# SPATIAL VARIATIONS IN GUST FACTOR ACROSS THE COASTAL ZONE DURING HURRICANE OPAL IN 1995

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***Abstract***

*On 4 October 1995, Hurricane Opal made landfall near Pensacola Beach, Florida, as a marginal category 3 hurricane. On the basis of extensive surface wind data (including 4 buoys, 5 C-MAN and 32 land stations compiled by Lawrence et al. in 1998) the peak gust was found to be approximately 30%, 40% and 50% higher than the sustained wind speed across the coastal zone from deep water, near shoreline and on inland environments, respectively. These spatial variations are explained statistically and physically. Two formulas relating the gust factor and the exponent of the power-law wind profile are proposed for onshore and offshore applications.*

## 1. Introduction

The gust factor is defined as the ratio of the maximum gust speed to the sustained wind speed (e.g., Simpson and Riehl 1981, p. 205). On the other hand, Panofsky and Dutton (1984, p. 376) suggest that, for a quick estimate of wind maxima,

$$u_{max} = \bar{u} + 3\sigma_u \quad (1)$$

where $u_{max}$ is an estimate of the wind maximum, $u$ is the mean wind speed, and $\sigma_u$ is the standard deviation of the horizontal wind speed (downwind direction).

From a statistical viewpoint, Eq. (1) says that $u_{max}$ is approximately the peak wind speed at 99.73%. Now, if we also assume $u_{gust} = u_{max}$ then Eq. (1) becomes

$$G = \frac{u_{gust}}{\bar{u}} = 1 + 3\frac{\sigma_u}{\bar{u}} \quad (2)$$

where G is the gust factor, $u_{gust}$ is the maximum gust speed, and $\frac{\sigma_u}{\bar{u}}$ is the turbulence intensity in the down wind direction. Note that the turbulence intensity is defined as the ratio of the standard deviation over the mean, which is also called the coefficient of variation in statistics. Eq. (2) states that the gust factor is linearly related to the turbulence intensity along the x-axis, which is parallel with the horizontal wind direction. Because the turbulence intensity varies with the sampling period, height, stability, terrain, and other factors (i.e., anemometer type, exposure, and instrument response), G also varies with those parameters (e.g., Roll 1965, pp. 167 - 171; Simpson and Riehl 1981, p. 200; and Panofsky and Dutton 1984, p. 303).

Across the coastal zone, Atkinson (1971, pp. 9-23 and 9-25) suggests that the 50% gust factor is typical of inland stations while over the ocean or at coastal stations with little frictional influences a 20% gust factor would be expected. The purpose of this study is to first verify Eq. (2). If the verification is acceptable for operational use, a better parameterization scheme will be proposed employing turbulence intensity data which are now readily available. Finally, further verification of this improved parameterization will be made and applied to the G variation across the coastal zone.

## 2. Parameterization of Equation (2)

From Eq. (2), we have

$$G = 1 + 3\left(\frac{\sigma_u}{u_*}\right)\left(\frac{u_*}{\bar{u}}\right) \quad (3)$$

where $u_*$ is the friction (or shear) velocity.

According to Panofsky and Dutton (1984, p. 377), in strong winds when mechanical turbulence dominates, the stability is neutral such that

$$\sigma_u = 2.4\,u_* \quad (4a)$$

for onshore use and for offshore applications, according to Geernaert et al. (1987)

$$\sigma_u = 2.253\,u_* \quad (4b)$$

From Hsu (1988, p. 200), under neutral conditions,

$$\frac{u_*}{\bar{u}} = \kappa p \quad (5)$$

where K (= 0.4) is the von Karman constant and $p$ is the exponent of the power-law wind profile. Substituting Eqs. (4) and (5) into (3) under hurricane conditions, one obtains for onshore applications

$$G = 1 + 3 \times 2.4 \times 0.4p = 1 + 2.88p \quad (6a)$$

and for offshore

$$G = 1 + 2.70p \quad (6b)$$

**Table 1.** The gust factor associated with Hurricane Opal in 1995 based on data provided in Lawrence et al. (1998). Only measured sustained winds and peak gusts are included in this analysis.

| | Sustained Wind (m $s^{-1}$) | Peak Gust (m $s^{-1}$) | Gust Factor |
|---|---|---|---|
| Buoy Stations | | | |
| 42001 | 27 | 34 | 1.26 |
| 42003 | 22 | 28 | 1.27 |
| 42007 | 27 | 35 | 1.30 |
| 42036 | 18 | 22 | 1.22 |
| Buoy Station Mean | | | 1.26 |
| C-MAN Stations | | | |
| Grand Isle (GDIL1) | 21 | 27 | 1.29 |
| S.W. Pass (BURL1) | 33 | 39 | 1.18 |
| Dauphin Is. (DPIA1) | 27 | 34 | 1.26 |
| Keaton Beach (KTNF1) | 15 | 24 | 1.60 |
| Cedar Key (CDRF1) | 16 | 24 | 1.50 |
| C-MAN Stations Mean | | | 1.37 |
| Land Stations | | | |
| Louisiana (LA) | | | |
| New Orleans (NEW) | 15 | 21 | 1.40 |
| Mississippi (MS) | | | |
| Gulfport | 15 | 20 | 1.33 |
| Meridian (MEI) | 12 | 18 | 1.50 |
| Alabama (AL) | | | |
| Evergreen | 15 | 22 | 1.47 |
| Mobile (MOB) | 17 | 26 | 1.53 |
| Downtown Mobile | 23 | 29 | 1.26 |
| Maxwell AFB (MXF) | 21 | 40 | 1.90 |
| Montgomery (MGM) | 21 | 28 | 1.33 |
| Auburn (AUB) | 12 | 23 | 1.92 |
| Birmingham (BHM) | 14 | 22 | 1.57 |
| Anniston (ANB) | 13 | 18 | 1.38 |
| Huntsville (HSV) | 19 | 25 | 1.32 |
| LA, MS, and AL Land Station Mean | | | 1.49 |
| Florida | | | |
| Pensacola (I-10 E. Bay) | 22 | 32 | 1.45 |
| Pensacola Airport (FAA) | 28 | 32 | 1.14 |
| Pensacola (NPA) | 27 | 34 | 1.26 |
| Hurlburt Field (HRT) | 38 | 64 | 1.68 |
| Eglin AFB Mesonet: | | | |
| B-71 | 28 | 46 | 1.64 |
| C-52N | 28 | 45 | 1.61 |
| C-72 | 28 | 44 | 1.57 |
| Panama City (PAM) | 28 | 38 | 1.36 |
| Appalachicola (AQQ) | 14 | 26 | 1.86 |
| Tallahassee (TLH) | 14 | 23 | 1.64 |
| Turkey Point (TURF) | 19 | 31 | 1.63 |
| Brooksville (BKV) | 10 | 14 | 1.40 |
| New Port Richey | 12 | 16 | 1.33 |
| Tampa (TPA) | 11 | 20 | 1.82 |
| St. Petersburg (PIE) | 13 | 20 | 1.54 |
| Sarasota | 14 | 19 | 1.36 |
| Winter Haven | 15 | 19 | 1.27 |
| Florida Land Station Mean | | | 1.50 |
| Georgia | | | |
| Warner Robins AFB | 15 | 23 | 1.53 |
| Atlanta (ATL) | 14 | 22 | 1.57 |
| Marietta | 12 | 31 | 2.58 |
| All Land Station Mean | | | 1.54 |

Eq. (6) is our proposed formula to estimate the gust factor for on- and off-shore applications under hurricane conditions. However, this equation must be verified before we can proceed to study the variability of G across a coastal zone experiencing hurricane effects.

Measurements taken during Hurricane Opal (1995) will be used due to the extensive data set available as compiled by Lawrence et al. (1998) and shown in Table 1 in which a strong peak gust of 64 m $s^{-1}$ or 143 mph was recorded at Hurlburt Field in Florida.

## 3. Verification of Equation (6b)

Over the water, p is approximately 0.10 (see Simpson and Riehl 1981, p. 201; Hsu 1988, pp. 199 - 203; and Hsu et al. 1994). Substituting this value into Eq. (6b), one gets G = 1.27. During Hurricane Opal (1995) (see Lawrence et al. 1998) the mean G from offshore buoy stations shown in Table 1 was 1.26 with a standard deviation (s.d.) of 0.03. Since the coefficient of variation (= s.d. / mean) is only 3% for the buoy stations ranging from the deep Gulf of Mexico (Buoys # 42001 and 42003) to the coastal waters (Buoy 42007) via shelf water (Buoy 42036), Eq. (6b) is useful for overwater applications.

## 4. Variations Across the Coastal Zone

According to Lawrence et al. (1998), Hurricane Opal made landfall at Pensacola Beach, Florida, near 2200 UTC 4 October 1995. As discussed previously, if we use p = 0.10 for offshore conditions, G = 1.27. This is in good agreement with G = 1.26 from the buoy measurements shown in Table 1. If one uses p = 0.14 for open country near the coastline (see Simpson and Riehl 1981, p. 202) as represented by the C-MAN stations, G = 1.40. Again, this is in fair agreement with that of 1.37 shown in Table 1 for C-MAN measurements. Further, this G (= 1.40) value is in excellent agreement with G (= 1.39) as obtained by Powell (1982, Table 2, p. 1928) along the shoreline region during Hurricane Frederic (1979).

For suburban and wooded areas, p = 0.22 (see Simpson and Riehl 1981, p. 202). Substituting this value into Eq. (6a), G = 1.63. However, the mean G for all measurements shown in Table 1 is 1.54. This discrepancy may be explained by the fact that some airports are located in the open country rather than in the suburban areas. Note that the aerodynamic roughness over the airport is smaller than that over the suburban region, where the wind experiences more resistance because of obstacles presented by cities or towns. If one takes the average condition of p (= 0.18) for those land stations as between the open country near the coastline (p = 0.14) and those of suburban and wooded areas (p = 0.22), G = 1.52, which is in good agreement with the mean value of 1.54 for all land-based stations.

Table 1 also shows that the mean G from Louisiana, Mississippi, and Alabama was 1.49 and for Florida was 1.50. In other words, the difference in G between the east and the west of the storm track is negligible.

## 5. Concluding Remarks

During Hurricane Opal (1995) the gust factor was found to vary from approximately 1.3 over the Gulf of Mexico to 1.4 over the shoreline and to 1.5 further inland. These spatial variations are found to be related to the turbulence intensity which is in turn correlated to the exponent of the power-law wind profile. For operational applications, Eq. (6) is proposed to estimate the gust factor. Since this is a generalized formula, a proper exponent value must be used for site-specific investigations. Also, the 3 standard deviation as suggested in Eq. (1) by Panofsky and Dutton (1984) is not a rigid value but for practical usage, it is an excellent choice.


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Dr. S. A. Hsu has been a Professor of Meteorology at LSU since 1969, after he received 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.

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