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A Gust Changes Everything: Local Wind Information in Unprecedented Detail with *WindWizard* and *WindNinja*

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Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Managers now have two new tools to give them the information they need about wind direction and speed at small, local scales. One does it on a laptop in under 60 seconds. Credit: Revensis at Dreamstime.com.

A Gust Changes Everything: Local Wind Information in Unprecedented Detail with *WindWizard* and *WindNinja*

Summary

Fire behavior model accuracy has suffered from a lack of specific information about how winds shift in direction and speed in mountainous terrain at fine scales. Before this project, fire managers lacked a tool that could provide real-time status of changing wind conditions at the scale of a specific ridge or drainage. This project resulted in two wind simulation tools that focus on this critical need: *WindWizard* and *WindNinja*. *WindWizard*, based on commercial computational fluid dynamics software, comes with a price tag and is computationally slower due to the complexity of the calculations it performs. *WindNinja* was developed as *WindWizard's* lighter, faster, free, and more field-friendly cousin. Fire managers have found that these tools provide the reliable, timely, detailed information needed for informed fire management decisions, as well as valuable information about conditions leading to firefighter entrapments.

Key Findings

- Fire behavior forecasts, fire growth projections, fire potential estimates, and firefighter safety all benefit from more accurate and detailed local wind information.
- The two models are based on known laws of physics and generate wind information at a resolution of a few hundred feet.
- The models can be used in a "gaming" mode to explore the impact that various forecasted wind scenarios might have on a fire at a local scale.
- These tools allow fire managers with little specialized knowledge to simulate/visualize surface wind field information at the 300 foot to 1,000 foot scale in relatively short times using laptop computers.

Gambling on a gust

One of the primary sources of uncertainty in fire behavior predictions is the way in which wind speed and direction change near the ground in mountainous terrain. In most cases, fire incident personnel have to estimate local winds based on coarse scale weather forecasts and/or weather observations from a few specific locations, none of which may actually be near the fire. Existing wind simulation models typically used to develop weather forecasts do so at the regional scale, estimating a range of wind speeds and directions over broad areas for a given time period. Although this is important information, its utility in real-time wildland fire scenarios is extremely limited. Due to their coarse scale the models typically can't show what happens to those winds at a smaller scale—as it drops down the lee side of a ridge, curls behind a rocky outcropping, or funnels up a draw. They require a lot of computational power and time not generally available in the field, and users must have extensive, specialized technical skills. They can't be used on a laptop in the field and they can't provide "what-if" scenarios when someone needs information about alternate wind situations ahead of time to explore their impact on fire intensity and growth.

For optimal wildland fire application—incident managers need information about what wind is likely to do at a specific time in a specific place—like at sunrise tomorrow at the bottom of a cliff-ridden canyon ringed with homes, or where firefighters were deployed overnight defending communications infrastructure. For this project, Bret Butler and Jason Forthofer, along with Mark Finney, Larry Bradshaw, and Kyle Shannon, all of the Missoula Fire Sciences Laboratory, focused on developing a wind model that would do just that. In the process they ended up creating two models—*WindWizard* and *WindNinja*. Both are physics based models that translate upper airflow into local surface flow by taking into account the influence of ridges, outcroppings, cliffs, gullies, and canyons.

WindWizard is based on existing commercial, computational fluid dynamics software. It's the bigger, slower, more brainy, and in some situations more accurate of the two. Because of its commercial origins, it comes with a price tag of close to $1,000. *WindNinja* is *WindWizard's* smaller, faster, free, more field-friendly offspring. Both can be run on a laptop without specialized computer skills. Each model has pros and cons. Each has a different set of scenarios for which its use is appropriate. But Butler and Forthofer have used them both to support wildland fire management teams by completing more than 2000 wind simulations for hundreds of fire incidents located across the country. The result? Improved fire behavior forecasts, fire growth projections, and fire potential estimates—all benefitting from the more accurate and detailed local wind information the models provide. "A gust of wind changes everything," Butler explains. "Every point along a fireline is like the pull of the lever on a blackjack machine. Somewhere on that line is the potential for a jackpot that could injure people or do more damage. Any improvement in resolution is a step in the right direction. That's why we've seen such an improvement in predictive capability for fire behavior when we include more detailed wind information."

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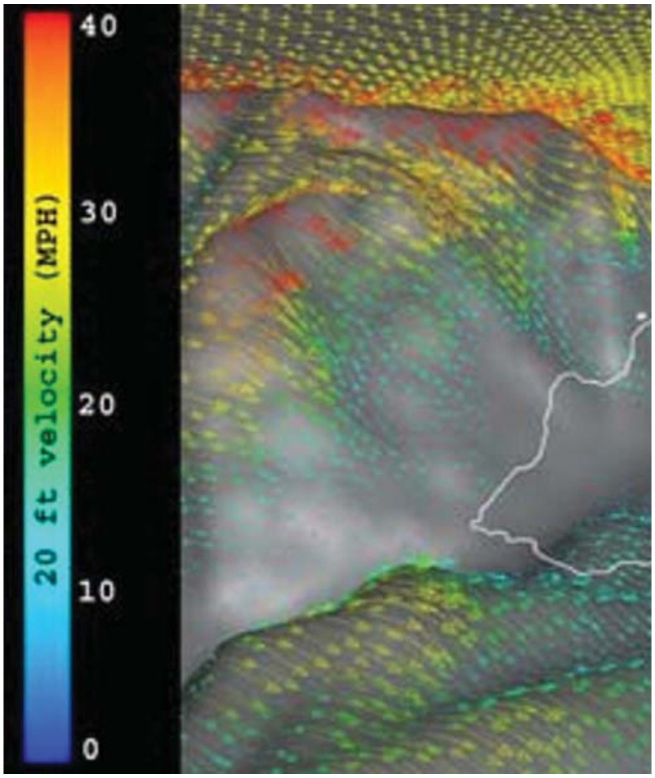
Think small

"A fire manager wants to know what's going to impact the safety of firefighters and the public at very specific areas," Butler says. "That's the major contribution of these models—are you going to put people out on the fireline for the next burning period or not? That morning? That afternoon or that evening? In order to be relevant to people who are making these decisions in short time frames you've got to be able to take the input, run the calculations and get your answers in an hour or less. You can't do that with the large-scale, complex weather service models—it is impossible. It cannot be done."

In order to provide more of what incident managers need, Butler and Forthofer had to think local and small. Both *WindWizard* and *WindNinja* represent a significant and potentially lifesaving improvement over previous methods. "We wanted to better support fire management by building something that included more detailed information about wind at smaller scales to significantly increase the accuracy of our fire growth predictions" Butler continues. "This is a primary factor that's been missing." Weather service



This image was used by the Incident Management Team to determine the optimum management strategy for this fire. Displays predicted wind vectors over the Columbia Gap west of Glacier National Park. Input winds are from the west. The image shows the significant channeling of the wind flow downstream of the gap. The white line represents a fire perimeter that was burning in the area.

models are based on the large-scale domain of the science of meteorology. If you're a meteorologist you're trying to predict flow over the surface of the earth. But Butler and Forthofer use methods of calculating wind fields based on the physics that describe the flow over something of infinitely smaller scale—an aircraft wing. The same physical laws apply. "These models really act as physics based tools that interpret the coarse scale wind forecasts to a much finer scale," Butler explains. "Our argument is based on the assumption that looking at flow over an airplane wing is an appropriate way to make rapid wind flow calculations at this scale—10 or 20 feet off the ground over a distance of couple hundred feet. We include some of the components important to meteorology—yet we're ignoring most of what meteorologists consider very important, like the effect of moisture, evaporation and condensation on the air flow over the Earth's surface. The bottom line, he says, is that people are using the models, the models are helping them and they're accurate enough for the job." Butler stresses that *WindWizard* and *WindNinja* outputs are not forecasts, but predictions of the wind field that would exist at one point in time given a general wind speed and direction obtained either from weather forecasts or possibly historical weather data. They convert the general wind speed and direction to fine scale detailed wind speed and direction over the entire area included in the simulation.

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Why two?

WindWizard owes its heavy lifting computational abilities—and its price tag—to the thousands of hours that went into the development of the underlying engineering tool designed for commercial use. Butler and Forthofer modified the general software tool for the specific application of modeling wind flow over mountains. They were happy with what it could do, but for people working on real fires it took too much time. "A lot of our users are operating in a real time fire environment," Forthofer says. "They have a hundred other jobs to do besides looking at the wind. For a fire behavior analyst on a fire who only has 30 minutes to spend on wind stuff today, *WindNinja* is probably the best option."

"To be operationally relevant a program has to be able to make these calculations in tens of minutes, or less than an hour. Any longer than that is too long." Butler adds. The team wanted an alternative that was fast, free, and easy to use in the field. So Forthofer took the opportunity to develop *WindNinja* as his master's degree project with programming help from physical science technician Kyle Shannon. He included the capability to calculate the position of the sun based on user location and the date. It also includes elevation data, slope and surface information, vegetation type, and whether there is bare rock or soil. Using these parameters *WindNinja* calculates how much the surface will heat up during the day or cool off at night, and how that will affect local up-slope and down-slope winds. Information about this 'diurnal flow contribution' is most important when ambient winds are low. When ambient winds are high, the diurnal contribution is washed out and has little affect. Diurnal flow information isn't included in *WindWizard* because Butler and Forthofer don't have access to the source code. "That's one of the things we gave up in *WindWizard* by going with the commercial software package," Butler says. "It's easier for us to add and control new features in *WindNinja* because we wrote it."

How do they work?

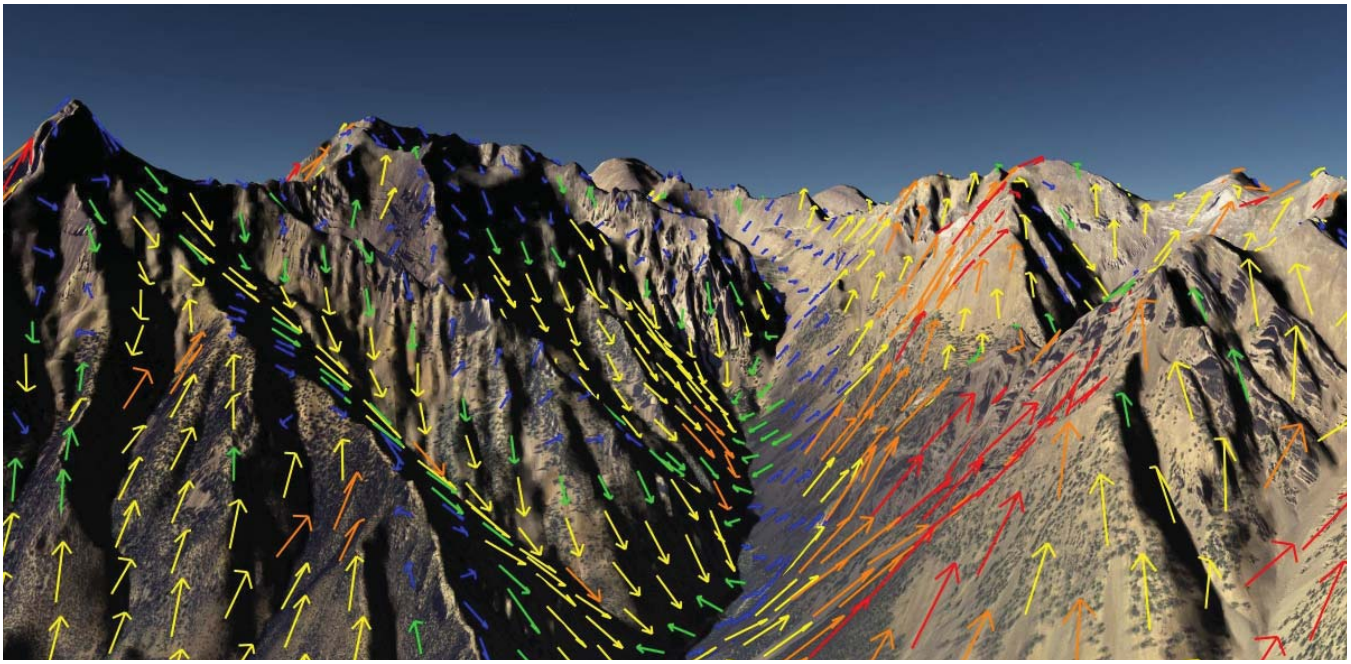
Wind modeling for specific fires consists of simulating multiple combinations of unobstructed wind speed and direction—for example, ridge top wind from the southwest at twenty-five miles per hour. *WindWizard* and *WindNinja* have the capacity to generate different wind scenarios based on historical weather patterns or current forecasts. They basically draw a line between two points of forecast wind speeds, a couple of miles from each other. Then, based on weather service information and physics derived from what is known about the terrain and vegetation, they show what the flow will do in between. Typically, the area of interest is rectangular with the fire located at the center. Depending on which tool is used, a solution can be achieved in anywhere from 60 seconds to several hours. Outputs consist of wind speed and direction over the entire surface, and are geo-referenced so that they can be incorporated into standard Geographical Information Systems (GIS). Only computer hardware and terrain models limit resolution. Another important aspect of these models is that they can be used in a "gaming" mode, which can't be done with the complex, large-scale weather service models. In winter, when managers are planning prescribed burns this feature can be used to simulate all kinds of wind scenarios and how they will impact local wind flows that they're really interested in—right down to a very small drainage. They can ask questions about what will happen in there if the wind is doing X or Y, and discover the optimal conditions for achieving a management goal. Once these calculations are run the files can be saved and accessed at any time in the future. Integration of Google Earth provides users with a picture of small-scale variations in wind direction and speed twenty feet off the ground in the form of color-coded arrows overlaid on a shaded 3D terrain map. The arrows identify high and low wind speed areas within the fire perimeter caused by the channeling and sheltering effects of the topography.

WindWizard and *WindNinja* simulations have been used to provide wind input for possible future fire scenarios, as well as for FARSITE reconstruction simulations of previous fires. The use of these wind simulations markedly increases the accuracy of fire spread projections when compared to actual fire spread histories.

Which one's for me?

Because of the differences between the two models potential users are often confused about which one to use. Each model has certain advantages and disadvantages and the best choice will depend on the particular situation.

Besides the presence/absence of the diurnal flow contribution, another major difference is that *WindNinja's* simulations of what winds are likely to do on the lee sides of hills or mountains aren't as accurate. *WindNinja* can't simulate eddies that may form when wind encounters an



The integration of Google Earth provides users with a picture of small-scale variations in wind direction and speed twenty feet off the ground in the form of color-coded arrows overlaid on a shaded 3D terrain map.

This graphic shows fire growth predictions from the model reconstructions of the 1994 South Canyon Fire, west of Glenwood Springs, Colorado. The uniform wind field is on the left, the *WindNinja* wind field in the center, and the *WindWizard* wind field at right.

obstacle and reverses direction. The other most notable difference is simulation time. *WindNinja* simulations are much faster (8–45 seconds) than *WindWizard* runs (30 minutes to 2 hours). A final difference is cost. *WindNinja* is free, where *WindWizard* has a price tag of nearly $1,000 (as of July 13, 2009).

Forthofer recommends *WindWizard* for situations where the primary wind source is a cold front or similar strong pressure gradient. It is best for someone who has enough time on their hands to let the computer run for about an hour per wind scenario, or even overnight, perhaps someone who's planning for prescribed burns that are months away. "That's how long it can take" he says. "Because you would generally run multiple simulations and scenarios of different wind speeds and directions. It's fine for someone who's planning far into the future. It's also the most accurate tool for predicting the influence of ridges and turbulence on the surface wind. It does not consider diurnal flow."

WindNinja is best for the fire behavior analyst in the field or for people dealing with fires in real-time who might be able to sacrifice some accuracy for speed in some cases. *WindNinja* is more accurate when diurnal slope flows are the significant factor driving wind flow. If *WindWizard* is unusable because of cost, licensing or long simulation times, *WindNinja* can be used for all cases.

A ninja you should get to know

The future vision is to eliminate the need for users to have to choose between the two. Butler and Forthofer hope that eventually *WindNinja* will include all of the physics of *WindWizard*. Users could then choose a simple, fast solution, or one that would include more physics and provide better accuracy but take longer. A primary goal is to make *WindNinja* even easier to use by adding more automated features, like the ability to directly ingest data from the coarse scale weather models to initialize a simulation. "We'd like *WindNinja* to automatically import it in a gridded manner for the whole domain instead of using just a single wind speed and direction like it does now" Forthofer says. "Then we could run it at all weather model time steps but at our smaller, finer scale. Open it—click on it—there it is."

"We also want to add the ability to go out and grab the terrain automatically," he continues. "Embed a Google Maps window where users could just zoom into the area they want and get the digital elevation file. It's all about making it easier." Also, because recent evidence suggests that wind flow at the one-meter scale is critical to fire behavior—especially the transition from ground to surface to crown. "I believe it comes down almost to the individual shrub scale," Butler says. "This is where you see these changes occur. I think ultimately we'll need to focus there even though we can't yet because we don't have the data or the capabilities."

Although the models are still fairly new and many fire management teams aren't aware of them, Butler, Forthofer and the Joint Fire Science Program continue to spread the word. "I know everyone is overwhelmed with models" Butler says, "but with all the passion I can muster I'm saying this is probably one of the tools everyone should at least consider. The bottom line is that there is little excuse for any fire management team not having some capability to simulate surface airflow. 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." Forthofer, a former wildland firefighter concurs, saying, "For anyone who's trying to predict fire behavior on extended attack, large fires—we think it's a good idea to run *WindNinja*. There aren't a lot of reasons not to."

"The bottom line is that there is little excuse for any fire management team not having some capability to simulate surface airflow."

Management Implications

- If *WindWizard* is unusable for high winds because of cost, or long simulation times, *WindNinja* can be used for all cases.
- Output resolution is limited only by computer hardware and terrain models.
- The models can be used in a "gaming" mode to explore the impact that various forecasted wind scenarios might have on a fire at a local scale, something not possible with large-scale weather models.
- Once completed, wind simulations can be saved and used in the future when similar wind situations exist.

Further Information: Publications and Web Resources

Installation, help files, and tutorials are available for both tools at: http://www.firemodels.org.

Scientist Profiles

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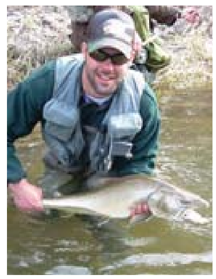

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