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Engineering Applications of the Newly Available Roughness-Length Measurements by AOML at 213 ASOS Stations

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Abstract- Most recently, the Hurricane Research Division of the U. S. Atlantic Oceanographic and Meteorological Laboratory (AOML) has made extensive surveys of the roughness length (Zo) in each of the 213 Automated Surface Observation Stations (ASOS) located in tropical-cyclone prone regions. The original 8 values of Zo for each of the 45 degree segments within the 360 degree compass in each ASOS station are averaged geometrically to obtain one typical value for each of these 213 ASOS stations. Six ASOS stations are verified independently by the gust factor method during 5 hurricanes. Since the difference is within the 10 % composite accuracy for field measurements in wind speed, the computed geometric mean Zo values for each of the 213 ASOS stations are recommended for practical use. Applications of the proposed geometric mean Zo value to estimate the 3-second gust, peak gust, and peak factor during Hurricane Katrina are also provided for engineers as an example.

Keywords: roughness length; hurricanes; asos stations, turbulence intensity; power-law exponent; gust factor; peak factor.

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Abstract - Most recently, the Hurricane Research Division of the U. S. Atlantic Oceanographic and Meteorological Laboratory (AOML) has made extensive surveys of the roughness length (Zo) in each of the 213 Automated Surface Observation Stations (ASOS) located in tropical-cyclone prone regions. The original 8 values of Zo for each of the 45 degree segments within the 360 degree compass in each ASOS station are averaged geometrically to obtain one typical value for each of these 213 ASOS stations. Six ASOS stations are verified independently by the gust factor method during 5 hurricanes. Since the difference is within the 10 % composite accuracy for field measurements in wind speed, the computed geometric mean Zo values for each of the 213 ASOS stations are recommended for practical use. Applications of the proposed geometric mean Zo value to estimate the 3-second gust, peak gust, and peak factor during Hurricane Katrina are also provided for engineers as an example.

Keywords: roughness length; hurricanes; asos stations, turbulence intensity; power-law exponent; gust factor; peak factor.

I. Introduction

Most recently, in its "Tropical Cyclone Wind Exposure Documentation Project", the Hurricane Research Division (HRD) at the Atlantic Oceanographic and Meteorological Laboratory (AOML), U. S. National Oceanic and Atmospheric Administration (NOAA), has made an extensive survey and monitoring of the roughness length (Zo) at 213 Automated Surface Observation Stations (ASOS). Most ASOS are located at hurricane-prone airports (see www.aoml.noaa.gov/hrd/asos/index.html). Because Zo is a parameter needed for wind and turbulence estimates for civil, structural and environmental engineers (see, e.g., Hsu, 2013), the purpose of this study is to utilize these newly available Zo measurements by AOML for engineering applications.

II. Geometric Mean zo for each ASOS Environment

According to AOML the 360 degree compass for the wind direction measurement is divided into 8 segments so that there is one Zo value for each 45 degrees at each ASOS. These 8 Zo values may be needed for aviation safety reasons. However, since the wind direction in a tropical cyclone is rotational in nature and since the strongest wind may come from any direction, it is not necessary for practical operation to have 8 Zo for each ASOS. Instead, a typical Zo value or the geometric mean for each ASOS is needed for most engineering applications. Therefore, the original list which consists of 8 Zo values for each ASOS is geometric averaged. Our results are provided in the Appendix with one geometric mean Zo for each of the 213 ASOS.

III. Validating the Relation between zo, Gust Factor and Turbulence Intensity

According to Panofsky and Dutton (1984, pp.130-131), it is common in engineering practice to describe the variation of the wind speed with height, i.e. the wind profile with a power law such that

$$U_2 / U_1 = (Z_2/Z_1) \wedge p \qquad (1)$$

According to Hsu (2008),

$$P = 0.2996\ Zo \wedge 0.168 \qquad (2)$$

Where U_2 and U_1 are the wind speed at height Z_2 and Z_1, respectively, p is the power-law exponent, and Zo is the roughness length.

Now, for each ASOS Station the appropriate value of p based on Eq. (2) is also provided in the Appendix.

According to Hsu (2013), for 5 second gust over the 2 minute duration, which is available routinely from the wind speed measurements by ASOS, we have

$$G = 1 + 2.04\ P \qquad (3)$$

$$= 1 + 2.04\ TI \qquad (4)$$

Where G is the gust factor (the ratio of 5-s gust to 2-min sustained wind speed) and TI represents the longitudinal turbulence intensity.

A forementioned equations are validated as follows :

a) Composite Field Accuracy for Wind Speed Measurements

In order to validate Equations (1) thru (4), one must first determine the composite field accuracy for the

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wind speed measurements. According to U. S. National Data Buoy Office (see http://www.ndbc.noaa.gov/rsa.shtml), The composite accuracy of field measurements for the wind speed and wind gust is +/- 10 %. In other words, if the difference between measurements and estimates related to wind and gust characteristics is within 10 %, one may accept those estimates as reasonable. Note that this 10 % margin of error can also be related to the different anemometers used in the field. An example is shown in Table 1.

Table 1 : Comparison of generated longitudinal turbulence intensity (TI) from different anemometers during Hurricane Bonnie in 1998

(1). UVW anemometer	(2). Propeller-Vane anemometer	Difference between (1) and (2)	Mean TI between (1) and (2)
0.175	0.195	10 %	0.185

(Data source: Schroeder, 1999)

b) Validation during Hurricane Bonnie in 1998

On the basis of Tables 2 and 3 and Fig.1, we can say that the geometric mean Zo for KILM as listed in the Appendix is valid for engineering applications. Furthermore, it is shown that p = TI.

Table 2 : Comparisons of wind speed measurements by ASOS and Texas Tech University at Wilmington Airport (KILM), North Carolina, USA, during Hurricane Bonnie in 1998

	ASOS Station	Texas Tech Station
0.2-Second Gust (m/s)	NA	38.2
3-Second Gust (m/s)	NA	33.6
5-Second Gust (m/s)	32.9	33.5
1-minute Sustained (m/s)	NA	25.0
2-minute Sustained (m/s)	25.2	24.4

(Data Source : Schroeder, 1999).

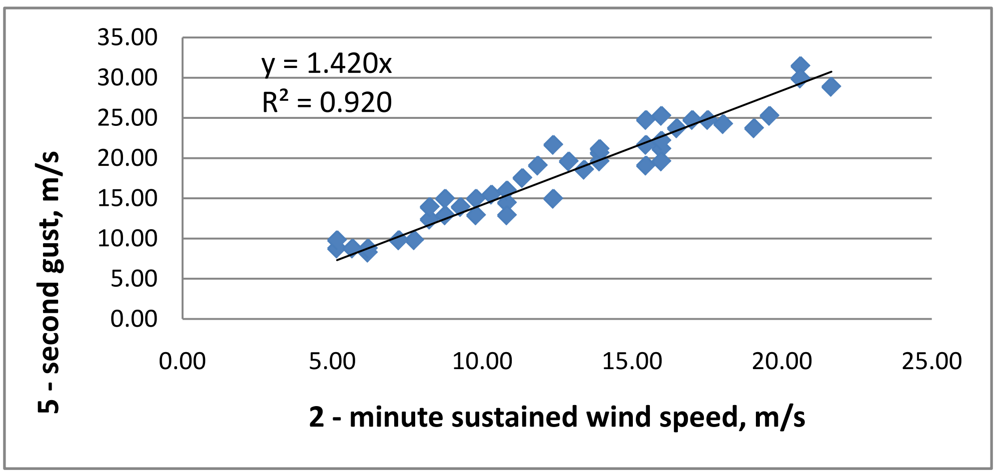

Figure 1 : Wind speed and gust measurements at ASOS Station at Wilmington Airport, N.C., USA, during Hurricane Bonnie in 1998

Table 3 : A comparison of measurements against 3 estimates of p using Eq. (3) and the geometric mean of Zo from Appendix at Wilmington Airport during Hurricane Bonnie in 1998

Source	(1). P based on either measured or estimated	(2). P from Appendix for KILM	Difference between (1) and (2)
UVW, Table 1	0.175	0.185	0.054
Prpeller-vane, Table 1	0.195	0.185	0.051
ASOS, Table 2	0.150	0.185	0.189
TTU, Table 2	0.183	0.185	0.011
Fig. 1	0.206	0.185	0.102
Mean	0.182	0.185	0.016

c) Validation during Hurricane Katrina in 2005

According to Henning (see http://ams.confex.-com/ams /pdfpapers/108816.pdf), when Katrina was coming ashore near Pass Christian, MS, the aircraft measure- ments of maximum wind speed was 68.4 m/s at 350 m and at the near-surface (77m) it dropped down to 47 m/s. Therefore, according to Eq. (1), we have

$$(68.4/47) = (350/77) \wedge p$$

$$\text{So that } p = \text{Ln}\,(68.4/47)/\text{Ln}\,(350/77) = 0.248 \qquad (5)$$

Since this value is identical to that at KASD for Slidell Airport, LA (which is not very far from Pass Christian), as provided in the Appendix, we can say that the geometric mean Zo for KASD is verified for practical use. Note that, during Katrina, nearly all surface wind measurements were not available because of massive power failure. Therefore, these aircraft measurements by U.S. Air Force Hurricane-Hunters are greatly appreciated.

d) Validation during Hurricane Rita in 2005

In 2005 Hurricane Rita passed near Lake Charles, Louisiana, USA. On the basis of Fig. 2 and Eq.

(3), P = 0.172. According to the Appendix for KLCH, p = 0.182. Since the difference between these two p values is 5.5 %, we can say that the mean geometric Zo value and the computed p value are validated.

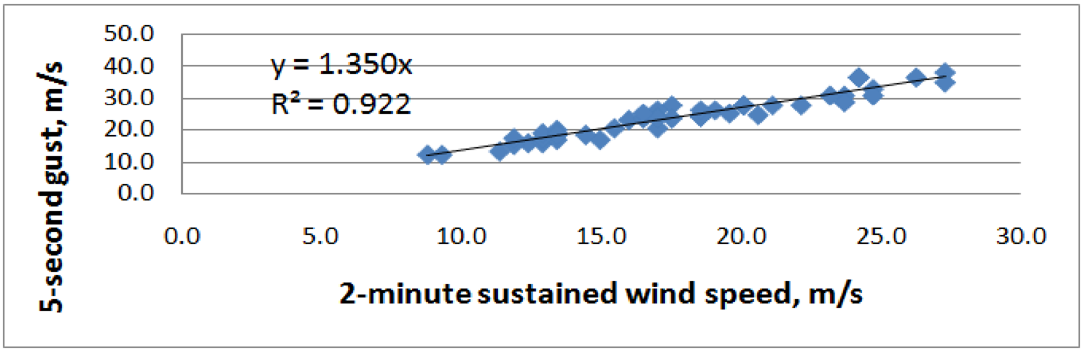

Figure 2 : Relation between sustained wind speed and gust on 23 Septmber 2005 at Lake Charles, Louisiana, USA during Hurricane Rita

e) Validation during Hurricane Ike in 2008

In 2008 Hurricane Ike passed over Houston, Texas, near an instrumented tower operated by Texas A & M University. According to Schade (2012), the mean Zo = 1m and p = 0.29. Substituting these values into Eq. (1), we have p = 0.2996. Since the difference between 0.29 and 0.2996 is approximately 3 %, we can say that Eq. (1) is further verified.

Now, according to Fig.3 and Eq. (3), p = 0.180. Since this value is nearly equal to that of 0.177for KHOU as shown in the Appendix, we can say that the geometric mean Zo for KHOU is validated.

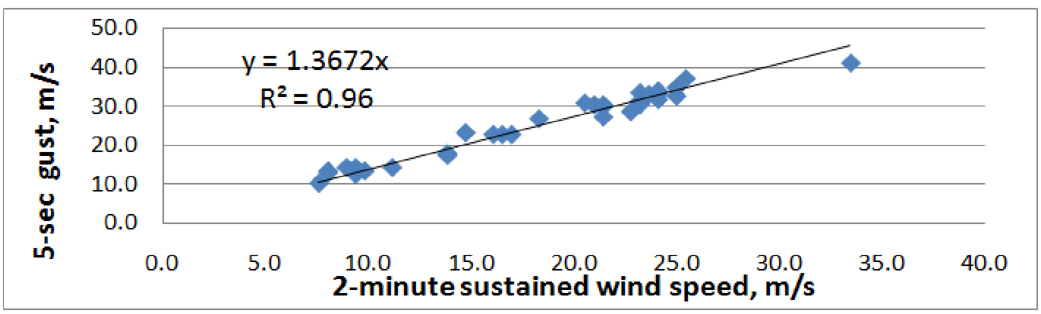

Figure 3 : Relationship between sustained wind speed and gust on 12-13 September 2008 in Houston Hobby Airport during Hurricane Ike

f) Validation during Hurricane Isaac in 2012

In 2012 Hurricane Isaac passed near New Orleans International Airport (KMSY), Louisiana,USA. This gave us the opportunity to validate the geometric mean Zo for p = 0.225 as shown in the Appendix. On the basis of Fig. 4 and Eq. (3), p = 0.239. Since the difference between p = 0.225 and p = 0.239 is approximately 5.9 %, we can say that the geometric mean Zo value as computed in the Appendix is acceptable for engineering applications. Another validation during Isaac is done in Fig. 5. Based on Fig. 5 and Eq. (3), p = 0.239. Since the difference between this value and that shown in the Appendix for KBVE, where p = 0.219, is 8.4 %, we can say that the geometric mean Zo provided in the Appendix for KBVE is validated.

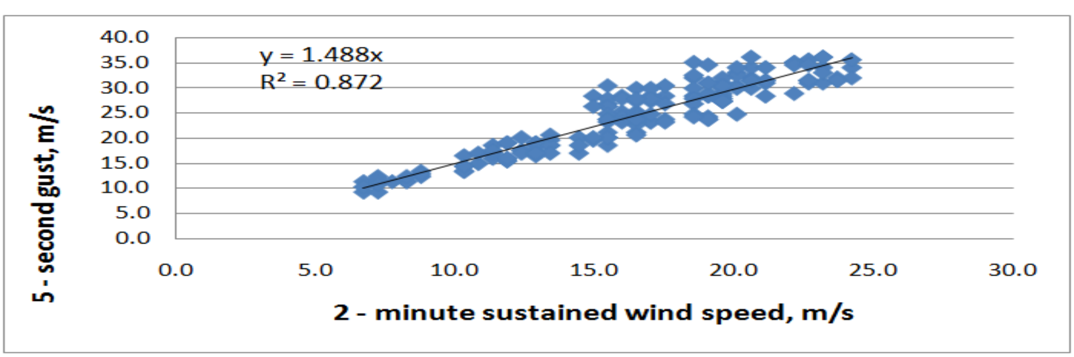

Figure 4 : Relation between sustained wind speed and gust from 27 to 30 August 2012 at New Orleans International Airport (KMSY) , Louisiana, USA during Hurricane Isaac

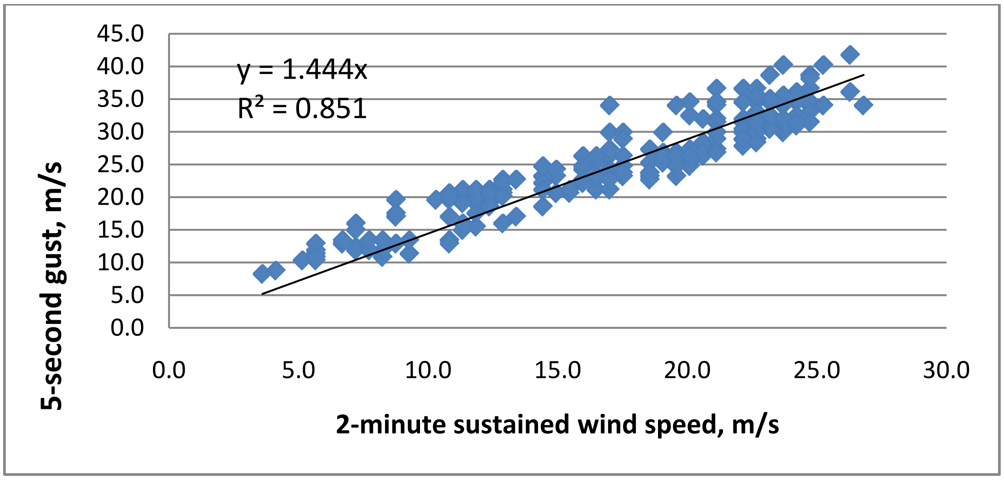

Figure 5 : Relation between sustained wind speed and gust from August 27 to 30, 2012 at Boothville (KBVE),Louisiana, USA during Hurricane Issac

IV. Applications: A Case Study During Hurricane Katrina in 2005

Since the information on both 3-second and peak gusts are needed for wind load analyses (see, e.g., Irwin, 2006) and since some data during Katrina are available, we can use Katrina as a case study. This is done as follows :

a) Application to estimate 3-second gust

In 2005 Hurricane Katrina devastated northern Gulf of Mexico including New Orleans, Louisiana and Waveland and Bay St. Louis, Mississippi, USA. Numerous infrastructures including the Louisiana Superdome were destroyed or damaged.

According to the Hurricane Katrina Post-Tropical Cyclone Report (http://www.srh.noaa.gov/lix/?n=psh_katrina) by the National Weather Service (NWS) in New Orleans,LA, there was an ASOS station located at 50 feet (or 15.2 m) over Lake Pontchartrain. That station recorded max 2-min sustained wind speed of 68 knots (35.1 m/s) and 5-second gust of 86 knots (44.3 m/s). Therefore, according to Eq. (3), p = 0.130. According to Hsu (2013) and Fig. 6, the gradient height over the Lake was 309 m so that the wind speed at 309 m is estimated to be

$$U_{309m} = U_{15.2m}(309/15.2)^{\wedge}\ 0.13 = 35.1*1.48 = 51.9\ \text{m/s} \quad (6)$$

Now, according to the Appendix, p = 0.225 for New Orleans International Airport (KMSY). Substituting this p value into the equation provided in Fig. 6, the gradient height over KMSY is estimated to be 467m. Therefore, based on Eq. (6), the 2-minute sustained wind speed over KMSY at the elevation of 467m was 51.9 m/s during Katrina. Although much of the data were not available due power failure during Katrina, there were two peak wind speed measurements located at 120 and 30 feet (36.6 and 9.1m), respectively.Thus, we can compare our estimates against the measurements. This is done as follows:

$$U_{36.6m} = U_{467m}\,(36.6/467)^{\wedge}0.225 = 51.9*0.564 = 29.3\ \text{m/s},$$

therefore the 3-second gust based on Eq. (3) is

$$U_{36.6m,3\text{-}s} = 29.3*(1+2.04*0.225) = 42.7\text{m/s} \quad (7)$$

Similarly,
$U_{9.1m} = U_{467m}(9.1/467)^{\wedge}0.225 = 51.9 * 0.412 = 21.4$ m/s, and

$$U_{9.1m,3\text{-}s} = 21.4*(1+2.04*0.225) = 31.2\ \text{m/s} \quad (8)$$

These results can be used to compare the two gust measurements made around the New Orleans International Airport during Katrina as provided in the website as quoted above. This is done in Table 4.Since the difference between estimated and measured is 5.5 % or less, the methods provided in this study should be useful in engineering applications.

Table 4 : Comparison of estimated and measured 3-second gust around New Orleans International Airport during Katrina

Height, m	Estimated, m/s	Measured, m/s	Difference In per cent
36.6	42.7 from Eq.(7)	43.8 From NWS	2.5 %
9.1	31.2 From Eq.(8)	33.0 From NWS	5.5 %

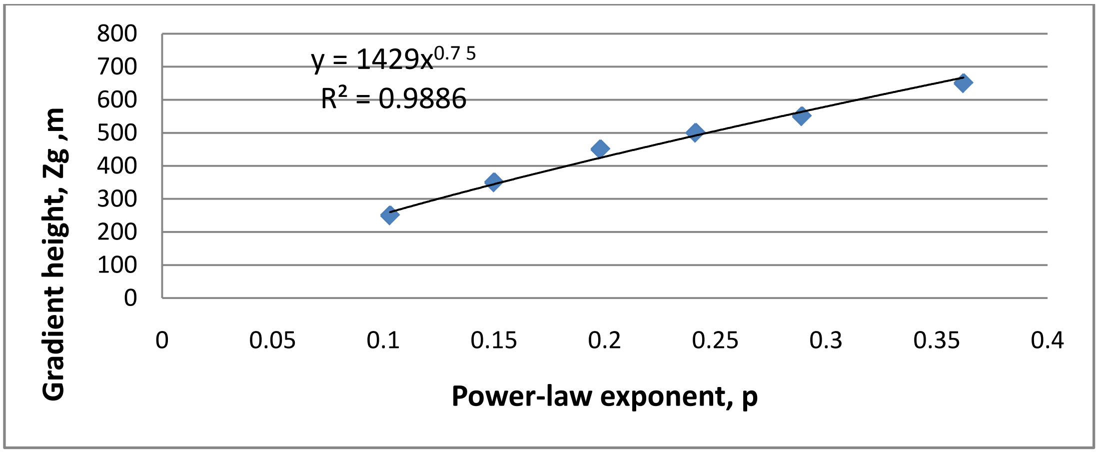

Figure 6 : Relationship between the gradient height and power-law exponent (Data source: Choi, 2009)

b) Application to estimate peak gust

As stated in 3.3 above, massive power outage made most ASOS stations out of order during Hurricane Katrina in 2005. Even though, some measurements of peak gust from non-ASOS stations were available for this study. They were:

1. Eastern New Orleans – NASA Michoud Facility, wind equipment at 40 feet (12.2 m), at Gage 2, the peak wind was 107 knots (55.2 m/s) measured at 1415UTC on 29 August 2005; and
2. Eastern New Orleans – Air Product Facility, wind equipment at 30 feet (9.1 m), the peak wind was 104 knots (53.6m/s) measured at 1400UTC on 29 August 2005.

A question was raised by some civil and structural engineers during their hurricane-damage assessment whether these peak gust measurements were for 3-second or less.In order to answer this question, we need to know the one-minute sustained wind speed measured in the general area and near the same time. Fortunately, there were two experimental wind towers set up specifically to study the hurricane impacts in the general area. One was operated by Florida International University (FIU) at Belle Chase to the south of Eastern New Orleans. The FIU10 m tower recorded the one-minute sustained wind speed of 68 knots (35.1 m/s) at 1427UTC and the 3-second gust of 89 knots (45.9 m/s) at 1132UTC on the same day.The other was operated by the Texas Tech University (TTU) at Slidell to the north of Eastern New Orleans. The TTU 10-m tower measured 61 knots (31.4 m/s) for the sustained wind speed and 87knots (44.8 m/s) for the 3-second gust. Since the peak gusts in the Eastern New Orleans area exceeded 104 knots (53.6 m/s), which was much stronger than the 3-s gust as measured both by FIU and TTU, the measured period must be less than 3-s.

Now, according to Hsu (2008), the maximum instantaneous gust (U_{max}) can be approximated by

$$U_{max} = U_{1\text{-}min}\,(1 + 3\,p) \qquad (9)$$

According to Choi (2009) and Hsu (2013), the terrain category for Eastern New Orleans area may be represented as Category III (for the suburban) so that p = 0.198. By substituting this p value and the averaged $U_{1\text{-}min}$, which is (35.1 +31.4)/2 = 33.3 m/s into Eq. (9), we have

$$U_{max} = 33.3*(1+3*0.198) = 53.0 \text{ m/s} = 103 \text{ knot} \qquad (10)$$

This estimated value is in good agreement with those measured value which ranged from 53.6 to 55.2 m/s or from 104 to 107 knots. Therefore, the answer to the questions raised by the civil and structural engineers is that those “peak gust” measurements in the Eastern New Orleans area as provided in its Hurricane Katrina – Post Tropical Cyclone Report by the National Weather Service in New Orleans were in fact not the 3-second gust but the maximum instantaneous gust, which represents the 3 standard deviation or within the top 1 % probability.

c) Application to estimate peak factor

Depending on anemometer system and averaging period, each dataset for the wind speed measurement consists of the duration of sampling such as 1 minute (e.g. see Table 2), 2 minutes (such as from ASOS station),10 minutes, or even one hour. Within this sampling duration, there is a maximum or peak gust, which represents the shortest period of measurement such as 0.2 second as shown in Table 2. Therefore, the generic formula similar to Eq. (9) is

$$U_{peak} = U_{duration}\,(1 + A\,p) \qquad (11)$$

$$\text{Or, } A = (U_{peak}/U_{duration} - 1)/\,p \qquad (12)$$

Where “A” is the peak factor.

An example is provided as follows:

According to Table 2, the maximum 1- min wind speed was 25.0 m/s and the max 0.2-second 38.2 m/s.

According to Table 1, p= 0.185, substituting these values into Eq. (12), we get A = 2.85. Since the difference between 2.85 and 3 (see Eq. 3) is 5 %, we can say that the 0.2-second gust measurement is near the top one per cent during a one minute period. Statistically, one can also get this "A" value from the ratio of 0.2 second and one minute such that 0.2/60 = 0.0033 or within the top 1 % probability. Furthermore, from statistics (see, e.g., Spiegel, 1961, p.343), (1-0.2/60)/2 = 0.4983 so that "A" = 2.93 for areas under standard normal curve from zero to z, where z is our peak factor. Note that this value of 2.93 is even closer to 3 as shown in Eq. (9).

V. Conclusions

On the basis of aforementioned analyses and discussions, several conclusions may be drawn:

1. Because of the instrument response and system design the composite accuracy of the anemometer for field application is illustrated to be approximately within 10 %.
2. The roughness length (Zo) measurements around the 360 compass in each of the 213 ASOS stations located in tropical-cyclone prone regions have been averaged geometrically.
3. Six geometric mean Zo values have been verified during 5 hurricanes including Bonnie, Katrina, Rita, Ike, and Isaac. And
4. Applications of these geometric mean Zo values to estimate the 3-second gust, peak gust, and peak factor are provided as an example for engineers during Hurricane Katrina in 2005.

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Appendix : A list of geometric mean for Zo and power-law exponent for p.

Station ID	Station Location	City	State	Geometric mean, Zo	p, based on Hsu (2008)
K40J	Perry-Foley Airport	Perry-Foley	FL	0.113	0.208
KAAF	Apalachicola Airport	Apalachicola	FL	0.191	0.227
KABY	Albany SW GA Regional Airport	Albany	GA	0.099	0.203
KAEX	Alexandria Intl Airport	Alexandria	LA	0.127	0.212
KAGS	Augusta Bush Field	Augusta	GA	0.165	0.221
KAHN	Athens Ben Epps Airport	Athens	GA	0.102	0.204
KAKH	Gastonia Municipal Airport	Gastonia	NC	0.339	0.25
KAKQ	Wakefield Municipal Airport	Wakefield	VA	0.479	0.265
KALB	Albany County Airport	Albany	NY	0.079	0.196
KALI	Alice International Airport	Alice	TX	0.03	0.166
KAMG	Alma Bacon County Airport	Alma	GA	0.213	0.231
KANB	Anniston Metro Airport	Anniston	AL	0.223	0.233
KAND	Anderson County Airport	Anderson	SC	0.089	0.2
KAOO	Altoona Blair County Airport	Altoona	PA	0.083	0.197
KAQW	North Adams Harriman	North Adams	MA	0.152	0.218
KARA	New Iberia Acadiana Regional	New Iberia	LA	0.154	0.219
KASD	Slidell Airport	Slidell	LA	0.322	0.248
KATL	Atlanta Hartsfield Intl Airport	Atlanta	GA	0.311	0.246
KAUS	Austin-Bergstrom Intl Airport	Austin-Bergstrom	TX	0.032	0.168
KAVL	Ashville Regional Airport	Ashville	NC	0.15	0.218
KAVP	Wilkes- Barre Scranton Intl Airport	Wilkes-Barre	PA	0.119	0.21
KBAZ	New Braunfels Municipal Airport	New Braunfels	TX	0.03	0.166
KBED	Bedford Hanscom Field	Bedford	MA	0.141	0.215
KBFD	Bradford Regional Airport	Bradford	PA	0.092	0.201
KBFM	Mobile Downtown Airport	Mobile	AL	0.15	0.218
KBGM	Binghamton Regional Airport	Binghamton	NY	0.068	0.19
KBHM	Birmingham International Airport	Birmingham	AL	0.216	0.232
KBKV	Brooksville Hernando Co. Airport	Brooksville	FL	0.149	0.218
KBLF	Bluefield Mercer Co. Airport	Bluefield	WV	0.258	0.239
KBMQ	Burnet Municipal Airport	Burnet	TX	0.329	0.249
KBOS	Boston Logan Intl Airport	Boston	MA	0.065	0.189
KBPT	Port Arthur Jefferson County	Beaumont	TX	0.035	0.17
KBRO	Brownsville S Padre Isle Intl Airport	Brownsville	TX	0.057	0.185
KBTR	Baton Rouge Ryan Airport	Baton Rouge	LA	0.186	0.226
KBUY	Burlington Alamance Rngl Airport	Burlington	NC	0.182	0.225
KBVE	Venice Phi Heliport	Venice	LA	0.153	0.219
KBVY	Beverly Municipal Airport	Beverly	MA	0.047	0.179
KBWI	Baltimore-Washington Int'l Airport	Baltimore	MD	0.089	0.2
KCAE	Columbia Metropolitan Airport	Columbia	SC	0.065	0.189
KCEU	Clemson-Oconee Co. Airport	Clemson	SC	0.083	0.197
KCEW	Crestview Bob Sikes Airport	Crestview	FL	0.216	0.232
KCHO	Charlottesville Albemarle Airport	Charlottesville	VA	0.126	0.212
KCHS	Charleston Intl Airport	Charleston	SC	0.048	0.18
KCLT	Charlotte Douglas Intl Airport	Charlotte	NC	0.056	0.185
KCOF	Cocoa Beach Patrick AF Base	Cocoa	FL	0.058	0.185
KCOT	Cotulla La Salle Co. Airport	Cotulla	TX	0.054	0.184
KCQX	Chatham Municipal Airport	Chatham	MA	0.145	0.217
KCRE	N. Myrtle Bch. Grand Strand Airport	N Myrtle Beach	SC	0.078	0.195
KCRG	Jacksonville Craig Municipal Airport	Jacksonville	FL	0.091	0.2
KCRP	Corpus Christi Intl Airport	Corpus Christi	TX	0.03	0.166
KCTY	Cross City Airport	Cross City	FL	0.082	0.197
KCUB	Columbia Owens Field Airport	Columbia	SC	0.25	0.237
KCXO	Conroe Montgomery County Airport	Conroe	AL	0.078	0.195
KCXY	Harrisburg Capital City Airport	Harrisburg	PA	0.065	0.189
KDAB	Daytona Bch Intl Airport	Daytona Beach	FL	0.092	0.201

KDAN	Danville Regional Airport	Danville	VA	0.052	0.182
KDCA	Washington Reagan National Airport	Washington	D.C.	0.043	0.177
KDCU	Decatur Pryor Field	Decatur	AL	0.043	0.176
KDDH	Bennington Morse State Airport	Bennington	VT	0.074	0.193
KDHN	Dothan Regional Airport	Dothan	AL	0.052	0.182
KDNL	Augusta Daniel Field Airport	Augusta	GA	0.092	0.201
KDRT	Del Rio International Airport	Del Rio	TX	0.034	0.17
KDTN	Shreveport Downtown Airport	Shreveport	LA	0.348	0.251
KDTS	Destin Ft. Walton Bch Airport	Destin	FL	0.301	0.245
KDWH	Houston Hooks Memorial Airport	Houston	TX	0.073	0.193
KDYL	Doylestown Airport	Doylestown	PA	0.144	0.216
KECG	Elizabeth City Coast Guard Airport	Elizabeth City	NC	0.062	0.188
KEET	Alabaster Shelby County Airport	Alabaster	AL	0.266	0.24
KELM	Elmira Corning Regional Airport	Elmira	NY	0.049	0.181
KEQY	Monroe Airport	Monroe	NC	0.079	0.195
KESF	Alexandria Esler Regional	Alexandria	LA	0.053	0.183
KEWB	New Bedford Municipal Airport	New Bedford	MA	0.093	0.201
KEWN	New Bern Craven Regional Airport	New Bern	NC	0.046	0.178
KFFC	Peachtree City Flacon Field	Atlanta	GA	0.069	0.191
KFIG	Clearfield Lawrence Airport	Clearfield	PA	0.041	0.175
KFIT	Fitchburg Municipal Airport	Fitchburg	MA	0.093	0.201
KFLL	Ft Lauderdale/Hollywood Intl Airport	Ft. Lauderdale	FL	0.087	0.199
KFLO	Florence Regional Airport	Florence	SC	0.034	0.17
KFMY	Ft Myers Page Field	Ft. Myers	FL	0.102	0.204
KFPR	Ft. Pierce/St. Lucie Co. Intl	Ft. Pierce	FL	0.157	0.219
KFTY	Atlanta Fulton Co Airport	Atlanta	GA	0.084	0.198
KFWN	Sussex Airport	Sussex	NJ	0.201	0.229
KFXE	Ft. Lauderdale Executive Airport	Ft. Lauderdale	FL	0.091	0.2
KGED	Georgetown Sussex Co Airport	Georgetown	DE	0.077	0.195
KGFL	Glens Falls Airport	Glens Falls	NY	0.074	0.193
KGIF	Winter Haven's Gilbert Airport	Winter Haven	FL	0.059	0.186
KGLS	Galveston Scholes Airport	Galveston	TX	0.038	0.173
KGMU	Greenville Downtown Airport	Greenville	SC	0.057	0.185
KGNV	Gainesville Regional Airport	Gainesville	FL	0.049	0.181
KGPT	Gulfport - Biloxi Regional Airport	Gulfport	MS	0.135	0.214
KGRD	Greenwood County Airport	Greenwood	SC	0.078	0.195
KGSO	Greensboro Piedmont Triad Intl	Greensboro	NC	0.069	0.191
KGSP	Greer Greenville - Spartanburg Airport	Greer	SC	0.052	0.182
PGUM	Guam Intl Airport	Agana	GU	0.082	0.197
KGVL	Gainesville Lee Glimer Mem Airport	Gainesville	GA	0.076	0.195
KGZH	Evergreen Middleton Field	Evergreen	AL	0.21	0.23
KHDO	Hondo Municipal Airport	Hondo	TX	0.034	0.17
KHGR	Hagerstown Washington Co. Regional	Hagerstown	MD	0.066	0.19
KHKY	Hickory Regional Airport	Hickory	NC	0.048	0.18
PHNL	Honolulu International Airport	Honolulu	HI	0.034	0.17
KHOU	Houston William P Hobby Airport	Houston	TX	0.043	0.177
KHRL	Harlingen Rio Grande Valley Airport	Harlingen	TX	0.03	0.166
KHSE	Hatteras Billy Mitchell Field	Cape Hatteras	NC	0.232	0.234
KHSV	Huntsville International/ Jones Field	Huntsville	AL	0.03	0.166
KHYA	Hyannis Barnstable Municipal Airport	Hyannis	MA	0.045	0.178
KIAD	Washington DC Dulles Intl Airport	Washington	DC	0.068	0.191
KIAH	Houston Bush Intercontinental Airport	Houston	TX	0.057	0.185
KIGX	Chapel Hill Williams Airport	Chapel Hill	NC	0.125	0.211
KIJD	Willimantic Windham Airport	Willimantic	CT	0.054	0.184
KILM	Wilmington Intl Airport	Wilmington	NC	0.056	0.185
KIPT	Williamsport Lycoming County Regional Airport	Williamsport	PA	0.063	0.188
KISP	Islip Long Island Macarthur Airport	Islip	NY	0.045	0.178
PITO	Hilo Intl Airport	Hilo	HI	0.038	0.173

KJAX	Jacksonville International Airport	Jacksonville	FL	0.034	0.17
KJFK	New York J F Kennedy Intl Airport	New York	NY	0.034	0.17
TJSJ	Luis Munoz Marin Intl Airport	San Juan	PR	0.073	0.193
KJST	Johnstown Cambria Airport	Johnstown	PA	0.038	0.173
PKOA	Kailua Kona Ke-Ahole Airport	Kailua	HI	0.03	0.166
KLBT	Lumberton Municipal Airport	Lumberton	NC	0.035	0.17
KLBX	Angleton / Lake Jackson Brazoria Airport	Angleton	TX	0.064	0.189
KLCH	Lake Charles Regional Airport	Lake Charles	LA	0.052	0.182
KLEE	Leesburg Municipal Airport	Leesburg	FL	0.052	0.182
KLFK	Lufkin Angelina City Airport	Lufkin	TX	0.066	0.19
KLFT	Lafayette Regional Airport	Lafayette	LA	0.04	0.174
PLIH	Lihue Airport	Lihue	HI	0.038	0.173
KLNS	Elizabethtown	Lititz	PA	0.034	0.17
KLVJ	Houston Clover Field	Houston	TX	0.091	0.2
KLWN	Lawrence Municipal Airport	Lawrence	MA	0.052	0.182
KLYH	Lynchburg Airport	Lynchburg	VA	0.076	0.194
KMAI	Marianna Municipal Airport	Marianna	FL	0.163	0.221
KMCB	McComb Pike County Airport	McComb	MS	0.054	0.184
KMCN	Macon Middle Regional Airport	Macon	GA	0.036	0.172
KMCO	Orlando Intl Airport	Orlando	FL	0.031	0.167
KMDT	Middletown Harrisburg Intl Airport	Harrisburg	PA	0.046	0.178
KMFE	McAllen Miller Intl Airport	McAllen	TX	0.039	0.173
KMGM	Montgomery Donnelly Airport	Montgomery	AL	0.096	0.202
KMIA	Miami International Airport	Miami	FL	0.032	0.168
PMKK	Molokai Kaunakakai Molokai Airport	Kaunakakai	HI	0.047	0.179
KMLB	Melbourne International Airport	Melbourne	FL	0.043	0.177
KMOB	Mobile Regional Airport	Mobile	AL	0.195	0.228
KMPO	Mount Pocono Pocono Mountains	Mount Pocono	PA	0.061	0.187
KMRH	Beaufort M Smith Field Airport	Beaufort	NC	0.036	0.172
KMSL	Muscle Shoals Regional Airport	Muscle Shoals	AL	0.035	0.17
KMSY	New Orleans International Airport	New Orleans	LA	0.18	0.225
KMVY	Martha's Vineyard Airport	Vineyard Haven	MA	0.043	0.177
KNEW	New Orleans Lakefront Airport	New Orleans	LA	0.055	0.184
KNGP	Corpus Christi Naval Air Station	Corpus Christi	TX	0.091	0.2
KNGW	Cabaniss Navy Auxiliary Landing Field	Cabaniss	TX	0.03	0.166
KNQI	Kingsville	Kingsville	TX	0.065	0.189
KOFP	Richmond Ashland Hanover Co.	Richmond	VA	0.069	0.191
KOGB	Orangeburg Airport	Orangeburg	SC	0.221	0.232
POGG	Kahului Airport	Kahului	HI	0.032	0.168
KOPF	Miami Opa Locka Airport	Miami	FL	0.03	0.166
KORE	Orange Municipal Airport	Orange	MA	0.034	0.17
KORF	Norfolk International Airport	Norfolk	VA	0.041	0.175
KORL	Orlando Executive Airport	Orlando	FL	0.034	0.17
KOWD	Norwood Memorial Airport	Norwood	MA	0.06	0.187
KOXB	Ocean City Municipal Airport	Ocean City	MD	0.042	0.176
KP92	Salt Point	Salt Point	LA	0.113	0.208
KPDK	Atlanta DeKalb - Peachtree Airport	Atlanta	GA	0.041	0.175
KPEO	Penn Yan Airport	Penn Yan	NY	0.052	0.183
KPFN	Panama City-Bay County Airport	Panama City	FL	0.164	0.221
KPGD	Punta Gorda Charlotte County Airport	Punta Gorda	FL	0.032	0.168
KPHF	Newport News International Airport	Newport News	VA	0.045	0.178
KPIE	St. Petersburg/Clearwater Airport	St. Petersburg	FL	0.036	0.172
KPIL	Port Isabel Cameron County Airport	Port Isabel	TX	0.042	0.176
KPNS	Pensacola Regional Airport	Pensacola	FL	0.039	0.174
KPOU	Poughkeepsie Dutchess Co Airport	Poughkeepsie	NY	0.05	0.181
KPQL	Pascagoula Lott Intl Airport	Pascagoula	MS	0.12	0.21
KPSF	Pittsfield Municipal Airport	Pittsfield	NY	0.068	0.19
KPTW	Pottstown Limerick Airport	Pottstown	PA	0.051	0.182

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KPVD	Providence Green State Airport	Providence	RI	0.03	0.166
KPYM	Plymouth Municipal Airport	Plymouth	MA	0.087	0.199
KRDU	Raleigh Durham International	Raleigh	NC	0.049	0.18
KRIC	Richmond Intl Airport	Richmond	VA	0.041	0.175
KRKP	Rockport Aransas Municipal Airport	Rockport	TX	0.046	0.178
KRMG	Rome RB Russell Airport	Rome	GA	0.034	0.17
KROA	Roanoke Regional Airport	Roanoke	VA	0.036	0.172
KRSW	Ft. Myers SW Regional Airport	Ft. Myers	FL	0.076	0.194
KRWI	Rocky Mount Wilson Airport	Rocky Mount	NC	0.039	0.174
KSAT	San Antonio International Airport	San Antonio	TX	0.034	0.17
KSAV	Savannah Intl Airport	Savannah	GA	0.049	0.18
KSBY	Salisbury Wicomico Rgnl Airport	Salisbury	MD	0.052	0.182
KSEG	Selinsgrove Penn Valley Airport	Selinsgrove	PA	0.036	0.172
KSFB	Orlando Sanford Airport	Orlando	FL	0.073	0.193
KSHV	Shreveport Regional Airport	Shreveport	LA	0.035	0.17
KSMQ	Somerville Somerset Airport	Somerville	NJ	0.138	0.215
KSPG	St. Petersburg Albert-Whitted Airport	St. Petersburg	FL	0.043	0.176
KSRQ	Sarasota-Bradenton Airport	Sarasota	FL	0.054	0.184
KSSF	San Antonio Stinson Municipal Airport	San Antonio	TX	0.032	0.168
KSSI	Brunswick Malcolm McKinnon Airport	Brunswick	GA	0.032	0.168
TSTT	Charlotte Amalie Cyril E. King Intl Airport	Charlotte Amalie	St. Tomas USVI	0.034	0.17
TSTX	Christiansted Airport	Christiansted	St. Croix USVI	0.032	0.168
KSYR	Syracuse Hancock Intl Airport	Syracuse	NY	0.03	0.166
KTAN	Taunton Municipal Airport	Taunton	MA	0.08	0.196
KTCL	Tuscaloosa Regional Airport	Tuscaloosa	AL	0.165	0.221
KTHV	York Municipal Airport	York	PA	0.045	0.178
KTLH	Tallahassee Rngl Airport	Tallahassee	FL	0.159	0.22
KTOI	Troy Municipal Airport	Troy	AL	0.058	0.186
KTPA	Tampa International Airport	Tampa	FL	0.039	0.173
KUCA	Utica Oneida County Airport	Utica	NY	0.034	0.17
KUTS	Huntsville Municipal Airport	Huntsville	AL	0.141	0.216
KUUU	Newport State Airport	Newport	RI	0.046	0.179
KUZA	Rock Hill York County Airport	Rock Hill	SC	0.048	0.18
KVAY	Mount Holly South Jersey Regional	Mount Holly	NJ	0.078	0.195
KVCT	Victoria Regional Airport	Victoria	TX	0.03	0.166
KVLD	Valdosta Regional Airport	Valdosta	GA	0.052	0.182
KVRB	Vero Beach Municipal Airport	Vero Beach	FL	0.032	0.168
KWAL	Wallops Island Wallops Flight	Wallops Island	VA	0.045	0.178
KWST	Westerly State Airport	Westerly	RI	0.054	0.183