SIGNIFICANT WAVE HEIGHT IN THE GULF OF MEXICO: VALIDATION OF JASON-1 MEASUREMENT AGAINST BUOY DATA

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1. INTRODUCTION

Knowledge of ocean surface waves is critical for a safe and efficient operation of such offshore activities as transportation, fisheries and oil exploration, because energy carried by the ocean waves is considerably large and may cause significant damage to ships and fixed structures. An important parameter which characterize wave conditions is the significant wave height (SWHT), defined as the crest-to-trough height of the 1/3 highest waves in the field of view. The ability of a satellite altimeter to measure SWHT was first demonstrated with NASA's GEOS-3 satellite in the 70's. Since then, SWHT data from different satellites – Seasat (1978), Geosat (1985-1990), TOPEX/POSEIDON (1992-present), ERS-1 (1991-1996), ERS-2 (1995-present), Envisat (2002-present) – became available. The advantage of satellite over pointwise in-situ measurements is that it provides the global representation of the sea state as a map, enabling us to study the large-scale dynamics of the ocean surface. The accuracy of altimeter estimates, however, must be carefully tested against the in-situ data before being accepted as true sea states. Numerous studies based on comparisons with collocated buoy observations confirmed that SWHT data from each satellite have a different bias and require the application of individual calibration corrections [Chelton (2001)].

Jason-1 satellite was launched by NASA (United States) and CNES (France) space agencies on December 7, 2001, and measures the sea surface topography using Poseidon-2 radar altimeter, operating at 13.575 GHz (Ku band) and 5.3 GHz (C band). The measurements made at the two frequencies are combined to obtain the altimeter range, wind speed, significant wave height (SWHT), and the ionospheric corrections. Despite the long, stable data acquisition from Jason-1, only a few validation studies of its SWHT measurement exist [Queffeulou (2003), Hóyer (2006), Queffeulou (2007)]. In this report, we will present a validation analysis of the Jason-1 SWHT in the Gulf of Mexico region.

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2. DATA SOURCE

Jason-1 SWHT data used are the Ku-band one per frame significant wave height taken from the Jason-1 Sea Surface Height Anomaly product (Product 132) distributed by NASA's PO.DAAC (Physical Oceanography Distributed Active Archive Center) between January 2002 and December 2006 (`http://podaac.jpl.nasa.gov/PRODUCTS`). This product is derived from the Jason-1 Geophysical Data Record (J1-GDR), also by PO.DAAC. The editing criteria for selecting good records from the J1-GDR for Product 132 are described in Berwin (2003). The J1-GDR is a fully validated product that uses precise orbit and applies ground retracking. It is available online with 30-day latency and said to have an accuracy of ±4.2 cm over 1-second

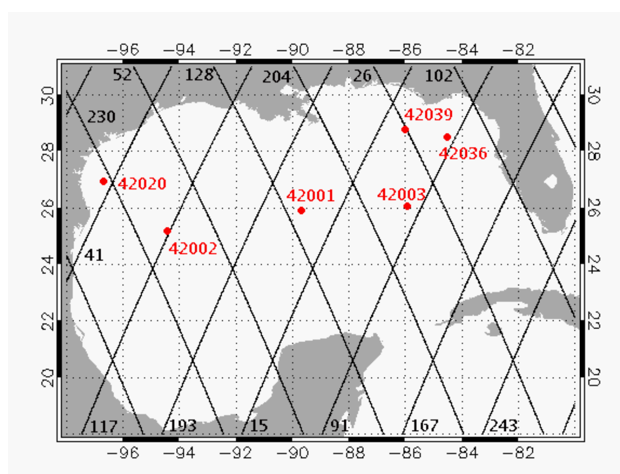

Figure 1: Paths of Jason-1 satellite (solid lines, numbered with path indeces) and locations of NDBC buoys (filled circles, numbered with station IDs).

Station ID	Position		Water	Descending J1 Path		Ascending J1 Path	
	Latitude [deg-N]	Longitude [deg-W]	Depth [m]	Number of Coincidence	Distance [km]	Number of Coincidence	Distance [km]
42001	25.90	89.67	3246	150	56	156	134
42002	25.17	94.42	3200	156	114	153	8
42003	26.07	85.94	3233	145	131	144	52
42020	26.94	96.70	88	153	31	158	35
42036	28.50	84.52	55	155	130	146	28
42039	28.79	86.52	291	142	5	147	90

Table 1: Offshore NDBC buoys in the Gulf of Mexico.

averages for typical oceanic conditions [JPL (2003)]. The ground-track of Jason-1 satellite repeats every 9.9156 ($\sim$ 10) days, completing a cycle. There are 127 orbits per cycle, and each orbit has a period of 112 minutes. Each orbit is composed of 2 passes, one ascending from -66 degree to +66 degree latitude and the other descending in the opposite direction. By convention, ascending and descending passes are indexed with odd and even numbers, respectively, in PO.DAAC products. In-situ SWHT data are from the online data archive of National Data Buoy Center (NDBC) (`http://www.ndbc.noaa.gov`). The SWHT data at each NDBC buoy are collected every hour and posted online in real time. The Jason-1 paths in the Gulf of Mexico and the location of 6 NDBC buoys we study are shown in Figure 1, and Table 1 summarizes the station ID, position, and water depth of the NDBC buoys.

3. COLLOCATION PROCEDURE

To obtain a set of simultaneous SWHT data from Jason-1 satellite and in-situ measurements at each NDBC buoy location, we averaged the Jason-1 data points in the closest ascending/descending path that are within the radius of $d + 5$ kilometers from the NDBC buoy, where d is the distance between the buoy and the Jason-1 path. The distance d for each NDBC buoy is given in Table 1. It ranges from 5 km (at station 42039) to 134 km (at station 42001). Along-path measurements of Jason-1 are approximately 1 sec and 6 km apart. We discarded Jason-1 data as unreliable unless there are more than 2 points in the radius of averaging. On the other hand, the corresponding buoy measurements are found by selecting data that are taken within the time-window of $\bar{t} \pm 30$ minutes, where $\bar{t}$ is the acquisition time of Jason-1 data averaged within the radius of $d + 5$ kilometers. The number of coincident data collected in this manner at each buoy location is shown in Table 1. Values of SWHT in the joint data set of Jason-1 and NDBC buoys ranged from 0 to 6 meters between 2002 to 2006, while the maximum SWHT recorded by NDBC buoys alone in the same period was 12.05 meters (at station 42039 on September 15, upon passing of hurricane Ivan). This is because the Jason-1 measurement taken under extreme weather conditions are flagged out and not included in the final PO.DAAC products.

One of the issues in validation of altimeter SWHT measurements against in-situ data is the different spacial and temporal scales that characterize each measurement [Chelton (2001)]. That is, altimeter measurements are averaged over an area around buoy locations, whereas buoy measurements are available only in hourly intervals at a point location. To avoid this problem, it has been suggested to compare monthly averages of buoy with monthly averages of altimeter data over 2° by 2° areas around the buoys [Cotton (1994)]. We do not, however, follow this approach in our study for the follow-

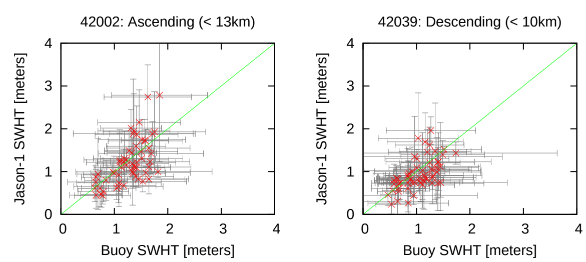

Figure 2: Scatter plot comparisons between monthly averaged SWHT from buoy and Jason-1 at 2 buoy locations that are closest to the Jason-1 paths. Error bars show the standard deviation of monthly averages in both buoy and Jason-1 measurements. Note that Jason-1 data are spatially averaged as well inside the radius shown. Points should lie on the solid line for perfect agreement.

Station ID	Descending			Ascending		
	Slope	Intercept [m]	Slope with Zero Intercept	Slope	Intercept [m]	Slope with Zero Intercept
42001	1.01 ±0.02	0.00±0.03	1.009±0.009	0.83 ±0.03	0.20±0.04	0.96 ±0.02
42002	0.86 ±0.03	0.21±0.05	0.99 ±0.01	0.92 ±0.02	0.12±0.02	0.996±0.009
42003	0.73 ±0.04	0.16±0.05	0.84 ±0.02	0.91 ±0.02	0.08±0.02	0.965±0.009
42020	0.90 ±0.02	0.05±0.04	0.934±0.008	0.87 ±0.02	0.10±0.03	0.932±0.009
42036	0.86 ±0.04	0.22±0.05	1.03 ±0.02	0.90 ±0.01	-0.01±0.02	0.893±0.006
42039	0.98 ±0.02	-0.22±0.03	0.811±0.009	0.86 ±0.02	0.12±0.03	0.94 ±0.01

Table 2: Correlation between Jason-1 and buoy measurements at offshore NDBC stations.

ing reasons. First, temporal variation of SWHT in the Gulf of Mexico is too vigorous for monthly averaging. This is illustrated in Figure 2, where we plot the monthly averaged SWHT from buoy and Jason-1 at 2 buoy locations that are closest to the Jason-1 paths. The standard deviation of monthly averages in those figures are as large as 1 meter in most cases, and the correlation between the averaged SWHT data are not very good at either stations despite their close distance from Jason-1 paths ($d = 5$ and 8 km). Secondly, averaging the Jason-1 data from two different paths, just because they are in the same proximity, is not recommended because they can be taken at very different times and therefore different weather conditions. Therefore, neither monthly-averaging nor mixing of ascending and descending paths is done to Jason-1 data in our analysis.

4. RESULTS

We compared the SWHT values of Jason-1 Ku band altimeter in the Gulf of Mexico with in-situ measurements at each NDBC buoy separately. Table 2 summarizes the results of correlation analysis between the Jason-1 and the buoy measurements,

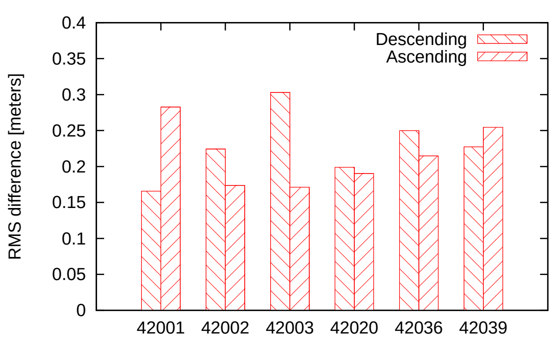

Figure 3: RMS differences between buoy measurements and Jason-1 data.

and their root-mean-square (RMS) differences are shown in Figure 3. There are two comparisons made for each buoy, one with ascending Jason-1 paths and another with descending. We observed good correlations in general, with linear slopes ranging from 0.73 to 1.01. For those Jason-1 paths that are less than 10 km away from the stations, the slopes were 0.92 and 0.98. The RMS differences fall in the range of 17 to 30 centimeters. The average value of slopes with zero intercepts is 0.94, meaning that Jason-1 measurement is 6% low with respect to the buoy data. It should be noted that the slope of less than one in correlation plots is expected between two measurements of a non-negative quantity such as SWHT when there are random errors in both measurements and therefore not indicative of systematic errors in Jason-1 data [Chelton (2001)].[1]

Lastly, in Figure 4, we plot SWHT from Jason-1 against in-situ measurements and their best fit at two stations, that are good representatives for offshore (42002) and near-coast (42039) measurements. It is normal that, in both stations, fluctuations in Jason-1 measurements are larger when taken from more distant ($d \gg 50$ km) paths. The Jason-1 measurements at station 42039, however, show a few data points with large, sporadic fluctuations at low (less than 1 meters) SWHT. This may be related to the fact the station 42039 is located at shallow water ($<$ 1000 meters) where altimeter measurements are known to be unreliable.

5. CONCLUSION

In this report, Jason-1 altimeter estimates of SWHT are compared with the buoy measurements

[1]PO.DAAC suggests to use only data from "deep" water where tide models are more accurate and to get away from shelf effects. Typically, deep water is considered to be 1000 meters or greater. If we exclude stations that are less than 1000-meter deep, then the average slope with zero intercept becomes 0.96.

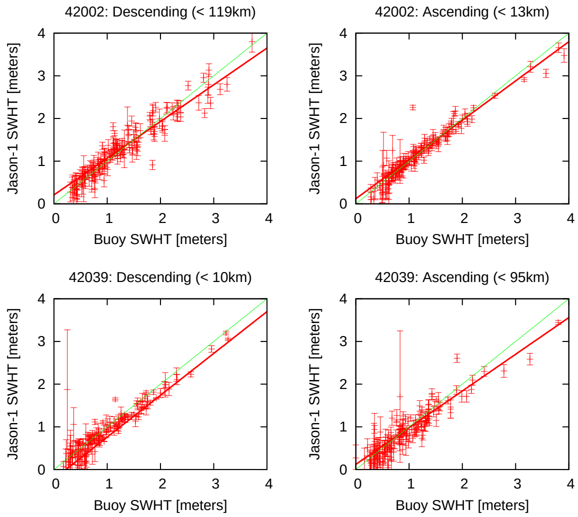

Figure 4: Correlation plots between buoy and Jason-1 data (averaged inside the radius shown) at station 42002 and 42039. Perfect-fit line is also shown as a reference.

at 6 offshore NDBC stations in the Gulf of Mexico. They are shown to be in good agreements, with correlation slopes of 0.73-1.01 and RMS differences of 17-30 centimeters. The Jason-1 measurements were smaller than the buoy measurements by 6% on average.

ACKNOWLEDGMENTS

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