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THE CLIMATOLOGY OF HURRICANE WIND PROFILES

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1. INTRODUCTION

For applications such as windstorm underwriting (Vickery and Twisdale 1995) or storm-surge forecasting (Jelesnianski 1967), hurricane wind profiles are often approximated by a single continuous function that is zero at the vortex center, increases to a maximum in the eyewall, and then decreases asymptotically to zero at large radius. Since lives and a great deal of money depend upon decisions made using these models, it is crucial that they be as realistic as possible.

2. THE HOLLAND MODEL

In the Holland (1980) model, the profile shape is determined by three parameters: V_{max}, maximum wind, R_{max}, radius at which the maximum wind occurs, and B, which controls the sharpness of the wind maximum. Least-squares fits of this profile to 493 independent aircraft observations yield descriptions of the parameters' behavior. The database used actually contains 606 aircraft sorties, but 113 of these failed quality-control screening, largely because the radius of maximum wind was too large a fraction of the sampling domain. Ensemble mean values of R_{max} (geometric mean) and B are 45 km and 1.31, respectively. Comparisons of the fitted profiles with the raw observations reveal a systematic pattern of errors. Although the winds around the peak are too strong, away from the peak they decrease with distance too rapidly--both inside and outside the eye, resulting in exaggeration of the occurrence of both the strongest and weakest wind speeds (Fig.1). The RMS dependant-data wind error between the Holland profiles and the observations is 5.84 m s^{-1}. The Holland pressure-wind relation overestimates the maximum wind for a given minimum pressure. Empirically determined equations for R_{max}, and B as functions of maximum wind and latitude, φ, are:

$$R_{\max} = 46.29\exp\{-0.0153V_{\max} + 0.0166\varphi\}$$
$$B = 0.886 + 0.0177V_{\max} - 0.0094\varphi$$

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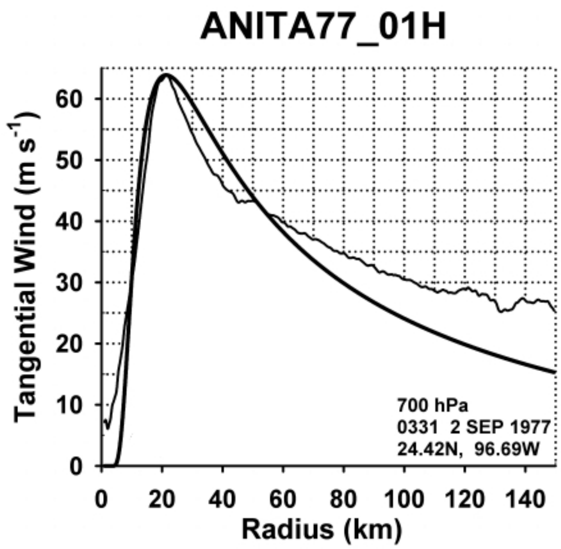

Fig. 1. *Fit of the Holland profile to Hurricane Anita on 2 September 1977. The darker, smooth curve is the fitted profile and the lighter, more irregular curve represents the observations.*

The exponential in the equation for R_{max} arises because its distribution function has a long tail on the large R_{max} side so that it is more nearly lognormal than normal.

3. A NEW PROFILE

A promising alternative is a family of piecewise continuous profiles in which the wind increases as a power of radius inside the eye and decays exponentially outside the eye after a smooth polynomial transition across the radius of maximum wind (Willoughby and Rahn 2002). Based upon a sample of 493 observed profiles, the mean exponent for the power law is n = 0.79, and the mean decay length is X_1=243 km. Hurricanes stronger than Saffir-Simpson category 2 generally require a superposition of two exponentials in order to match the observed relatively fast decrease of wind with radius just outside the eye and slower decrease farther away. After some experimentation, we found that a fixed value of X_2=25 km was satisfactory for the faster decay length, and the mean value of the slower decay length, which was fitted by least squares to each hurricane, was 295 km. The mean value of A, the fraction of the wind in $r \geq R_{max}$ attributed to the faster exponential was 0.10, but for the most intense hurricanes *A* sometimes exceeded 0.5.

$$X_1 = 317.1 - 2.026V_{\max} + 1.915\varphi ,$$

$$X_2 = 25 ,$$

$$n = 0.4067 + 0.0144V_{\max} - 0.0038\varphi ,$$

$$A = 0.0696 + 0.0049V_{\max} - 0.0064\varphi, (A \geq 0) .$$

Thus, the power-law exponent and proportion of the faster decay length in the profile outside the eye increase with maximum wind speed and decrease with latitude; whereas the slower decay length decreases with intensity and increases with latitude. These results are consistent with the qualitative observation that more intense hurricanes in lower latitudes have more sharply peaked wind profiles than do weaker hurricanes in high latitudes. The RMS dependant-data wind error between the dual-exponential profiles and the observations is 2.03 m s^{-1}.

A key consequence of the parameter variation is that the maximum wind is proportional to a power > ½ of the geopotential height fall from the environment to the storm center and that, on average, a greater height fall is required to sustain the same maximum wind in higher latitudes.

$$V_{\max} = 0.929(Z_e - Z_c)^{0.659}, \quad (\varphi = 15°\mathrm{N})$$

$$V_{\max} = 0.661(Z_e - Z_c)^{0.701}, \quad (\varphi = 25°\mathrm{N})$$

$$V_{\max} = 0.508(Z_e - Z_c)^{0.730}, \quad (\varphi = 35°\mathrm{N})$$

$$V_{\max} = 0.410(Z_e - Z_c)^{0.752}, \quad (\varphi = 45°\mathrm{N})$$

Here, Z_e is the environmental geopotential height and Z_c is that at the vortex center.

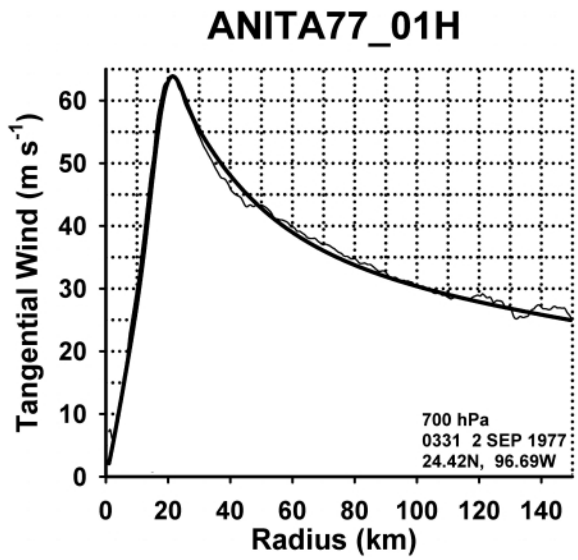

Fig. 2*. As in Fig. 1, but with a fitted dual-exponential profile.*

4. REFERENCES

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