Final Report for JFSP funded project entitled:

Delivery and demonstration of surface wind simulation tool for fire management decision support

JFSP Project 06-1-1-09

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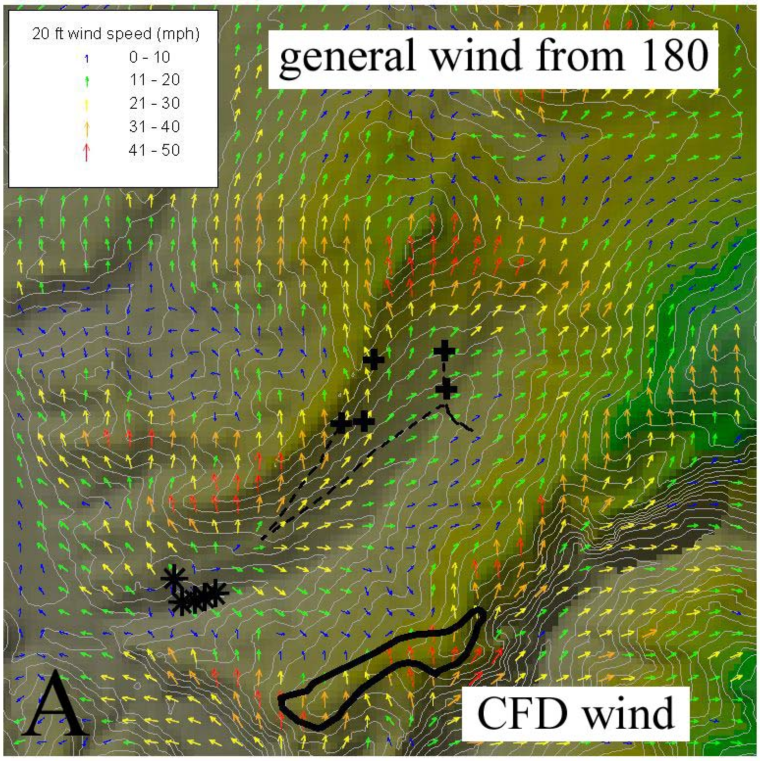

Executive Summary

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. 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. This project had three primary objectives:

1. Support wildland fire incident management teams with surface wind flow simulations.
2. Validate, improve and document the utility of gridded wind as a fire management decision support tool.
3. Produce technical documentation, including a user’s guide, help tools, and tutorials for the standalone wind simulation tool.

A rapid response team was formed and supported fire management operations in the US during the 2006, 2007 and 2008 fire seasons. More than 2000 wind simulations on hundreds of fires across US have been completed. The wind models developed are being used to support research and land management focused on fire growth and intensity but also unexpected applications like flying insect pheromone dispersion, and seed dispersal. Fire managers have found the wind simulation tools to provide reliable, timely, and detailed information needed for informed fire management decisions. The tools have also provided valuable information about the conditions leading to firefighter entrapments.

In the original proposal we proposed that success of the research team in meeting the stated objectives be measured by three methods: 1) the degree to which gridded wind technology is adopted and used by fire management teams (simply accounting of the number of people using it), 2) keeping a record of comments and statements from users regarding the utility of the technology as a decision support tool, 3) objective comparison of simulated and measured wind data to quantify the accuracy of the tool. By all three metrics this effort has been a success.

Not one, but two wind simulation tools have been developed. One is based on a commercial software code and therefore comes with an associated license fee, but it also is more accurate due to additional included physics and is computationally more intensive. The second was developed by the research team as a free, less accurate, but computationally faster alternative. The bottom line is that there is little excuse for any fire fighting crew or fire management team not having some capability to simulate surface air flow. Our efforts have demonstrated significant advantages in terms of more accurate fire behavior predictions, increased public and firefighter safety, and more effective use of firefighting resources.

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Introduction

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 200m 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.

With support from the USDA Forest Service and the Joint Fire Science Program, our research team has worked to develop a tool that can provide fine scale (100-200m) wind information for use by fire managers. Research efforts have shown that fire behavior forecasts, fire growth projections, fire potential estimates, and firefighter safety all benefit from accurate and detailed local wind information.

A significant additional product has been that two wind simulation tools were developed. One is based on commercial engineering software that is used widely in industry for simulating internal and external flows. The second was programmed inhouse and includes less physics but is computationally much faster and simpler to run. Both tools have been completed and are available to the fire community.

The research team has used this technology to support wildland fire management teams by completing more than 2000 wind simulations for hundreds of fire incidents located across the country. Additional uses for this technology such as insect pheromone dispersion, seed dispersion by wind, and smoke transport are being discovered and explored as more people become aware of it.

Background

Wind models fall into two categories: diagnostic and prognostic. Diagnostic wind models estimate winds at one time. Prognostic models are those typically used to develop weather forecasts, essentially estimating how the winds will behave over time.

The most widely known prognostic models, at least in North America, are the North American Meso (NAM) and the Global Forecast System (GFS) models. NAM output is available at 12 km (7.5 miles) resolution, while the highest resolution GFS output is 81 km (50 miles). Another prognostic model, the NCAR/Penn State Mesoscale Model 5 (MM5), is primarily a research model. Spatial resolution is rarely finer than 4 km (2.5 miles). A new prognostic model (WRF) is capable of running with a grid as fine as 100 m (330 feet), although the computational cost is huge. Zeller and others (2003) are exploring the application of meso-scale atmospheric flow prognostic models for the prediction of surface winds. Ferguson (2001) uses atmospheric scale models to assess the dispersion of smoke from natural and prescribed fires. In 2004 the National Weather Service (NWS) provided public access to the National Digital Forecast Database (NDFD). Meso-scale forecast data are available for the entire US on a daily basis at scales ranging from 36 to 4 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 US (NWS 2004). 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 requirement times. Nor are meso-scale models easily configured for "what if" applications wherein a single user can simulate alternate wind scenarios ahead of time to explore their impact on fire intensity and growth. They cannot be used on a laptop in the field and require users with extensive specialized technical skills. However, increasingly available remote internet access is allowing meteorologists access to the output from these models from fire camps.

This research effort has focused on diagnostic models. Lopes and others (2002) describe a diagnostic type wind simulation model that calculates a surface wind field and includes topographical influences. However, their model remains a research tool; they have not provided a process through which their system can be used operationally by fire managers. With increased interest in the application of wind generated power, new wind simulation tools are being developed and becoming available; however, with the exception of the tools developed by this research team, no other alternatives currently exist that allow fire managers to simulate/visualize surface wind field information at the 100-200m scale in a short time on a laptop computer with little specialized knowledge.

Our approach is clearly diagnostic; we have commonly referred to our models as gridded wind or CFD-based wind simulations. Wind modeling for specific fires consists of simulating multiple combinations of free-air wind speed and direction (i.e. ridge top wind from SW at 25 mph). 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. Typically, the area of interest is rectangular (nominally 1000 km^2) with the fire located approximately at the center. Depending on which tool is used, a solution can be achieved in a 1 to 60 minutes. Outputs consist of wind speed and direction at the ~100m scale over the entire surface of the area. Output files are geo-referenced so that they can be incorporated into standard Geographical Information Systems (GIS). The resolution is limited only by computer hardware and terrain models.

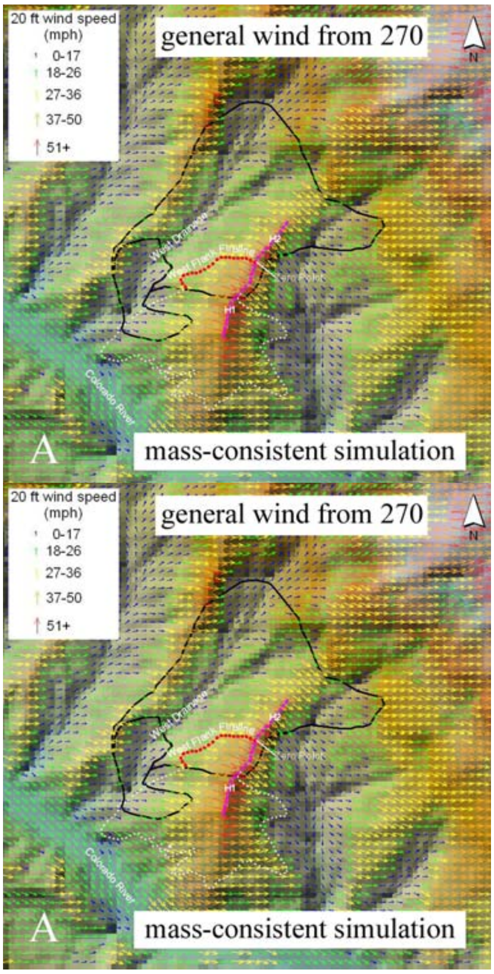

Figure 1--Wind fields produced by WindNinja (upper figure) and WindWizard (lower figure) for South Canyon Fire location.

Transfer of results from the wind simulations to fire managers and field personnel is in three forms: 1) Images consisting of wind vectors overlaid on a shaded relief surface image (see Figure 1); 2) Google Earth, or shape files of wind vectors and 3) files for use by the FlamMap and FARSITE (Finney 1998) programs. These 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 actual past fires; in all of the simulations the accuracy of short term (< one day) fire spread projections, as compared to

Figure 2--Fire growth predictions for South Canyon Fire based on the uniform wind field (upper) WindNinja wind field (middle) and WindWizard wind field (lower).

actual fire spread histories, has markedly increased.

FBANs, LTANs and local fire specialists with whom we worked found the wind simulations to be highly useful for visualizing the channeling effect of terrain on the wind. Larry Hood (an IMT FBAN) states “As FBAN I used it on both the Crazy Horse Incident in Montana and the Grindstone Complex in California. The best aspects of the technology were the visual display of changes in wind speed and direction over complex topography. I can look at a topo map with the meteorologist and discuss drainages that will be sheltered and ones that the winds will be enhanced. The visual display assures that everyone is looking at it consistently. I really like the idea that it can be used to enhance spatial fire spread modeling.”

Results and Discussion

The two models are called WindWizard and WindNinja.

WindWizard is based on a commercial computational Fluid Dynamics software platform. Because of the extensive development by the software developer the numerical equation solvers are computationally efficient. This model solves both the equations describing conservation of mass and conservation of momentum. Computing times are nominally 1 hour per simulation, but also increased accuracy. This software license is available from the developer for nominally $1000 per license. The WindNinja model was developed as a free alternative to WindWizard. It only solves the equations for conservation of mass and is therefore computationally very fast (nominally 5 minutes per simulation), but also not as accurate as WindWizard. Both models have 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)], Mann Gulch Fire (Rothermel, 1993) and others.

Two methods have been utilized to quantify the accuracy and effectiveness of 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, generally gridded wind speeds were within 9 percent of measured data and wind direction was within 13 degrees.

Figure 2 presents a comparison of fire spread predictions for the South Canyon Fire based on three wind sources: (uniform winds, WindNinja, and WindWizard). All other inputs being equal, clearly the best fire behavior prediction occurs when the wind field is based on the model with the most physics (WindWizard). However, even the use of the faster, free, and simple WindNinja wind field results in more accurate fire growth predictions than the uniform wind method.

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 accurate representations of actual winds for similar free-air wind events. At the very least CFD-based wind models represent a significant improvement over the previous method of using a single wind speed and direction obtained from point measurements such as a weather station or observer. We emphasize the gridded wind simulations are not forecasts but rather a technique for determining the fine scale winds that result from a specific broader scale wind scenario.

Products

Deliverables specified for this project were:

- Form a rapid response team and support wildland fire incident management teams with surface wind flow simulations.
-Validate, improve and document the utility of gridded wind as a fire management decision support tool.
-Produce technical documentation, including a user's guide, help tools, and tutorials for the standalone wind simulation tool.

A rapid response team was formed. In some cases wind simulations were completed from our home location and results were transferred to specific incidents electronically, in other cases team members traveled to fire incidents and provided direct support through wind simulations completed at the Incident.

The CFD-based wind simulation tools represent 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.

Version 1.0 or WindWizard has been available for more than one year and Version 2.0 or WindNinja is currently available. Installation files, help files, and tutorials are available for both tools from www.firemodels.org

There continues to be a limitation associated with just getting the word out about the tool. Everyone that either uses or is exposed to this technology immediately recognizes the utility of the information for making better fire management decisions. The tools are easy to use, run on a laptop computers, and provide output in multiple formats.

One completed wind simulation tool, with associated installation, tutorial and help files was promised, two have been delivered. One workshop was produced, six conference presentations have been completed including associated papers in conference proceedings. Three journal papers that present the technical aspects of these tools are in review. A master's thesis and degree was completed. Appendix A presents the product summary in a table format.

Future Research Needs

The two models developed in this project are really physics based interpolation routines that translate the upper air to surface flow, accounting for the influence of terrain. An obvious improvement could be gained by using the new gridded output from large scale prognostic weather models to initialize the calculations of these simpler diagnostic models. This approach could provide users with the benefits of the complex physics of prognostic models but the computational speed and fine scale resolution of diagnostic models. There is limited quantitative information that is supported by substantial qualitative observations that wind flow at the 1 meter scale is critical to fire behavior and especially transition from ground to surface to crown fire. Models of wind flow through forest canopies and brush vegetation and the subsequent microscale changes in wind flow caused by variations in vegetative cover could be very useful. Other questions could address the conditions and physics whereby upper atmospheric winds affect surface flow, and on what horizontal scale these processes need to be considered.

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Appendix 1. Deliverables Table:

PROPOSED	DELIVERED	STATUS
WindWizard V1.0	A validated, tested and documented gridded wind tool. Its utility to IMTs will be demonstrated by comparison against measured wind fields, numbers of wildland fire personnel using it, and comparison of fire growth predictions with and without the gridded winds.	Done
User's Guide	WindWizard User's Guide	Done
Tutorials	Tutorials for WindWizard	Done
Measurements	Instruments acquired, one set of data collected, additional deployment planned for 2009 on Big Southern Butte in southeastern Idaho.	Done
Conference/Sym-posia/Workshop		
Training	4 hour workshop sponsored in conjunction with 2nd Fuels and Fire Behavior Conference, March, 2007.	Done
Powerpoint Presentations	Over 11 presentations were made in workshops, training courses, and conferences about various aspects of surface wind modeling since May 2006.	Done
	Butler, B.W., Finney, M., Bradshaw, L.S., Forthofer, J.M., Stratton, R. and McHugh, C., 2006b. How wind simulations can be used by Incident Management Teams, 9th Wildland Fire Safety Summit. International Association of Wildland Fire, Pasadena, CA.	Done
	Butler, B.W., Forthofer, J.M., Finney, M., McHugh, C., Stratton, R. and Bradshaw, L.S., 2006c. The impact of high resolution wind field simulations on the accuracy of fire growth predictions. In: D.X. Viegas (Editor), V Intl. Conference on Forest Fire Research. Elsevier, Figueira da Foz, Portugal.	Done
	Forghani, A., Cechet, B., Radke, J., Finney, M. and Butler, B.W., 2007. Applying fire spread simulation over two study sites in California, IGARSS 2007. IGARSS, Barcelona, Spain.	Done
	Forthofer, J.M. and Butler, B.W., 2007. Differences in Simulated Fire Spread over Askervein Hill using Two Advanced Wind Models and a Traditional Uniform Wind Field. In: B.W. Butler and W. Cook (Editors), The Fire Environment - innovation, management, and policy. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort	Done

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	Butler, B.W., Finney, M., Bradshaw, L.S., Forthofer, J.M., McHugh, C., Stratton, R. and Jimenez, D., 2006a. WindWizard: A new tool for fire management decision support. In: P. Andrews and B.W. Butler (Editors), Fuel Management - How to Measure Success: Conference Proceedings. 28-30 March; Proceedings RMRS P-41. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO., Portland, OR; 809 p., pp. 787-796.	Done
	Butler, B.W., 2007. Final Report to RMRS/CEMML Research Fellowship Directed at the Development of an Advanced Model for the Prediction of Wind for Fire Management Use: Otherwise known as Jason Forthofer's thesis work. USDA Forest Service, Fire Sciences Laboratory, Missoula, Montana, pp. 3.	Done
Refereed Papers		
	Forthofer, J.M. and B.W. Butler. in review. Simulation of find scale winds for fire behavior prediction part 1: computational fluid dynamics model. International Journal of Wildland Fire	In Review
	Forthofer, J.M. and B.W. Butler. in review. Simulation of find scale winds for fire behavior prediction part 2: Mass-consistent model. International Journal of Wildland Fire	In Review
	Forthofer, J.M. and B.W. Butler. in review. Simulation of find scale winds for fire behavior prediction part 3: Fire behavior simulation. International Journal of Wildland Fire	In Review
Website	www.firemodels.org	Done
Unexpected Products		
Thesis	Forthofer, J. 2007. Modeling wind in complex terrain for use in fire spread prediction. M.S. Thesis, Colorado State University.	Done
WindNinja v2.0	A validated, tested, documented surface wind prediction model was developed and made available.	Done