CENTRAL REGION TECHNICAL ATTACHMENT 93-12

VARIATION IN THE FORCE OF WIND WITH ELEVATION

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1. Introduction

Warning for high winds is part of the National Weather Service mission. Currently, the general criteria for issuing High Wind Warnings is for sustained winds of 40 mph (18 ms^{-1}) for an hour or more or gusts of 58 mph (26 ms^{-1}) (WSOM C-44, 1992). At higher elevations of the Rockies and High Plains, winds frequently exceed these thresholds from late fall through early spring. The significance of these winds is complicated not only by their frequency but also the physical reality of lower air density at higher elevations. Since the force of the wind is a function of the mass of the air and hence the density, a faster wind speed will be required to generate a force equal to the force of wind near sea level.

This discussion will analyze the differences in the force of wind when the decrease in density with elevation is accounted for. In other words, the differences in damage potential with elevation will be analyzed.

2. Methodology and Calculations

As a reference point the force of wind near sea level (i.e 1013 mb at 10°C (50°F) may be calculated. Assuming instantaneous deceleration (i.e. wind impacting an immovable object).

$$F = \frac{mv^2}{2}$$

or for 1 kg of air

$$F = \frac{p}{RT} * \frac{V^2}{2}$$

where F = force in Newtons, m = mass in kg and V = wind velocity in ms^{-1}, p = pressure in Pa, T = temperature in Kelvin and R = the gas constant for dry air. At 40 mph, the normal force of the wind blowing perpendicular to a surface is 199.8 N for 1 kg of dry air. At 58 mph, the force generated under the above conditions would be 418.3 N. The wind velocities required to generate these forces at a given elevation[1] may be calculated if the density or, more realistically, temperature[2] and pressure are known. For example, if the pressure at 5000 ft (1.5 km) is 845 mb and the temperature is still 10°C then the wind speed required to generate a force of 199.8 N is 43.8 mph (19.6 ms^{-1}). Likewise, a wind of 63.4 mph (28.4 ms^{-1}) would be required to generate a force of 418.3 N.

3. Results of Calculations Over a Range of Elevations:

Figure 1 represents the increase wind speed required to generate forces equivalent to the force of 40 and 58 mph at sea level. For example, at 10000 ft (3 km) a wind speed of over 48 mph is required to generate the same force as 40 mph near sea level. At the same elevation, nearly 70 mph is needed to generate the same force as 58 mph near sea level. These figures represent about a 20 percent increase in wind speed in order to generate the equivalent sea level force.

Figure 2 represents the decrease in wind force with elevations for constant wind speeds of 40 and 58 mph. For example, at 10000 ft a wind of 40 mph will generate a force of about 137 N, while a 58 mph wind will generate a force of around 287 N at 10000 ft. These figures represent over a 30 percent decrease in wind force when compared to winds at the same speed near sea level.

Figure 3 represents the wind speed required to generate force equivalent to near sea level forces of 199.8 N and 418.3 N when surface temperatures are decreased with elevation. The rate of decrease in this case is 3°F (1.7°C) per 1000 ft (305 m)[3]. Since temperature and pressure are inversely proportional when

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[1]These calculations use geo-potential elevation which is assumed to equal actual elevation in the lower troposphere.

[2]In these calculations dry air temperature is assumed.

[3]This rate of temperature decrease was arbitrarily selected to reflect near surface conditions at any elevation.

calculating density, a decrease in temperature will reduce the rate of density decrease with elevation. However, at 10000 ft with the temperature about 20°F, nearly 47 mph (21 ms^{-1}) of wind is required to generate a force of 199.8 N and nearly a 68 mph (30 ms^{-1}) wind is required to generate a force of 418.3 N. These figures still show about a 17 percent increase in wind speed is required to generate a force equivalent to the surface. Table 1 is derived from the data used to generate the graph in Figure 3[4].

Table 1
Wind speeds required to generate equivalent force for surface winds of 40 and 58 mph at selected elevations and temperatures.

Elevation (ft)	Temperature (degrees F.)	Surface Wind 40 mph Equivalent Wind Speed	Surface Wind 58 mph Equivalent Wind Speed
2000	44	41.2	59.6
4000	38	42.6	61.6
6000	32	44.0	63.6
8000	26	45.4	65.7
10000	20	46.9	67.8
12000	14	48.3	69.9
14000	8	49.1	72.4

4. Summary and Conclusions

As seen from the previous discussion, pressure and hence density decreases with elevation are important factors when considering the force of any given wind speed. When warning criteria are established, factors such as local frequency of occurrence, as well as subjective factors are considered. However, justification for adjustment of criteria, based on physical factors alone, may be considered for higher elevations of the west. For example, based on the information in this paper, one could consider general criteria for high winds at 5000 ft to be 44 mph with gusts to 64. At 10000 ft, one might consider 48 mph with gusts to 70.

5. References

National Weather Service, 1992: Non-Precipitation Weather Hazards, National Weather Service Operations Manual, Part C, Chapter 44., National Weather Service, Silver Spring, MD.

[4]The generalized temperatures at the higher elevations are probably unrealistically low. High winds often occur in the Rockies when air temperatures are in the 30 to 50 degree range, even at elevations around 10,000 feet.

Holton, J. R. 1992: *An Introduction to Dynamic Meteorology*, Third Edition, Academic Press, San Diego, CA.

List, R. J., 1951: Smithsonian Meteorological Tables, 6th rev. Smithsonian Institution Press, Washington, D. C.

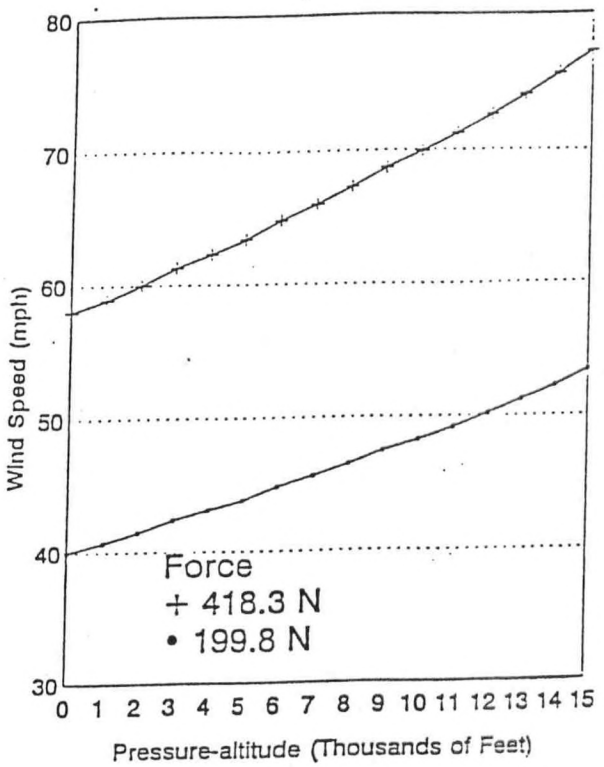

FIG. 1. Wind speed required to generate an equivalent force, allowing for pressure changes with elevation. Initial force calculated at 1013 mb, 10 C for wind speeds of 40 mph (17.9 ms^{-1}) and 58 mph (25.9 ms^{-1}).

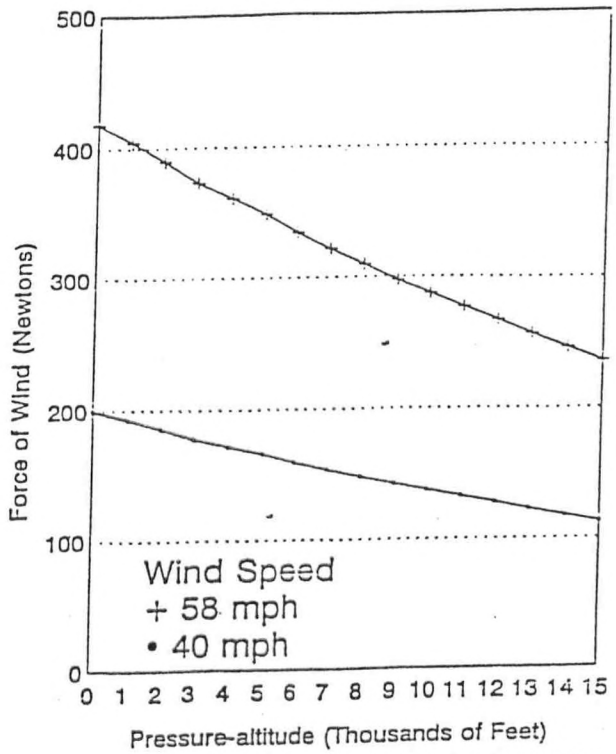

FIG. 2. Force of specified wind speed, allowing for pressure changes with elevation. Initial conditions as in FIG. 1.

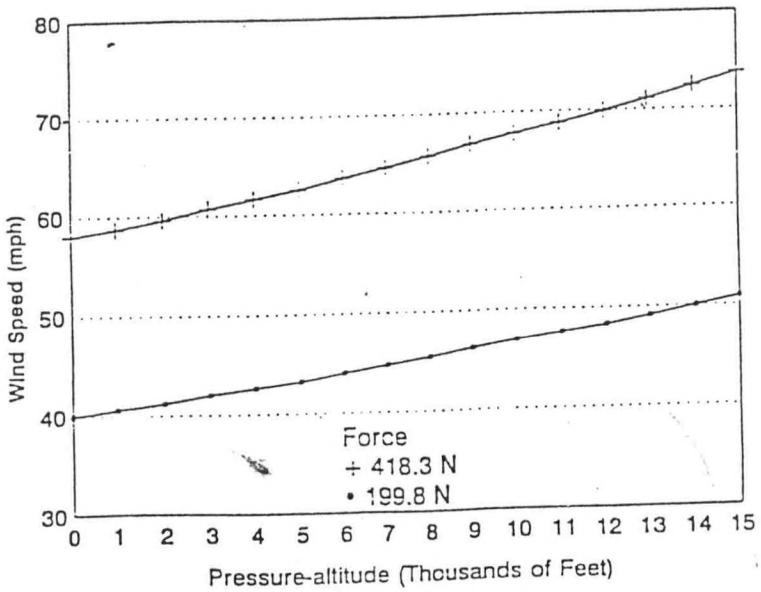

FIG 3. Wind speed required to generate an equivalent force, allowing for pressure and temperature changes with elevation. Initial conditions as in FIG 1. Temperature decrease 3 deg F (1.7 deg C) per 1000 feet (305 m).