terrain. Surface wind data from these simulations can be directly imported into fire growth models like FARSITE resulting in more accurate predictions of fire spread and intensity. Such data can dramatically affect the accuracy of fire perimeter predictions (Thomas and Vergari, 2002 and Graham, 2002). To the author's knowledge, commercial CFD tools have not been applied to wildland fire related problems.

Preliminary work completed to date has resulted in the development of a system for converting digital elevation models into a format usable in CFD codes. The team has also developed a methodology for transferring the CFD predictions to FARSITE. During the months of August and September of 2003 more than 267

* *Corresponding author address*: Jason Forthofer, Fire Sciences Laboratory, P.O. Box 8089, Missoula, MT 59807; e-mail: jaforthofer@fs.fed.us

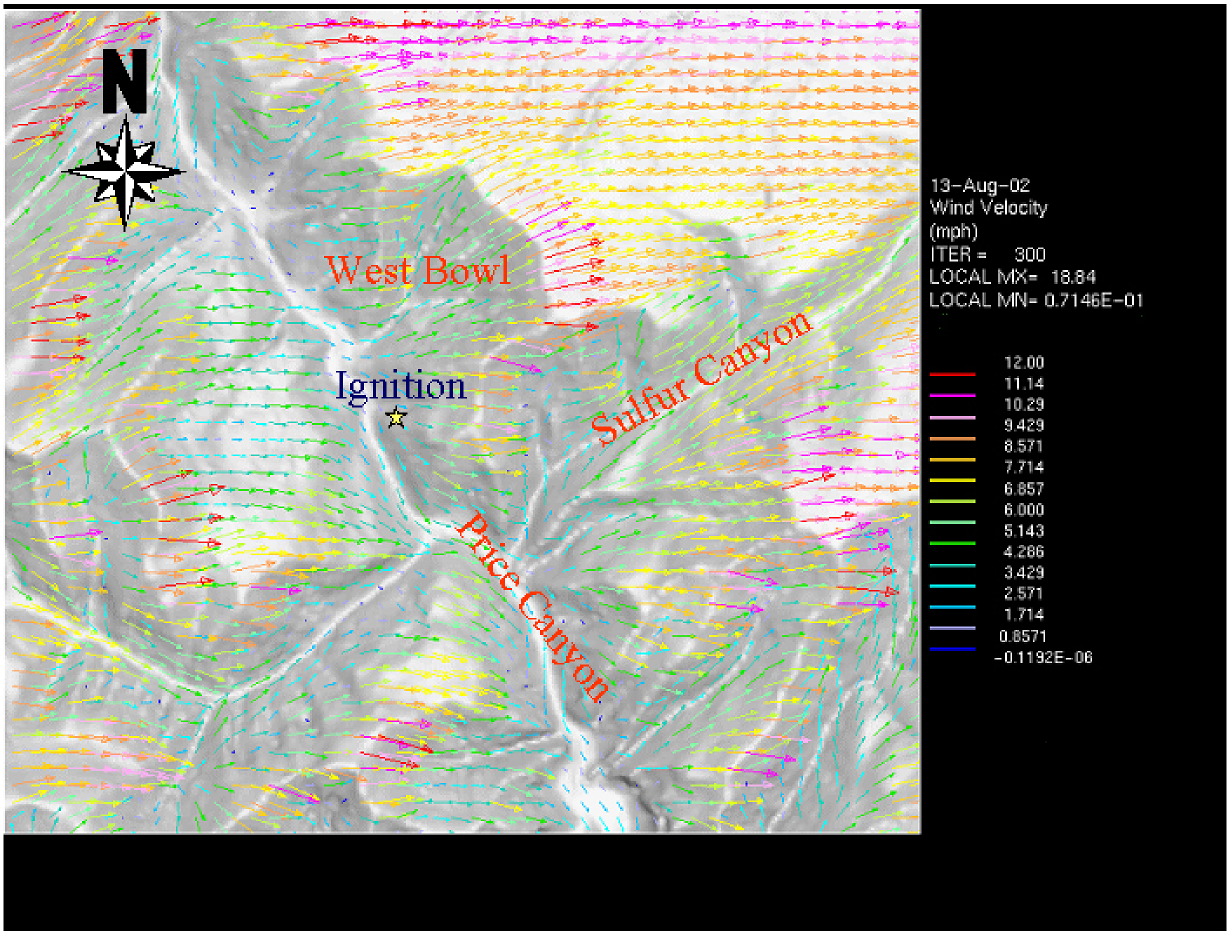

Figure 1--CFD simulation of 50-meter height wind velocities of the Price Canyon Fire area.

wind scenarios were simulated for over 26 fires or complexes in the Northern Rockies. Products provided to fire personnel included images of wind vectors over shaded topography and FARSITE simulations with spatially varying wind. Additionally 3 RAWS stations and 6 datalogging weather stations were deployed to collect wind data for comparison against simulated flows.

2. WIND MODELING PROCESS

The process by which the gridded wind data are produced occurs in three steps. First detailed information about the terrain is obtained in the form of a digital elevation model (DEM). A computational grid of the terrain and atmosphere above the terrain is developed using the DEM as the bottom surface and a top boundary at 5 km. For computational efficiency, the size of grid cells grow with distance vertically above the ground. Cells near the ground surface are 10 to 100 meters tall. The horizontal resolution of the grid was 90 m or larger. Cell counts ranged from 500,000 cells to 2.5 million cells.

A general wind flow is introduced by direction and speed and the conservation of mass and momentum equations are solved for every cell in the domain.

Wind modeling for a specific fire typically consisted of simulating several different combinations of wind speeds and direction. The simulations would typically be run to match either a forecasted wind or an extreme wind situation such as a cold front passage. The horizontal resolution of the data produced from the simulations was 90m at the surface over a 50 by 50km area. This resolution provides adequate resolution of the flow yet minimizes the computation time. A typical solution (10^1 to 10^2 m resolution wind speed and direction) on a grid measuring 50 by 50 kilometers was achieved in 1-3 hours.

Transfer of results from the wind simulations to fire managers and field personnel took many different forms. One method that proved useful, especially for field personnel, was JPEG pictures consisting of wind vectors shown overlaid on a shaded relief surface map (see figure 1). An

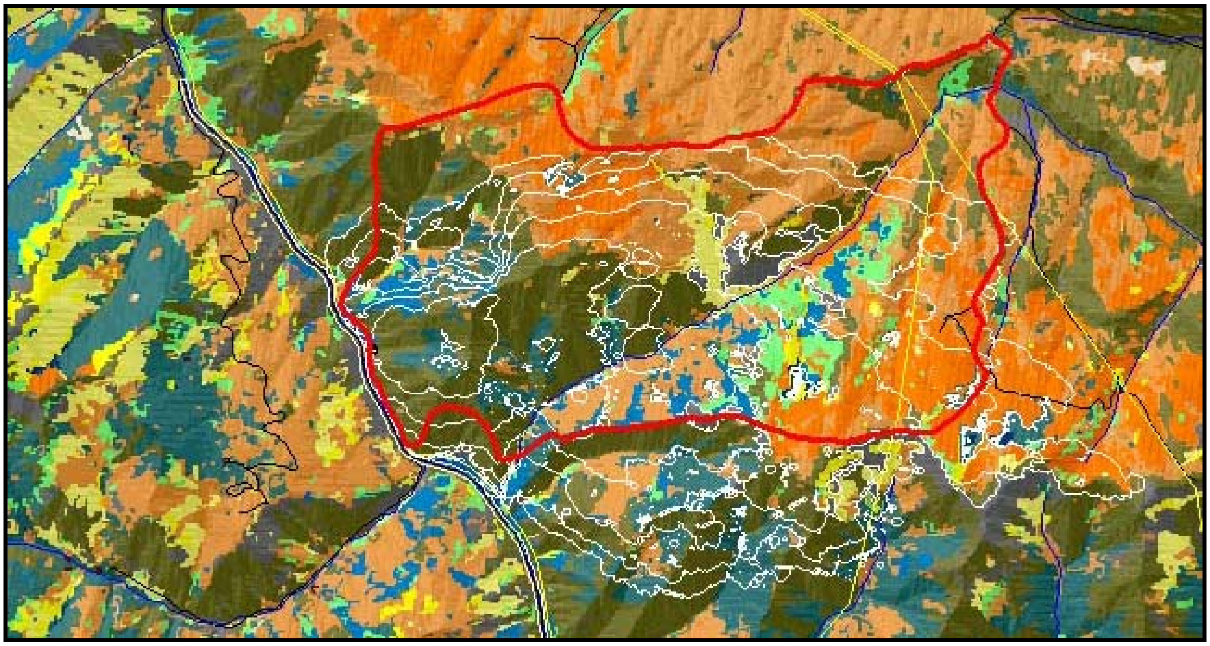

Figure 2--FARSITE simulation of the 2002 Price Canyon Fire using constant speed and direction winds.

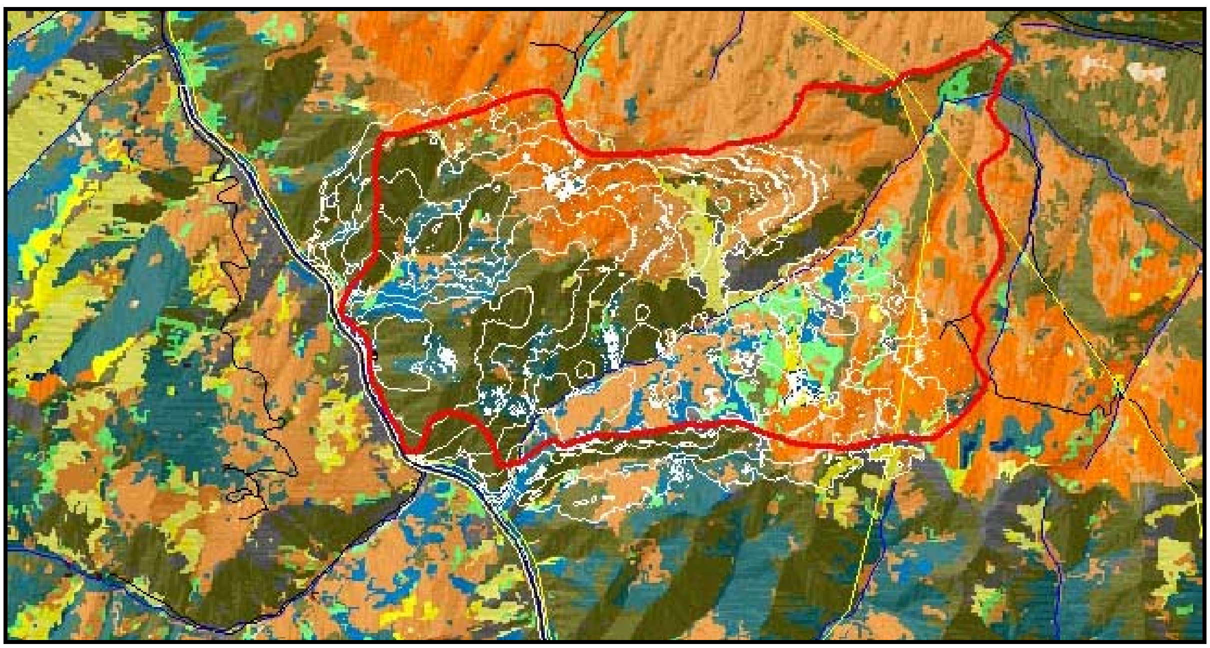

Figure 3--FARSITE simulation of the 2002 Price Canyon Fire using gridded winds produced by commercial CFD software.

overlay of the fire perimeter and prominent landmarks were added to orientate the viewer. These images displayed the spatial variation of the wind speed and direction and were used to identify high/low wind speed areas along the fire perimeter and channeling and sheltering effects of the topography. Another output of the wind simulations were ARCView or ARCMap shapefiles of wind vectors. The simulated winds can be geo-referenced to Digital Elevation Maps (DEM) meaning that vector output from the simulation could be overlayed on any GIS layer. Some useful combinations produced were wind vectors combined with fuels maps, IR based fire perimeters, and 7.5 minute quad maps with contour lines, roads, trails, etc. The simulation process also produced input files for use by the FARSITE fire area simulator program. FARSITE modeling combined with the gridded wind has been shown to improve predictive accuracy of fire spread in all cases.

This technique was used on the Price Canyon Fire and the Hayman fires in 2002 and resulted in significant improvements in the capability of FARSITE to accurately predict fire growth. Figure 1 below presents a vector map of high resolution wind data prepared for the Price Canyon Fire Case Study (Thomas and Vergari, 2002). Figure 2 is a fire perimeter map based on FASITE simulations using local RAWS data for the wind input. The figure indicates that fire progression is overpredicted along the lower and right sides of the fire. Figure 3 presents the same image with the exception that high resolution surface winds derived from a CFD simulation were supplied to FARSITE. A comparison of figures 2 and 3 clearly indicates the dramatic improvement in FARSITE predictive accuracy using the gridded wind data.

These simulations assume a neutral stable atmosphere and do not take into account density driven flows (diurnal winds and fire induced winds). Neglecting these flows will introduce some error into the predicted winds. For diurnal winds this error will be greatest when the synoptic or upper air flows are low. However as the upper air wind speed increases the relative magnitude of this flow) will decrease.

3. SUMMARY

Preliminary results suggest that the process described above can produce information useful to fire incident management teams. The wind information were used to identify areas of potentially high intensity wind driven fire behavior and also areas that were sheltered and consequently would not be significantly influenced by the synoptic winds. Comparisons of FARSITE simulations with and without the high resolution surface wind indicate that in all cases there was improved accuracy of FARSITE fire growth projections. Future work will compare wind simulations against measured wind data and will continue to improve and streamline the wind simulation process.

4. REFERENCES

Barman, P., 2001, "Computational Fluid Dynamics (CFD) analysis to study the effect of spool slot configuration on spool and valve body erosion of hydraulic valve", Summer ASME Fluids Meeting, New Orleans, USA.

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 RMRS Res. Pap. RP-9.

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.

Graham, R.T. 2002. “Interim Hayman Fire Case Study Analysis” USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Launder B.E. and Spaulding D.B., "The Numerical Computation of Turbulent Flows", *Computer Methods in Applied Mechanics and Engineering*. Vol. 3, pp 269-289, 1974.

Lopes, A.M.G., M.G. Cruz, D.X. Viegas. 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.

Patankar, S.V. 1980. Numerical Heat Transfer and Fluid Flow. Hemisphere Publishing Corp.

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

5. ACKNOWLEDGMENTS

Funding for this work was provided by the Joint Fire Science Program; and the USDA Forest Service, Rocky Mountain Research Station Fire Behavior Project located in Missoula, MT.