Open Access

Verifying Wind Profile Equations Under Hurricane Conditions

S. A. Hsu*

Coastal Studies Institute, Louisiana State University, Baton Rouge, LA 70803

Abstract: During Hurricanes Gustav and Ike in 2008 simultaneous measurements of wind speed at 122 m and both wind speed and gust at 5 m as well as wave parameters were made at National Data Buoy Center Stations 42364 and 42040, respectively, in the Gulf of Mexico. It is found that the wind speed at 122 m can be estimated satisfactory by either the logarithmic wind profile equation (using either roughness length or gust factor as the input) or the power-law wind profile equation using the exponent value of 0.10. It is recommended that for the wind load analysis at any height under hurricane conditions, the input for wind speed can be estimated by the standard buoy measurements at 5 or 10 m available routinely.

Keywords: Offshore wind profile, roughness length, friction velocity, hurricane winds and waves, hurricanes Gustav and Ike.

INTRODUCTION

During a storm, wind, wave and current loadings on offshore structures are all important. For many offshore wind load analysis, the wind speed at the elevation higher than the normal buoy anemometer height at either 5 or 10 m is required. During Hurricanes Gustav and Ike in 2008, simultaneous wind speed measurements at 122 m and both wind speed and gust at 5 m along with the wave parameters were made at the National Data Buoy Center (NDBC) Stations at 42364 and 42040, respectively, in the northeastern Gulf of Mexico (for station locations and hurricane tracks, see www.ndbc.noaa.gov). This unique data set is used in this study to evaluate or verify the wind profile equations.

EQUATIONS

Traditionally, both logarithmic and power-law wind profiles are used to estimate the wind speed variation with height. According to Hsu [1], during a storm, the familiar logarithmic wind profile is valid such that

$$Uz = (U^*/k)\,(\ln(Z/Zo)) \tag{1}$$

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

Whereas the power-law equation states that (see, e.g. Hsu [1])

$$Uz/Uref = (Z/Zref)^{p} \tag{2}$$

For Z > Zref

Where Uref is the wind speed measurements at the anemometer or reference height, Zref, at either 5 or 10 m on the NDBC buoys and p is the exponent for the power-law wind profile.

Because Equation (1) has two unknown parameters (i.e., U* and Zo) in one equation and (2) requires the exponent from the literature, it is the purpose of this article to provide engineers with simplified equations to estimate offshore wind speed at any height for more accurate wind load analysis, since the inputs are based only upon both direct wind speed and gust or wave measurements from numerous NDBC buoys, which are available routinely.

METHODS

According to Equation (1), the difference in wind speed between level Z (higher elevation) and level Zref (lower elevation), i.e. by eliminating U*, is

$$Uz / Uref = \ln(Z/Zo) / \ln(Zref/ Zo) \tag{3}$$

According to Taylor and Yelland [2], the roughness parameter Zo can be computed such that,

$$Zo/Hs = 1200*(Hs/Lp)^{4.5} \tag{4}$$

And, for deep water wave,

$$Lp = 1.56*Tp^{2} \tag{5}$$

Where Hs and Lp are the significant wave height and peak wavelength for the combined sea and swell spectrum, and Tp is the corresponding wave period. Note that Hs is defined as the average height of the highest one-third of the waves observed at a specific point during the 20-minute sampling period.

According to Hsu [3, p.112], Equation (1) can also be used to estimate Uz from U* by eliminating Zo such that

$$Uz - Uref = (U^*/k)\ln(Z/Zref) \tag{6}$$

Furthermore, according to Hsu and Blanchard [4] that

$$U^* = 0.2\,(U5gust - U5) \tag{7}$$

Where U5gust and U5 are the wind gust and mean wind speed measurements at 5 m, respectively. All units of U*, U5gust and U5 are in m/s.

Now, if we set Uz and Uref for the wind speed measurements at 122 m and 5 m, respectively, Equation (6) becomes

$$U122 = U5 + 8\,U^*$$

*Address correspondence to this author at the Coastal Studies Institute, Louisiana State University, Baton Rouge,LA 70803; Tel: 225-578-2962; Fax: 225-578-2520; E-mail: sahsu@lsu.edu

Or, = U5 + 1.6 (U5gust – U5) (8)

The exponent p (=0.10) in Equation (2) was measured by Hsu [3, p.202] under neutral stability conditions. Thus, Equation (2) can be reduced to

Uz/Uref = (Z/Zref)^0.10 (9)

Or, simply, by substituting Uz = U122, Uref = U5, Z=122 m and Zref = 5 m, we have

U122 = 1.38 U5 (10)

Our purpose is to verify all foregoing equations against the measurements as listed in Table **1**. Note that from August 31 thru September 2, 2008 our stations were affected by Gustav and from September 11 thru 12 by Ike.

Table 1. Nearly Simultaneous Measurements of Wind Speed at 122 m at NDBC Station 42364 and Wind Speed and Gust at 5 m and Wave Parameters at Buoy 42040 During Gustav and Ike in 2008 in Gulf of Mexico

42364				Wind	U122m	42040				Wind	U5	G5	Hs	Tp
Month	**Day**	**Hour**	**Min.**	**Dir.**	**m/s**	**Month**	**Day**	**Hour**	**Min.**	**Dir.**	**m/s**	**m/s**	**m**	**Sec.**
8	31	2	0	70	9	8	31	1	50	76	6.6	7.5	0.6	4
8	31	5	0	70	11	8	31	4	50	73	8.9	10.7	0.73	4.17
8	31	6	0	70	13	8	31	5	50	69	8.5	9.8	0.85	4
8	31	8	0	70	12	8	31	7	50	72	8.7	10.3	1.14	4.76
8	31	13	0	50	13	8	31	12	50	51	10.9	13.4	1.76	6.67
8	31	16	0	50	17	8	31	15	50	50	10.9	12.9	2.5	6.25
8	31	19	0	60	15	8	31	18	50	48	12	15.2	2.82	7.14
8	31	21	0	50	22	8	31	20	50	45	13.2	16.2	3.17	8.33
8	31	22	0	60	18	8	31	21	50	59	15.3	19.6	3.54	7.69
8	31	23	0	50	19	8	31	22	50	64	17	20.8	3.69	8.33
9	1	0	0	50	21	8	31	23	50	54	18.7	23.6	5.79	16
9	1	1	0	50	26	9	1	0	50	58	19.3	23.5	7.95	13.79
9	1	2	0	40	28	9	1	1	50	48	18.8	22.7	7.8	13.79
9	1	3	0	40	27	9	1	2	50	58	20.6	26.9	7.57	13.79
9	1	4	0	70	31	9	1	3	50	60	20.6	25.4	7.77	12.12
9	1	7	0	80	29	9	1	6	50	83	21.9	27.3	10.32	12.9
9	1	8	0	110	32	9	1	7	50	91	21.7	27	9.67	11.43
9	1	9	0	120	28	9	1	8	50	103	21.7	27.8	8.44	13.79
9	1	10	0	130	28	9	1	9	50	116	20.7	25.5	8.2	12.9
9	1	11	0	140	28	9	1	10	50	123	19.7	25	8.56	12.9
9	1	12	0	150	24	9	1	11	50	136	21.6	27.2	7.9	11.43
9	1	13	0	150	27	9	1	12	50	133	19.3	24	8.33	11.43
9	1	17	0	160	20	9	1	16	50	141	17.1	22.2	5.62	11.43
9	1	20	0	150	14	9	1	19	50	136	12	14.2	5.26	10
9	2	3	0	140	16	9	2	2	50	135	12.6	15.6	3.75	9.09
9	2	6	0	150	14	9	2	5	50	140	11.5	13.2	3.25	7.69
9	11	7	0	70	17	9	11	6	50	91	10.5	14.1	6.43	14.81
9	11	9	0	60	21	9	11	8	50	69	12.4	15.2	7.33	14.81
9	11	10	0	70	19	9	11	9	50	65	11	13.1	7.54	14.81

Table. 1. Cont….

9	11	12	0	80	22	9	11	11	50	79	17.4	21	7.58	11.43
9	11	13	0	70	19	9	11	12	50	79	16.8	21.5	7.61	14.81
9	11	14	0	70	20	9	11	13	50	84	15.4	18.8	7.59	14.81
9	11	15	0	80	21	9	11	14	50	83	15.8	19.4	8.6	12.9
9	11	16	0	70	22	9	11	15	50	84	15.9	19.4	8.2	12.9
9	11	17	0	80	25	9	11	16	50	81	15.8	19.3	7.56	14.81
9	11	18	0	80	23	9	11	17	50	82	17.2	21.9	7.61	14.81
9	11	19	0	70	21	9	11	18	50	80	16.4	19.9	7.75	13.79
9	11	20	0	90	20	9	11	19	50	84	16.9	21.2	7.79	13.79
9	11	21	0	90	20	9	11	20	50	84	16.2	20.2	6.99	14.81
9	11	22	0	80	23	9	11	21	50	89	15.5	20.2	8.23	13.79
9	11	23	0	80	23	9	11	22	50	90	16	20	7.73	13.79
9	12	0	0	80	18	9	11	23	50	87	15.2	17.7	8.03	14.81
9	12	1	0	100	22	9	12	0	50	89	16.3	19.9	7.75	13.79
9	12	3	0	110	24	9	12	2	50	94	15.5	22.5	7.07	14.81
9	12	4	0	100	18	9	12	3	50	97	15.3	19.5	6.88	13.79
9	12	5	0	110	24	9	12	4	50	97	15.5	19.9	7.08	13.79
9	12	6	0	100	22	9	12	5	50	105	15.6	19.8	6.4	13.79
9	12	7	0	110	23	9	12	6	50	104	16.4	20.2	6.41	13.79
9	12	8	0	90	19	9	12	7	50	105	15.6	19.8	7.2	12.9
9	12	9	0	110	19	9	12	8	50	107	15.1	19.8	5.72	12.9
9	12	10	0	110	22	9	12	9	50	107	16	20.3	6.09	12.9
9	12	11	0	110	19	9	12	10	50	107	16.4	21.4	6.52	12.9
9	12	12	0	120	21	9	12	11	50	111	16.1	20.9	6.4	12.12
9	12	13	0	120	22	9	12	12	50	115	17.1	20.1	5.74	12.12
9	12	14	0	120	18	9	12	13	50	113	15.6	19.3	5.47	12.12
9	12	15	0	130	20	9	12	14	50	117	15.1	18.1	5.63	12.12
9	12	16	0	130	17	9	12	15	50	118	14.8	18.1	5.5	12.12
9	12	17	0	130	18	9	12	16	50	121	14.2	17.6	5.38	11.43
9	12	19	0	140	16	9	12	18	50	130	13.5	17.3	5.36	11.43
9	12	21	0	130	18	9	12	20	50	127	12.3	15	5.05	10.81
9	12	22	0	140	17	9	12	21	50	124	13.3	16.2	5.03	11.43
9	13	1	0	130	19	9	13	0	50	124	12.8	15.9	4.81	12.9
9	13	2	0	130	17	9	13	1	50	123	12.5	15.4	4.87	12.9
9	13	3	0	130	16	9	13	2	50	125	12	14.6	4.26	10.81
9	13	4	0	140	15	9	13	3	50	125	12.7	14.8	5.1	12.9
9	13	5	0	140	16	9	13	4	50	125	12.4	14.9	4.76	12.12
9	13	7	0	150	13	9	13	6	50	133	10.9	13.4	4.7	12.12

Table. 1. Cont....

9	13	8	15	140	15	9	13	7	50	129	12.1	14.5	4.52	11.43
9	13	9	0	140	14	9	13	8	50	133	11.5	13.9	4.05	10.81
9	13	10	0	150	14	9	13	9	50	134	10.9	13	4.23	11.43
9	13	12	0	140	15	9	13	11	50	134	10.1	13	3.59	11.43
9	13	17	0	160	12	9	13	16	50	144	9.8	11.3	2.58	10.81
9	13	19	0	150	12	9	13	18	50	144	9.3	11.2	2.62	10.81
9	14	0	0	150	11	9	13	23	50	141	8.5	10.7	2.39	10
9	14	1	0	150	11	9	14	0	50	143	8.6	9.9	2.46	7.69
9	14	3	0	160	11	9	14	2	50	146	8.8	10.6	2.38	10
9	14	12	0	180	10	9	14	11	50	173	7.2	8.6	1.89	7.14

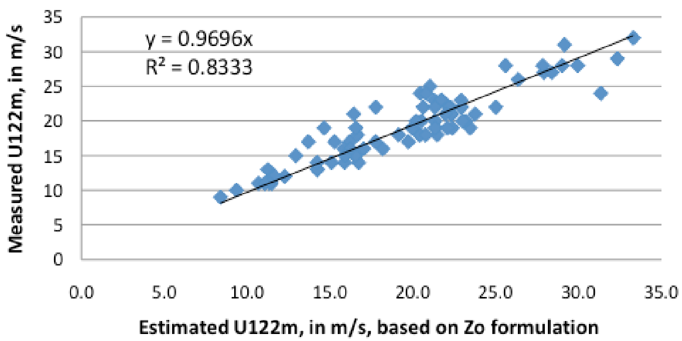

Fig. (1). A comparison between estimated and measured wind speed at 122 m based on Zo formulation.

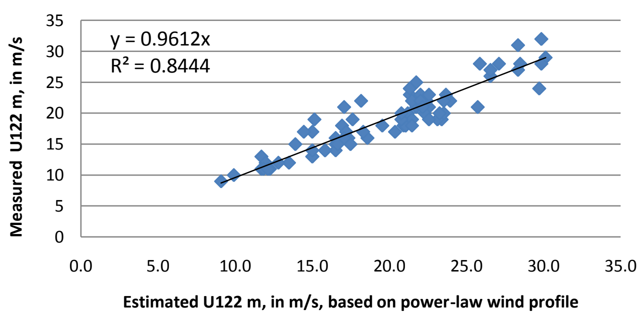

Fig. (2). A comparison between estimated and measured wind speed at 122 m based on the power-law wind profile.

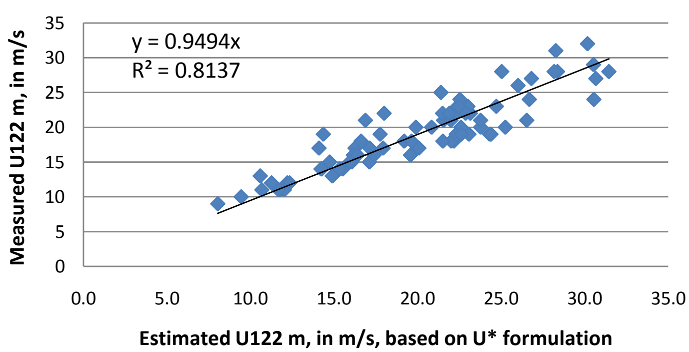

Fig. (3). A comparison between estimated and measured wind speed at 122 m based on U* formulation.

RESULTS

Our results are presented in Figs. (**1** to **3**). Note that for better comparison the intercept in the linear regression is imposed to equal to zero. Now, if one accepts these high R^2 values, then, the foregoing wind profile equations are verified. Note that according to NDBC, the margin of error in the wind speed measurement is approximately plus or minus10 %. Since the slopes in these Figures are close to one, which are within the 10 % margin of errors, it is recommended that these equations be employed operationally using only the direct measurements of both wind speed and gust or wave parameters from nearby NDBC buoy stations. It is surprising that the exponent in Equation (9), i.e. p (= 0.10), works also well under hurricane conditions.

CONCLUSIONS

On the bases of simultaneous measurements of wind speed at 122 m and both wind speed and gust at 5 m along with the wave parameters in the Gulf of Mexico during Hurricanes Gustav and Ike in 2008, both logarithmic and power-law wind profile equations are verified. These equations can be used to estimate the wind speed at any height for wind load analysis under hurricane conditions using the direct buoy measurements which are available routinely. If the buoy data are not available, one can set the exponent, p=0.10, in the power-law wind profile equation.

REFERENCES

[1] S.A. Hsu, “Estimating overwater friction velocity and exponent of Power-law wind profile from gust factor during storms”, *J. Waterways, Port, Coast. Ocean Eng.*, vol. 129, no. 4, pp. 174-177, 2003.

[2] P.K. Taylor, and M.J. Yelland, “The dependence of sea surface Roughness on the height and steepness of the waves”, *J. Phys. Oceanogr.*, vol. 31, pp. 572-590, 2001.

[3] S.A. Hsu, *Coastal Meteorology*. Academic Press, USA, 1988.

[4] S.A. Hsu, and B.W. Blanchard, “Estimating overwater turbulence Intensity from routine gust-factor measurements”, *J. Appl. Meteorol.*, vol. 43, no. 12, pp.1911-1916, 2004.

Received: February 9, 2011 Revised: March 31, 2011 Accepted: April 5, 2011