Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 15 Issue 1 Version 1.0 Year 2015
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Relations between Sea Surface Roughness, Wind Speed at 10m, and Wave Parameters during a Tropical Cyclone

By Professor S. A. Hsu

Louisiana State University, United States

Abstract- Measurements of wind and wave parameters during Hurricanes Kate and Lili and Typhoons Man-Yi and Krosa are analyzed. It is found that the wave characteristics are similar in both hurricane and typhoon. Relations amongst sea surface roughness, wind speed at 10m, and wave parameters are also formulated and presented for engineering applications.

Keywords: sea surface roughness, waves during a tropical cyclone, hurricane kate, hurricane lili, typhoon man-yi, and typhoon krosa.

GJSFR-H Classification : FOR Code: 300899

Strictly as per the compliance and regulations of :

Relations between Sea Surface Roughness, Wind Speed at 10m, and Wave Parameters during a Tropical Cyclone

Professor S. A. Hsu

Abstract- Measurements of wind and wave parameters during Hurricanes Kate and Lili and Typhoons Man-Yi and Krosa are analyzed. It is found that the wave characteristics are similar in both hurricane and typhoon. Relations amongst sea surface roughness, wind speed at 10m, and wave parameters are also formulated and presented for engineering applications.

Keywords: sea surface roughness, waves during a tropical cyclone, hurricane kate, hurricane lili, typhoon man-yi, and typhoon krosa.

I. INTRODUCTION

In the atmospheric boundary layer under hurricane conditions at sea, the logarithmic wind profile is valid (Hsu, 2003) so such

$$U10 = (U^*/k)\text{Ln}\,(10/Zo) \qquad (1)$$

According to Taylor and Yelland (2001),

$$Zo/Hs = 1200^*\,(Hs/Lp)\ \hat{}\ 4.5 \qquad (2)$$

$$Lp = (g/2\pi)\,Tp\ \hat{}\,2 = 1.56\,Tp\,\hat{}\,2 \qquad (3)$$

Where U10 is the wind speed at 10m, U* is the friction velocity, k (=0.4) is the von Karman constant, Zo is the aerodynamic roughness length, Hs is the significant wave height, Lp is the dominant wave length, g (=9.8 m/s^2) is the gravitational acceleration, and Tp is the dominant wave period.

In air-sea interaction studies, particularly the wind-wave interaction for engineering applications such as estimation of design winds and waves,on-site measurements ofU10, Hs, and Tp are needed but are not normally available. It is therefore the purpose of this research to find relations amongst these parameters so that if one of these parameters is known, one may use these relations to estimate the other.

II. METHODS AND DATA ANALYSIS

Simultaneous measurements of wind and wave parameters are available during Hurricane Kate in November 1985. The dataset is provided in Table 1. In order to investigate the wind-wave interaction, the effects of swell need to be minimized. According to Drennan et al (2005), the criterion to do so is to set that

$$Hs/Lp \geq 0.020 \qquad (4)$$

Wherethe parameter, Hs/Lp, is called wave steepness.

Table 1 indicates that the maximum U10 was 47.3m/s (with gust to 58.5m/s) and Hs was 10.7m at 17UTC on November 20 in 1985 at the National Data Buoy Center (NDBC) Buoy 42003 in the Gulf of Mexico.

Table 1 : Measurements of wind and wave parameters at Buoy 42003 during Kate In November 1985 (Data source: www.ndbc.noaa.gov), see text for explanation

Day	Hour, UTC	U10, m/s	Gust, m/s	Hs, m	Tp, sec	Hs/Lp
18	0	8.1	8.9	1.2	5.9	0.022
18	2	8.2	8.9	1.1	5.9	0.020
18	5	7.7	8.4	1.1	5.9	0.020
18	7	7.7	8.4	1.1	5.9	0.020
18	16	8.9	9.9	1.5	6.3	0.024
18	17	9.2	10.4	1.5	6.3	0.024
18	18	9.5	10.4	1.5	6.3	0.024
18	19	8.9	10.4	1.6	6.3	0.026
18	20	8.7	9.4	1.6	6.7	0.023

Author: Louisiana State University, Baton Rouge, LA.
e-mail: sahsu@lsu.edu

18	21	9.6	10.4	1.6	7.1	0.020
18	22	9.7	10.4	1.6	7.1	0.020
18	23	9.8	10.4	1.7	7.1	0.022
19	0	10.2	11.5	1.7	6.7	0.024
19	1	8.8	9.9	1.6	6.7	0.023
19	2	9.2	9.9	1.5	6.7	0.021
19	3	9.4	10.4	1.5	6.7	0.021
19	4	9.8	11	1.5	6.7	0.021
19	5	9.2	10.4	1.5	6.3	0.024
19	6	9.2	11	1.4	6.7	0.020
19	7	11.7	13.1	1.5	6.3	0.024
19	8	10.7	12.5	1.6	5.6	0.033
19	9	11	13.1	1.8	5.9	0.033
19	10	10.4	11.5	1.6	6.7	0.023
19	11	11.4	12.5	1.9	6.3	0.031
19	12	9.9	11.5	1.9	6.7	0.027
19	13	9.4	10.4	2	7.1	0.025
19	14	10.3	11	2.1	7.7	0.023
19	15	11	13.6	2.2	7.1	0.028
19	16	10.8	12.5	2	7.1	0.025
19	17	11.2	13.1	2	7.7	0.022
19	18	12	13.6	2	7.7	0.022
19	19	12.5	14.1	2	7.7	0.022
19	20	13.2	15.7	2	7.7	0.022
19	21	13.6	15.2	2	7.1	0.025
19	22	13.3	15.7	2.4	7.1	0.031
19	23	13.6	15.2	2.3	7.1	0.029
20	0	12	14.1	2.4	7.7	0.026
20	1	10.8	12.5	2.3	7.7	0.025
20	2	12	14.1	2.4	7.7	0.026
20	3	13.4	15.7	2.6	7.7	0.028
20	4	14.3	16.2	2.6	7.7	0.028
20	5	16.9	19.9	2.7	7.7	0.029
20	6	16.2	18.8	3.1	7.7	0.034
20	7	16.6	21.9	3.7	8.3	0.034
20	8	20	24	4.6	11.1	0.024
20	9	21.6	26.7	5.5	11.1	0.029
20	10	24.1	29.3	5.4	11.1	0.028
20	12	23.1	27.2	7.4	14.3	0.023
20	13	23.6	28.7	7.5	12.5	0.031
20	14	26	31.9	7.2	12.5	0.030
20	15	29.3	37.1	8.6	14.3	0.027
20	16	35.9	43.4	9.4	12.5	0.039
20	17	47.3	58.5	10.7	12.5	0.044
20	19	36.5	47.6	7.1	11.1	0.037
20	20	35.5	47.6	6.6	9.1	0.051
20	21	29.9	37.6	6	10	0.038

20	22	23	27.7	5.6	8.3	0.052
20	23	22.2	26.7	5.3	9.1	0.041
21	0	20.9	26.7	4.8	9.1	0.037
21	1	20.8	24.6	4.5	10	0.029
21	2	21.5	26.1	4.4	9.1	0.034
21	3	20.4	24.6	4.3	10	0.028
21	4	22.2	26.7	3.8	7.7	0.041
21	5	22.7	27.2	5.1	9.1	0.039
21	6	19.2	22.5	5.2	9.1	0.040
21	7	16.7	19.9	4.5	9.1	0.035
21	8	16.1	18.8	4.5	10	0.029
21	9	15.2	18.3	4.3	10	0.028
21	10	14.6	16.7	4.3	10	0.028
21	11	15	19.3	3.9	9.1	0.030
21	12	14	17.2	3.7	9.1	0.029
21	13	13.4	15.7	3.9	9.1	0.030
21	14	13.9	16.7	4.6	10	0.029
21	15	13.8	15.7	3.8	9.1	0.029
21	16	12.3	14.1	4.1	10	0.026
21	17	13.4	15.2	3.9	9.1	0.030
21	18	12.2	14.6	4.1	10	0.026
21	19	11.2	14.6	3.7	10	0.024
21	20	10.2	12	3.6	10	0.023
21	21	10.4	12.5	3.4	9.1	0.026
21	22	10.6	12	3.4	8.3	0.032
21	23	9.4	12.5	3.3	10	0.021

Based on the dataset as listed in Table 1, a relation between Hs and Tp is found and presented in Fig.1, which is

$$Tp = 5.56\ Hs\ ^{\wedge}0.37 \tag{5}$$

So that, from Eq.(3),

$$(Hs/Lp)\ ^{\wedge}\ 4.5 = (Hs/\ (1.56*Tp\ ^{\wedge}\ 2))\ ^{\wedge}\ 4.5 = 2.66*10^{\wedge}(-8)\ Hs^{\wedge}1.2 \tag{6}$$

Now, substituting Eq. (6) into Eq. (2), we get

$$Zo = 3.2*10\ ^{\wedge}\ (-5)*Hs\ ^{\wedge}2.2 \tag{7}$$

Therefore,

$$10/Zo = (10/(3.2*10\ ^{\wedge}\ (-5)))*\ Hs\ ^{\wedge}\ (-2.2) \tag{8}$$

Hence

$$Ln(10/Zo) = 12.7 - 2.2\ Ln\ (Hs) \tag{9}$$

Eq. (9) is also shown in Fig. 2.

Similar results for Typhoon Man-Yi are presented in Figs.3 and 4 based on the dataset provided in Table 2.

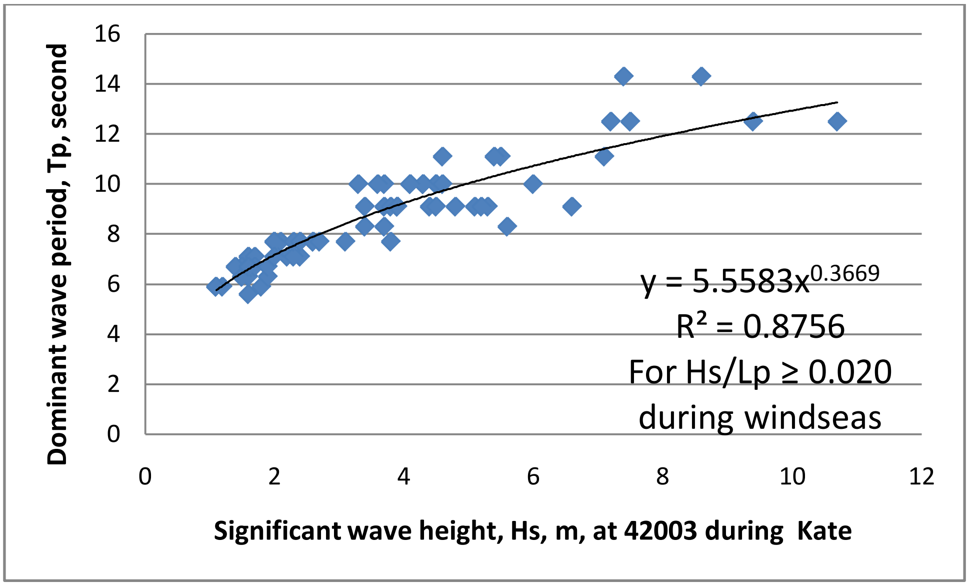

Figure 1 : A relation between significant wave height, Hs, and dominant wave period, Tp, at NDBC Buoy 42003 during Hurricane Kate in November 1985 (see Table 1)

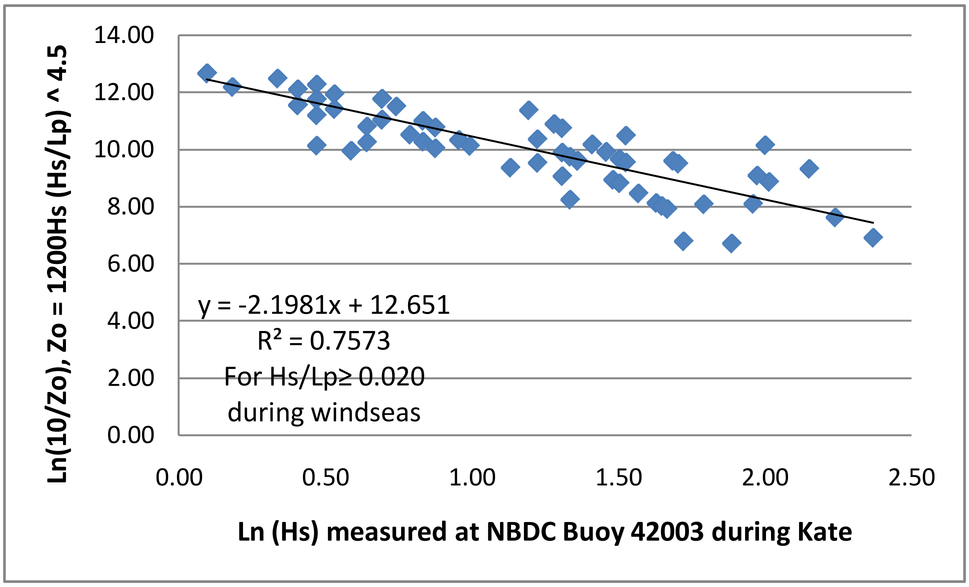

Figure 2 : A relation between sea surface roughness, Zo, and Hs during Kate

Table 2 : Wave measurements at 52200 near Guam during Typhoon Man-Yi In July 2007by Scripps Institution of Oceanography (www.ndbc.noaa.gov)

Day	Hour, UTC	Hs, m	Tp, sec	Hs/Lp	Ln(Hs)	Ln(10/Zo)
7	13	1.4	5	0.036	0.34	9.8
7	15	1.5	6	0.027	0.41	11.1
7	16	1.4	5	0.036	0.34	9.8
7	17	1.4	6	0.025	0.34	11.5
7	18	1.5	6	0.027	0.41	11.1
7	19	1.5	6	0.027	0.41	11.1
7	20	1.6	7	0.021	0.47	12.1
7	21	1.5	6	0.027	0.41	11.1

7	22	1.6	7	0.021	0.47	12.1
7	23	1.6	7	0.021	0.47	12.1
8	0	1.7	7	0.022	0.53	11.8
8	1	1.7	7	0.022	0.53	11.8
8	3	1.6	7	0.021	0.47	12.1
8	6	2	8	0.020	0.69	12.1
8	7	2	6	0.036	0.69	9.5
8	8	2.3	8	0.023	0.83	11.3
8	9	2.3	8	0.023	0.83	11.3
8	10	2.7	8	0.027	0.99	10.5
8	11	2.9	8	0.029	1.06	10.1
8	12	3.1	8	0.031	1.13	9.7
8	13	3.3	8	0.033	1.19	9.4
8	14	3.1	8	0.031	1.13	9.7
8	15	3.5	8	0.035	1.25	9.0
8	16	3.5	8	0.035	1.25	9.0
8	17	3.5	9	0.028	1.25	10.1
8	18	3.7	9	0.029	1.31	9.8
8	19	4.2	9	0.033	1.44	9.1
8	20	4.9	9	0.039	1.59	8.2
8	21	5.5	10	0.035	1.70	8.6
8	22	5.3	11	0.028	1.67	9.6
8	23	6.2	10	0.040	1.82	7.9
9	0	6.8	11	0.036	1.92	8.3
9	1	6.3	10	0.040	1.84	7.8
9	2	7	11	0.037	1.95	8.1
9	3	6.5	11	0.034	1.87	8.5
9	4	7	11	0.037	1.95	8.1
9	5	6.8	11	0.036	1.92	8.3
9	6	6.2	11	0.033	1.82	8.8
9	7	6	11	0.032	1.79	8.9
9	8	6	11	0.032	1.79	8.9
9	9	5.4	11	0.029	1.69	9.5
9	10	5.4	10	0.035	1.69	8.7
9	11	5.2	10	0.033	1.65	8.9
9	12	5.3	11	0.028	1.67	9.6
9	13	5.2	11	0.028	1.65	9.7
9	14	5	11	0.026	1.61	9.9
9	15	5.7	10	0.037	1.74	8.4
9	16	4.8	11	0.025	1.57	10.2
9	17	4.6	11	0.024	1.53	10.4
9	18	4.6	11	0.024	1.53	10.4
9	19	5	11	0.026	1.61	9.9
9	20	4.7	10	0.030	1.55	9.4
9	21	4.6	11	0.024	1.53	10.4

9	22	5.4	11	0.029	1.69	9.5
9	23	5.4	11	0.029	1.69	9.5
10	0	4.3	11	0.023	1.46	10.8
10	1	3.9	10	0.025	1.36	10.5
10	11	2.6	9	0.021	0.96	11.7
11	18	1.1	5	0.028	0.10	11.2
11	19	1.2	6	0.021	0.18	12.3
11	20	1.1	5	0.028	0.10	11.2
11	21	1.1	6	0.020	0.10	12.8
11	23	1.1	5	0.028	0.10	11.2

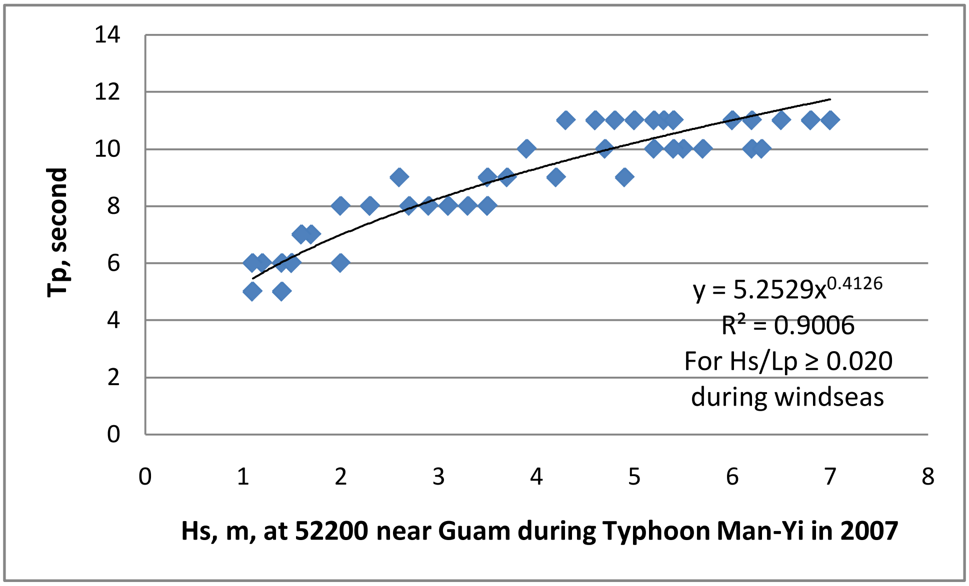

Figure 3 : A relation between Hs and Tp at Buoy 52200 near Guam during Typhoon Man-Yi in July 2007 (see Table2)

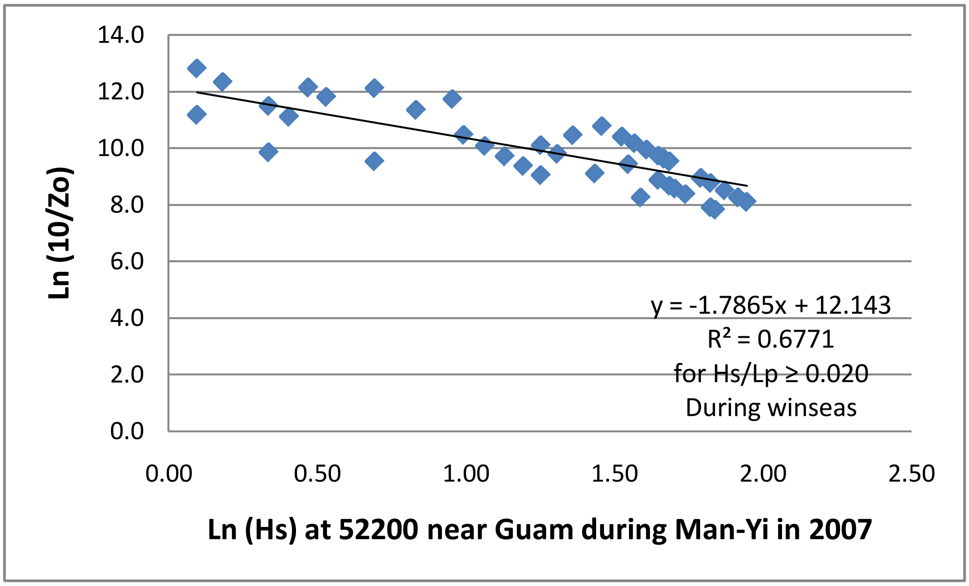

Figure 4 : A relation between Zo and Hs at Buoy 52200 near Guam during Man-Yi

III. RESULTS

According to Eq. (1) we need to find a relation between U10 and U* before we can find the relation between U10 and Hs. This is accomplished by employing the sonic anemometer measurements made over the North Sea during storms (for details, see Geernaertet al.1987). The results are presented in Fig.5, so that

$$U^* = 0.0195\ U10\ ^\wedge\ 1.285 \qquad (10)$$

A comparison of Eqs. (1) and (10) is presented in Fig. 6. Since they are nearly identical, we can say that both equations are useful. Now, from Eqs. (1), (9), and (10), we derive the relation between U10 and Hs as follows:

$$U10 = (21/(12.7 - 2.2\ \mathrm{Ln}\ (Hs)))\ ^\wedge\ 3.5 \qquad (11)$$

Eq. (11) is presented in Fig.7, which is further simplified as

$$Hs = 0.27\ U10 \qquad (12)$$

Since the coefficient of determination, R^2 (= 0.99), is almost perfect, Eq.(12) is recommended for practical applications.

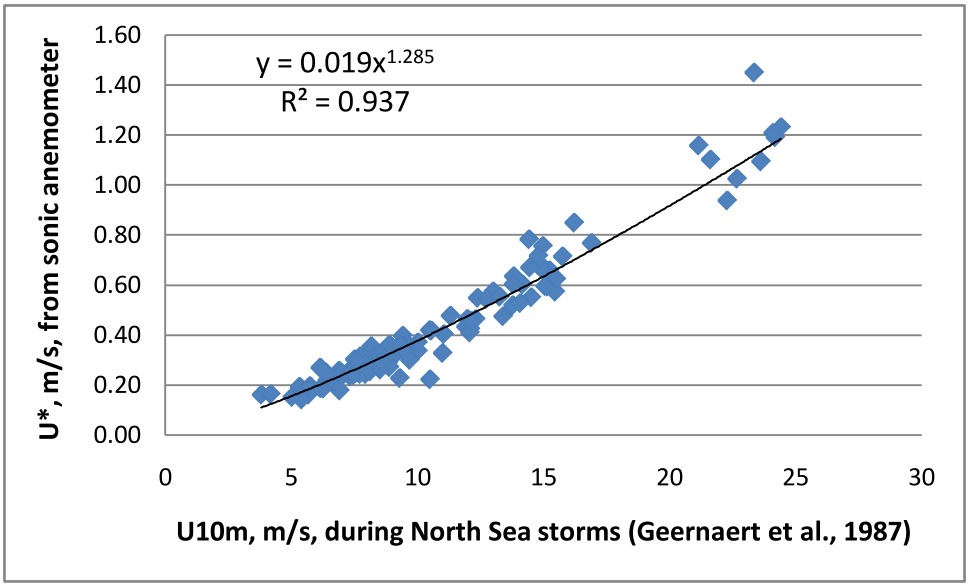

Figure 5 : A relation between U* and U10 as measured during Storms over the North Sea by sonic anemometers (Data source: Geernaert et al., 1987)

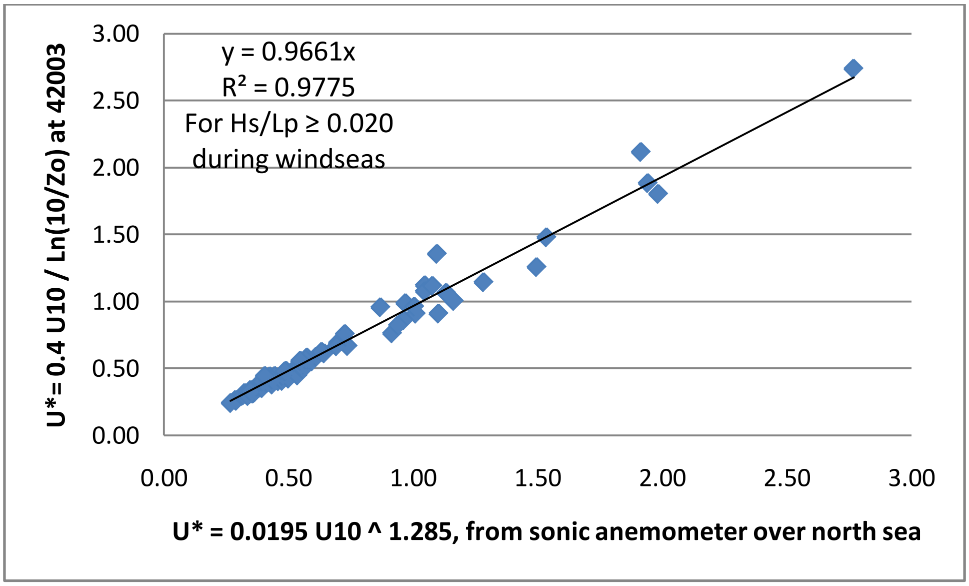

Figure 6 : A comparison of Eqs. (1) and (10) using the dataset provided in Table 1

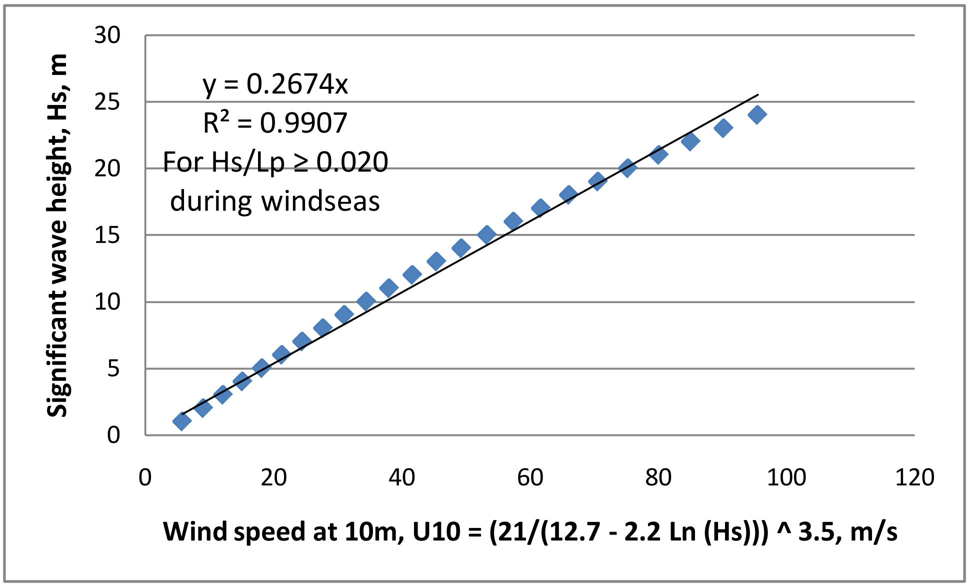

Figure 7 : A simplification of Eq. (11)

IV. VERIFICATIONS

Using the data provided in Table3, Eq. (11) is verified as shown in Fig.8.

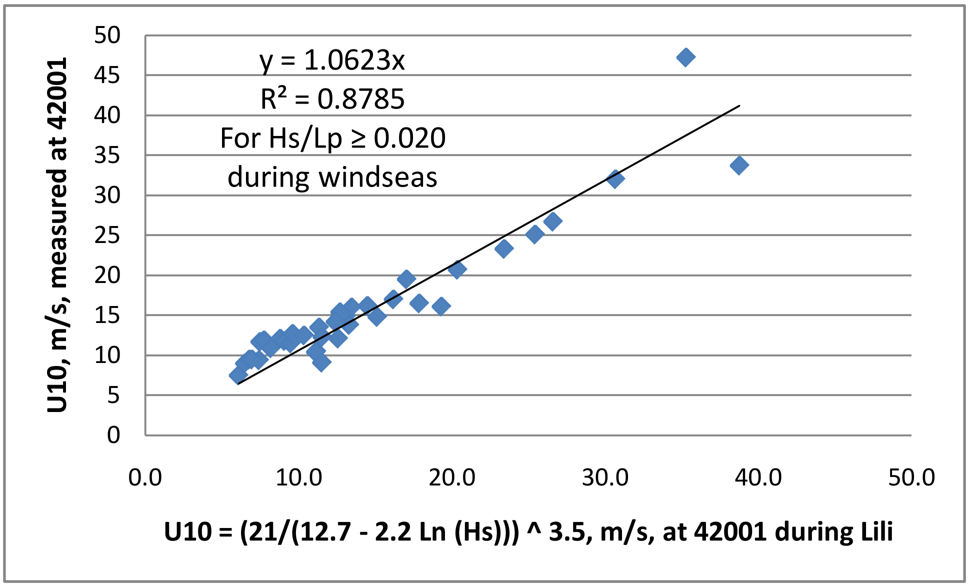

Figure 8 : A verification of Eq. (11) during Hurricane Lili based on the dataset provided in Table 3

Table 3 : Measurements of wind, wave, and atmospheric pressure at NDBC Buoy 42001 duringHurricane Lili in October 2002 (Data source: www.ndbc.noaa.gov), see text for explanations

Day	Hour UTC	Wind direction	U10m m/s	Gust m/s	Hs m	Tp second	Hs/Lp	Pressure hPa
1	15	63	6.9	8.2	1.02	5.56	0.021	1015.4
1	17	79	7.5	8.8	1.08	5.88	0.020	1014.9
1	19	68	9	10.5	1.2	6.25	0.020	1013.4
1	22	66	9.4	11.5	1.48	6.67	0.021	1012.4
1	23	77	9.5	10.8	1.29	4.35	0.044	1012.4

2	0	75	9.5	10.7	1.34	5.88	0.025	1012.5
2	1	74	11.7	13.2	1.5	6.25	0.025	1012.3
2	2	64	11.9	13.7	1.58	5	0.041	1012.7
2	3	62	10.9	13.8	1.72	5.88	0.032	1012.8
2	4	58	12.1	14.5	1.91	5.88	0.035	1012.7
2	5	54	11.8	14.5	2	6.67	0.029	1012.1
2	6	57	11.5	13.2	2.13	7.69	0.023	1011.2
2	7	64	12.7	14.8	2.17	7.69	0.024	1010.6
2	8	53	12.5	14.6	2.41	7.69	0.026	1009.1
2	10	67	13.5	16.1	2.73	7.14	0.034	1008.1
2	11	55	14.9	19.1	3.31	9.09	0.026	1007.4
2	12	49	14.8	17.4	3.98	10.81	0.022	1006.6
2	15	44	16.5	20.6	4.88	12.12	0.021	1004.8
2	16	48	16.1	23.4	5.35	12.12	0.023	1003.3
2	17	63	23.3	28.9	6.66	13.79	0.022	1000.3
2	18	61	26.7	32.8	7.65	12.9	0.029	995.1
2	19	59	32	39.1	8.88	13.79	0.030	984.6
2	20	103	47.2	65.6	10.22	13.79	0.034	956.1
2	21	158	33.7	40.5	11.2	12.9	0.043	975.4
2	22	178	25.1	32.5	7.29	10.81	0.040	988.4
2	23	190	20.7	24.5	5.69	9.09	0.044	994.2
3	0	195	19.5	26.3	4.61	10.81	0.025	998
3	1	200	17	21.5	4.33	7.14	0.054	1001.1
3	2	199	16.2	20.3	3.77	6.67	0.054	1003.6
3	3	191	16	19.2	3.43	7.69	0.037	1004.9
3	4	190	15.4	18	3.18	6.67	0.046	1006.7
3	5	186	13.8	16.6	3.38	6.67	0.049	1007.2
3	6	192	12.1	14.1	3.14	7.14	0.039	1007.4
3	7	184	14.2	16.6	3.08	7.14	0.039	1007.2
3	8	192	12.3	15.1	2.8	6.67	0.040	1007.2
3	9	191	10.5	12	2.67	6.67	0.038	1007.6
3	11	176	10.4	12.6	2.66	8.33	0.025	1009.3
3	12	169	9.1	10.6	2.79	8.33	0.026	1009.7
3	13	176	7.2	8.9	3.09	7.69	0.033	1010.9
3	15	171	8.3	10	2.65	8.33	0.024	1012.1
3	16	177	7.6	9.8	3.01	8.33	0.028	1012.2
3	17	174	7	8.3	2.71	7.14	0.034	1012.2
3	18	165	6.3	7.3	2.43	7.14	0.031	1012.1
3	19	170	5.5	6.4	2.62	6.67	0.038	1011.5
3	20	162	4.9	5.7	2.43	7.14	0.031	1011.2
4	1	152	5.9	7.1	1.84	7.14	0.023	1011.8
4	17	125	2.8	3.7	1.09	5.26	0.025	1015.7
4	20	111	4.5	5.2	1.08	5.26	0.025	1014.5
4	22	115	3.9	4.5	1.01	5.26	0.023	1014.2

Further verification of Eq. (12) for a typhoon is presented as follows:

According to the Joint Typhoon Warning Center (see Fig.9), on 6 October 2007, Super Typhoon Krosa was near northeastern Taiwan. The wind speed was 125kts (or 64m/s). Substituting this value into Eq. (12), we get the maximum significant wave height to be approximately 17m. Now, according to Liu et al. (2008), the maximum trough-to-crest wave height was measured to be 32.3m by a data buoy near northeast Taiwan in the western Pacific that was operating during the passage of Krosa.

According to the World Meteorological Organization (1998), the maximum trough-to-crest wave height may be statistically approximated by 1.9 times the significant wave height. Therefore, the maximum significant wave height is 32.3/1.9 = 17m during Typhoon Krosa near NE Taiwan. Since this value is identicalto that of 17m as obtained from Eq. (12), we can say that Eq. (12) is further verified under a typhoon condition.

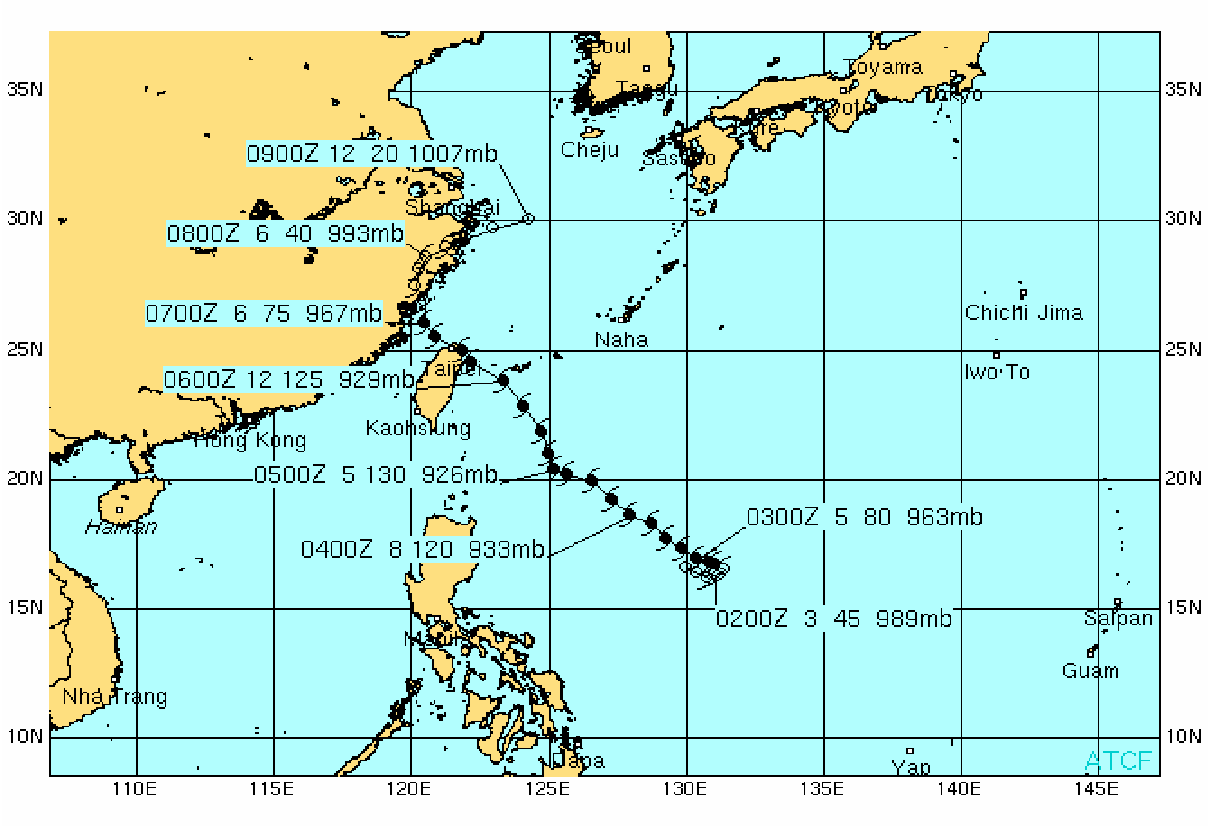

Figure 9 : Best Track of Super Typhoon Krosa in October 2007 (http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/atcr/2007atcr.pdf)

V. CONCLUSIONS

On the basis of aforementioned analyses and discussions, it is concluded that

(1) There are no appreciable differences in wave characteristics during a hurricane or a typhoon, indicating that the knowledge gained from hurricanes can be applied to typhoons;

(2) Significant wave height, Hs, and dominant wave period are related thru Eq. (5);

(3) Sea surface roughness and Hs are related thru Equations (7) and (9);

(4) The friction velocity and the wind speed at 10m are related thru Eq. (10), and finally,

(5) The wind speed at 10m and Hs are related thru Eq. (11) and for practical use thru Eq. (12).

REFERENCES RÉFÉRENCES REFERENCIAS

1. Drennan, W.M., P.K. Taylor and M.J. Yelland, 2005: Parameterizing the sea surface roughness, Journal of Physical Oceanography, 35, 835-848.
2. Geernaert, G. L., S. E. Larsen, and F. Hansen, 1987: Measurements of the wind stress, heat flux, and turbulence intensity during storm conditions over the North Sea, Journal of Geophysical Research, 92, C12, 13,127-13,139.
3. Hsu, S. A., 2003: Estimating overwater friction velocity and exponent of power-law wind profile from gust factor during storms, Journal of

Waterway, Port, Coastal, and Ocean Engineering, Vol. 129 (4), 174-177.

4. Liu, P.C., H.S.Chen, D.-J.Doong, C.C. Kao, andY.-G. Hsu, 2008: Monstrous ocean waves during Typhoon Krosa, AnnalesGeophysicae, 26, 1327-1329.
5. Taylor, P. K., and M. J. Yelland, 2001: The dependence of sea surface roughness on the height and steepness of the waves, Journal of Physical Oceanography, 31, 572-590.
6. World Meteorological Organization, 1998:Guide to Wave Analysis and Forecasting, Second Edition, WMO No-702, Geneva, p10.

This page is intentionally left blank