Application of Remote Sensing in Ocean Wave Data Collection for Engineering Purpose

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Abstract: Presently, available wave data in Malaysian seas are based on visual observations from ships, oil platforms and limited wave buoys whose accuracy, reliability and comprehensiveness are often questioned. This paper presents an effort to develop a more reliable and comprehensive wave database for Malaysia sea areas using satellite altimetry. Significant wave height data is extracted from oceanographic satellite TOPEX/Poseidon for areas with the grid of 2°x 2° in the South China. Methods to derive wave periods from altimetry readings are also investigated. A review of three available methods to derive wave periods is presented together with a newly developed method. This paper 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. Results are presented in the form of probability distribution functions and 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: Satellite Altimetry, altimeter, ocean wave data

1. Introduction

The need for wave data for design purposes are currently fulfilled by provided of publications by Marine Meteorology and Oceanography, Malaysian Meteorological Service (MMS), for example Monthly Summary of Marine Meteorological Observation 1999 [1] and sometimes Global Wave Statistics (GWS) data published by British Maritime Technology [2]. GWS data for Malaysian sea is given in Table 1.

The accuracy, reliability and comprehensiveness of such data have often been questioned, for example in Shinkai & Wan, 1996 [3] and Bitner & Cramer, 1994 [4]. Remote sensing is a new approach to get the information on waves over vast sea areas. Altimetry and Synthetic Aperture Radar (SAR) have been used to observe the significant wave height and directional spectrum, respectively. Many satellites have been launched with altimetry or SAR until now, such as TOPEX/Poseidon, ERS-1/2 and Jason 1.

Effort to develop engineering oriented wave database for Malaysian sea using satellite altimetry has been presented by the present authors, for example in ref [5] and [6]. These papers discuss the derivation of wave data from TOPEX/Poseidon (T/P) satellite data. Comparison of T/P wave heights with data from MMS and GWS has been made.

One of the weaknesses of satellite altimetry is the unavailability of information on wave periods. Whilst the probability of occurrence of significant wave heights is normally enough for some engineering design calculations, in some cases such as the use of sea spectra to estimate downtime of floating vessels, wave period data is required.

This paper presents a survey of a number of methods to derive wave periods from various parameters and compares the results of their implementation for Malaysian sea.

Table 1. GWS Joint probability distribution for Area 62 [2]

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

SIGNIFICANT WAVE HEIGHT	<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

ZERO CROSSING PERIOD (s)

2. Wave Periods Derivation

The derivation of wave periods from altimeter data is still in its early development (Carter et al., [7]; Davies et al., [8]). There are a number of methods being developed by researchers in this area, for example by Davies et al, [8], Hwang et al, [9] and Gommengiger et al. [10]. In this paper, a review of the methods will be given together with examples of their implementation for Malaysian sea. The methods are explained briefly in this section.

i. Davies et al. [8]

Relating the $sigma_0$ 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 be converted into the temporal spectral moments. As a result we can obtain an estimate of the fourth spectral moment, m_4, as a function of $sigma_0$. Combining this with m_0, obtained from the significant wave height value, allows the altimeter to estimate wave period. So, by analogy an altimeter wave period as equal to;

$$Ta = \left(\frac{m_0}{m_4} \right)^{1/4} \tag{1}$$

ii. Hwang et al. [9]

Empirically, peak period of the wave field, T, is related to wind speed, U, and wave height, H, and is given by

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

Where g is the gravitational constant. Hwang reported that using the T/P data to derive U and H, the period calculated from (2) was found to be slightly less (by 6%) than the buoy measured peak period.

iii. Gommengiger et al. [10]

This method uses the radar backscatter coefficient that is related under the Geometrical Optics approximation to the inverse of the mean square slope (mss) of the long ocean waves:

$$\sigma^0 \sim \frac{1}{mms} \tag{3}$$

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

$$slope \sim \frac{SWH}{L} \tag{4}$$

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:

$$c = \frac{gT}{2\pi} \tag{5}$$

So that $L \sim T^2$
And

$$mss \sim \frac{SWH^2}{T^4} \tag{6}$$

and thus:

$$T \sim (\sigma^0 SWH^2)^{0.25} \tag{7}$$

From this, simple empirical model was built by performing a linear regression of wave period from buoy against this approximate T. Then the coefficients fitted using Orthogonal Distance Regression for linear models in log-log space of the form to derive zero up-crossing periods, T_z are;

$$Log_{10}(T_z) = 0.361 + 0.967 * Log_{10}(T) \tag{8}$$

3. Results and Discussions

The above methods to derive probability of occurrence of wave periods and joint probability distribution of wave heights and periods are applied to a particular Malaysian sea area. Results of application of the methods are described for a selected sea area in the South China Sea between the longitude of 106°E to 108°E and latitude 6°N to 8°N. This area was chosen because of the availability of measured sea surface data from Petronas Research and Scientific Services Sdn. Bhd. (PRSS) [12] for easier comparison.

PRSS data is based on wave radar measurement on the offshore oil and gas production platforms in the South China Sea. The altimetry data extracted were based on repeat cycle of the T/P satellite within this area for year 1997-2000. Each data file contains text data for 8 hours cycle giving information about date and time, locations (latitude and longitude in micro degrees), significant wave height (0.1m), sea surface height (mm), etc.

3.1 Wave Heights Data

The comparison of 4-year marginal probability of occurrence of wave heights is given in Table 2 and Figure 1. Although the buoy data shows a preponderance of lower wave heights, it is noted that the distribution of the probabilities are closely matched, Both data sets show that no waves are recorded beyond 4m wave heights in the area within the period 1997-2000.

TABLE 2. Comparison of marginal probability occurrence of wave height

Hs	PRSS	Topex
0-1m	0.72	0.51
1-2m	0.25	0.39
2-3m	0.03	0.10
3-4m	0.00	0.00
4-5m	0.00	0.00
5-6m	0.00	0.00
6-7m	0.00	0.00
7-8m	0.00	0.00
8-9m	0.00	0.00
9-10m	0.00	0.00

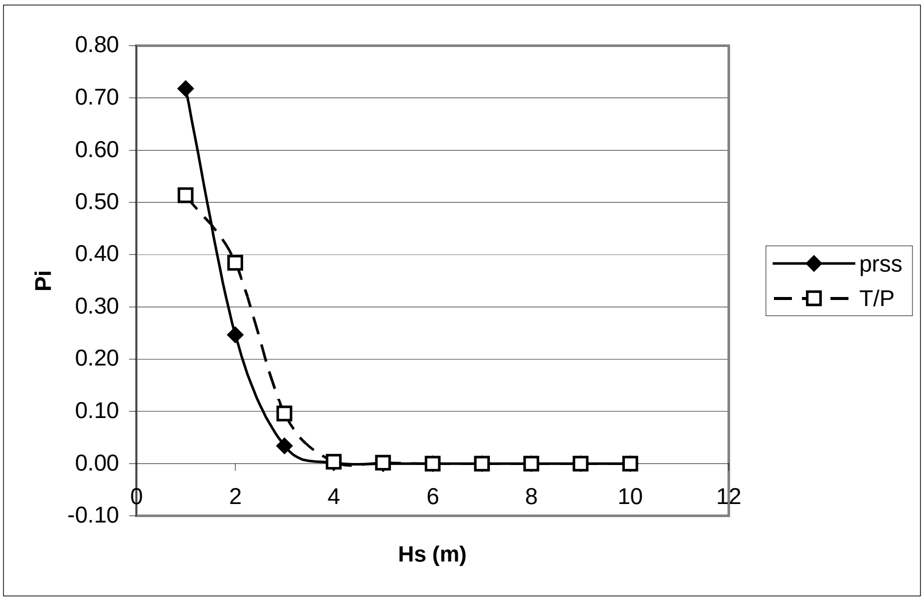

Fig. 1. Comparison of marginal probability occurrence of wave height

3.2 Joint-Probability Data

Scatter diagrams representing the joint probability distributions of wave heights and periods are presented in Tables 3 to 6. The data are presented in format similar to GWS shown earlier in Table 1. Table 3 shows joint probability distributions for measured data from PRSS while the distributions for satellite data derived using the three methods are shown in Table 4, 5 and 6 respectively.

It is quite difficult to see any resemblance or discern any pattern of similarities between the probability distributions obtained using the various methods. To investigate just period distribution, comparison of marginal probability occurrence of wave periods from PRSS wave data with the marginal probability occurrence of wave periods derived using the various methods is given in Table 7. The data is plotted in Figure 2.

Fig. 2 indicates that there seems to be a very close match between Hwang and the measured PRSS period distribution. The GWS, Davis and Gommengiger results show peak probabilities between 3 to 5 seconds while Hwang and PRSS indicate peak probabilities around 6 seconds. In addition, unlike others, Hwang and PRSS show there are appreciable occurrences of wave periods between 6 to 9 seconds. It should be noted however, that the various methods use different types of wave periods. PRSS data is given as mean periods, Gommengiger, Davis and GWS derive zero-crossing periods, while Hwang uses peak periods.

TABLE 3. PRSS Measured data

SIGNIFICANT WAVE HEIGHT \ MEAN PERIOD (s)	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	>13	TOTAL
TOTAL	112	267	282	183	122	31	2	1	1	0	0	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
2-3				1	12	21						34
1-2		13	42	89	94	8						246
0-1	112	254	240	94	16	1	1	1	1			718

TABLE 4. DAVIES ET AL. METHOD

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	618	314	38	27	1	1	1					1000
>14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7												
5-6												
4-5		2										2
3-4		3										4
2-3	75	21										96
1-2	294	83	4	1	1	1	1					385
0-1	249	205	34	26								514

TABLE 5. GOMMENGINGER ET AL. METHOD

SIGNIFICANT WAVE HEIGHT	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	>13	TOTAL
TOTAL	465	290	186	53	5	1						1000
>14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7												
5-6												
4-5					2							2
3-4				1	3							4
2-3			44	52								96
1-2	1	241	141	1								384
0-1	464	49										513

ZERO CROSSING PERIOD (s)

TABLE 6. HWANG ET AL. METHOD

SIGNIFICANT WAVE HEIGHT	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	>13	TOTAL
TOTAL	61	232	248	229	154	52	17	5	2			1000
>14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7												
5-6												
4-5							1	1				2
3-4						1	2					4
2-3				6	58	28	4					96
1-2	3	9	109	181	66	10	3	1	2			384
0-1	58	223	138	43	30	14	6	2				515

PEAK PERIOD (s)

Table 7. Comparison of marginal probability occurrence of wave periods.

	PRSS	Hwang et al.	Davies et al.	Gommengiger et al.
0-1	0.00	0.00	0.00	0.00
1-2	0.00	0.00	0.00	0.00
2-3	0.00	0.01	0.00	0.07
3-4	0.11	0.05	0.62	0.39
4-5	0.27	0.23	0.31	0.29
5-6	0.28	0.25	0.04	0.19
6-7	0.18	0.23	0.03	0.05
7-8	0.12	0.15	0.00	0.00
8-9	0.03	0.05	0.00	0.00
9-10	0.00	0.02	0.00	0.00
10-11	0.00	0.00	0.00	0.00
11-12	0.00	0.00	0.00	0.00
12-13	0.00	0.00	0.00	0.00

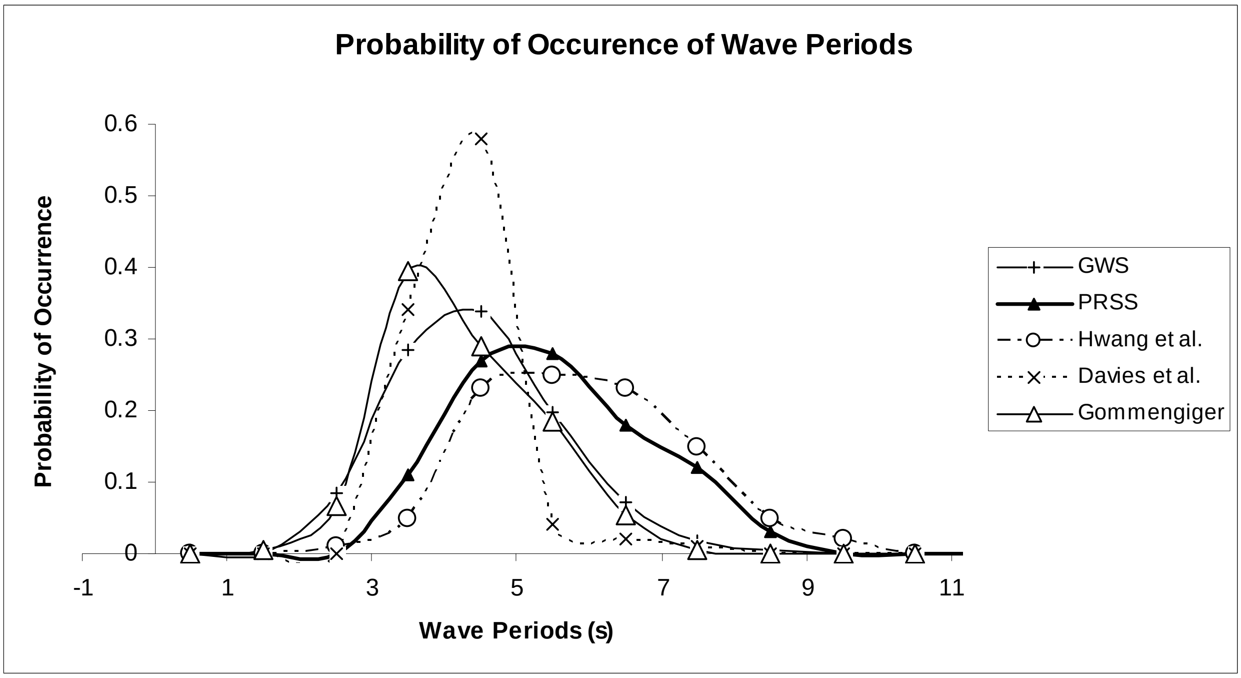

Fig. 2. Comparison of marginal probability occurrence of wave periods.

4. Conclusions

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. Three 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 Hwang method produce similar trends with the local data. Further work is continuing in comparison with buoy data from other areas and developing a web-based database using GWS format.

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References

[1] Malaysian Meteorological Department, 1997-2000, *Monthly Summary of Marine Meteorological Observation*, Kuala Lumpur

[2] British Maritime Technology Ltd., (BMT), 1986. *Global Wave Statistics*, Unwin,London.

[3] Shinkai A. and Wan S., 1996. *Statistical Characteristics of the Global Wave Statistics Data and Long-term Predictions*, ASME, Japan.

[4] Bitner-Gregersen E.M. and Cramer E. H., 1994. *Accuracy of the Global Wave Statistics Data*, IOPEC, Japan.

[5] Yaakob, O., Zainudin, N. and Shariff, R. , 2004. *Developing Malaysian Ocean Wave Database Using Satellite Altimeter*.Marine Technology Conference (MARTEC 2004), Johor, Malaysia.

[6] Yaakob, O. and Zainudin, N. , 2004. *Preliminary Work In Using Satellite Wave Data To Develop Malaysian Ocean Wave Database.* Ecological and Environmental Modeling 2004 (ECOMOD 20004). Pulau Pinang, Malaysia.

[7] Carter, D.J.T., Challenor, P.G. and Srokosz, M.A., 1992. *An assessment of GEOSAT wave height and wind speed measurements.* J. Geophys. Res. 97, C7, pp 11383-11392. Abstract-INSPEC.

[8] Davies, C.G., Peter, G.C. and Cotton, P.D., 1998. *Measurements of wave period from radar altimeters.* Proceedings of the International Symposium on Ocean Wave Measurement and Analysis, Volume 2, pp 819-826.UK.

[9] Hwang, P.A., Teague, W.J., Wang D.W.C., Thompson, E.F. and Jacobs, G.A., 1997. *A Wave/Wind Climatology For The Gulf of Mexico,* Proceeding of 7th International Offshore and Polar Engineering Conference, USA.

[10] Gommengiger, C.P., Srokosz, M.A., Challenor, P.G. and Cotton, P.D., 2003. *An empirical model to retrieving ocean wave period from Nadir altimeter data,* International Geosciences and Remote Sensing Symposium, volume 4, pp 2706-2708, France.

[11] Tucker, M.J., 1991. Waves in Ocean Engineering: Measurement, analysis, and interpretation, Ellis Horwood Ltd, England.

[12] Petronas Research and Scientific Services Sdn Bhd., 1997-2000. Physical Oceanography Data, (Unpublished)