NOWCASTING THE VARIATION OF WIND SPEED WITH HEIGHT USING GUST FACTOR MEASUREMENT

S. A. Hsu

Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana

Abstract

In the atmospheric surface boundary layer from the ground level up to a few hundred feet, the wind speed normally increases with height under near-neutral conditions. Knowledge of the vertical variation of the wind speed is important to operational meteorologists so that they can provide reasonable estimates to emergency managers and structural engineers. For example, during hurricane conditions in New Orleans, Louisiana, what would be the expected wind gust on the elevated bridges crossing the Mississippi River? What would be the expected wind loading on a high-rise building which might be used as a vertical evacuation shelter? This increase in wind speed is often estimated operationally using the power-law wind profile. However, its exponent needs to be determined objectively. This note provides a solution through the utilization of gust factor measurements. It is shown that the formula G = 1 + 2.88P is verified under the conditions of one tropical storm and ten hurricanes for a total of 148 samples as measured from various airports, where G is the gust factor (i.e., the ratio of wind gust to the mean wind speed) and P is the exponent of the power-law profile.

1. Introduction

From time to time an operational meteorologist may be called upon to assist in the determination of the variation of wind speed with height at an elevation other than 10 m, the typical Automated Surface Observing System (ASOS) height. Nowcasting this vertical distribution of the wind speed is often needed, particularly during storm conditions or for emergency preparedness (such as the event of an industrial fire) when routine weather measurements are available from airports located in the general region of the accident. This note intends to provide a rapid estimation for this practical application using the gust factor measurement for input.

2. Method and Justification

In the atmospheric surface boundary layer which extends from the ground up to a few hundred feet, the wind speed generally increases with height. Operationally, this power-law wind profile is often used (e.g., Panofsky and Dutton 1984)

$$v_2 = v_1 \left(\frac{z_2}{z_1} \right)^P \tag{1}$$

where v_1 is the reference (or known) wind speed (e.g., from ASOS) at the known height of z_1 (e.g., 10 m), v_2 is the wind speed needed at the height of z_2, and P is the exponent of this power-law profile.

According to Simpson and Riehl (1981, p. 202), for open country near the coastline, P = 1/7 = 0.14. Since airports are normally located in the open country, we use the wind measurements from airports for this study. Under near-neutral conditions, P varies with the roughness length, z_0, which is a function of surface irregularities (i.e., average spacing and height of surface features (Simpson and Riehl 1981, p. 201)). According to Justus (1985, p. 922), P = 0.13 when the roughness z_0 = 0.01 m and P = 0.19 when z_0 = 0.1 m. Because these variations are not linear, we use the power-curve fit as follows: let

$$P_1 = a z_{01}^b \tag{2a}$$

where P_1 = 0.13 and z_{01} = 0.01 m and

$$P_2 = a z_{02}^b \tag{2b}$$

where P_2 = 0.19 and z_{02} = 0.1 m. Solving Eqs. (2a) and (2b) simultaneously using the known boundary conditions, we get

$$P = 0.278 z_0^{0.165} \tag{2c}$$

for the z_0 range between 0.01 and 0.1 m. According to Panofsky and Dutton (1984, p. 123), z_0 = 0.025 m for airports (runway area). Substituting this z_0 into Eq. (2c), we have

$$P = 0.15 \tag{3}$$

This supports P = 0.14 as recommended in Simpson and Riehl (1981) as reasonable.

Based on the formula for estimating wind maxima as suggested in Panofsky and Dutton (1984, p. 376), a rela-

Table 1. Measured Gust Factors During ten Hurricanes and one Tropical Storm at Various Airports (Data sources: Pasch et al. (2001), Lawrence et al. (2001), and Franklin et al. (2001))

Hurricane	Station	G
Bonnie	St. Thomas AP U.S. V.I.	1.43
1998	Charleston Intl. AP	1.32
	Florence AP	1.29
	Oceana NAS	1.42
	Langley AFB	1.26
	Norfolk AP	1.40
	Norfolk NAS	1.33
Earl	Moisant Intl. AP	1.24
1998	New Orleans Lakefront AP	1.10
	Pascagoula/Trent Lott AP	1.38
	Mobile Regional AP	1.22
	Mobile Brookley Field	1.29
	Dothan AP	1.41
	Pensacola Regional AP	1.53
	Pensacola NAS	1.34
	Hurlburt Field AFB	1.42
	Whiting Field (Milton)	1.61
	Panama City AP	1.28
	Marianna Municipal AP	1.31
	Tallahassee Regional AP	1.38
	Perry-Foley AP	1.33
	Cross City AP	1.37
	Tampa AP	1.22
	MacDill AFB	1.42
	Sarasota AP	1.28
	Regional SW AP	1.26
Georges	Hamilton AP, St. Croix	1.23
1998	Cyril E. King AP, St. Thomas	1.23
	Luis Martin AP P.R.	1.17
	Roosevelt Roads NAS	1.22
	Patrick AFB	1.53
	Miami Intl. AP	1.33
	Tamiami AP	1.73
	Tampa AP	1.50
	MacDill AFB	1.85
	Sarasota AP	1.24
	Regional SW AP	1.54
	Tallahassee AP	1.21
	Panama City AP	1.54
	Milton/Whiting Field	1.32
	Hurlburt AFB	1.57
	Eglin AFB	1.88
	Pensacola AP	1.32
	Pensacola NAS	1.53
	Mobile Regional AP	1.25
	Mobile Brookley Field	1.15
	Gulfport AP	1.50
	Pascagoula/Trent Lott AP	1.31
	Moisant Intl. AP	1.31
	New Orleans Lakefront AP	1.23
Mitch	Key West AP	1.37
1998	Boca Chica NAS	1.52
	Marathon AP	1.67
Mitch	Homestead AFB	1.75
continued	Tamiami AP	1.65
	Miami Intl. AP	1.95
	Opalocka AP	1.36
	Fort Lauderdale AP	1.24
	Fort Lauderdale Ex. AP	1.36
	Pampano Beach AP	1.39
	Naples AP	1.50
	Vero Beach AP	1.68
	Patrick AFB	1.37
	Fort Pierce AP	1.45
	Orlando Intl. AP	1.26
	Tampa AP	1.64
	MacDill AFB	1.83
	Sarasota AP	1.67
	Fort Myers Regional AP	1.22
Bret	Brownsville AP	1.62
1999	Cameron City AP	1.28
	Harlington AP	1.26
	McAllen AP	1.32
	Kingsville NAS	1.26
Dennis	Cherry Pt. Marine Corps.	1.29
1999	Wilmington AP	1.26
	Norfolk AP	1.24
	Langley AFB	1.47
Floyd	Fort Lauderdale Ex. AP	1.43
1999	Fort Lauderdale Intl. AP	1.44
	Melbourne AP	1.31
	Patrick AFB	1.16
	Tamiami AP	1.48
	Savannah AP	1.31
	Charleston Intl. AP	1.32
	Florence AP	1.50
	Seymour Johnson AFB	1.33
	Wilmington AP	1.39
	Langley AFB	1.38
	Norfolk AP	1.48
	Norfolk NAS	1.26
	Patuxent NAS	1.20
	Newark Intl. AP	1.21
	Teterboro AP	1.58
	Farmingdale AP	1.61
	Islip/MacArthur AP	1.37
	JFK Intl. AP	1.37
	LaGuardia AP	1.37
	Montgomery AP	1.52
	Montauk Point AB	1.68
	Westhampton AP	1.54
	White Plains AP	1.68
	Bridgeport AP	1.34
	Danbury AP	1.40
	Meridan Markham AP	1.70
Irene	Key West Intl. AP	1.24
1999	Tamiami AP	1.33
	Homestead AFB	1.76
	Miami Intl. AP	1.49
	Pompano Beach AP	1.25
	Fort Lauderdale Ex. AP	1.25
	Opalocka AP	1.26
	West Palm Beach AP	1.43
	North Perry AP	1.35
	Orlando Intl. AP	1.27
	Melbourne AP	1.45
	Vero Beach AP	1.59
Lenny	V.C. Bird Intl. AP	1.43
1999	Hamilton AP St. Croix	1.33
	Cyril King AP St. Thomas	1.33
	Luis Martin AP	1.17
Opal*	NEW	1.40
1995	MEI	1.50
	MOB	1.53
	MXF	1.90
	MGM	1.33
	AUB	1.92
	BHM	1.57
	ANB	1.38
	HSV	1.32
	NPA	1.26
	HRT	1.68
	PAM	1.36
	AQQ	1.86
	TLH	1.64
	BKV	1.40
	TPA	1.82
	PIE	1.54
	ATL	1.57
T.S. Frances	Acadiana Regional AP	1.30
1998	Jefferson Parish AP	1.30
	Lake Charles AP	1.25
	Lafayette Regional AP	1.30
	Galveston AP	1.27
	Houston Intl. AP	1.29
	Houston/Hobby AP	1.25
	Palacios AP	1.59
	Corpus Christi NAS	1.31
	GRAND MEAN	1.42
	Standard Deviation	0.18
	Coefficient of Variation	13%

**from Hsu (2001)*

tionship between the gust factor and P has been proposed by Hsu (2001, Eq. 2) that, under near-neutral conditions,

$$G = 1 + 2.88P \quad (4)$$

Therefore, using Eq. (1) the wind speed at any height in the atmospheric surface boundary layer, which is typically between the ground and 100 m, can be estimated if P can be determined objectively. With the gust factor measurements, this is accomplished by applying Eq. (4).

The purpose of this note is to further verify Eq. (4) so that Eq. (1) may be correctly applied for operational use. First, we need to define what is meant by "near-neutral stability". According to the Pasquill stability classification (see, e.g., Panofsky and Dutton 1984, p. 242), the neutral class D should be assumed for overcast conditions during day or night or whenever the wind speed is higher than 6 m s^{-1} except under strong incoming solar radiation (i.e., when the solar altitude is greater than 60° with clear skies (see Hsu 1988, p. 193)). On the other hand, since the minimum gust speed reported by ASOS is 7 m s^{-1} (or 14 kt), and since the minimum G is 1.0, the hourly mean wind speed of 7 m s^{-1} exceeds the required 6 m s^{-1}. Thus one may safely assume that the gust factor measurements for ASOS can be applied under near-neutral stability conditions. Note that neutral stability exists when mechanical turbulence dominates the thermal stratification or buoyancy effect.

In order to verify Eq. (4), a large sample representing a similar environment (such as from airports) is required. In the data sets compiled by Pasch et al. (2001), Lawrence et al. (2001), and Franklin et al. (2001) there were 10 hurricanes and one tropical storm yielding a total of 148 samples for use in this analysis. These data are listed in Table 1. Analyses of these data indicate that the grand mean of the gust factor for these 148 samples is 1.42 and the standard deviation is 0.18. In order to estimate the dispersion of this data set, the coefficient of variation is employed, which is the ratio of standard deviation to mean so that 0.18 / 1.42 = 12.7%. If we accept this 13% value as reasonable, then G = 1.42 is a useful magnitude to proceed further.

3. Conclusion

Now, substituting G = 1.42 into Eq. (4), we get P = 0.15. Since this value is the same as Eq. (3), we conclude that Eq. (4) can be used to get P objectively from G and then this P can confidently be employed in Eq. (1) for operational applications such as nowcasting. Since Eq. (4) is verified, it may be applied to other environments on land if G is available. Note, that if the mean wind speed is less than 6 m s^{-1} (or 12 kt), P is a function of not only Z_0 but also stability. In this regard, the method to estimate P provided in Justus (1985) should be consulted.

Acknowledgments

Comments to improve this paper from Mary M. Cairns from the Office of the Federal Coordinator for Meteorological Services and Supporting Research are appreciated.

Author

Dr. S. A. Hsu has been a Professor of Meteorology at Louisiana State University since 1969, after he earned his Ph.D. in Meteorology from the University of Texas at Austin. He is the author of *Coastal Meteorology* (Academic Press, 1988) and numerous papers on coastal and marine meteorology and air-sea interaction. Dr. Hsu is also an AMS Certified Consulting Meteorologist. Dr. Hsu can be contacted at the LSU Coastal Studies Institute, 308 Howe-Russell Geoscience Building, Baton Rouge, Louisiana 70803-7527;
e-mail: sahsu@antares.esl.lsu.edu.

References

Franklin, J. L., C. A. Avila, J. L. Beven, M. B. Lawrence, R. J. Pasch, and S. R. Stewart, 2001: Atlantic hurricane season of 2000. *Mon. Wea. Rev.*, 129, 3037 - 3056.

Hsu, S. A., 1988: *Coastal Meteorology*, Academic Press, 260 pp.

_________, 2001: Spatial variations in gust factor across the coastal zone during Hurricane Opal in 1995. *Natl. Wea. Dig.*, 25:1 - 2, 21 - 23.

Justus, C. C., 1985: Wind Energy, in *Handbook of AppliedMeteorology*, D. Houghton (Editor), Wiley, pp. 915 - 944.

Lawrence, M. B., L. A. Avila, J. L. Beven, J. L. Franklin, J. L. Guiney, and R. J. Pasch, 2001: Atlantic hurricane season of 1999. *Mon. Wea. Rev.,* 129, 3057 - 3084.

Panofsky, H. A., and J. A. Dutton, 1984: *Atmospheric Turbulence*. John Wiley & Sons, 397 pp.

Pasch, R. J., L. A. Avila, and J. L. Guiney, 2001: Atlantic hurricane season of 1998. *Mon. Wea. Rev.,* 129, 3085 - 3123.

Simpson, R. H., and H. Riehl, 1981: *The Hurricane and Its Impact*. Louisiana State University Press, Baton Rouge, Louisiana, 398 pp.