# USING THE 'WNDCOM' WIND PREDICTION MODEL IN A FIRE DISPATCHING SYSTEM

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Sending the right numbers and kinds of fire-fighting resources to a reported forest fire is an art traditionally learned by experience. Expert dispatchers are often intimately familiar with their areas of responsibility. They usually know what fuel types to expect on the basis of past fires in an area. Day-to-day fire weather reporting gives them a feel for how fast a fire is liable to grow, how intensely it is liable to be burning when the first fire fighters arrive and what the chances of catching the fire are. But experts aren't universally available, and can't always be replaced quickly if they retire, transfer, or leave. So systems that can substitute computer models for some of the expert's experience are growing in popularity and application.

Over the last few years, a number of mathematical models and other tools have been developed which have potential application in fire dispatching. Chief among these is the U.S. Forest Service's BEHAVE fire behavior prediction system (Andrews and Rothermel 1984). BEHAVE contains a module specifically to help dispatchers estimate fire behavior and fire suppression requirements at the time of the initial fire report. Other dispatching aids and tools include tables for estimating fuel moisture at remote sites. Recent applications of remote sensing from satellite platforms (e.g. LANDSAT) have provided cover type, and in some cases fuel type information for operational use in dispatching.

The direction and speed of surface winds is perhaps the last remaining data item needed to make BEHAVE and similar systems truly usable in fire dispatching. Several possibilities for estimating winds at remote sites exist. Three such possibilities are slope wind tables (Albini, Latham and Baughman 1982), and two surface wind models for mountainous terrain (Fosberg 1984; Ryan 1984). This paper describes how Ryan's model was incorporated into a computer-based dispatch information system presently in use on the Okanogan National Forest in Washington State.

## 1. THE OKANOGAN FIRE DISPATCHING SYSTEM

The Okanogan National Forest Computerized Fire Management System stores and retrieves information about fire conditions in the forest on a Data General MV4000 computer and on IBM PC-AT and PC-XT microcomputers (Gum 1986). The data required as input for the Okanogan system come from two main sources:

a. a data base containing the average NFFL fuel type, slope, aspect, and elevation for individual 80-acre cells;

b. wind, temperature and relative humidity data from the nearest or most representative weather station;

When a fire is reported, BEHAVE uses these inputs to model the fire and display the time required for suppression forces with various line-building rates to "catch" the fire. This helps the dispatcher choose the mix of forces which best meets the current situation.

During its first season of operation, this system assumed that wind speed and direction at the reported fire site were the same as that reported from the nearest RAWS (Remote Automated Weather Station) site. While this assumption caused no major problems during the first season, a better estimate of wind at the fire site is certainly desirable. Ryan's WNDCOM model appeared to provide the necessary information and have the least demanding data requirements of the wind models which we investigated. We therefore set about to adapt this model for use in the Okanogan Fire Management System.

## 2. THE WNDCOM SURFACE WIND MODEL

Ryan's model considers the surface wind in mountainous terrain to be the resultant of four vectorially-combined winds: the geostrophic wind brought to the surface as the general wind; the land-sea breeze; the slope wind; and the valley wind. Since the Okanogan dispatch area is over 150 miles from the ocean and separated from it by the Cascade Mountains, we dropped the sea breeze component.

The types of data required by WNDCOM are given in Table 1. Date is expressed as julian day. Time of day and date are obtained from the system clock. Sunrise and sunset times are computed from latitude, longitude and elevation. Latitude and longitude are taken as constants for the Okanogan National Forest. Thus, the time difference between Greenwich Mean and Local Standard times is also constant. We followed Ryan's suggestion for estimating atmospheric transmissivity: 0.9 for clear weather and 0.4 for cloudy or overcast skies.

The most difficult data to obtain are the vertical angles from a reported arbitrary fire location to the horizon at various azimuths. Ryan suggests scaling these angles from a topographic map. This method is obviously too cumbersome and slow for use in a dispatching situation. However, each 80-acre cell in the Okanogan data base contains the maximum elevation for that cell, and this information can be used to trace the approximate horizon around any arbitrary point.

We experimented with the use of "stylized" topography based on the 80-acre cell data (Pickford 1986). While the idea shows promise, it was not taken beyond the experimenting stage.

The horizon obtained from the maximum elevations of each 80 acre cell seems sufficiently accurate for WNDCOM purposes. However, Ryan gives no indication of the sensitivity of the estimated surface wind to errors in horizon angle. Therefore, I tested the sensitivity of WNDCOM output to the various required horizon angles and other input variables.

TABLE 1. Data Required by WNDCOM

| Data Item | General Wind | Valley Wind | Slope Wind |
|---|---|---|---|
| Time | | | |
| Date | | * | * |
| Time of Day | * | * | * |
| Sunrise | | | * |
| Sunset | | | * |
| Geographic Position | | | |
| Longitude | | | * |
| Latitude | * | | * |
| GMT - LST | | | * |
| Topographic Position | | | |
| Elevation | | | * |
| Aspect | | | * |
| Slope % | | | * |
| Angle to Horizon | * | * | * |
| Upvalley Direction | | * | |
| Aspect of Area Downwind | * | | |
| Atmospheric Transmissivity | | * | * |
| Geostrophic Wind | | | |
| Speed | * | | |
| Direction | * | | |

Ryan's model also requires knowledge of the geostrophic, or free-stream wind speed and direction. Ryan (1984) suggests using the 850 mbar winds at the nearest NWS Limited-are Forecast Model grid point. Much of the Okanogan terrain is already above the 850 mbar level, and local fire weather forecasters did not have ready access to the data for grid points. Other sources for geostrophic wind data included rawinsonde data for Quillayute, WA; Vernon, BC; or Spokane, WA. These data are as hard to obtain on a regular basis as the grid-point predictions. Furthermore, none of the three stations are particularly representative of the Okanogan area. Comparison of the observed winds at RAWS sites with WNDCOM estimates using rawinsonde data were unsatisfactory.

Another alternative was to use any RAWS or other weather station, and solve the WNDCOM model "backwards" to obtain the geostrophic winds. A computer routine was written to do the calculations, and initial trials seemed to give reasonable results. Similar trials by Ryan on data from California were also encouraging. However, another method was tried which was more direct and easier to implement.

Fire Behavior Analysts often use windspeed and direction measurements from lookouts and exposed ridges to represent free-stream winds. Three of the RAWS sites on the Okanogan were located at or near the tops of exposed ridges. We tested WNDCOM using wind data from these exposed RAWS sites as the geostrophic wind. The results were encouraging. When the decision to move one remote RAWS station was made, a new site on an accessible but exposed high point was chosen expressly for use in representing the geostrophic winds.

## 3. ASSESSING WNDCOM'S ACCURACY FOR FIRE BEHAVIOR FORECASTING

The consequences of errors in estimating fire behavior during the dispatching process are probably more severe than those attending fire danger rating, and somewhat less severe than those in real-time fire suppression planning. With this in mind, and because dispatchers customarily work within fairly wide limits of uncertainty, the results of WNDCOM were judged to be acceptable if wind direction could be estimated within 45 degrees of its actual direction, and 5 mph of its actual speed at standard anememometer height.

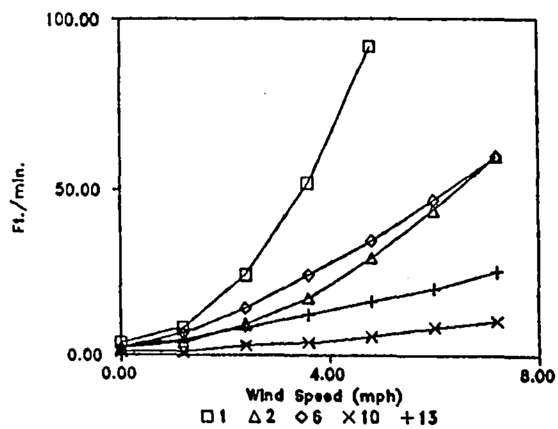


Figure 1. Rate of Fire Spread versus Surface Windspeed. Data from the BEHAVE system using a sheltering factor of 0.5. Wind speeds shown are mid-flame and are half that of wind speeds at standard anemometer height. Fine fuel moistures, live fuel moisture and slope were 5, 150, and 0 percent, resp.

As figure 1 shows, the consequences of a 5 mph error in the 20-ft windspeed are greatest for light fuels such as the grass fuel models. The slower rates of spread in brush, slash and the duff under closed conifer canopies make 5 mph errors less important when dispatching to fires in these fuels.

A difference in the direction of the estimated wind direction at the fire amounting to 45 degrees or less from the actual direction seemed acceptable. If one were planning line location on a going fire, such an error might not be acceptable. During dispatch however, a 45-degree error in wind direction would probably not change the general direction of fire movement enough to affect allocation decisions.

## 4. GENERAL WINDS: TIME, GEOSTROPHIC WIND, SHELTERING AND DIVERSION

WNDCOM estimates the general component ($V_{20}$) of the surface wind from the speed and direction of the geostrophic or free-stream wind ($V_g$). If $V_g$ is greater than 26 mph, then $V_{20}$ is a nearly linear function of $V_g$. If $V_g$ is less than 11 mph, then $V_{20}$ depends sinusoidally on time of day. For $V_g$ between 11 and 26 mph, $V_{20}$ depends partly on time of day and partly on $V_g$. Figure 2 shows the variation in the surface wind component as a function of time of day.

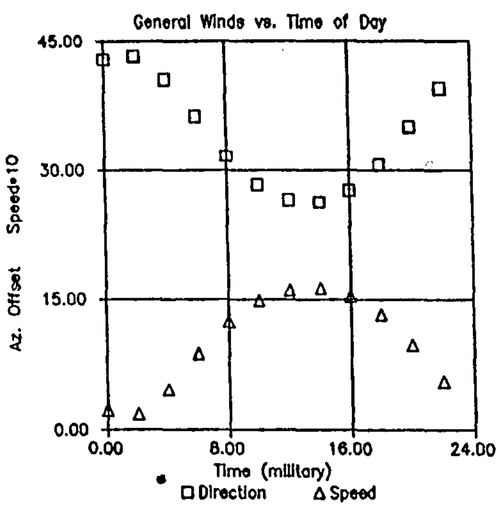


Figure 2. Variation in the General Component of Surface Wind Speed and Direction as a Function of Time of Day, for Moderate (5-25 mph) Geostrophic Winds.

Using a RAWS station as the source of geostrophic wind data means that the data may be delayed by as much as three hours. Figure 2 suggests that such a delay would produce an error of about one mph in surface wind speed and a 10 to 12 degree error in azimuth.

No estimates were made of the errors to be expected from assuming that ridge-top winds represented the free-stream winds. It seems unlikely that such errors would cause significant problems.

The surface wind component is slowed if sheltered by high ground upwind, and is diverted if it encounters high ground downwind. WNDCOM uses the vertical angle from the fire site to the horizon to estimate the effect of sheltering on wind speed. This effect operates as a percent reduction in windspeed, depending on the vertical angle.

Figure 3 show that the effect increases rapidly for slope angles up to about 14 degrees. Upwind obstructions higher that this reduce the surface windspeed to about 20 percent of its unsheltered value. The Okanogan process of reconstructing the horizon about an arbitrary point would tend to underestimate the actual height of these obstructions. These errors, as they affect the sheltering routine, would probably cause an overestimate of the general component of the surface wind speed.

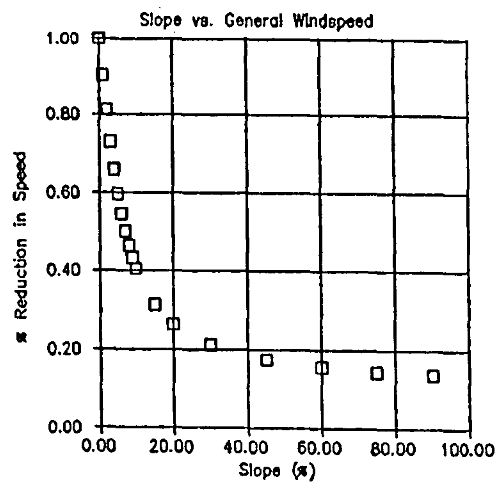


Figure 3. Reduction in the General Component of Surface Wind Speed as a Function of Vertical Angle to Upwind Horizon (Sheltering).

Diversion depends on the aspect of the terrain downwind and the angle from the fire site to the downwind horizon. Diversion is a large-scale effect; that is, it only occurs where the valley system makes a major bend. The worst-case situation occurs when the aspect of the diverting terrain is 45 degrees to the undiverted wind direction. As Table 2 shows, the correction in wind direction for' diverting terrain is less than 25 degrees for any realistic horizon angle.

TABLE 2. Effect of Vertical Angle to Downwind Horizon on Diversion of General Winds.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vert. Angl (%) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Divrted Wind (deg) | 0 | 1.6 | 3.2 | 4.8 | 6.4 | 8.0 | 9.6 | 11.1 | 12.7 |

In general, WNDCOM should produce estimates of the general wind component of surface winds well within the 5 mph and 45 degree accuracy limits.

## 4. VALLEY WINDS: DATE, TIME, TOPOGRAPHY, AND TRANSMISSIVITY

WNDCOM estimates the valley component of the surface wind by adjusting a computed maximum valley wind speed for the date, time of day and depth of the valley ("valleyness"). Since both the date and time are taken from the system clock, there should be no error in the valley component arising from this source.

WNDCOM determines the effect of the shape of the terrain at the fire site on wind speed by computing a valleyness index. This index depends on the sum of the vertical angles from the fire site to the horizons at right angles to the axis of the valley. Valleyness varies between 0 and 0.8 and reaches its maximum when horizon angles reach 100 percent in both directions.

The computed maximum valley wind speed peaks in clear weather at about 1340 hrs on the summer solstice. Under these conditions, the direction changes from down valley to upvalley between 0800 and 0900 hours, and back again between 1800 and 1900 hours. The horizon angles and the atmospheric transmissivity are therefore the only sources of error introduced by the input data.

The effect of errors in vertical angles to the horizon on estimated valley wind speed are linear, and amount to an eight percent error in windspeed for combined errors in both directions of 11 degrees. Again assuming that the actual height of the horizon is underestimated, WNDCOM estimates of the valley component will also be underestimated. The underestimate is probably small--less than 1 mph in most cases.

## 5. SLOPE WINDS: DATE, TIME AND TOPOGRAPHY

The slope wind routine is the most complex set of computations in WNDCOM. The slope component of the surface wind depends primarily on the length of time the site is exposed to solar radiation, or else is shaded. It also depends on the angle of incident radiation which in turn depends on the aspect of the fire site.

A significant source of error in estimating slope winds with the Okanogan system is the need to use the average topographic characteristics of an 80-acre cell for any point within the area. In rough terrain, slope percent, aspect and elevation can each vary widely from one place to another over such an area. Unless a smaller cell size is used, or site specific information about the topography at the reported fire is available, there is little that can be done about this problem in the Okanogan system. Fortunately, many areas are fairly uniform over cells of this size. The problems will be the worst in extremely broken terrain.

During mid-July, the effect of errors in estimating slope at the site depend on both the actual slope and time of day (Table 3). Slopes from 30 to 50 percent experience the strongest upslope daytime winds. Wind speeds decrease as slope angles increase beyond 50 percent. The Okanogan database contains the average slope over each 80-acre cell, so the actual slope at a point could as easily be greater or smaller than the figure used for input to WNDCOM. The windspeed data in Table 3 fall off more rapidly for slopes over 50 percent than for more gentle slopes, especially after 1000 hours. Thus WNDCOM will tend to underestimate slope wind speeds, probably by about 1 to 2 mph during midday.

TABLE 3. Variation in Slope Component windspeed with Time of Day and Horizontal Angle to the Horizon. Data represent a south-facing slope at the latitude and longitude of Okanogan National Forest for clear weather on 15 July.

| TIME | SLOPE ANGLE TO HORIZON (percent) | | | |
|---|---|---|---|---|
| | 30 | 50 | 70 | 90 |
| | Windspeed (mph) | | | |
| 0700 | 0.59 | | | |
| 0800 | 1.69 | 0.92 | | |
| 0900 | 3.13 | 2.23 | 1.37 | |
| 1000 | 4.66 | 3.72 | 2.82 | 1.99 |
| 1100 | 6.04 | 5.13 | 4.26 | 3.46 |
| 1200 | 7.06 | 6.24 | 5.45 | 4.72 |
| 1300 | 7.57 | 6.87 | 6.20 | 5.58 |
| 1400 | 7.47 | 6.91 | 6.38 | 5.88 |
| 1500 | 6.75 | 6.33 | 5.94 | 5.57 |

Most of the remaining errors in the WNDCOM estimates of slope winds will be due to errors in estimating the vertical angle to the horizon in the direction of sunrise and sunset. Errors in these angles will change the time of sunrise or sunset, and will therefore change the amount of time the slope is exposed to solar radiation. At night, these errors will produce the opposite effect.

TABLE 4. Variation in Slope Component windspeed with Time of Day and Slope of Site. Data represent a south-facing slope at the latitude and longitude of Okanogan National Forest for clear weather on 15 July.

| TIME | Slope of Site | | | |
|---|---|---|---|---|
| | 30 | 50 | 70 | 90 |
| | Windspeed, mph | | | |
| 0700 | 0.59 | 0.78 | 0.80 | 0.72 |
| 0800 | 1.69 | 2.16 | 2.11 | 1.80 |
| 0900 | 3.13 | 3.75 | 3.40 | 2.76 |
| 1000 | 4.66 | 5.21 | 4.43 | 3.49 |
| 1100 | 6.04 | 6.30 | 5.11 | 3.96 |
| 1200 | 7.06 | 6.91 | 5.38 | 4.13 |
| 1300 | 7.57 | 6.96 | 5.29 | 4.01 |
| 1400 | 7.47 | 6.48 | 4.78 | 3.61 |
| 1500 | 6.75 | 5.51 | 3.96 | 2.96 |
| 1600 | 5.45 | 4.17 | 2.89 | 2.11 |
| 1700 | 3.17 | 2.58 | 1.68 | 1.16 |
| 1800 | 1.75 | 0.96 | 0.48 | 0.22 |

I have assumed that most dispatching problems will occur during daylight hours, so errors in estimating the angle to the horizon will produce errors in the time of sunrise. For instance, on a 30 percent slope at the latitude of the Okanogan National Forest during mid-July, a 10-degree error in estimating the angle to the horizon will produce a one-hour delay in sunrise (Table 4). In WNDCOM, an error of one hour in the duration of irradiation of the slope corresponds to approximately a one mph error in windspeed. Overestimates of duration will overestimate windspeed, and vice versa. On this basis, the Okanogan topographic data base would introduce errors that underestimate slope wind speeds by one to two mph.

## 6. SUMMARY AND CONCLUSIONS

WNDCOM estimates of wind speed and direction at remote sites are potentially very valuable in wildfire dispatching situations, but only if these estimates represent actual winds at the site with sufficient accuracy for dispatching purposes. In this paper, I assumed that estimates of wind direction within 45 degrees and speeds within five mph of actual wind conditions were acceptable for dispatching purposes.

Errors in WNDCOM estimates are introduced primarily through errors in estimating the vertical angles to the horizon at various azimuths, errors in estimating the aspect, elevation and slope of the site. In addition, the age of free-air wind observations will affect general winds. These are errors that cannot be reduced or eliminated with the present system, because site data are averages for 80-acre areas, and RAWS data used for free-air winds may be delayed from one to as many as six hours by equipment failures, glitches, etc.

Delayed observations of free-air winds may introduce errors of one mph and ten degrees in the general winds at a site. Estimation errors for the general wind component are relatively insensitive to horizon angle, except for upwind sheltering. Overall, the Okanogan system is expected to estimate the general wind component within five mph and 45 degrees of actual conditions.

The valley wind component is relatively insensitive to errors in estimating horizon angles, particularly for angles less than about 30 degrees. The Okanogan system is expected to underestimate valley winds by eight percent in speed, or about one mph or so on the average.

The slope wind component is sensitive to the general slope at the site, and to horizon angle. The Okanogan system probably underestimates site slope, and will thus underestimate daytime upslope winds by one to two mph. The system probably underestimates horizon angles as well, which will further underestimate slope winds by another one to two mph.

When these errors are combined as vectors in a worst-case situation, the resulting error component is 5.6 mph at an angle of 45 degrees to the upvalley direction and toward the wall opposite the site of the fire. This worst-case situation meets the direction criterion and nearly meets the speed criterion for usable accuracy. WNDCOM predicts wind speed and direction at remote sites using information in the Okanogan database and other easily obtainable information. The program appears to be robust in tolerating the kinds and sizes of errors that occur in Okanogan input data. WNDCOM should produce usefully accurate wind predictions for use in most dispatch situations on the Okanogan National Forest.

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