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Validating Wind Profile Equations during Tropical Storm Debby in 2012

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Validating Wind Profile Equations during Tropical Storm Debby in 2012

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I. Introduction

In the atmospheric boundary layer, vertical distribution of the wind speed (under strong wind conditions so that the thermal effects may be neglected, see Hsu, 2003) can be formulated according to the logarithmic wind profile (e.g. Panofsky and Dutton, 1984) as:

$$U_z = (U^*/k) \,\text{Ln}\, ((Z\text{-}d)/Z_0) \quad (1)$$

Where U_z is the wind speed at height Z, U* is the friction velocity, k (=0.4) is the von Karman constant, d is the displacement height, and Z_0 is the roughness length.

Note that when Z is much larger than d, Eq. (1) may be reduced to

$$Uz = (U^*/k) \,\text{Ln}\, (Z/Z_0) \quad (2)$$

Note also that, for offshore conditions, Z_o can vary with wave characteristics since the sea state is mobile depending on the wind speed, duration and fetch (Hsu, 1988).

Because the log-law requires several parameters including U*, d, and Z_0, the power-law wind profile has been widely used instead in the engineering community (e.g. Irwin, 2006) that:

$$U_2/U_1 = (Z_2/Z_1) \wedge p \quad (3)$$

For $Z_2 > Z_1$

Where U_2 and U_1 are the wind speed at Z_2 and Z_1, respectively, and p is the exponent, which is related to the gust factor, G, via following formulation (see Hsu, 2003 and 2008) and Hsu and Blanchard (2004) such that,

$$G = 1 + 2p \quad (4)$$

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The purpose of this study is to validate wind-profile equations, whether it is logarithmic or power, for over water applications.

II. Methods

In order to compare Equations (2) and (3) statistically, they are rearranged as follows:
From Equation (2), we have

$$\text{Ln}\, Z = \text{Ln}\, Z_0 + (k/U^*)\, U_z \quad (5)$$

This equation has a least-square linear regression form such that

$$Y = A + B X \quad (6)$$

Where Y = Ln Z, A = Ln Z_0 or $Z_0 = e^A$, $X = U_z$, and B = k/U*.

If the anemometer is located at 10 m, one can normalize the wind speed at higher elevation by NDBC measurements so that Equation (3) becomes

$$U_z/U_{10} = (Z/10) \wedge p \quad (7)$$

Where U_{10} is the wind speed at 10 m, which is routinely available from Buoy 42040.

III. Validating Wind Profile Equations

When Tropical Storm Debby in 2012 was over the Gulf of Mexico (www.nhc.noaa.gov), there were 3 meteorological stations, which measured wind speed at 3 different heights ranging between 10 and 122m above the sea surface. These data are available online from NDBC (http //www.ndbc.noaa.gov). Since these 3 stations were close-by, their data are listed in Table 1. Using the mean value for each height as listed in the Table, Figures 1 and 2 provide the analyses for the logarithmic and the power-law wind profiles, respectively. Since the coefficient of determination, R^2, values are very high, both profiles are verified. For operational applications off shore, it is found that the power-law is as good as the log-law. This finding is very important because over vast ocean, only one level measurement of wind speed from few buoys or ships is available.

Table 1 : Simultaneous measurements of wind speed at 10 m at NDBC Station 42040, at 54.9m at 42376 and at 122m at 42364 during Tropical Storm Debby in 2012 over the Gulf of Mexico

Year	month	day	hour	min	wind	U122m	U54.9m	U10m
			UTC		direction	m/s	m/s	m/s
2012	6	25	19	30	340	13	10	8
2012	6	25	18	30	340	14	11	9
2012	6	25	16	30	350	15	12	11
2012	6	25	6	30	360	18	16	12
2012	6	25	4	30	360	19	18	14
2012	6	25	3	30	10	19	18	14
2012	6	25	0	30	360	24	22	16
2012	6	24	23	30	360	22	20	16
2012	6	24	20	30	360	19	17	14
2012	6	24	19	30	360	19	16	13
					mean	18.2	16	12.7

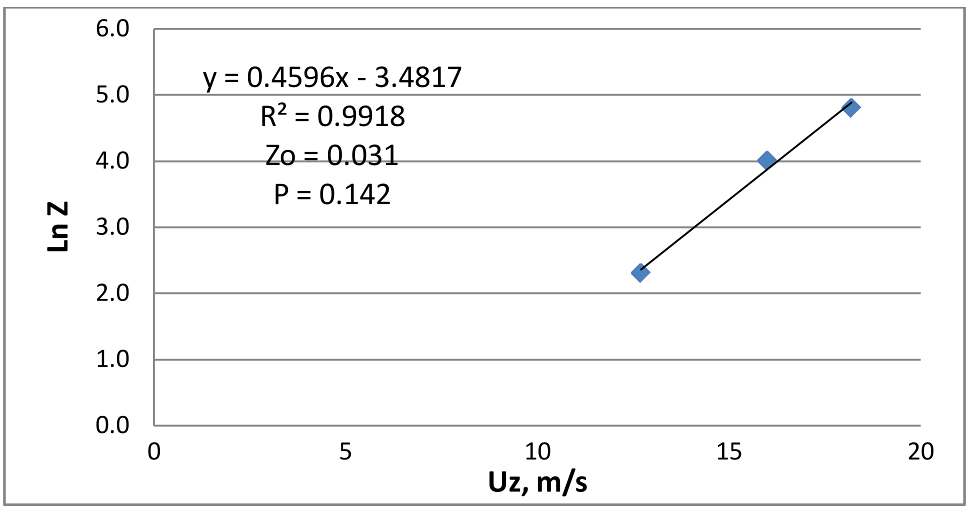

Figure 1 : Logarithmic wind profile over the Gulf of Mexico during Tropical Storm Debby in 2012

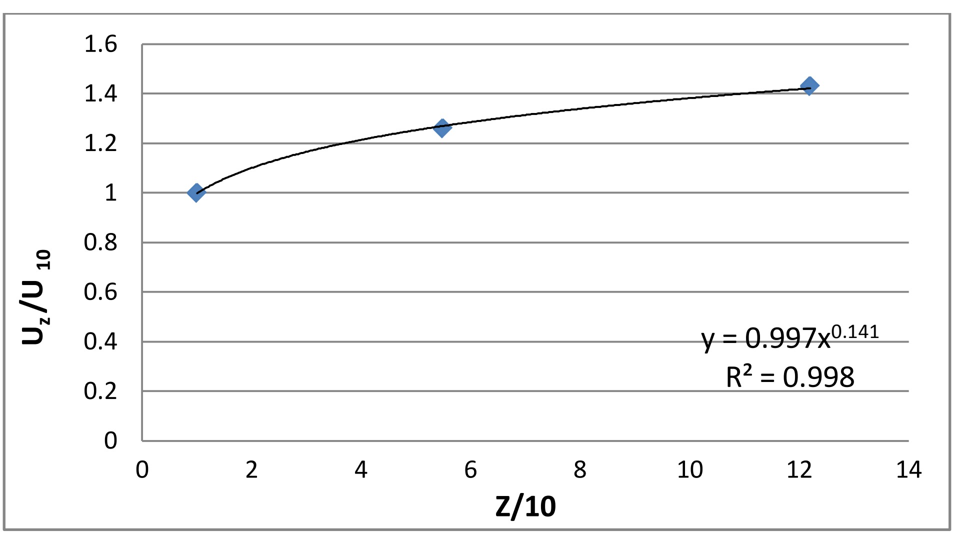

Figure 2 : Power-law wind profile over the Gulf of Mexico during Tropical Storm Debby in 2012

IV. Vertical Variation of the Gust Factor

Vertical variation of the gust factor for offshore conditions has been studied by Hsu (2012). Our results during Debby are shown in Figs. 3 and 4. It is found that for operational applications, the gust factor does not decease with height between 10 and 160 m as compared to that over land as shown in Fig. 5 near land-falling Hurricanes Frances and Jeanne in 2004 (based on Merceret, 2009) and Fig.6 for Typhoon Muifa in 2012 (based on An et al.,2012).

In addition, according to Hsu (2012), the mean overwater gust factor between 5 and 160 m during Tropical Storm Lee in 2011 is 1.273 with the standard deviation of 0.11 so that the coefficient of variation, which is the ratio of standard deviation and the mean, is 8.6% (which is within the 10% composite error margin in the field measurements for the wind speed). This means that p=0.137 is a good value to use for offshore conditions. Comparison of this p value with the power-law analysis shown in Fig.2 (where p=0.142) indicates that P = 0.14 should be useful for practical applications. Furthermore, by substituting this p (=0.142) value from fig. 2 into Eq.4, we have G=1+2*0.142=1.284, which is in good agreement with the normally quoted G value of 1.30. In other words, the common use of 30% gust factor for offshore applications receives further support from this study.

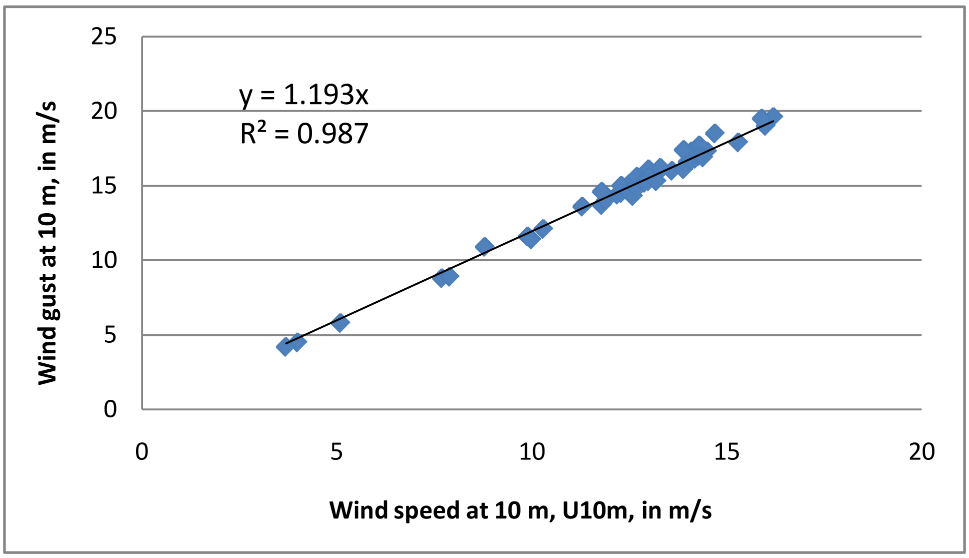

Figure 3 : Relationship between wind speed and wind gust at 10 m during Debby

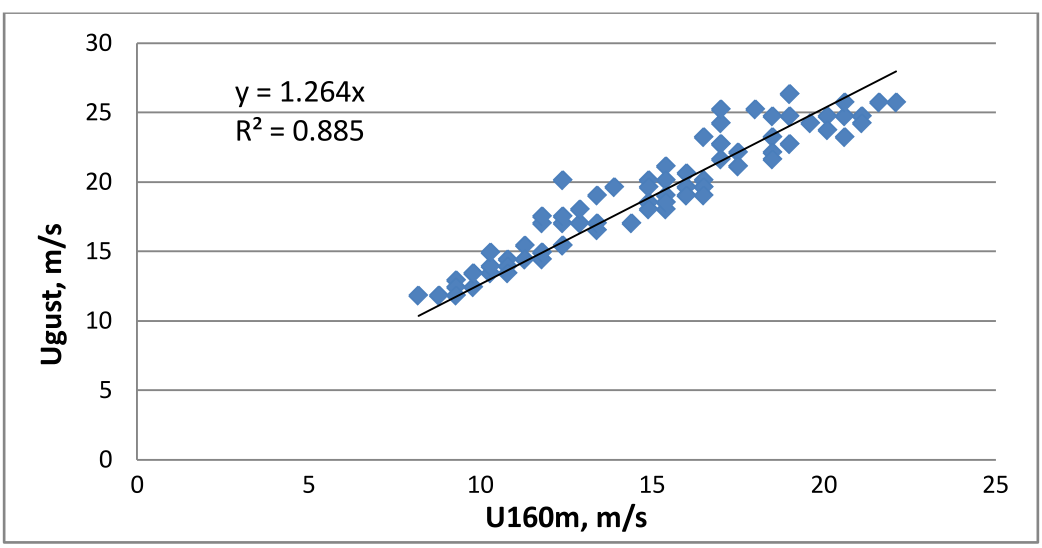

Figure 4 : Relationship between wind speed and wind gust at 160 m during Debby

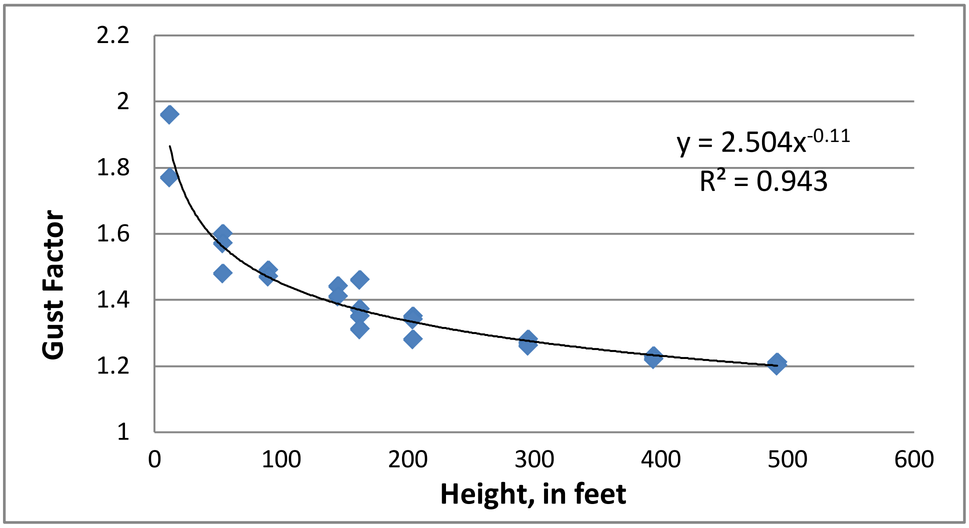

Figure 5 : Height variation in gust factor during land-falling Hurricanes Frances and Jeanne

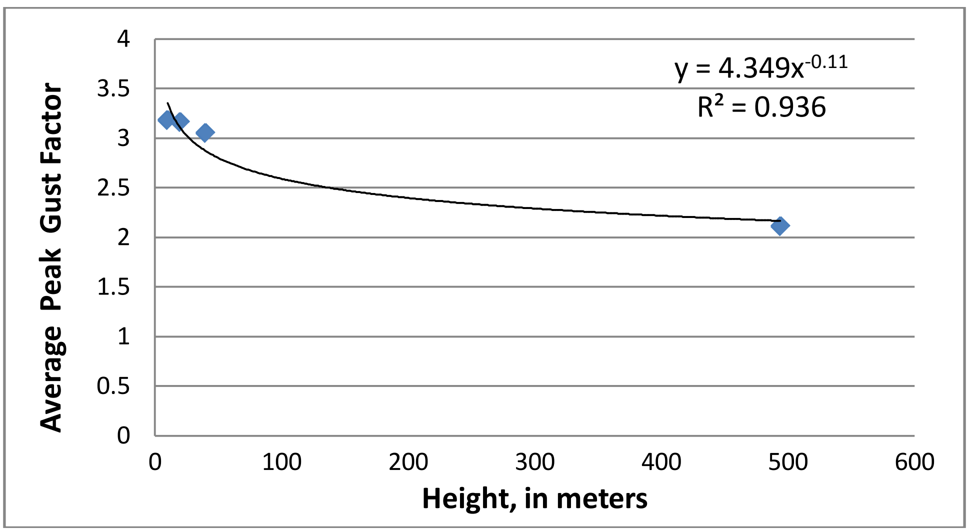

Figure 6 : Height variation in peak gust factor during land-falling Typhoon Muifa in 2011

V. CONCLUSIONS

On the basis of foregoing analyses and discussions, following conclusions can be drawn:

- A comparison between logarithmic and power-law wind profiles is made for offshore conditions (up to 122m or 400ft from the sea surface). It is found that, although the log law has more theoretical support, the power-law is as good as the log-law based on statistical analyses. Therefore, the powerlaw is recommended for operational applications since it involves only one unknown parameter, which is the exponent.
- The exponent of the power-law wind profile can be determined from the gust factor which is routinely available from NDBC measurements. It is also found the gust factor does not vary with the altitude statistically within 160m or 525ft from the sea surface. This finding, which is contrary to the common belief for onshore conditions, is very important for wind loading analyses for offshore structures as well as search and rescue mission planning during storms at sea.

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