PRESENTATION AND VALIDATION OF REMOTE SENSING OCEAN WAVE DATA

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ABSTRACT

The use of satellite wave altimetry has increased the possibility of getting better temporal and spatial coverage of wave data collection. Whilst the method to obtain wave heights is well established, such is not the case with methods of derivations of wave periods. This study presents a review of four available methods to derive wave periods and describes the implementation of such methods to obtain Malaysian ocean waves joint probabilities of wave heights and wave periods data from TOPEX/Poseidon satellite altimetry. Data is presented in formats similar to the commonly used Global Wave Statistics. Comparisons are made with measured data from a petroleum company offshore platform. Results indicate that two methods produced almost identical wave periods data to the measured data.

Keywords: *Aerospace application, Oceanographic data, Satellite Altimetry*

1. INTRODUCTION

Satellite altimetry is beginning to be accepted as a reliable method to obtain ocean wave data. Methods to derive wave data from satellite altimetry have been presented in previous studies, for example by Sakuno [1]. The overall accuracy of altimeter measurements of Significant Wave Heights (SWH) has been investigated by numerous comparisons with buoy observations. On average, the T/P estimates were found by Fu and Cazenave [2] to be smaller than the buoy estimates by about 5% ,

The probability of occurrence of significant wave heights is normally enough for most engineering design calculations. However, in some cases such as the use of sea spectra to estimate downtime of floating vessels, wave period's data is required. The most common source for this data is Global Wave Statistics (GWS) data published by British Maritime Technology, BMT [3]. For example, Table 1 shows GWS joint probability distribution of wave heights and periods for Area 62 that covers the whole of South China Sea and Gulf of Siam. The accuracy, reliability and comprehensiveness of such data have often been questioned, for example in Shinkai and Wan [4].

There is thus a need to find wave periods data from satellite altimetry. Although methods to obtain wave heights probabilities from satellite data are quite well established, this is not the case with wave periods. This study presents a survey of a number of methods to derived wave periods from various parameters and compares the results of their implementation for Malaysian sea.

2. MATERIALS AND METHODS

2.1 Wave periods derivation

The derivation of wave periods from altimeter data is still in its early development [5], [6]. There are a number of methods being developed by researchers in this area. Besides the method by Shinkai and Wan [4], other methods to derived wave periods are by Davies *et al*.[6]; Hwang *et al*. [7] and Gommengiger *et al* [8].

Table 1: GWS Joint probability distribution for Area 62 [3]

ALL DIRECTIONS
PERCENTAGE OF OBS = 100.00%
(INCLUDING 2.19% DIRECTION UNKNOWN)

SIGNIFICANT WAVE HEIGHT \ ZERO CROSSING PERIOD (s)	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	>13	TOTAL
TOTAL	84	284	339	197	72	19	4	1	-	-	-	1000
>14	-	-	-	-	-	-	-	-	-	-	-	-
13-14	-	-	-	-	-	-	-	-	-	-	-	-
12-13	-	-	-	-	-	-	-	-	-	-	-	-
11-12	-	-	-	-	-	-	-	-	-	-	-	-
10-11	-	-	-	-	-	-	-	-	-	-	-	-
9-10	-	-	-	-	-	-	-	-	-	-	-	-
8-9	-	-	-	-	-	-	-	-	-	-	-	-
7-8	-	-	-	-	-	-	-	-	-	-	-	-
6-7	-	-	1	1	1	-	-	-	-	-	-	3
5-6	-	1	2	2	2	1	-	-	-	-	-	7
4-5	-	2	6	6	4	2	1	-	-	-	-	20
3-4	1	7	19	19	10	3	1	-	-	-	-	60
2-3	3	30	62	49	21	6	1	-	-	-	-	172
1-2	17	103	146	84	27	6	1	-	-	-	-	385
0-1	63	142	104	36	8	1		-	-	-	-	354

In Shinkai and Wan [4]**,** the **p**eriod data are obtained by using a general relationship derived from instrumentally measured data. To obtain this relationship, a joint lognormal probability distribution is fitted to each set of SWH data. This distribution is given by:

$$P(T|H) = f_T = \frac{1}{T\sqrt{2\pi}\sigma(H)} \exp\left[\frac{(\ln T - \mu(H))^2}{2\sigma^2(H)}\right] \qquad (1)$$

where, the parameters $\mu(H)$ and $\sigma^2(H)$ of the fitting procedures are determined from its standard scatter diagram data by:

$$\begin{cases} \mu(H) = E[\ln T](H) \\ \sigma(H) = Var[\ln T](H) \end{cases} \qquad (2)$$

However, the $\mu(H)$ and $\sigma^2(H)$ could not get from scatter diagram because of little data when the SWH is greater than 7 m. In this case, they are derived approximately from:

$$\begin{aligned} \mu(H) &= a + a_1 \ln H \\ \sigma(H) &= b_1 \exp b_2 H \end{aligned} \qquad (3)$$

where, H is significant wave height. The parameters a, $a_{1,}$ b_1 and b_2 are specific constants are determined from its standard diagram data by using both the least squared method and extrapolation.

Hwang *et al*. (1997) has developed the empirical relationship between peak period of the wave field, T, to wind speed, U and wave height, H and is given by:

$$U/(gT) = 0.048(U^2/(gH))^{0.67} \qquad (4)$$

where, g is the gravitational constant. Hwang reported that using the T/P data to derive U and H, the period calculated from (4) was found to be slightly less (by 6%) than the buoy measured peak period.

Davies *et al*.[6], **r**elating the sigma0 value with the probability distribution of the sea surface slopes allows the variance of the slopes to be expressed in terms of the spatial spectral moments. Using the dispersion relationship these can easily be converted into the temporal spectral moments. As a result we can obtain an estimate of the fourth spectral moment, m4, as a function of sigma0. Combining this with m0, obtained from the significant wave height value, allows the altimeter to estimate wave period, Ta. So, by analogy an altimeter wave period as equal to:

$$Ta = \left(\frac{m0}{m4}\right)^{1/4} \qquad (5)$$

Gommengiger *et al*. [8] produced method that uses the radar backscatter coefficient that is related under the Geometrical Optics approximation to the inverse of the inverse of the mean square slope (mss) of the long ocean waves:

$$\sigma^0 \sim \frac{1}{mms} \qquad (6)$$

In turn, ocean wave slope is dimensionally equivalent to the ratio of some measure of the ocean wave height and the ocean wavelength, L:

$$slope \sim \frac{SWH}{L} \qquad (7)$$

The ocean wavelength is related to wave period, T and phase velocity, c, through L = cT.

Under the deep water approximation, the wave phase velocity is related to the ocean wave period through the dispersion relationship for gravity waves:

$$c = \frac{gT}{2\pi} \qquad (8)$$

so that

$$L \sim T^2 \text{ and } mss \sim \frac{SWH^2}{T^4} \qquad (9)$$

and thus:

$$T \sim (\sigma^0 SWH^2)^{0.25} \qquad (10)$$

2.2 Application to Malaysian sea

The above methods to derive probability of occurrence of wave heights and joint probability distribution of wave heights and periods are applied to a particular Malaysian sea area. Wave heights data are compared with data from publications by MMS [9].

3. RESULTS

Results of application of the methods are described for a sea area close to Sarawak Coast. The area selected is in the South China Sea between the longitude of 112-114°E and latitude 4-6°. This area was chosen because of the availability of data in MMS for easier comparison. The data extracted were based on repeat cycle of the T/P satellite within this area from 1999-2001. Each data file contains text data for 8 hours cycle giving various information including date and time, locations (latitude and longitude in micro degrees), significant wave height (0.1m) and sea surface height (mm).

3.2 Comparisons with MMS data

Comparison between quarterly T/P data and MMS data is given in Table 2 for each individual year as well as for the 3-year average. The 3-year averages are also plotted in Fig. 1. It needs to be noted that the comparisons shown are between averages from altimetry measurements and visual observations, which are in themselves not very accurate. Nevertheless, the results indicate that significant wave heights from T/P generally agree well with those from MMS. There is a larger variation in the

Table 2: Comparison of average of significant wave height between MMS and Topex/Poseidon quarterly for 1999-2001

	1999		2000		2001		3-Year average	
	MMS	T/P	MMS	T/P	MMS	T/P	MMS	T/P
Q01	1.1	1.1	1.0	1.0	0.9	0.8	1.000	0.967
Q02	0.6	0.6	0.7	0.7	0.7	0.8	0.667	0.700
Q03	0.8	0.6	0.8	0.7	0.8	0.7	0.800	0.667
Q04	1.2	1.0	0.9	1.4	0.8	1.2	0.967	1.200

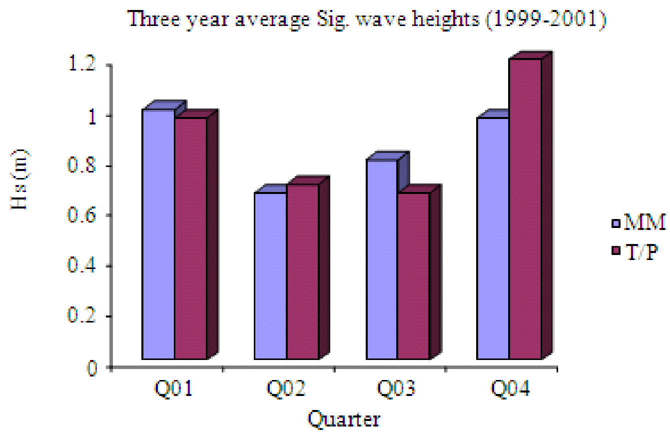

Fig. 1: Comparison of 3-year quarterly average of significant wave height between MMS and Topex/Poseidon

fourth quarter average. The difference could be attributed to the fact that there are fewer reports from ships during the monsoon seasons. For example in 2002, there are nearly one hundred ship reports in the month of July compared to only about 30 in the month of December. Moreover, the reports that come in are from masters of ships, which are in the open sea, most of whom will try to avoid heavy seas. Thus the observations from ships can be expected to be lower compared to the readings from T/P.

3.3 Comparison with GWS data

The annual probability distributions of one-metre classes of wave heights are obtained from T/P data in the period 1999-2001. The final distribution and comparison to GWS data is given in Table 3.The probability of exceedance curve for each distribution is plotted in Fig. 2. A 3-parameter Weibull function with the following equation are used to describe the distributions [10].

$$P(x \geq Hs) = \frac{\beta}{\alpha}\left[\frac{Hs-\gamma}{\alpha}\right]^{\beta-1} \exp\left[-\left(\frac{Hs-\gamma}{\alpha}\right)\right]^{\beta} \qquad (11)$$

where, α, β and γ are the parameters defining the shape of the curve. By curve fitting methods, the parameters describing the GWS and T/P distributions for this particular location are obtained and given in Table 4.

Table 3: Comparison of probability occurrence of significant wave height between GWS and TOPEX/poseidon for 1999-2001

	P (H) GWS	P (H) T/P
0-1	354	637
1-2	385	319
2-3	172	32
3-4	60	11
4-5	20	0
5-6	7	0
6-7	3	0
7-8	1	0
8-9	1	0

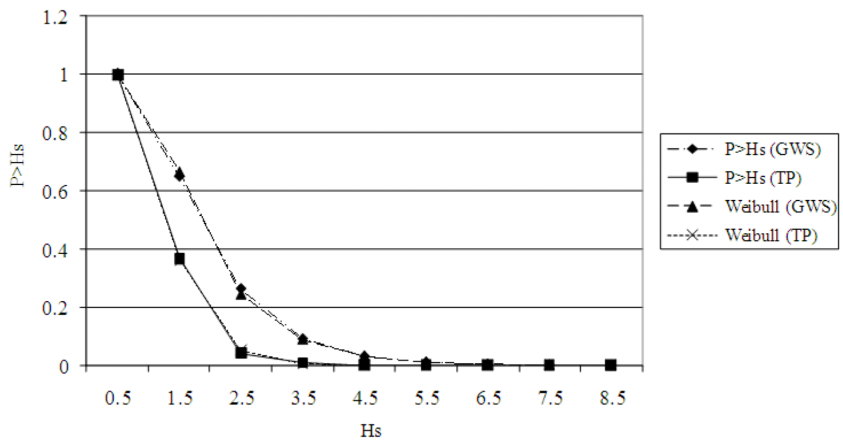

Fig. 2:Probability distribution of wave height exceedance

Table 4: Weibull parameters for wave height exceedance cumulative probabilities

Parameter	α	β	γ
GWS	1.1	1.6	0.2
T/P	0.5	1.0	0.2

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4. DISCUSSION

The results indicate that the data provided by T/P at the 2×2° grid is markedly different from that given by GWS Area 62. It should be noted that GWS gives wave height probability distribution for a large area covering Gulf of Siam and most of China Sea. As such, wave heights above 4 m are considered probable whilst in the selected location; such wave heights are never expected to occur. The shape of the probability exceedance curve shows that generally wave heights are lower at the selected area. Thus designing ocean structures in the selected area using GWS could lead to erroneous results, at best over design.

4.1 Comparison joint probabilities of wave heights and periods

The same altimetry data is used as input into Shinkai and Wan [4], Hwang *et al*. [7] and Gommengiger *et al*. [8] methods. Each method produces joint probability distributions of wave heights and periods and can be presented in a similar format to that of GWS. Results from Davis method are not available at the time of writing this study. Table 5 shows a typical scatter diagram obtained using Hwang *et al*. [7] method.
Comparison of marginal probability occurrence of wave periods obtained from GWS, Shinkai and Wan method, Hwang *et al*. [7] method and Gommengiger *et al*. [8] method are given in Table 6. The data is plotted in Fig. 3. It is shown that all methods show similar tends to that of GWS, giving most likely periods to be around 3-5 sec. There is a close agreement between results from Shinkai and Wan [4] and Gommengiger *et al*. [8] surprising because both use different concepts. Are significantly differences among these data. However, all the results from GWS and Shinkai and Wan method show a good agreement, but probability occurrence of wave period using the Hwang's results show a double hump which for now could not be characterised. There is a great need to carry out the validation purposes of this method.

Table 5: T/P Joint annual probability distribution for 1999-2001 using Hwang et al. [7]

SIGNIFICANT WAVE HEIGHT (cm)	<3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	>12	TOTAL
TOTAL	46	160	233	162	207	85	46	37	9	7	7	1000
>14	-	-	-	-	-	-	-	-	-	-	-	-
13-14	-	-	-	-	-	-	-	-	-	-	-	-
12-13	-	-	-	-	-	-	-	-	-	-	-	-
11-12	-	-	-	-	-	-	-	-	-	-	-	-
10-11	-	-	-	-	-	-	-	-	-	-	-	-
9-10	-	-	-	-	-	-	-	-	-	-	-	-
8-9	-	-	-	-	-	-	-	-	-	-	-	-
7-8	-	-	-	-	-	-	-	-	-	-	-	-
6-7	-	-	-	-	-	-	-	-	-	-	-	-
5-6	-	-	-	-	-	-	-	-	-	-	-	-
4-5	-	-	-	-	-	-	-	-	-	-	-	-
3-4	-	-	-	-	-	1	3	7	-	-	-	9
2-3	-	-	-	-	8	20	4	-	-	-	-	32
1-2	-	-	5	74	151	38	18	14	5	7	7	319
0-1	46	160	228	88	48	27	21	16	4	-	-	637

ZERO CROSSING PERIOD (s)

Table 6: Comparison of marginal probability of occurrence of wave period using GWS data, Shinkai and Wan method and Hwang et al method

	GWS	Shinkai and Wan (1996)	Hwang *et al.* (1997)	Gommengiger *et al.* (2003)
<3	84	156	46	141
3-4	284	254	160	239
4-5	339	238	233	241
5-6	197	168	162	135
6-7	72	101	207	111
7-8	19	55	85	75
8-9	4	29	46	35
9-10	1	0	37	9
10-11	0	0	9	3
11-12	0	0	7	2
>12	0	0	8	10

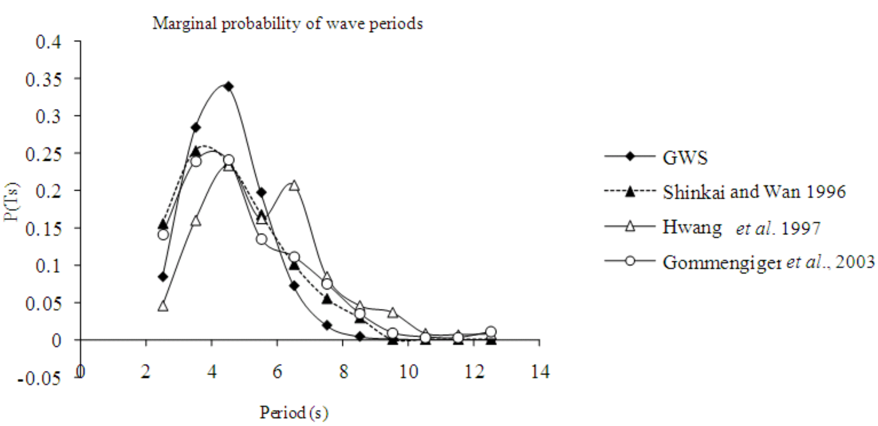

Fig. 3: Probability distribution of wave height exceedance

5. CONCLUSION

It has been shown that more comprehensive data can be obtained for all sea areas using satellite altimetry data. Comparison with presently available data based on visual observation has shown encouraging results. The data provided by TOPEX/Poseidon satellite can be used to derive wave periods, which can then be used to obtain joint probability distribution of wave heights and periods. Four methods to derive wave periods have been described and their implementation on a particular Malaysian sea area has been presented. The results indicate that the methods produces similar trends. However there is a need to obtain in-situ measurement for validation of these results.

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