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Estimating Hurricane-Induced Drift Velocity: A Case Study during Ivan

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ESTIMATINGHURRICANEINDUCEDDRIFTVELOCITYACASESTUDYDURINGIVAN

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Estimating Hurricane-Induced Drift Velocity: A Case Study during Ivan

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Abstract- During a tropical cyclone such as a hurricane, meteorological and oceanographic (met-ocean) conditions are severe. Estimates of these met-ocean parameters including winds, waves, current and storm surges are needed before and after the storm. Using Hurricane Ivan in 2004 as a case study, it is found that near surface wind measurements cannot be used to estimate waves and currents. An alternative method is proposed to estimate the wind drift velocity, i.e., Usea = 21 Hs^2/Tp^3, where Hs is the significant wave height and Tp the dominant wave period, both parameters are available routinely online from the National Data Buoy Center. Application of this Usea formula during Ivan shows that it is consistent with the near surface current measurements, particular the peak velocity.

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I. INTRODUCTION

About a decade ago in September 2004 Hurricane Ivan (see Figures 1 thru 3 and Table1) devastated numerous infrastructures including coastal bridges and offshore oil rigs and damaged or displaced miles of oil and gas pipelines in the northeastern Gulf of Mexico (see, e.g., Panchang and Li, 2006). Measurements of meteorological and oceanographic (met-ocean) conditions near Ivan's track were as follows:

According to Stewart (2004, p.15), wind and gust measurements at 400ft (122m) elevation on an oil rig named Ram Powell VK-956 located near the Ivan's track at 29.05N 88.10W indicated that at 2256Z on 15 September wind speed = 102 knots and wind gust = 135knots. According to the National Data Buoy Center (NDBC), this oil platform (code name as 42364) is very near Buoy 42040 (Fig.2) (see www.ndbc.noaa.gov), which recorded significant wave height (Hs) = 15.96m and dominant wave period (Tp) = 16.67 second as provided in Table 1. According to Teague et al. (2007), the maximum current speed reaching 2.14 m/s (see Fig.3) at a direction of almost due west was observed on the shelf in 60m of water at station M1 (see Fig.2) near the surface (6m). Similar speeds, ranging between 1.73 and 1.96m/s, were found near the surface at the other moorings on the shelf.

Normally, hourly wind speed is employed to estimate waves and currents. However, because the max wind speed measured at Buoy 42040 was only 28.2m/s (see Table 1), this wind speed was too low to generate 2m/s current and 16m significant wave height. Therefore, the use of wind speed to estimate waves and currents near the continental shelf could result gross error. The cause may be due to the effects of land mass near the hurricane's landfall and of low anemometer height (at 5m above the sea surface as compared to 16m significant wave height, the effect of wave shadow) on Buoy 42040. Because of these effects, we propose to employ hourly measurements of Hs and Tp instead of using the hourly wind speed. This is the purpose of this investigation.

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Figure 1 : Hurricane Ivan over the northern Gulf of Mexico on September 15, 2004, (http://catalog.data.gov/dataset/hurricane-ivan-poster-september-15-2004)

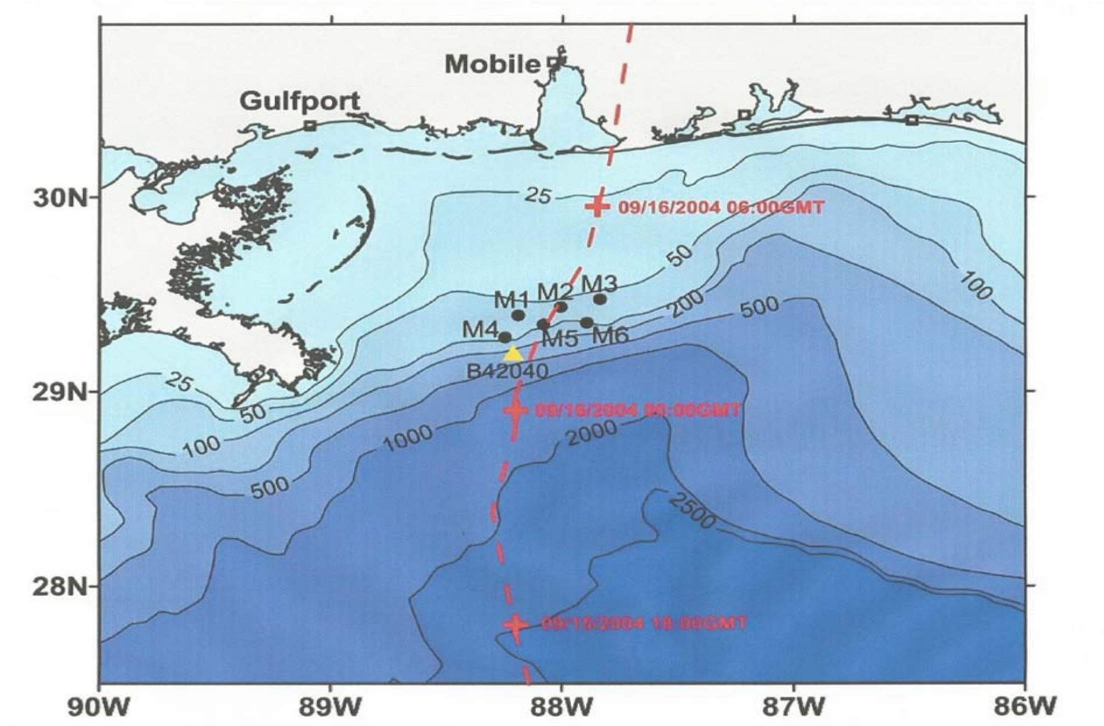

Figure 2 : Ivan Track and measurement stations (see Wijesekera et al., at http://www.motherjones.com/files/Source_177__High_Sea-Floor_Stress_Induced_by_Extreme_Hurricane_Waves_1.pdf)

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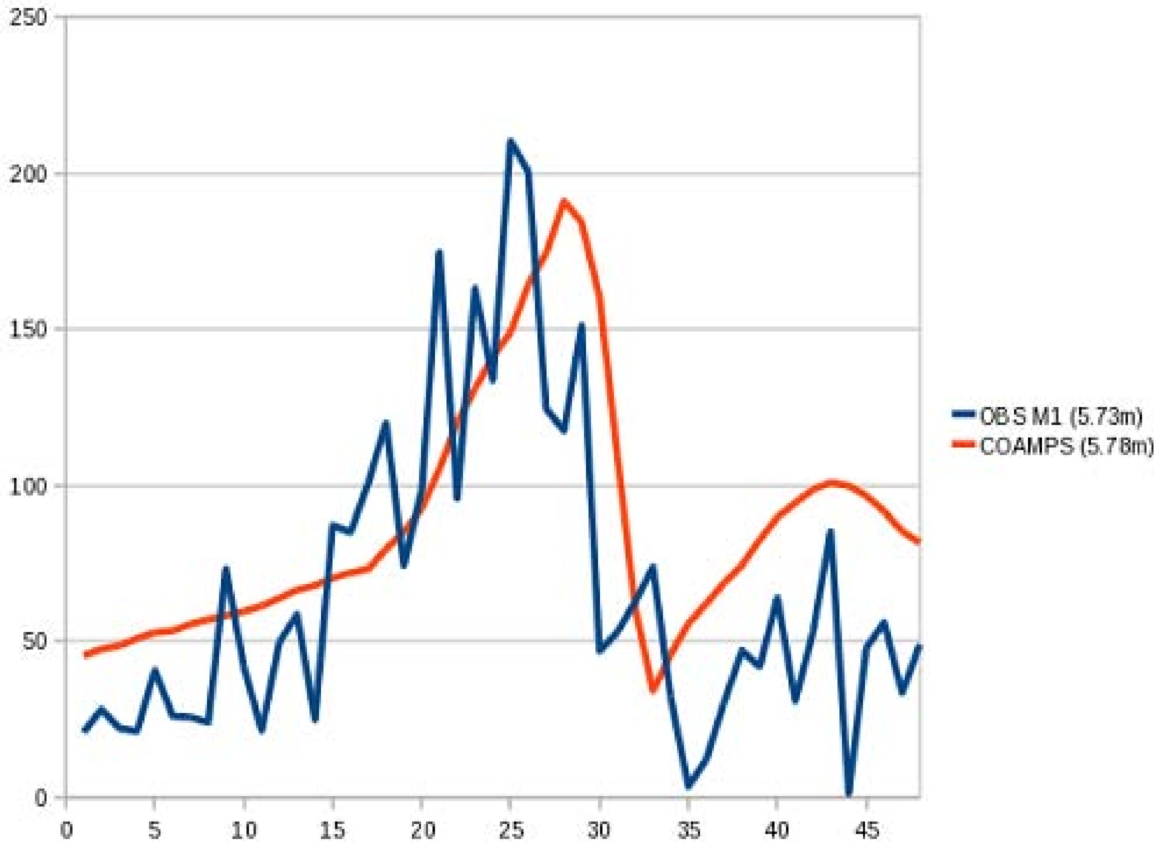

Figure 3 : Acoustic Doppler Current Profiler (ADCP) measurements of the near surface current speed (cm/s) at approximately 6 m water depth (blue) and Model simulation (red) at NRL Station M1 (see Fig.2) (see Chen et al., at www.onr.navy.mil/reports/FY10/npchen.pdf) over a 48-hour period from September 16, 2004

Table 1 : Measurements of wind speed (WSPD), wind gust (GST), Barometric pressure (BARO), significant wave height (Hs), and dominant wave period (Tp) at NDBC Buoy 42040 during Hurricane Ivan in September 2004. Both friction velocity (U*) and wind drift velocity (Usea) are computed from Hs and Tp according to Equations 5 and 6, respectively

Day	Hour	WSPD	GST	BARO	Hs, m	Tp, sec	U*, m/s	Usea, m/s
15	0	12.9	15.3	1008.5	3.45	11.11	0.33	0.18
15	1	13.4	15.7	1008.4	4.23	11.11	0.50	0.27
15	2	13.6	16.1	1008.4	4.59	11.11	0.58	0.32
15	3	13.7	17.1	1008.2	4.98	12.5	0.48	0.27
15	4	14	17.4	1008.1	5.09	14.29	0.34	0.19
15	5	13.4	16.2	1007.5	5.83	14.29	0.44	0.24
15	6	14.5	18.3	1006.6	5.96	14.29	0.46	0.26
15	7	15.1	19.8	1005.7	6.23	14.29	0.51	0.28
15	8	15.8	19.6	1004.4	6.93	14.29	0.63	0.35
15	9	16.5	20	1003.5	7.2	14.29	0.68	0.37
15	10	17.4	22.1	1002.5	7.47	14.29	0.73	0.40
15	11	17.6	21.9	1002.2	7.03	14.29	0.64	0.36

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15	12	19.3	24.2	1001.1	7.91	14.29	0.81	0.45
15	13	18	23.3	1001.3	8.2	16.67	0.55	0.30
15	14	19.5	24	1000.3	8.52	14.29	0.95	0.52
15	15	22.2	28.9	997.7	9.94	14.29	1.29	0.71
15	16	22.2	27.6	996	10.63	16.67	0.93	0.51
15	17	23.6	29	993.5	11.74	16.67	1.13	0.62
15	18	25.6	31.6	989.2	10.96	16.67	0.99	0.54
15	19	25.6	31.9	985.1	12.76	16.67	1.34	0.74
15	20	27.8	34.2	979.9	15.25	16.67	1.91	1.05
15	21	27.9	37.8	974.8	13.69	14.29	2.44	1.35
15	22	26.8	34.2	969	14.85	14.29	2.87	1.59
15	23	28.2	34.9	963.1	14	12.5	3.81	2.11
16	0	26.5	32.6	958.2	15.96	16.67	2.09	1.15
16	1	25.4	32.9	956.3	14.15	14.29	2.61	1.44
16	2	25.4	32.6	955.3	8.72	11.11	2.11	1.16
16	3	21.6	29.5	962	8.43	10	2.70	1.49
16	4	26.8	34.2	967.6	7.27	14.29	0.69	0.38
16	5	24.5	30.7	976	7.45	10	2.11	1.17
16	6	24.2	29.9	983.6	7.63	10	2.21	1.22
16	7	21.1	27	989.4	7.89	10	2.37	1.31
16	8	18.9	23.5	992.7	7.22	10	1.98	1.09
16	9	16.8	22.7	995.5	6.17	9.09	1.93	1.06
16	10	16.2	22.7	997.8	5.63	10	1.20	0.67
16	11	14.7	18.2	999.6	6.14	10	1.43	0.79
16	12	14	17	1001.6	5.66	11.11	0.89	0.49
16	13	12.5	16.3	1002.8	4.91	11.11	0.67	0.37
16	14	12.2	15.7	1003.9	4.8	9.09	1.17	0.64
16	15	11.6	15	1005	4.58	10	0.80	0.44
16	16	10.6	13.8	1005.8	4.29	10	0.70	0.39
16	17	10.9	13.4	1006.2	4.46	9.09	1.01	0.56
16	18	9.6	11.6	1006.7	4	9.09	0.81	0.45
16	19	8.9	10.4	1006.9	3.54	9.09	0.63	0.35
16	20	8.9	10.8	1006.4	3.09	7.69	0.80	0.44
16	21	7.2	8.8	1006.6	2.97	8.33	0.58	0.32
16	22	7.7	9.9	1007	2.84	8.33	0.53	0.29
16	23	7.4	9.2	1007.6	2.64	8.33	0.46	0.25

II. METHODS

According to Wu (1975),

$$Usea = 0.55\,U^* \qquad (1)$$

Where Usea is the surface drift velocity, in m/s, and U* is the friction velocity, in m/s.

Analysis of the direct measurements of U* and U10m by sonic anemometry over the North Sea during storms from the data provided in Geernaert et al. (1987) is shown in Fig.4. Our result indicate that

$$U^*=0.0195U10m^{1.285} \qquad (2)$$

Since the coefficient of determination (R^2) is 94 percent, meaning that 94% of the variation in U* can be explained by the U10m in this power law formula, therefore, we are confident to use Eq. (2) for our applications.

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In order to extend Eq. (2) into hurricane conditions, Fig. 5 is presented. Because the vorticity method is based on atmospheric physics (Anthes, 1982), it is used here. Since the slope between this method and Eq. (2) is near one and that the R^2 value reaches to 94%, we are confident that Eq. (2) can be extended into hurricane conditions.

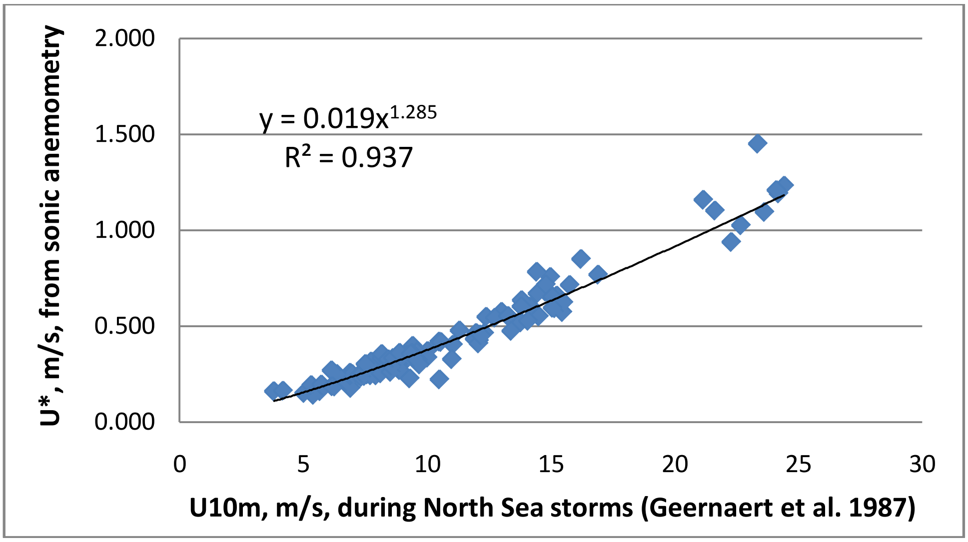

Figure 4 : Relation between direct measurements of U* and U10m using sonic anemometry based on data provided in Geernaert et al. (1987)

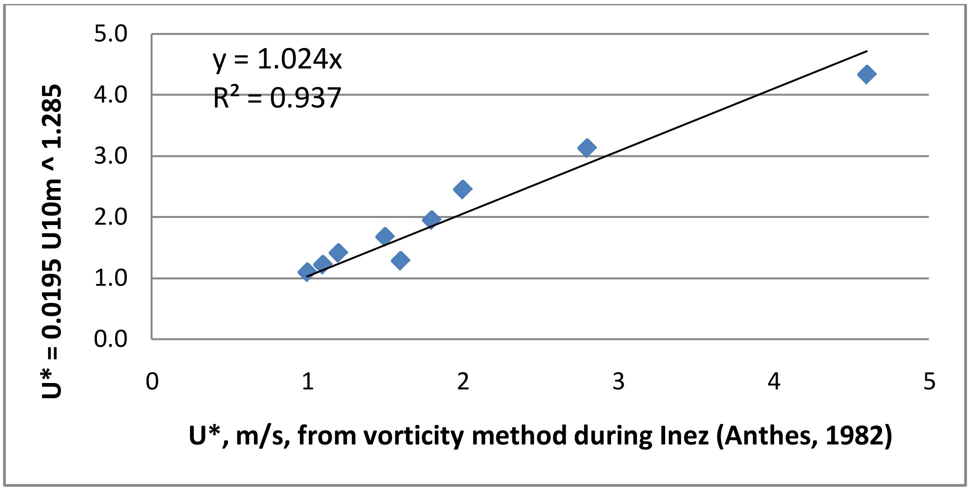

Figure 5 : An extension of Equation (2) into hurricane conditions during Inez based on the dataset provided in Anthes (1982, p.71)

Now, according to Csanady (2001, p.68),

$$g\,Hs/U*^2 = A\,(g\,Tp/U*)^{(3/2)} \qquad (3)$$

Where g (= 9.8 m/s^2) is the gravitational acceleration, Hs is the significant wave height, Tp is the dominant wave period, and A is the coefficient to be determined in the field during storms. Note that both Hs and Tp are measured by NDBC routinely.

With the data provided in Table 2, we can now compute U* from U10mbased on Eq. (2) (except one data point during the hour when the eye of Kate passed over Buoy 42003). Our results are shown in Fig.6. The coefficient "A" is determined to be 0.052 with R^2 = 0.93 so that Eq. (3) becomes

$$g\,Hs/U*^2 = 0.052\,(g\,Tp/U*)^{(3/2)} \qquad (4)$$

Or,

$$U* = 38\,Hs^{2}/Tp^{3} \qquad (5)$$

Now, substituting Equations (5) into (1), we have

$$Usea = 21\,Hs^{2}/Tp^{3} \qquad (6)$$

Eq. (6) is our proposed formula to estimate surface currents using wave parameters during a tropical cyclone.

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Table 2 : Measurements of wind and wave parameters at Buoy 42003 during Kate in November 1985 where U10m is the wind speed at 10m, Hs is the significant wave height, Tp is the dominant wave period, and U10m > 7.5m/s to ensure that mechanical turbulence dominants the thermal effects (see Hsu, 2003)

Day	Hour	Wind direction	U10m,m/s	Gust	Hs,, m	Tp, sec.
18	11	98	9.5	10.4	1.1	6.3
18	12	94	8.3	9.4	1.1	6.3
18	13	91	8.7	9.9	1.2	6.7
18	14	89	9	9.9	1.3	6.7
18	15	85	9.6	10.4	1.3	6.7
18	16	89	8.9	9.9	1.5	6.3
18	17	84	9.2	10.4	1.5	6.3
18	18	86	9.5	10.4	1.5	6.3
18	19	83	8.9	10.4	1.6	6.3
18	20	78	8.7	9.4	1.6	6.7
18	21	70	9.6	10.4	1.6	7.1
18	22	69	9.7	10.4	1.6	7.1
18	23	72	9.8	10.4	1.7	7.1
19	0	71	10.2	11.5	1.7	6.7
19	1	68	8.8	9.9	1.6	6.7
19	2	61	9.2	9.9	1.5	6.7
19	3	55	9.4	10.4	1.5	6.7
19	4	46	9.8	11	1.5	6.7
19	5	51	9.2	10.4	1.5	6.3
19	6	59	9.2	11	1.4	6.7
19	7	78	11.7	13.1	1.5	6.3
19	8	70	10.7	12.5	1.6	5.6
19	9	66	11	13.1	1.8	5.9
19	10	55	10.4	11.5	1.6	6.7
19	11	58	11.4	12.5	1.9	6.3
19	12	49	9.9	11.5	1.9	6.7
19	13	46	9.4	10.4	2	7.1
19	14	46	10.3	11	2.1	7.7
19	15	46	11	13.6	2.2	7.1
19	16	43	10.8	12.5	2	7.1
19	17	36	11.2	13.1	2	7.7
19	18	37	12	13.6	2	7.7
19	19	40	12.5	14.1	2	7.7
19	20	45	13.2	15.7	2	7.7
19	21	43	13.6	15.2	2	7.1
19	22	48	13.3	15.7	2.4	7.1
19	23	45	13.6	15.2	2.3	7.1
20	0	40	12	14.1	2.4	7.7
20	1	38	10.8	12.5	2.3	7.7
20	2	46	12	14.1	2.4	7.7

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20	3	51	13.4	15.7	2.6	7.7
20	4	51	14.3	16.2	2.6	7.7
20	5	59	16.9	19.9	2.7	7.7
20	6	52	16.2	18.8	3.1	7.7
20	7	50	16.6	21.9	3.7	8.3
20	8	61	20	24	4.6	11.1
20	9	70	21.6	26.7	5.5	11.1
20	10	55	24.1	29.3	5.4	11.1
20	11	34	23.3	27.2	6.2	14.3
20	12	40	23.1	27.2	7.4	14.3
20	13	38	23.6	28.7	7.5	12.5
20	14	42	26	31.9	7.2	12.5
20	15	40	29.3	37.1	8.6	14.3
20	16	41	35.9	43.4	9.4	12.5
20	17	64	47.3	58.5	10.7	12.5
20	Eye at 18	129	16.6	19.9	9.9	12.5
20	19	195	36.5	47.6	7.1	11.1
20	20	208	35.5	47.6	6.6	9.1
20	21	208	29.9	37.6	6	10
20	22	208	23	27.7	5.6	8.3
20	23	214	22.2	26.7	5.3	9.1
21	0	216	20.9	26.7	4.8	9.1
21	1	221	20.8	24.6	4.5	10
21	2	216	21.5	26.1	4.4	9.1
21	3	230	20.4	24.6	4.3	10
21	4	241	22.2	26.7	3.8	7.7
21	5	241	22.7	27.2	5.1	9.1
21	6	223	19.2	22.5	5.2	9.1
21	7	219	16.7	19.9	4.5	9.1
21	8	226	16.1	18.8	4.5	10
21	9	234	15.2	18.3	4.3	10
21	10	234	14.6	16.7	4.3	10
21	11	240	15	19.3	3.9	9.1
21	12	246	14	17.2	3.7	9.1
21	13	253	13.4	15.7	3.9	9.1
21	14	255	13.9	16.7	4.6	10
21	15	259	13.8	15.7	3.8	9.1
21	16	255	12.3	14.1	4.1	10
21	17	262	13.4	15.2	3.9	9.1
21	18	262	12.2	14.6	4.1	10
21	19	265	11.2	14.6	3.7	10
21	20	259	10.2	12	3.6	10
21	21	266	10.4	12.5	3.4	9.1
21	22	271	10.6	12	3.4	8.3
21	23	269	9.4	12.5	3.3	10

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22	0	257	8.8	10.4	2.8	10
22	1	278	8.7	9.9	2.6	10
22	2	275	8.6	9.9	2.5	10
22	3	267	7.6	8.9	2.5	9.1

(Data source: www.ndbc.noaa.gov)

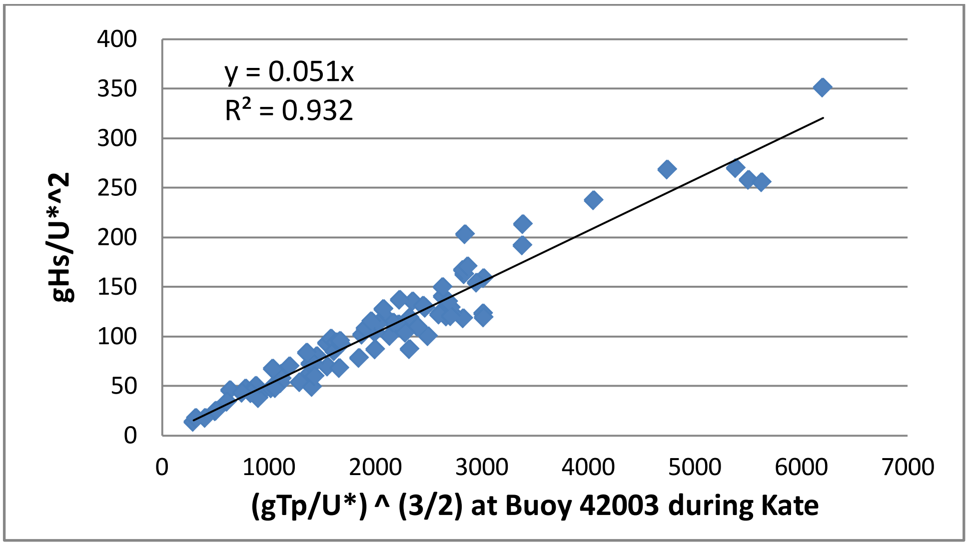

Figure 6 : A validation of Equation (3) based on data provided in Table 2 except during the passage of eye at 18UTC on November 20. Note that the coefficient "A" needed in Equation (3) is determined to be 0.052

III. Results

Based on aforementioned methodology we can now compute hourly U* and Usea values according to Equations (5) and (6), respectively. Our results are listed in the last 2 columns in Table 1. In order to compare with Fig.3, the time series of Ivan induced drift velocity is also presented in Fig.7. It can be seen that the comparison is reasonable, particularly the max Usea, which was 2.11m/s. This value is in excellent agreement with that of 2.14m/s as measured by Teague et al. (2007), which is also shown in Fig.3.

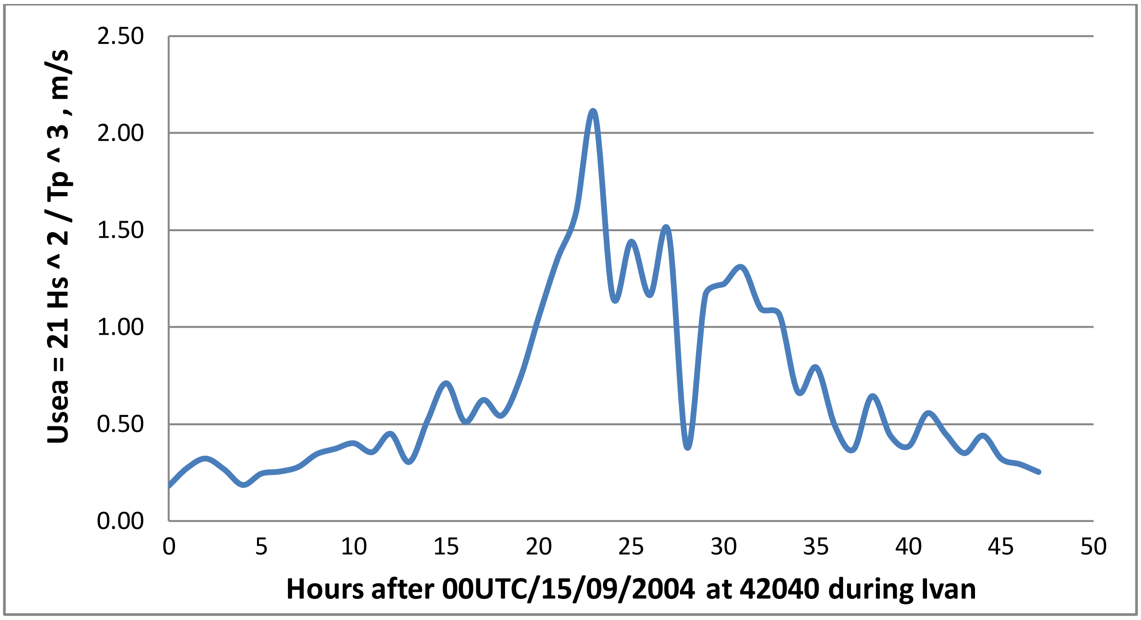

Figure 7 : Time series of the wind-drift velocity as estimated by Equation (6) based on wave measurements provided in Table 1 for Hurricane Ivan in 2004

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IV. CONCLUSIONS

On the basis of aforementioned analysis, several conclusions can be drawn:

- Using Hurricane Ivan in 2004 as a case study, it is demonstrated that near surface wind measurements cannot be used to estimate waves and currents.
- A power-law relationship (Eq.2) between the direct measurements of friction velocity (U*) and the wind speed at 10m over the North Sea is found with a coefficient of determination as high as 94%.
- Eq.2 is further supported by the atmospheric vorticity method during Hurricane Inez.
- Applications ofEq.2to the open sea during Katefound that U* = 38 Hs^2/Tp^3, and Usea = 21 Hs^2/Tp^3, where Hs is the significant wave height, Tp is the dominant wave period, and Usea is the wind drift velocity. And,
- Using Eq.5 during Ivan shows that this formula is consistent to the near surface current measurements, particular the peak velocity.

REFERENCES RÉFÉRENCES REFERENCIAS

1. Anthes, R. A., Tropical Cyclones: Their Evolution, Structure and Effects. Meteorological Monographs, Volume 19, Number 41, American Meteorological Society, Boston, MA (1982).
2. Csanady, G. T., Air-Sea Interaction, Laws and Mechanisms (Cambridge University Press, 2001).
3. Geernaert, G. L., Larsen, S. A. & and F. Hansen, F. Measurements of the wind stress, heat flux, and turbulence intensity during storm conditions over the North Sea. J. Geophysical Research, Vol.92, No. C12, 13,127-13,139 (1987).
4. Hsu, S. A. Estimating overwater friction velocity and exponent of power-law wind profile from gust factor during storms. J. of Waterway, Port, Coastal and Ocean Engineering, 129(4), 174-177 (2003).
5. Panchang, V. G. & Li, D. Large waves in the Gulf of Mexico caused by Hurricane Ivan. Bulletin of American Meteorological Society, vol.87, pp.481-489 (2006).
6. Stewart, S. R. Tropical Cyclone Report, Hurricane Ivan, National Hurricane Center (www.nhc.noaa.gov) (2004).
7. Teague, W. J., Jarosz, E., Wang, D. W. & Mitchell, D. A. Observed oceanic response over the upper continental slope and outer shelf during Hurricane Ivan. Journal of Physical Oceanography, 37, 2181-2206 (2007).
8. Wu, J. Wind-induced drift currents. J. Fluid Mech. 68, 49-70 (1975).

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