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An Expert System Application for Forecasting Severe Downslope Winds at Fort Collins, Colorado, U.S.A.

by

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INTRODUCTION

Severe downslope winds are relatively infrequent, but significant, weather events that occur uniquely along a geographic strip that is parallel to, and just downwind from, most mid-latitude mountain ranges. They are topographically accelerated flows which can result in wind speeds as high as 80 - 100 kts, or greater. Such speeds are well within the definition of "hurricane force."

This paper addresses the problem of forecasting severe downslope winds at a single site in Colorado. An expert system, called WIND, is described in which the knowledge-base is primarily the result of a twelve-year statistical study, but is forecaster-subjective in places where necessary.

KNOWLEDGE-BASE

A. Statistical Results. A comprehensive statistical study of atmospheric variables associated with severe downslope windstorms was conducted by the first author at Colorado State University (CSU) in Fort Collins for the years 1977-1988. In the study, a spreadsheet entry was completed each time multiple downslope wind gusts at CSU exceeded 45 kts for a period of 30m or longer. Another entry was completed if the event lasted more than 6 h. The synoptic conditions used were for data times closest to the wind occurrence. Variables included such parameters as sea level pressure gradient (direction and strength), 500 mb height gradient (direction and strength), 500 mb temperature, and many others. For a more complete listing, refer to Lee et al., (1989). By the end of the study, a total of 77 cases had been documented. When the spreadsheets were complete, various statistical techniques (principally multiple regression analysis) were applied to identify "important" parameters.

Briefly, it was found that only a few of the many variables recorded were of first order importance to downslope occurrence. These included the sea level pressure gradient (direction AND strength) and the 700 mb height gradient (direction AND strength). 500 mb negative vorticity advection (NVA) was found to be only slightly less than first order importance.

B. Subjective Results. Since severe downslope windstorms are not well understood, we felt that it would be quite possible that even a massive record of variables might miss some important clue to the event. Such a clue might be an ignored variable, or some combination of variables not obvious from a simple aggregate listing. Thus, in addition to the spreadsheet described above, a log was kept in which subjective impressions and observations were recorded. These observations included not only those of the principal investigator, but also many comments overheard during informal map discussions at CSU. Some of these comments were made frequently over time, and thus became more important as the study progressed.

An example of one such subjective observation was the evidence on satellite imagery of subsidence downwind from the mountains during downslope wind events when mid-level moisture was sufficient to form mountain wave clouds. Specifically, it was observed that a clear slot often appears along the eastern edge of the Rockies on VIS imagery, along with dark (i.e., warm) bands on IR, and dark (i.e., drier) bands on 6.7 micron imagery. This phenomenon has been recently documented by another NESDIS group (see Ellrod, 1987).

One subjective finding resulted from a careful study of analog wind charts following the events. It was noted that there appears to be a pre-cursor signature on the local wind trace just prior (20m - 2h) to the onset of the event in about two-thirds of the cases studied. This pre-cursor manifests itself as erratic shifts in wind direction accompanied by low amplitude waves on the speed trace (Fig. 1). When observations have been available from qualified, on-site meteorologists, the usual report mentions a background flow of fairly gentle (and cool) easterly or southerly flow; mixed with weak, warmer gusts from the west. Descriptive accounts often include remarks to the effect that the westerlies seem to be trying to "mix down."

An important point that became very obvious as time went on, was that if a very cold, very deep airmass were present in the region, when severe downslope winds were otherwise expected, the event might not occur at all. This observation, by the author and others (see acknowledgments), led to the modeling study by Lee et al., (1989). Results from that study

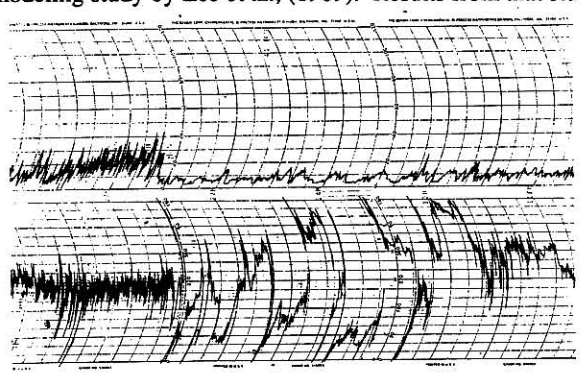

Figure 1. Anemometer trace, February 16-17, 1986, from the instrument located at CSU in Ft. Collins, CO. Period from 1130 P.M. on 16 Feb to 0230 A.M. on 17 Feb is experiencing the erratic shifts in wind direction and low amplitude waves on the speed trace described in text.

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SYSTEM DESCRIPTION

A. Numerical Input. The WIND expert system begins by querying the user for the sea level pressure and 700 mb height gradient information discussed above. These are fairly straightforward inputs, and could actually be brought into the system automatically -- say be ingesting sea level and 700 mb geostrophic winds. However, when the statistical study was being conducted, the variables were read from the routinely available National Meteorological Center (NMC) facsimile maps. Thus, the format of most parameters relate to that format. Additionally, many forecast locations still do not have access to pre-computed, geostrophic wind data, so (at least for the present) it seemed more straightforward to work with the input formats described herein. It should be noted that we are currently working on a version of WIND which accepts geostrophic wind.

In the working version of WIND, the gradient direction information is obtained by asking the user to estimate the direction from which the surface and 700 mb geostrophic winds are blowing. These questions are easily answered from routinely available data. Figure 2 illustrates the weighting factors that various directions are assigned. Note that some wind directions at 700 mb (winds from 10-180 degrees) are assigned negative weights. These values were initially zero, but a reevaluation following a field test during the winter of 1988-89 found that 700 mb winds from the south and east work more strongly against downslope winds than had previously been estimated.

The gradient strengths are input according to a so-called "reference distance" equal to the distance from the northwestern tip of Colorado, to the southeastern tip of Wyoming (Fig. 3). This method of measuring gradient strength was chosen due to its commonality to most maps, satellite photos, etc. That is, this distance is independent of map scale or projection. Again, this method of entering gradient strength is an artifact of the empirical study, and could easily be replaced by the velocity of the geostrophic wind. Though this method of judging gradient strength seems somewhat subjective, our experience has been that users adapt quickly to the measure, and reported estimates seem to converge with those of practiced forecasters after minimal experience.

The last step for the numerical input is a query for the 500 mb NVA (if any), in units of $(10)^{-5}$, $(s)^{-1}$. These are the analyzed units of relative vorticity which are presented on NMC, 500 mb prognosis maps. The system asks for an estimated value of NVA in the +/- 3h surrounding forecast-valid time.

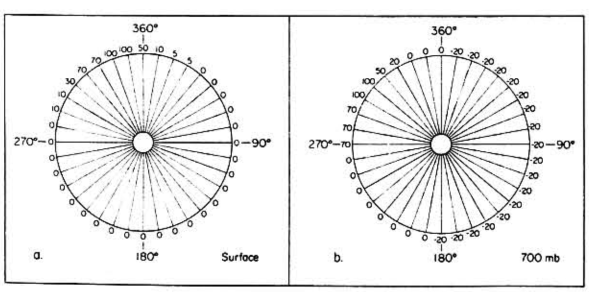

Figure 2. Weighting factors associated with various geostrophic wind directions at a) the surface, and b) 700 mb.

```
                                   |---------
                                   |
|<---- ref.  distance ---->|
                   Wyoming | Nebraska
-----------------------------------
|                          Colorado|
|            CSU +                 |
|                                  |-------
|                                  | Kansas
|                                  |
|                                  |

**********************************************************
**********************************************************

   STRENGTH OF SURFACE GRADIENT ???

        A reference distance (indicated above) is used
   to estimate the strength of the sea level pressure
   gradient.    Please enter the number of 4 millibar
   increments that you expect over  CSU  (as measured
   normal to the pressure gradient) at forecast time,
   in an interval equal to the reference distance.

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Figure 3. Sample query in the expert system, WIND. Screen format is for the question regarding the strength of the surface sea level pressure gradient measured relative to the reference distance discussed in text.

B. Windspeed Estimations. Once the above inputs have been entered, they are passed to an equation based upon results from the statistical study. This formula will not be addressed in detail in this report, but is defined as:

GS = W1*SGD + W2*SGS + W3*UGD + W4*UGS + NVA, where

GS = the maximum gust speed in knots

SGD = 15, SGS = 25, UGD = 20, UGS = 20, and

W1 = weighting factor shown in Figure 1a,

W2 = 0.2 * sea level pressure gradient strength,

W3 = weighting factor shown in Figure 1b,

W4 = -0.2 for 700 mb height gradient strength <2, otherwise, = 0.2 * 700 mb height gradient strength,

NVA = absolute value of entry for NVA.

(Note that in this formulation, both the surface pressure and the 700 mb height gradients -- each a combination of two terms -- outweigh the NVA term by nearly 3:1.)

C. "Subjective" Input. In the subjective portion of WIND, the system attempts to gather information about the possible presence of a cold airmass at forecast-valid time. It does so in a way that is designed to minimize the burden on the forecaster's time. Thus, the first query simply asks:

"Will there be a cold airmass present in the region during the 3-12h period prior to forecast time?

RESPOND: 0 = NO, 1 = YES, 2 = Cannot determine"

For a "NO" answer, the system simply concludes by presenting the computed windspeed, along with a descriptive account of what can be expected. A typical "conclusion" might read:

> "Chances for severe downslope winds are EXCELLENT ... If the outbreak does occur, maximum wind gusts can be expected to reach 45 knots."

If the answer to the first query had happened to be YES, the system then leads the user to a second question:

"Will the cold airmass be:

1) less than, or equal to, 1 km deep,
2) between 1 km and 2 km deep,
3) greater than 2 km deep, or
4) don't know anything about the depth."

The following actions are taken, depending on the answer to this section: 1) same as answering "NO" to the very first query, 2) system goes on to further questions, 3) concludes that severe downslope winds are unlikely, 4) goes on to further questions.

The system will continue probing, as necessary, until it has extracted as much knowledge as required to make an informed decision, or at least as much knowledge as is available. Depending upon the cumulative answers received, a final decision is reached regarding the probability of severe downslope winds, given a preëxisting cold airmass. While these judgments could be couched in probabilities given as percentages, WIND uses descriptive adjectives instead. The list includes:

"Chances for severe downslope winds are ________ (slight, fair, good, excellent) ... ," and are meant to convey approximate values of about < 10%, 10% - 30%, 30% - 60%, and > 60%, respectively.

A FIELD TEST

A field test was conducted during the winter season 1988-89 at CSU. Nine hour (+/- 3 h) forecasts were made daily at 1500 UT, based upon the morning (1200 UT) data. Additionally, "perfect prog forecasts" were made from the actual verification data (i.e., at forecast-valid time = 0000 UT).

Though the sample size was somewhat limited, results were extremely encouraging. Using the definition for Probability of Detection (POD), False Alarm Ratio (FAR), and Critical Success Index (CSI) as given by Donaldson et al., (1975), the following contingency tables were prepared.

The first table includes all 55 forecasts, irrespective of weather. These results are almost too encouraging, and do not really present a "fair" picture of forecasting for the unusual event. That is, the extreme event is so unusual that the non-cases dominate the statistics -- making the accuracy seem much better than it really is. (For example, one could forecast "no tornadoes" for everyday during the winter, and come out looking pretty good, even though those stats would have little meaning.)

TABLE I. All (55) cases.

	POD	FAR	CSI
12h forecast	0.93	0.10	0.84
Perfect prog	0.99	0.04	0.95

Table II presents the results for the extreme event cases only. That is, only the cases in which high winds were forecast, and/or actually occurred (23 cases), have been included in these results. Notice that even though the accuracy is diminished somewhat, the numbers are, nonetheless, pretty impressive. The accuracies even surprised the authors, and we are looking forward to future tests to see whether or not the statistics hold up. In the "perfect prog" case, WIND was able to forecast to an 89% accuracy (CSI). Even with the errors introduced by 9h forecast parameters, success remains high. Here, the CSI indicates a forecast accuracy of 61%. This is considered very good for any forecast scheme, or parameter.

TABLE II. Wind cases only (forecast or observed).

	POD	FAR	CSI
12h forecast	0.79	0.27	0.61
Perfect prog	0.98	0.09	0.89

DISCUSSION

It appears to us, at least initially, that the statistics for the wind cases are suggesting that roughly 11% of the error in forecasting severe downslope winds can be attributed to a lack of dynamical understanding. About 28% seems to be due to bad forecast products. Future testing will teach us more. Right now we feel that even if we had a perfect understanding of the downslope wind event, we should still expect only around 70% accuracy in the forecast, due to inaccuracies in numerical guidance. It will be interesting to repeat this experiment when the new model guidance comes on line in 1991.

In November 1989, the National Weather Service (NWS) Forecast Office at Denver, CO began running a version of WIND, along with a version of a severe downslope wind decision tree designed at NOAA/ERL (see Brown, 1986), in a real-time forecast mode. The purpose of this informal experiment is to attempt to gain insight from professional forecasters into the usability and accuracy of both systems. For at least the first year, we expect that this insight will be primarily subjective in nature. We are also hoping that, since WIND was designed specifically for Fort Collins, and Brown's decision tree was designed for application at Boulder, CO, that the NWS experiment can furnish some information about generalizing the two applications, either individually, or in some combination, for other locations around the state.

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The authors would also like to acknowledge some of the people who, over the years, were involved in informal discussions regarding some of the more subjective aspects of severe downslope winds at Fort Collins. The list is not meant to be all-inclusive, but does mention several of the most frequent participants in the discussions relating to the cold air pool. Briefly, they are Dr. Roger Pielke, Dr. Richard Johnson, Tsengdar (John) Lee, Doug Wesley, and Bob Kessler (all of CSU), and Dr. John Brown (NOAA/ERL, Boulder, CO). Thanks to Mrs. Debbie Eckdahl for typing the manuscript.

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