Low Level Wind Maxima and Temperature Inversions Over the Northern Great Plains

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ABSTRACT

Discriminant analysis is employed with kite sounding data from Drexel, Nebraska in an attempt to clarify the interaction between the wind shear and temperature inversions in the planetary boundary layer. The mean height of the inversion layer and a measure of the vertical wind shear either above or below the wind maximum combine in a statistically significant function to discriminate between cases when the level of the wind maximum is coincident either with the top or with the base of the inversion near sunrise.

1 Introduction

Nocturnal temperature inversions play a prominent role in the development of the Great Plains low-level jet. Indeed, the widely-accepted explanation for the vertical profile of the horizontal wind (Blackadar, 1957) not only requires the prior formation of an inversion but further specifies that the wind maximum will lie immediately above the inversion top. In support of his thesis, Blackadar draws upon low-level wind and temperature data taken at Drexel, Nebraska between 1916 and 1918. The influence exerted by his interpretation of the Drexel observations suggests that a reexamination of the data is warranted, possibly yielding even more interesting relationships.

2 Data Source

From the latter part of 1915 through 1918 the atmosphere above Drexel, Nebraska was observed through the use of kites. Nominally, flights were made each day near sunrise; from beginning to end a flight reaching several thousand meters altitude would last three or four hours. For various reasons this was not always achieved. In some instances later flights were substituted; on other occasions one flight followed on the heels of another for a period of 36 hours or so. As a result the observations of the lowest few thousand meters are scattered throughout the day. Temperature, pressure, horizontal wind speed and direction as well as ambient vapor pressure were recorded with the time for every 250 m and selected crucial heights. During the flight, surface conditions were recorded every 15–30 minutes. The original data are compiled in

TABLE 1. Occurrence of simultaneous low-level wind maxima and temperature inversions for Drexel, Nebraska (and, in parentheses, the percentage based on the occurrence of wind maxima)

	July	August	September	Total
1916	27 (42)	52 (70)	47 (56)	126 (57)
1917	38 (58)	34 (63)	58 (74)	129 (66)
1918	30 (45)	42 (57)	35 (53)	107 (52)
total	95 (48)	128 (63)	139 (61)	362 (58)
soundings	228	250	273	741

TABLE 2. Percentage of wind maxima with inversions, cumulative by criterion, for each of four times of day.

Criterion	midnight	6 a.m.	noon	6 p.m.
0	100	100	100	100
1	52	46	19	20
2	41	26	7	10
3	31	14	3	4

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3 Data Selection

Since nocturnal wind maxima are most common over the Great Plains during the summer (Bonner, 1968), the months July, August and September have been selected for study. Table 1 reveals that the occurrences of low-level wind maxima and temperature inversions within the same 250 m height interval are rather evenly divided between the chosen months.

The observed wind maxima were classified according to criteria (slightly modified) established by Bonner (1968):

0: wind maximum in the first 2000 m above ground
1: wind at level of maximum at least 12 m s^{-1}, decreasing by 6 m s^{-1} before the next minimum or below 3400 m
2: wind at least 16 m s^{-1}; decreasing 8 m s^{-1} etc.
3: wind at least 20 m s^{-1}; decreasing 10 m s^{-1} etc.

The individual wind maximum observations were placed into four time intervals consisting of the three hours either side of midnight, 6 a.m., noon and 6 p.m. The usual observational procedure was to make soundings at sunrise and occasionally conduct sequential launchings around the clock for 1–1½ days; consequently, most of the observations fall into the 6 a.m. time period.

Consistent with theory, the greatest relative frequency occurs around midnight, with the hours immediately following showing a strong residual intensity. Since the occurrence of criterion 1, 2, and 3 maxima in the 6 a.m. interval is similar to that at midnight, and especially in view of the much larger sample for this interval, the subsequent discussion is confined to this group.

Eliminating a few instances of multiple wind maxima and choosing the observation closest to 6 a.m. (in the event the same maximum was present on a succeeding sounding), the height of the wind maximum is found to coincide exactly with the level of the inversion top in 99 cases; further, the wind maximum coincides with the inversion base on 22 occasions. The latter phenomenon does not appear to have been mentioned previously. In the following the former phenomenon will be denoted as "+1"; the latter as "−1".

4 Application of Discriminant Analysis

In the absence of a specific physical theory underlying the occurrence of both phenomena "+1" and "−1", it is of interest to begin sorting out the factors which characterize the two; in this respect, the technique of discriminant analysis first employed by Fisher (1936) – and elaborated on by many others – is most suitable. Choosing two characteristics which may be of importance to the phenomena in somewhat different respects, a linear function Z of the observations is sought which significantly discriminates between the two phenomena "+1" and "−1":

$$Z = b_1x_1 + b_2x_2 \text{ or } Z = b_1x_1 + b_3x_3$$

where x_1, x_2 and x_3 are the observed characteristics.

Two possible forms were considered:

a $x_1 =$ mean height of inversion layer
$= \frac{1}{2}(h_t + h_b)$ where h_t is height of inversion top
h_b is height of inversion base
$x_2 = V_m - V_s$ where V_m is wind at maximum
V_s is surface wind

b $x_1 =$ mean height of inversion layer
$x_3 =$ Criterion (0, 1, 2, or 3)

According to Tintner (1952), with the assumption that the x's are normally distributed within each group ("+1" and "−1") an F statistic may be formed to test the hypothesis that $R = 0$, where

$$R_2 = (mn/(m+n))\ (b_1d_1 + b_2d_2) \text{ or } (mn/(m+n))\ (b_1d_1 + b_3d_3)$$

is a kind of multiple correlation coefficient; m and n are the numbers of individuals in each group, and the d's are the differences in the means of the x's between groups. Thus, we wish to test the hypothesis that there is no ability to distinguish the two groups wtih the discriminant function obtained, using

$$F = \frac{m+n-p-1}{p}\left\{\frac{R^2}{1-R^2}\right\}$$

where p is the number of characteristics (two).

5 Results

a Group "+1" is characterized by a low mean inversion height (~240 m) and $V_m - V_s \sim 11$ m/sec; "−1" has a high mean inversion height (~540 m) and somewhat lower wind shear ($\sim$9.5 m s^{-1}). The critical F for 2 and 119 degrees of freedom at the 0.995 level is 5.5; the computed $F = 52$. Therefore the hypothesis that there is no ability of the characteristics to distinguish the two groups is rejected with a probability 0.005 of error.

Inserting the means of the characteristics, the individual discriminant functions are

$$x_1 = 688 + 2.46x_2 \qquad \text{for "+1"}$$
$$x_1 = 910 + 2.26x_2 \qquad \text{for "−1"}$$

Since the two groups are of different size, the group means cannot be used to obtain a single discriminant function; inserting the arithmetic means instead yields

$$x_1 = 759 + 2.36x_2$$

b Group "+1" again has a lower mean inversion height, but also a lower mean value of the criterion (0.86 vs. 1.14 for group "−1"). The computed $F = 70$, and thus the null hypothesis is once more rejected in favor of the alternative hypothesis; i.e., a statistically significant discriminant function has been determined. The individual functions are

$$x_1 = 658 - 26.6x_3 \qquad \text{for "+1"}$$
$$x_1 = 943 - 26.6x_3 \qquad \text{for "−1"}$$

and using the arithmetic means of the characteristics

$$x_1 = 996 - 26.6x_3$$

6 Conclusions

The coincidence of a low-level wind maximum with the top of a temperature inversion may be distinguished from coincidence with the base of the inversion by means of a linear function of the mean height of the inversion and the vertical shear of the horizontal wind either above or below the maximum.

A slight improvement of the above study might be obtained by restructuring the Criterion 0 somewhat. Also Johnson (1950) has illustrated a technique for maximizing the information from scores (such as the Criterion classification) in discriminant analysis. In fact Suzuki (1964, 1966, 1969) has apparently independently devised methods along the same lines and applied them to meteorological problems. Certainly this approach should be implemented in the second case here.

Furthermore, the relation of the wind maximum height to the inversion characteristics could be investigated more closely in several respects. By and large, the data is tabulated at 250 m intervals; as a result, the wind speed maximum may appear to occur at the base or the top of an inversion — or in between in the case of a deep inversion. Additionally, occasional soundings include data for intermediate levels. Together, these would allow for a distribution of wind maximum height between the inversion base and top, rather than a dichotomous separation; the data selected however included few maxima between the base and top.

Finally, it is perhaps of importance that the mean height of the inversion is greater for the "−1" phenomenon than for the "+1" case. However, a physical theory which not only explains the "−1" phenomenon but encompasses this observed difference is not presently available.

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