NOAA Technical Memorandum NWS WR-154

REGRESSION EQUATION FOR THE PEAK WIND GUST 6 TO 12 HOURS IN ADVANCE AT GREAT FALLS DURING STRONG DOWNSLOPE WIND STORMS

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July 1980

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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This Technical Memorandum has been reviewed and is approved for publication by Scientific Services Division, Western Region.

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REGRESSION EQUATION FOR THE PEAK WIND GUST 6 TO 12 HOURS IN ADVANCE AT GREAT FALLS DURING STRONG DOWNSLOPE WIND STORMS

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Introduction

Strong downslope winds are common in Montana along the East Slopes of the Rockies from Fall to Spring. Wind gusts over 100 MPH occur in some areas each year producing property damage and personal injuries. These winds occur in a variety of synoptic weather patterns, but the most frequent with the strongest winds occur in well-defined warm air advection patterns ahead of an eastward advancing upper trough (Figures 1 to 6). This suggests that the speed of downslope winds for the above cases can be objectively predicted with a multiple regression equation similar to the MOS equations produced by TDL. This paper describes the development and verification of a regression equation for the peak wind gust 6 to 12 hours in advance at Great Falls. The purpose of this research project was an objective criterion that would alert the forecaster to the synoptic potential for damaging winds, so that a high wind warning can be issued well in advance, if needed.

I. GENERAL SYNOPTIC PATTERN

A typical synoptic sequence that produced strong downslope winds along the East Slopes of the Rockies is presented in Figures 1 to 6. These are the 500-mb and surface maps for 00Z and 12Z, December 4. 1979 and 00Z, December 5, 1979. Several features are worth noting as they relate to strong downslope winds: (1) the upper winds at 500 mb are strong through Montana, (2) the upper trough is of moderate strength with the vorticity center moving eastward just north of Montana, and (3) a surface low-pressure center develops in Southern Alberta, moves east and continues deepening.

Ideally, a high wind warning should be issued well in advance for cases like this. The high wind warning criterion for the Western Region of the National Weather Service is sustained winds greater than 35 kts and/or gusts greater than 48 kts. The evening of December 3rd, or the early morning of the 4th would be the time to issue a high wind warning in this case. However, there are several practical factors that may hinder this. One problem is that high wind situations often do not look very impressive as precipitation producers, which forecasters especially focus on. In this case, southwest winds would be expected along the East Slopes of the Rockies, but possibly not in the warning category since an upper ridge is over Montana and the upper trough is in the Eastern Pacific at the time the warning should be issued (Figures 1 and 3). This illustrates a persistent problem for Western Region forecasters: the initial analysis in the Eastern Pacific. The fact that the surface low deepened rapidly by 12Z, December 4th, in Southern Alberta after having moved inland and that the coldest air at 500 mb (not shown) was already in British Columbia strongly indicates that the 500-mb trough at 12Z had already moved to just off the coast. This is about 10° farther east than on the NMC analysis

(Figure 3). If this chart had been analyzed as suggested, it would have looked much more potent for strong winds in Montana, which actually had already begun at Cut Bank and Lethbridge, Alberta (Table 1). Another possible problem is that a new forecaster may not be familiar with strong wind patterns in Montana which many times deviate from the general pattern and can have subtle synoptic peculiarities. Even an experienced forecaster may have difficulty forecasting high winds in this case and in non-typical cases, especially if he has not forecast during a high wind pattern for several months.

As it turned out, this case produced widespread strong winds in the warning category. Great Falls airport received a peak gust of 45 kts, but much stronger winds blew at other locations along the East Slopes of the Rockies (Table 1). Property damage was estimated to be between $50,000 and $500,000.[1]

II. PROCEDURE

Since the purpose of developing a regression equation was to predict winds in the high wind warning category, a peak wind gust equal to or greater than 25 kts at Great Falls 6 to 12 hours after observation time was the dependent variable or predictand. A threshold speed of 25 kts was chosen because wind gusts below this value occur frequently in a wide range of weather patterns and would thus add too much variability and decrease predictability. The sample was further narrowed to the most frequent and clearly defined patterns of only warm air or neutral advection patterns with a southwesterly to west-northwesterly mean upper flow over North America. Sometimes, the full potential of warm pre-frontal winds from an approaching upper trough was not realized until the frontal passage. Therefore, wind gusts within two hours after the frontal passage were included in the developmental sample. After experimenting with three time intervals, the period of 6 to 12 hours after observation time was chosen because, (1) it provided a good lead time, but (2) was not too long from observed data for the correlation to deteriorate too much.

Thirty-eight independent variables or predictors were selected to run on a multiple regression computer program. Table 2 lists these predictors and their correlation coefficients with the predictand. These variables fall into four main groups: the 700-mb height gradient, the surface pressure-gradient, the 700-mb height-change gradient, and the 3-hour surface isallobaric gradient. The first two groups indicate the current strength of the weather system while the last two are a measure of the future development and speed and direction of movement. These were selected after examining a large number of strong wind cases and from calculating correlation coefficients with the predictand during the 1978-79 windy season (generally from October 1st to March 31st). Other main variables were tried during the project and found to have a poorer correlation and to be represented by one of the selected main groups. These were the 850-mb height gradient, the 12-hour surface isallobaric gradient, and the 500-mb height-change gradient. Height gradients were used instead of actual upper winds because Sangster [2,3] found the former better in developing a prediction equation for strong downslope winds at Boulder, Colorado. The reason for this probably is that the height and ruggedness of the terrain to

Table 1.

Peak Wind Gusts and the Time of Occurrence for Various Stations Along the East Slopes of the Rockies on December 4, 1979

STATION	PEAK GUST (KT)	TIME
Great Falls	45	18Z
Malmstrom AFB, Great Falls	50	18Z
Billings	46	19Z
Cut Bank	52	10Z
Lewistown	54	19Z
Havre	58	22Z
Lethbridge, Alberta	58	11Z
Harlowtown	64	16Z
Livingston	70	20Z
Big Timber	83	MM
Chateau	90	MM

Table 2.

Multiple Regression Predictors and Correlation Coefficients with the Peak Gust at Great Falls 6-12 Hrs. in Advance. Station WVK is Vernon, B.C.

PREDICTOR	CORRELATION COEFFICENT
700mb HEIGHT GRADIENT	
1. LND-GTF	.51
2. LND-YXD	.59
3. LND-YXS	.46
4. GTF-YXD	.53
5. BOI-YXD	.71
6. BOI-YXS	.61
7. MFR-YXS	.66
8. MFR-YXD	.66
9. GEG-YXS	.50
10. GEG-WVK	.57
11. UIL-YXS	.46
12. SLE-WVK	.60
SURFACE PRESSURE GRADIENT	
13. IDA-YSH	.45
14. IDA-GTF	.49
15. IDA-YYC	.44
16. BOI-GTF	.53
17. BOI-YYC	.49
18. BOI-YXH	.49
19. BOI-GEG	.55
20. GEG-YYC	.23
700mb HEIGHT CHANGE GRADIENT	
21. LND-GTF	.16
22. LND-YXD	.25
23. LND-WVK	.20
24. GEG-WVK	.14
25. BOI-WVK	.14
26. BOI-YXS	.22
27. SLE-WVK	.07
28. SLE-YXS	.14
29. YZT-YXS	.13
3-HOUR SURFACE ISALLOBARIC GRADIENT	
30. IDA-YXH	.17
31. IDA-GEG	.09
32. YZU-YXH	.24
33. YZU-GEG	.11
34. YZU-HLN	.25
35. YZU-YYC	.17
36. GTF-YXH	.15
37. IDA-HLN	.29
38. BOI-YXH	.18

the west causes low-level upper winds to be too variable and therefore, less correlated with surface winds than upper height gradients.

Data for the regression analysis was generously supplied by the Central Region Headquarters, where it had been stored previously on magnetic tape for use by the Severe Storms Forecast Center and by the Alberta Weather Center in Edmonton, Alberta. There was a fair amount of missing data in the former, some of which was found on local LCD's and on the Daily Weather Maps published by NOAA's Environmental Data and Information Service. A total of 138 cases from October 1, 1972 to December 31, 1976, were used for the developmental samples. Only wind gusts greater than or equal to 40 kts were selected before March 31, 1974, in order to balance the more numerous lower wind cases. The computer program used for the project is a four step Fortran 4 multiple regression program developed by the author and adapted to the AFOS computer at the Great Falls Forecast Office.

III. RESULTS

The resulting four variable regression equation with the predictors listed in the order selected is:

```
GTF WND GST = 18.4 + .07(BOI 700MB HGT - YXD 700MB HGT)
                   + .10(IDA 3HR SFC PRES CHG - HLN  3HR SFC PRES CHG)
                   + .04(MFR 700MB  HGT - YXS 700MB HGT)
                   + .04(LND 700MB HGT CHG - GTF 700MB HGT CHG)
```

700-mb heights and height changes are in meters and the surface-pressure changes are in tenths of millibars. The reduction in variance is 57%. The first variable, which represents the present winds aloft along the East Slopes of the Rockies, is the most important variable, having the highest correlation coefficient in Table 2. In practice, the third variable is fairly strong also, corresponding to the upstream winds aloft, which are often found in the forecast area 12 hours later. The second and fourth variables, which add to the wind speed when the pressure and upper heights fall more over Montana than farther south, were small most of the time. Essentially, the Great Falls wind depends upon the strength of the flow aloft at 700mb.

In order to objectively extend the predicted peak-wind gust at Great Falls to other areas along the East Slopes of the Rockies, average peak gusts from October 1, 1978, to March 31, 1979, for several other stations were calculated (Table 3). Cut Bank and Livingston average higher than Great Falls, but it is qualitatively known that other areas have stronger winds than even Livingston, which is well known for strong winds. East Glacier, Montana, where a recording wind gage is located and gusts called into the Great Falls Forecast Office during strong winds, is one of these stations. It is claimed that the wind speeds there are about 15 kts higher than at Livingston, and unofficial reports tend to substantiate this. Other locations that blow nearly as strong or stronger than Livingston are Stanford, Geyser, Big Timber, Judith Gap, Browning, and Chateau, Montana. Considering the number of areas that have stronger down-

Table 3.

Average Peak Gust for Several Stations Along the East Slopes of the Rockies During Downslope Wind Storms from October 1, 1978, to March 31, 1979

STATION	AVERAGE PEAK GUST (KT)
Billings	26
Lewistown	27
Havre	27
Great Falls	36
Cut Bank	41
Livingston	49

slope winds than Great Falls, a useful criterion for considering a high wind warning for other areas along the East Slopes of the Rockies would be a predicted peak gust at Great Falls of 35 kts or more. This is assuming there is no over-forecasting bias in the wind-speed equation, which there indeed is as the verification sample demonstrates. This bias is about 4 kts. In the example presented in Figures 1 to 6, the predicted peak gust at Great Falls from 00Z and 12Z, December 4th, data was 41.5 kts and 54.5 kts respectively. These estimates are clearly into the high wind warning category from the above criterion and even though they overestimated the wind at Great Falls airport, they were a good indication of future wind gusts elsewhere along the East Slopes of the Rockies. Also, they do not depend upon a correct initial analysis in the Eastern Pacific.

IV. VERIFICATION

The wind equation was used operationally and verified for the 1979-80 windy season. A simple Fortran 4 computer program was written and incorporated into an AFOS procedure to facilitate this. It was used when the forecaster judged that the weather pattern would likely produce moderate to strong winds and met all the developmental criteria. Since the wind equation was designed for strong winds, the verification includes only wind gusts greater than or equal to 35 kts, either predicted or observed. Lower wind speeds, which are influenced greatly by the diurnal cycle, did not verify well. Only two cases of observed wind gusts greater than or equal to 35 kts did not make the verification sample. This was during a long period of downslope winds, when the procedure was run 12 hours previously, and the forecaster did not feel it was significant enough to run again while the wind continued to blow.

From a total of 30 cases, the average error was 7.5 kts with an overforecasting bias of 6.2 kts. A case by case study revealed that some of the error was due to the timing of the strongest gusts because of local effects, fast or slow moving upper troughs, of just random variations in gustiness. It is concluded that a verification period of only 6 hours was not enough to catch the full potential of the weather pattern. Allowing a longer period from 3 to 15 hours after observation time, the average error was reduced to 5.9 kts and the bias to 4.2 kts. With this experience, the regression formula will be revised for the next season to include a 12-hour verification interval, and the constant term will be reduced from 18.4 to 14.2.

V. ACKNOWLEDGMENTS

The author appreciates the efforts of a number of individuals, without whose help, this project would never have started. In particular, I thank Wayne Sangster, SSD, Central Region Headquarters and Peter Kociuba of the Alberta Weather Centre for generously supplying the data. Also, I thank Jim Fors and Len Snellman of SSD, Western Region Headquarters, for providing the data for many of the strong wind case studies and for offering advice in the preparation of the manuscript. Finally, appreciation is extended to the personnel of WSFO, Great Falls, who helped during various phases of the work, especially

Ken Mielke who gave advice on adapting the regression program to AFOS, and Warren Harding, whose synoptic expertise aided in pinpointing many related wind variables.

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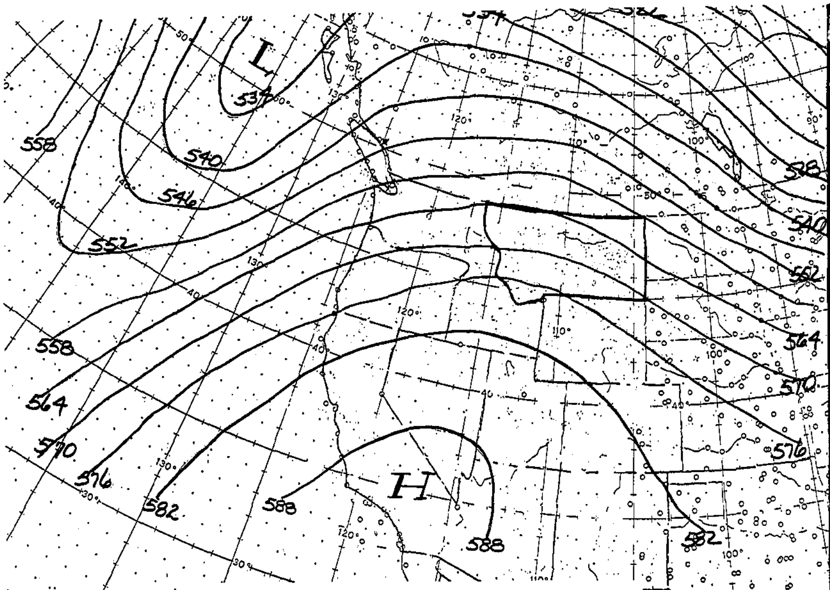

Figure 1 Redrawn NMC 500mb Chart for 00Z, December 4, 1979

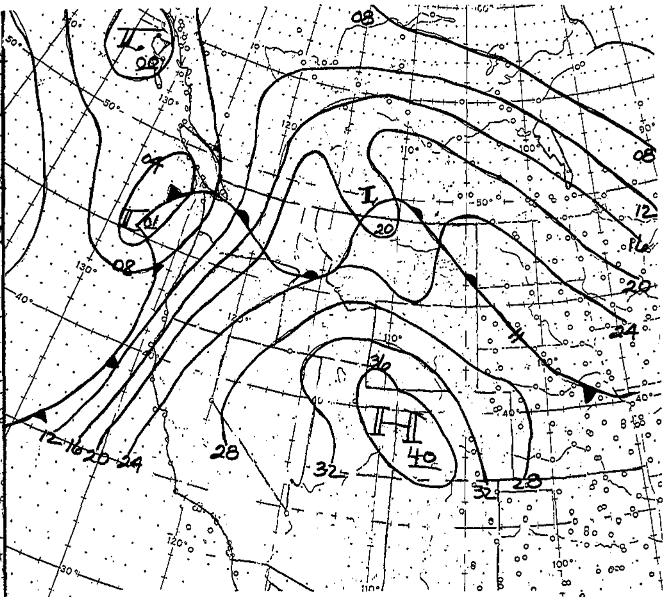

Figure 2 Redrawn NMC Surface Chart for 00Z, December 4, 1979

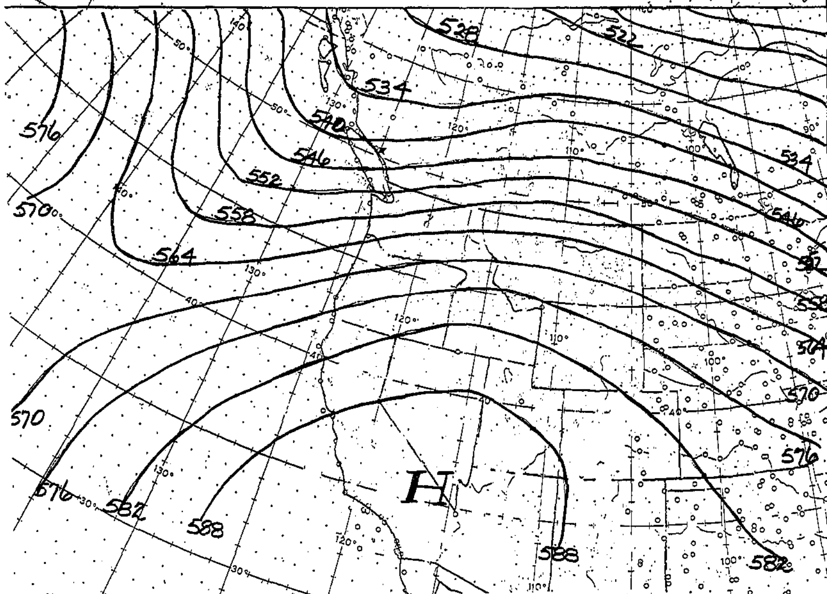

Figure 3 Redrawn NMC 500mb Chart for 12Z, December 4, 1979

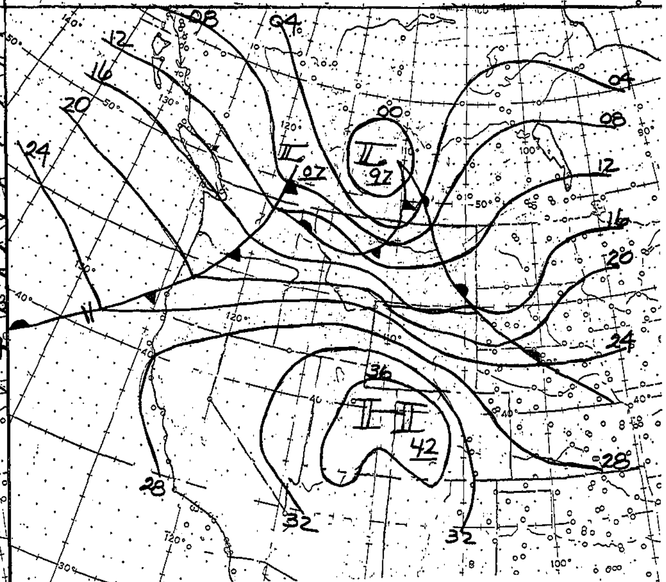

Figure 4 Redrawn NMC Surface Chart for 12Z, December 4, 1979

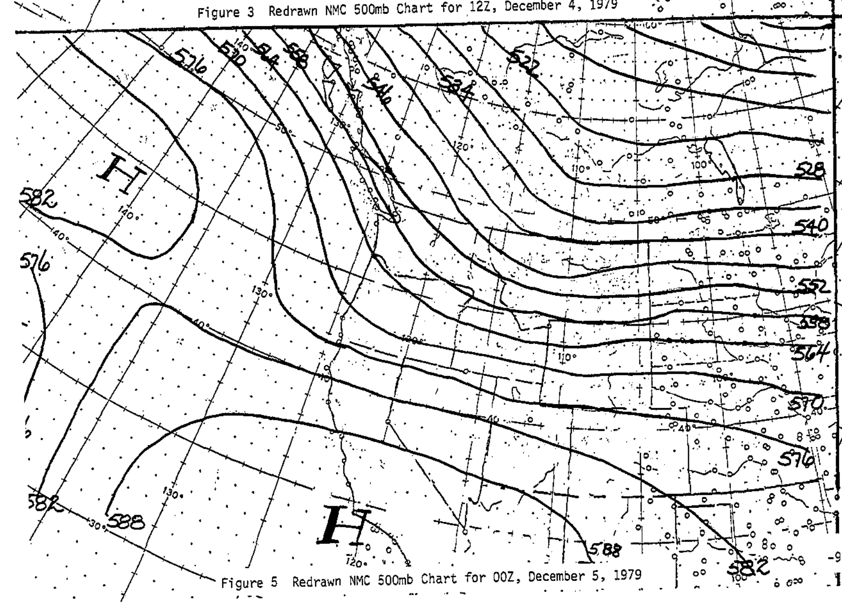

Figure 5 Redrawn NMC 500mb Chart for 00Z, December 5, 1979

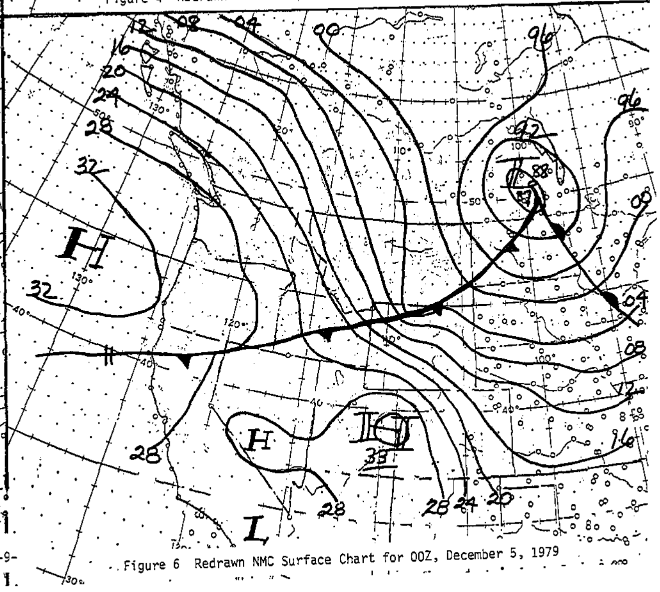

Figure 6 Redrawn NMC Surface Chart for 00Z, December 5, 1979

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