ON THE RADIAL VARIATION OF THE TANGENTIAL WIND SPEED OUTSIDE THE RADIUS OF MAXIMUM WIND DURING HURRICANE WILMA (2005)

Brian W. Blanchard and S. A. Hsu

Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana 70803

Abstract

The radial variation of the tangential wind speed (V_r) outside the radius of maximum wind (R_{max}) in a hurricane has been formulated in the literature that $V_r = V_{max} (R_{max}/r)^x$ where V_{max} is the maximum wind, r is the distance from R_{max}, and x is an exponent. When Hurricane Wilma was over the northwest Caribbean Sea in October 2005, the National Data Buoy Center (NDBC) operated two buoys with wind speed measurement at 10 m. Since both buoys were located on the right-hand side of the track, this provides a good opportunity to determine the exponent x objectively. It is found that, based on 27 samples, x = 0.62 ± 0.18. This result is in good agreement with the value of 0.7 found in the literature.

1. Introduction

Wilma formed from a large area of disturbed weather in the Caribbean Sea in October 2005. A surface low pressure system gradually became defined near Jamaica and a tropical depression developed about 215 miles southeast of Grand Cayman on 15 October. The cyclone moved erratically southward for about two days while strengthening into a tropical storm. Wilma became a hurricane and began a west-northwestward motion on 18 October. Later that day the storm strengthened rapidly, and on 19 October became a Category 5 on the Saffir-Simpson scale. The minimal central pressure dropped to an estimated 882 mb, while the small eye was centered about 365 miles southeast of Cozumel. On 20 October Wilma weakened slightly and turned northwestward, making landfall over Cozumel on 21 October and the northeastern Yucatan on 22 October. The storm emerged over the southern Gulf of Mexico on 23 October, weakened to a Category 2. It then turned northeastward and accelerated toward south Florida. It re-strengthened to a Category 3 before making landfall near Cape Romano, Florida on 24 October. After rapidly crossing the south Florida peninsula, Wilma traced northeastward over the western Altantic and eventually lost tropical characteristics by 25 October (Pasch et al., 2006).

According to Anthes (1982) and Hsu and Babin (2005), the radial variation of the tangential wind speed beyond R_{max} (the radius of maximum wind) in a mature tropical cyclone can be described by

$$V_r = V_{max} \left(\frac{R_{max}}{r} \right)^x \quad \textbf{(1)}$$

where $R_{max} \le r \le r_0$, and r_0 is a large radial distance near the edge of the area disturbed by the storm (generally about 1000 km), V_r is the wind speed at distance r, V_{max} is the maximum wind speed, and the exponent x has a typical value of 0.7 for near surface winds. Note that x is variable with height.

Values of R_{max} are usually obtained by direct aircraft measurement, or by pressure distribution at the sea surface. More recently, Hsu and Babin (2005) demonstrated that R_{max} may be determined from satellite imagery. Regardless of method, accurate and current values of R_{max} are frequently not available.

The passage of Wilma through the western Caribbean provided a unique measurement opportunity. Two National Data Buoy Center (NDBC) 10 m buoys, numbers 42056 (19°52'27"N 85°03'33"W) and 42057 (17°36'16"N 80°44'58"W), were located to the north of the storm track, and at the minimum, approximately 100 km (about 62 miles) from the storm center. During the period described in Section 2, the effects of Wilma encompassed both buoy locations. Since V_r was continuously recorded, a ratio of Eq. (1) yields

$$\frac{\dfrac{V_{r\,42056}}{V_{max}} = \left(\dfrac{R_{max}}{r_{42056}}\right)^x}{\dfrac{V_{r\,42057}}{V_{max}} = \left(\dfrac{R_{max}}{r_{42057}}\right)^x} \qquad \textbf{(2)}$$

Canceling like terms and taking the natural log on both sides gives

$$\ln\left(\frac{V_{r\,42056}}{V_{r\,42057}}\right) = x \ln\left(\frac{r_{42057}}{r_{42056}}\right) \qquad \textbf{(3)}$$

Hence

$$x = \frac{\ln\left(\dfrac{V_{r\,42056}}{V_{r\,42057}}\right)}{\ln\left(\dfrac{r_{42057}}{r_{42056}}\right)} \qquad \textbf{(4)}$$

The purpose of this brief paper is to verify the value of the exponent x using wind data from the two buoys while under the influence of tropical cyclone Wilma.

2. Data Set

The period of 00Z October 18 through 18Z October 21, 2005 was selected. As shown by the tracks in Fig. 1, the center of Wilma tracked generally northwestward over the warm western Caribbean before impacting Cozumel. Wilma reached her maximum intensity (estimated central pressure of 882 mb and maximum sustained winds of 184 mph) during October 19, approximately 1/3 of the way along the track depicted.

Storm positions were obtained from the National Hurricane Center Advisories as issued during the study period. In Fig. 1, these positions (in green) are compared to the 'best track' as depicted by the dotted orange line (Pasch et al., 2006). Because the Advisories allow a greater sample size (3-hour interval whereas best track is 6-hour) and the position differences are relatively small, we use the Advisory locations here. For each Advisory time, the corresponding GOES-12 channel 4 (IR) image was analyzed. Distances from the storm center to buoys 42056 and 42057 were acquired from the imagery (see example in Fig. 2). The image-derived distance values were then verified via an on-line latitude/longitude distance calculator (www.wcrl.ars.usda.gov/cec/java/lat-long.htm). Since the root mean square error between the image-derived and computed distances was only 2.7 km, we continue with the computed values as listed in Table 1.

3. Results

Table 1 lists the measurements and results. Four data records were mathematically excluded: the first three where V_r at both stations was within 1 m/s, and record 16 where distances r where nearly equal (since ln (1) = 0). Neglecting these records leaves 28 samples, and produces a mean and standard deviation x of 0.61 ± 0.19.

After the first three records in Table 1, the next four samples all have $x < 0.4$. Two possible explanations are advanced. First, Wilma reached hurricane intensity at 12Z October 18 (record 5). Since Eq. (1) is applied to 'mature' cyclones, records prior to this time may reflect the storm's formative stages before hurricane circulation was established. The second, and more likely, possibility is that buoy 42056 was too distant from the circulation induced by Wilma during these early hours. From the meteorological time series shown in Fig. 3, conditions at 42056 began to change significantly around mid-morning on October 19. Nevertheless, if we remove only the fourth record (prior to Wilma reaching hurricane strength) the result is mean and standard deviation x of 0.62 ± 0.18 with 27 samples.

4. Conclusion

Near surface (10 m) wind speed data from two buoys in the western Caribbean Sea recorded during the nearby passage of tropical cyclone Wilma in October 2005 are used to estimate the exponent needed for accurate computation of tangential wind speed at a point away from the storm center and radius of maximum wind (Eq. 1). Results achieved under hurricane conditions are $x = 0.62 \pm 0.18$, in good agreement with the value of 0.7 found in the literature.

5. References

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Brian W. Blanchard has been a Research Meteorologist at the Coastal Studies Institute, Louisiana State University since 1983, after earning his B.S. in Atmospheric Sciences from the University of Louisiana at Monroe (formerly NLU). He has co-authored several scientific journal papers, and has served as primary author on technical reports and contract deliverables. He can be reached at the LSU Coastal Studies Institute, 412 Howe-Russell Geoscience Building, Baton Rouge, LA 70803. Email: bblanc5@lsu.edu.

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, LA 70803-7527. Email: sahsu@lsu.edu.

Figure 1. MODIS visible image showing the track of Wilma through the Caribbean Sea and the location of the two NDBC buoys. Advisory positions are in green, best track is in orange.

Figure 2. An example of the GOES-12 IR imagery used to determine the distances from the eye of Wilma to the two buoy locations.

Figure 3. Hourly time series of selected parameters recorded at NDBC 42056 (red line) and 42057 (blue line) while under the influence of Wilma.

Table 1.
Measured Distances and Computed x

Advisory Time (LT) MM/DD HH	Julian Day	GMT	Eye Center	42056 V_r	42057 V_r	To 42056 (km)	To 42057 (km)	x
10/17 20EDT	291	0	15.7N 79.9W	9.5	9.3	716.2	230.2	-0.02*
10/17 23EDT	291	3	15.8N 80.2W	10.0	9.9	684.8	208.9	-0.01*
10/18 02EDT	291	6	15.7N 80.0W	11.9	10.5	708.2	226.2	-0.11*
10/18 05EDT	291	9	15.7N 80.0W	11.3	14.8	708.2	226.2	0.24
10/18 08EDT	291	12•	15.9N 80.2W	10.9	16.5	677.4	198.2	0.34
10/18 11EDT	291	15	16.5N 80.6W	12.1	18.1	601.7	123.7	0.25
10/18 14EDT	291	18	16.7N 81.1W	11.9	21.4	546.7	107.2	0.36
10/18 17EDT	291	21	16.7N 81.5W	10.7	18.6	515.1	128.3	0.40
10/18 20EDT	292	0	16.7N 81.8W	10.8	21.4	492.6	150.1	0.58
10/18 23EDT	292	3	16.8N 82.1W	9.0	19.5	462.7	168.9	0.77
10/19 01EDT	292	5	16.9N 82.0W	10.0	21.3	461.8	154.1	0.69
10/19 02EDT	292	6	17.0N 82.2W	8.0	20.4	439.1	167.9	0.97
10/19 05EDT	292	9	17.2N 82.5W	11.1	18.3	401.2	191.0	0.67
10/19 08EDT	292	12	17.2N 82.8W	11.5	17.9	380.7	222.0	0.82
10/19 11EDT	292	15	17.4N 83.2W	14.0	17.7	337.5	260.7	0.91
10/19 14EDT	292	18	17.5N 83.5W	15.5	14.1	310.7	291.6	-1.49*
10/19 17EDT	292	21	17.7N 83.7W	17.0	15.6	280.7	312.6	0.80
10/19 20EDT	293	0	17.9N 83.9W	17.2	13.9	250.9	335.0	0.74
10/19 23EDT	293	3	18.1N 84.3W	19.4	13.2	212.7	379.5	0.67
10/20 02EDT	293	6	18.1N 84.7W	23.6	12.9	200.7	421.5	0.81
10/20 04CDT	293	9	18.3N 85.0W	21.5	11.6	175.0	455.9	0.64
10/20 07CDT	293	12	18.3N 85.2W	20.3	13.3	175.5	476.8	0.42
10/20 10CDT	293	15	18.4N 85.5W	20.9	12.5	170.2	509.7	0.47

10/20 13CDT	293	18	18.6N 85.5W	21.8	13.5	148.9	513.8	0.39
10/20 16CDT	293	21	18.9N 85.7W	25.3	12.0	127.4	541.9	0.52
10/20 19CDT	294	0	19.1N 85.9W	29.5	12.0	123.1	568.0	0.59
10/20 22CDT	294	3	19.3N 86.0W	30.7	11.2	117.4	584.6	0.63
10/21 01CDT	294	6	19.5N 86.1W	31.5	10.1	116.6	601.7	0.69
10/21 04CDT	294	9	20.0N 86.2W	29.2	9.1	120.0	632.1	0.70
10/21 07CDT	294	12	20.1N 86.3W	26.3	9.7	132.0	646.1	0.63
10/21 10CDT	294	15	20.2N 86.5W	24.3	8.9	154.7	669.7	0.69
10/213CDT	294	18	20.4N 86.7W	21.6	8.3	108.9	698.0	0.71
Mean (* excluded)								0.61
St. Dev. (* excluded)								0.19

· Becomes Hurricane
Lowest Central Pressure

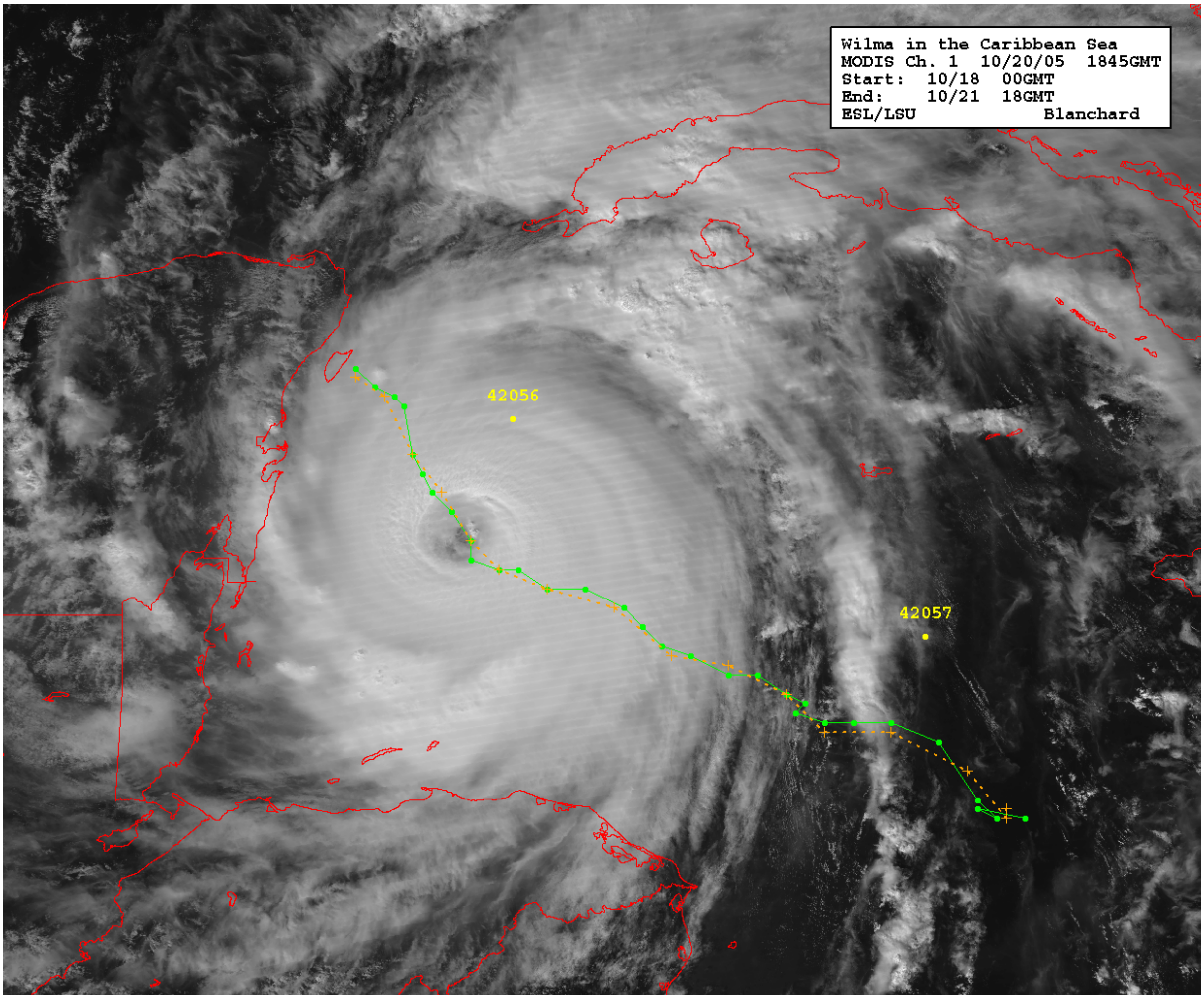

Wilma in the Caribbean Sea
MODIS Ch. 1 10/20/05 1845GMT
Start: 10/18 00GMT
End: 10/21 18GMT
ESL/LSU Blanchard
42056
42057

Figure 1

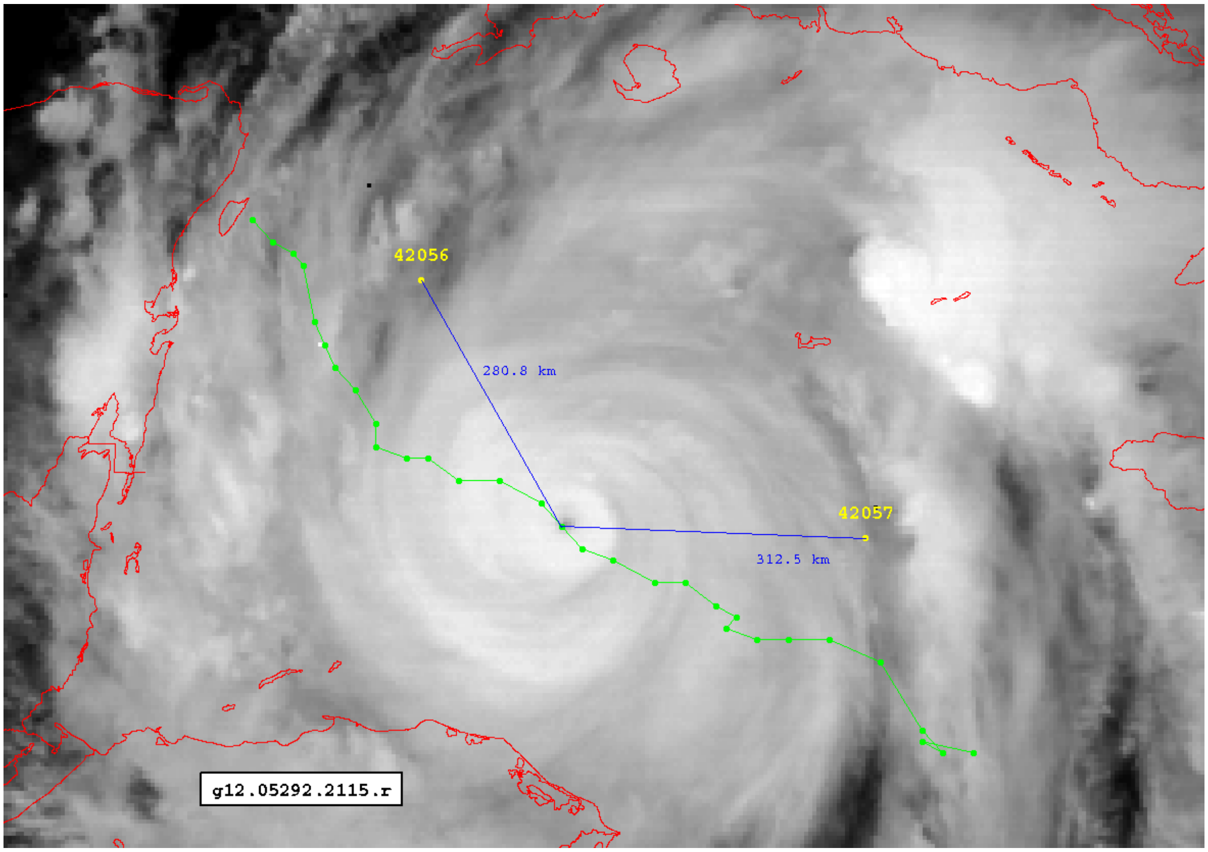
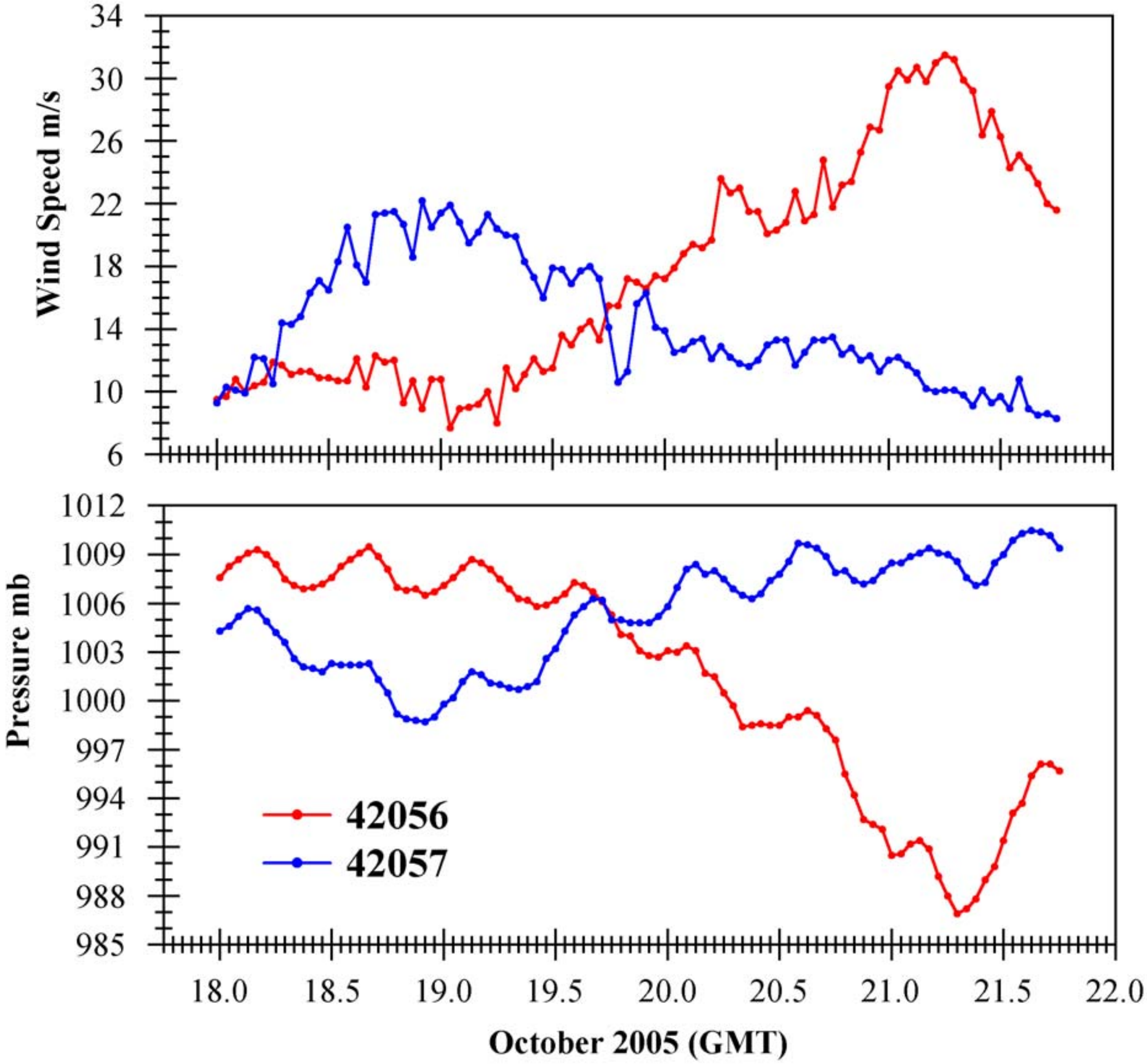


Figure 2



Wind Speed m/s
34
30
26
22
18
14
10
6
Pressure mb
1012
1009
1006
1003
1000
997
994
991
988
985
42056
42057
18.0
18.5
19.0
19.5
20.0
20.5
21.0
21.5
22.0
October 2005 (GMT)

Figure 3