THE USE OF COMPUTATIONAL FLUID DYNAMICS TO PROVIDE HIGH RESOLUTION WIND INFORMATION FOR USE IN FIRE GROWTH MODELING.

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I. ABSTRACT

Wind speed and direction can have a major influence on fire intensity and rate of spread. Accurate information about local wind flow around a fire perimeter has direct impacts on firefighter safety, allocation of firefighting resources and accuracy of fire intensity and spread predictions. Information currently available to prescribed fire planners and incident management teams is based on local observations, spot weather forecasts or local knowledge and experience. Recent advances in computer technology have resulted in commercially available software programs that can accurately simulate the flow in and around wind driven fires using low cost desktop computers. Here we describe a methodology followed to simulate the flow of air around a fire perimeter burning in complex terrain. The simulations indicate that this technique can provide valuable information about the flow field, providing new information about potential fire spread and intensity. A standalone software product is scheduled to be available late 2005.

II. INTRODUCTION

Methods to model local wind speed and direction are not readily available. In many cases, wind information available to fire incident personnel is 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 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, Thirtymile fire, and Price Canyon Fire (Thomas and Vergari 2002).

Some efforts are underway to approach the problem from the atmospheric modeling standpoint. Ferguson (2001) is using 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. And this year (2004) the National Weather Service provided public access to the National Digital Forecast Database (NDFD). The NDFD currently provides 2.5 km resolution, 8-day digital forecasts (and GIS support) for the conterminous US. These approaches include many of the important physical processes but suffer from relatively coarse scale surface wind predictions (nominally 10^3 m scale) and large computational requirements and/or times. And, importantly, the meso-scale model approach is not easily configured for “what if” applications wherein a single user can simulate various scenarios ahead of time to explore the relative effects of model inputs on surface wind flow and their impact on fire intensity and growth.

Lopes (2003) describe a software system that calculates a surface wind field and includes topographical influences. The wind field simulator has been used to generate wind inputs to a fire growth simulator. Lopes implements two methods for producing wind fields: a diagnostic model called NUATMOS and a Navier-Stokes solver called CANYON. Typically, models like NUATMOS cannot accurately predict flow effects such as the recirculation on the lee side of ridges in mountainous terrain. More detailed submodels including conservation of momentum and turbulence are needed to account for the interactions between wind and surface structures such as ridges and canyons.

This study was initiated with three objectives: 1) explore the utility of CFD software for simulating surface wind flows in mountainous terrain, 2) identify how detailed surface wind information can assist wildland fire operations, and 3) develop a methodology by which the technology may be accessed by wildland fire incident management teams.

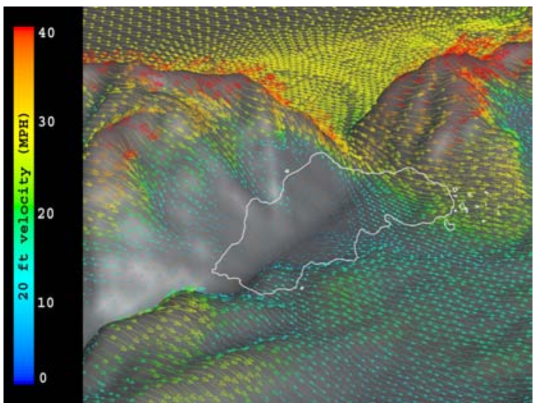

Figure 1. Typical wind simulation output.

III. DISCUSSION

The process of producing gridded wind information consists of importing elevation data in the form of digital elevation model (DEM) files into the CFD software and solving the Navier-Stokes equations to determine the flow speed and direction everywhere within the domain. The results from this set of calculations are then used to determined surface wind speed and direction at a resolution of nominally 100 m everywhere on the terrain of interest (fig. 1).

Wind 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 so that they can be incorporated into standard GIS information systems.

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. 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. The process can also produce input files for use by the FLAMMAP (Fig. 2) and FARSITE programs. 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.

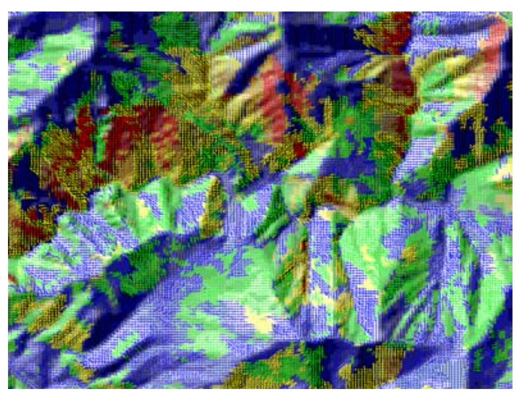

Figure 2. FlamMap file computed with gridded wind as one input.

These simulations assume a neutrally stable atmosphere, meaning that they do not take into account density driven flows (diurnal winds and fire induced winds). Neglecting these flows introduces some error (especially at low wind speeds);

however as the upper air wind speed increases the relative magnitude of this error decreases. Nor does this methodology account for momentum transfer due to thermal instability in the atmosphere.

The accuracy of CFD based wind simulations has been evaluated by comparing modeled wind speed and direction against direct measurements and comparing real versus predicted fire growth with and without gridded wind against actual fire growth.

A set of measurements were collected specifically for the purpose of characterizing surface wind simulations (Taylor and Teunissen 1987). 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. 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. Generally the modeled wind speeds were within 9 percent of those measured except for the location approximately 198 m downwind from the apex of the hill were the simulated wind speed was 32 percent greater than the measured value (fig 3). 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. This result suggests that the CFD-based methodology may not capture the transient nature of the flow. Similar results are obtained when comparing measured and predicted wind direction (fig. 4).

As noted previously, a method for evaluating the accuracy and impact of this technology is to compare fire growth simulations against those demonstrated by actual fires. Simulations were performed for the Price Canyon fire that burned in Southern Utah on June 30, 2002 (Thomas

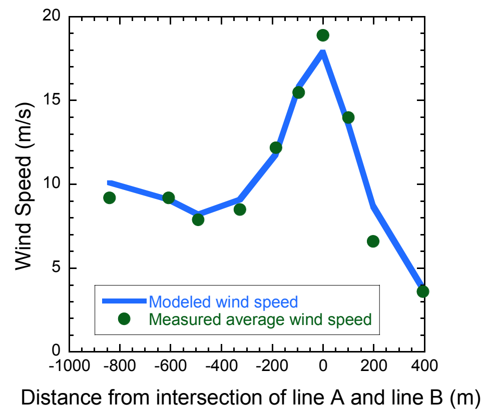

Figure 3. Comparison of simulated windspeed against measurement.

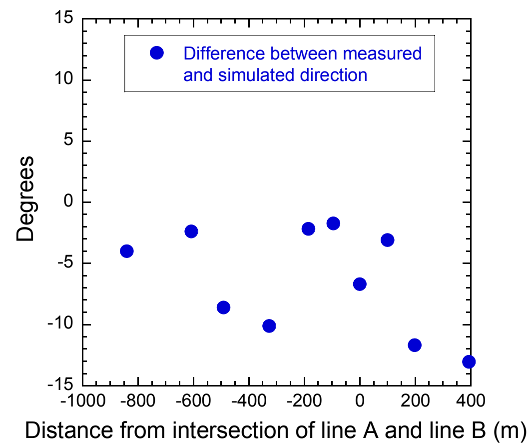

Figure 4. Measured and predicted wind direction.

and Vergari 2002) using the FARSITE fire area simulator. The first assumed a constant wind speed and direction for the time period of interest based on measurements obtained from remote weather stations in the vicinity. The increase in fire size over time is displayed by the fire perimeters (fig. 5). n this case the fire growth predictions for the conditions on June 30 are compared to the final fire perimeter published by the incident review team (Thomas and Vergari 2002). There is significant under prediction of the fire growth on the north edge of the fire and over prediction of fire growth on the southern edge of the fire. A second set of simulations were completed using gridded wind data for the same period keeping all other factors the same (fig. 6). Agreement between the actual and predicted final fire perimeters is much better. These initial tests suggest that surface wind modeling based on commercial CFD software increases the accuracy of short term (< one day) fire growth simulations.

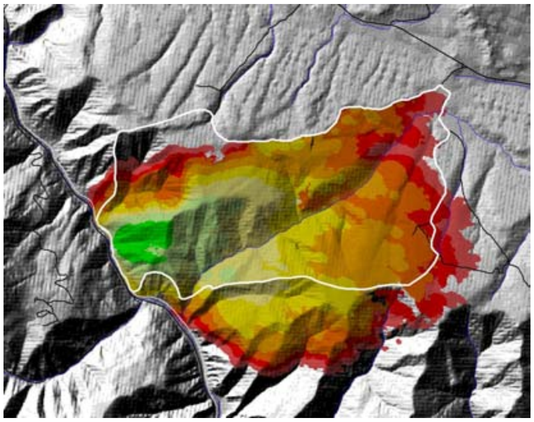

Figure 5. Price Canyon fire FARSITE simulation using general wind flow.

IV. CONCLUSIONS

The CFD-based methodology for simulating the influence of terrain on surface wind flow represents a new technology. Research efforts over the past two years have demonstrated that this technology can provide highly detailed wind speed and direction information in time frames suitable for use by fire incident management teams Comparison against measurements indicate general agreement and that the simulated gridded 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.

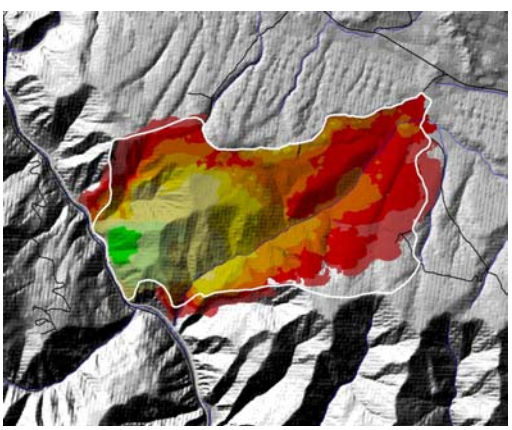

Figure 6. Price Canyon fire FARSITE simulation using gridded wind.

Gridded winds are not forecasts but rather are simulations of what the wind flow would be under different general (synoptic) wind scenarios.

V. ACKNOWLEDGEMENTS

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VI. References

Ferguson, S. A. 2001. Real-time mesoscale model forecasts for fire and smoke management: 2001. 4th Symposium on Fire and Forest Meteorology, 13-15 November 2001, Reno, NV. American Meteorological Society. 162-167

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

Taylor, P. A. and Teunissen, H. W. 1987. The askervein hill project: overview and background data. Boundary-Layer Meteorology 39:15-39.

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

Zeller, K; Nikolov, N; Snook, J; Finney, M; McGinley, J; Forthofer, J. 2003. Comparison of 2-D wind fields and simulated wildland fire growth. 5th Symp on Fire and Forest Met and 2nd Wildland Fire Ecology and Fire Management Congress, 16-20 November 2003, Orlando, FL. American Meteorological Society.

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