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SATELLITE ALTIMETER OCEAN WAVE HEIGHTS DATA IN SOUTH CHINA SEA

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ABSTRACT

The need for reliable wave data cannot be over-emphasised. Data in the form of wave heights and periods are crucial in the design of marine structures, especially during the monsoon periods. This paper presents a study to obtain the ocean wave heights characteristics over Malaysian seas using multi-mission satellite altimetry data. The study area covered in this paper is Malacca Straits, South China Sea, Sulu Sea and Celebes Sea. The Radar Altimeter Database System (RADS) located at GNSS and Geodynamics laboratory, Universiti Teknologi Malaysia was used to extract the significant wave height data. Validation was carried out using in-situ measurement. The monthly averages of altimetry significant wave height data starting from 2000 to 2008 are used in this study. The results are mapped using m_map function in MATLAB Software thus presenting the ocean wave characteristics over Malaysian seas.

Keywords: *Wave period*, *Significant Wave Height, Satellite Altimeter and Monsoon Periods*

1 INTRODUCTION

Precise measurement of the ocean wave period is of much scientific interest both for research and industries. Shipping and offshore industries are very interested and keen to obtain real-time and climatological information on wave period in the open ocean to assist the design of offshore structures and maximise safety at sea. Similarly, wave period is good for short-to-medium term ocean and weather forecasting, and more widely, to ocean circulation and climate research, given the reported dependence of atmosphere-ocean momentum transfer on some measure of sea state development. (Oost, W.A., et al., 2002)

Probabilistic approaches are often adopted in the design of coastal or offshore structures. In this kind of approaches, the failure modes of the structure are described in the form of limit states. The input parameters of the limit state function are the stochastic load and strength parameters corresponding with the failure mode, like wave heights, wave periods, soil characteristics, etc. the popular statistical methods are available to derive the marginal distributions of all stochastic wave parameters. However, in view of the dependence structure between wave heights and wave periods, marginal analysis is in itself insufficient to come to an accurate description of the long-term wave climate. (D. J. de Waal & P.H.A.J.M. van Gelder, 2004)

The most recent technologies to explore ocean dynamics such as sea level, surface current, wave height and wind speed is satellite altimeter. Theoretically, satellite altimeter is operated by the satellite transmitting a short pulse of microwave radiation with known power towards the sea surface. The sea surface and the microwave radiation will then interact and part of the signal is reflected back to the satellite altimeter where the travel time is measured precisely. Several corrections are involved in the determination of sea surface height, wave height and wind speed from the altimeter range measurement such as the behaviour of the radar pulse through the atmosphere, sea state bias and other geophysical signals. All of these corrections need special attention, particularly close to the coast and in shallow water cases (Andersen and Scharroo, 2011).

2 RADAR ALTIMETER DATABASE SYSTEM (RADS)

The arrival of radar altimetry dramatically changed the way we could look at the world's wave climate. Before we had this state of the art technology, our knowledge of the wave climate came from instrumented buoys or ships or from visual observations from merchant ships. Instrumented ships and buoys provide us with very useful information that is complementary to altimeter data. Visual estimates from ships have a much better spatial distribution, but do not give full global coverage (see Figure 1). With visual estimates there are also questions about the quality, and consistency, of the observations itself. (Gulev, S.K)

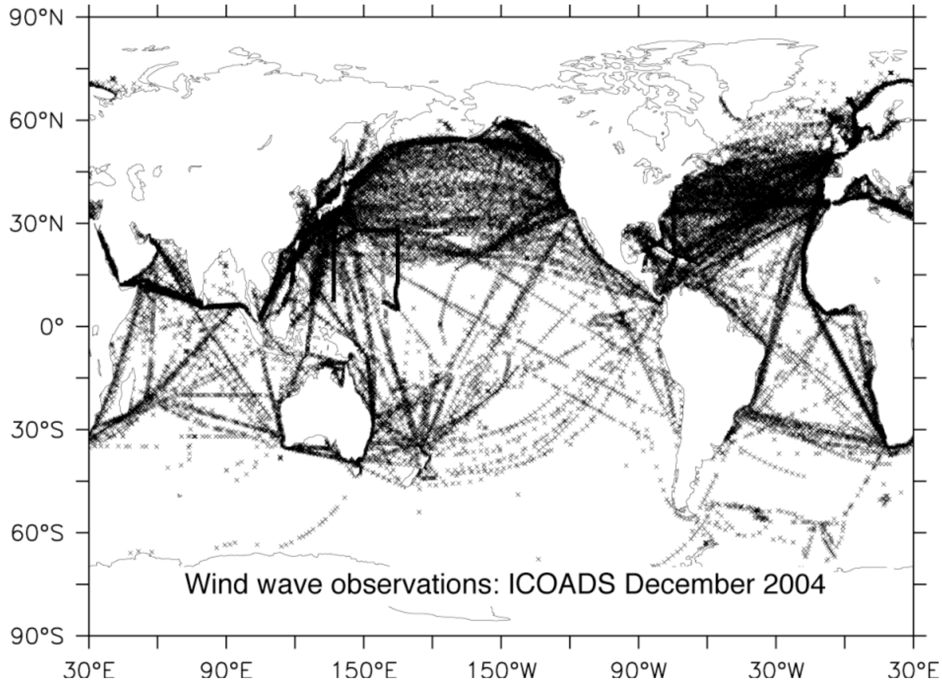

Figure 1. The coverage of visual wave observations from voluntary observing ships in December 2004. (Gulev et al., 2003)

When the first altimetry satellite GEOS-3 was launched in 1975, it did not have the capability to do on board recording of the data. With Seasat in 1978 that we get the first picture of the wave climate of the whole globe (Chelton et al., 1981). The advent of Geosat in 1985 gave us the first look at seasonal and inter-annual variation in the wave climate (Challenor et al., 1990).

Nowadays altimetry data has been dispensed through agencies like NOAA, AVISO, EUMETSAT and PO.DAAC. Aside that, the NOAA Laboratory and the Delft Institute for Earth-Oriented Space Research (DEOS) for Satellite Altimetry has been collaborating in the development of Radar Altimeter Database System (RADS). The RADS is established in a harmonized, validated and cross-calibrated sea level database from all satellite altimeter missions. In RADS, users able to access to the most present range and geophysical corrections and also can produce their own altimetric products based on their particular interest (Andersen and Scharroo, 2011).

In the frame of RADS, the DEOS is developing a database that incorporates validated and verified altimetry data products. Besides, the database is also consistent in accuracy, correction, format and reference system parameters. The capability of such a database will attract users with less satellite altimeter expertise like advisory councils, water management authorities and even high schools (Naeije et al., 2000). This system also caters the need of scientists and operational users to have value-added sea level data readily at one's disposal (Lucy Mathers, 2005). Currently, RADS enables users to extract the data from several present and past satellite altimeter missions like Geosat, ERS-1, ERS-2, ENVISAT, TOPEX/Poseidon (T/P), JASON-1 and JASON-2. The current status and detail information of the altimetry data in the RADS is shown in Figure 1.

Altimeter	Phase	Time	Cycles	Passes	Records
GEOSAT	A B D	31 Mar 1985 - 30 Sep 1986 08 Nov 1986 - 30 Dec 1989 31 Mar 1985 - 30 Sep 1986	001 - 025 026 - 093 001 - 025	61152	104395824
ERS-1	A B C D E F G	01 Aug 1991 - 14 Dec 1991 14 Dec 1991 - 25 Mar 1992 14 Apr 1992 - 20 Dec 1993 24 Dec 1993 - 10 Apr 1994 10 Apr 1994 - 28 Sep 1994 28 Sep 1994 - 21 Mar 1995 24 Mar 1995 - 02 Jun 1996	001 - 046 047 - 081 083 - 101 103 - 138 139 - 140 141 - 143 144 - 156	47890	83644555
TOPEX	A B N	25 Sep 1992 - 11 Aug 2002 20 Sep 2002 - 08 Oct 2005 11 Aug 2002 - 20 Sep 2002	001 - 364 369 - 481 365 - 368	111960	264208509
POSEIDON	A	01 Oct 1992 - 12 Jul 2002	001 - 361	7472	15718917
ERS-2	A	29 Apr 1995 - 04 Jul 2011	000 - 169	148130	168866998
GFO-1	A	07 Jan 2000 - 17 Sep 2008	037 - 223	82623	150249181
JASON-1	A B C	15 Jan 2002 - 26 Jan 2009 10 Feb 2009 - 03 Mar 2012 07 May 2012 - 05 Sep 2012	001 - 259 262 - 374 382 - 394	95120	259592804
ENVISAT1	B C	14 May 2002 - 22 Oct 2010 26 Oct 2010 - 08 Apr 2012	006 - 094 095 - 113	98894	258081831
JASON-2	A	22 Jun 2008 - 05 Sep 2012	998 - 153	39271	125238769
Total				692512	1429997388

Figure 2: Status of RADS (Source: http://rads.tudelft.nl/rads/status.shtml)

In Universiti Teknologi Malaysia (UTM), the RADS system has been installed since 2005 in the frame of the SEAMERGES project, an EU funded project (AUNP) that aimed for knowledge, methods and data exchange related to satellite altimetry, InSAR and GPS (www.deos.tudelft.nl/seamerges). Several universities and research group from France and the Netherlands (Europe representative), and Malaysia, Indonesia, and Thailand (South East Asia representative) are participating in this geodetic education and geodetic research project. The main goal of the SEAMERGES project is to accomplish the knowledge transfer, expertise and technology from Europe to South East Asia to locally enable the geodetic research at higher-level and to initiate the implementation of these technologies in the water management and risk assessment applications. It also aims at encouraging the scientific cooperation and collaboration among the different South East Asia countries.

3 WAVE HEIGHT DETERMINATION

The basic principle of satellite altimeter is based on the pulse that is reflected at the sea surface and backscattered according to wind and waves refer Figure 3. The pulse then will receive by the altimeter antenna after a few mili-seconds. The distance between the satellite and the sea surface is measured from the round-trip travel time of pulses emitted by the satellite radar, reflected back from the ocean (slope of the leading edge of the returned echo for wave height determination) and received again on antenna or receiver. There are three main parameters in reflecting the pulse from the ocean, they are the slope of the leading edge of the returned echo for wave height determination, travel time to measure distance to sea level and the energy of the impulse response for wind speed determination (W. Bosch, 2010). Meanwhile, the independent tracking systems are used to compute the satellite's three-dimensional position relative to a fixed Earth coordinate system. (Din et al., 2012).

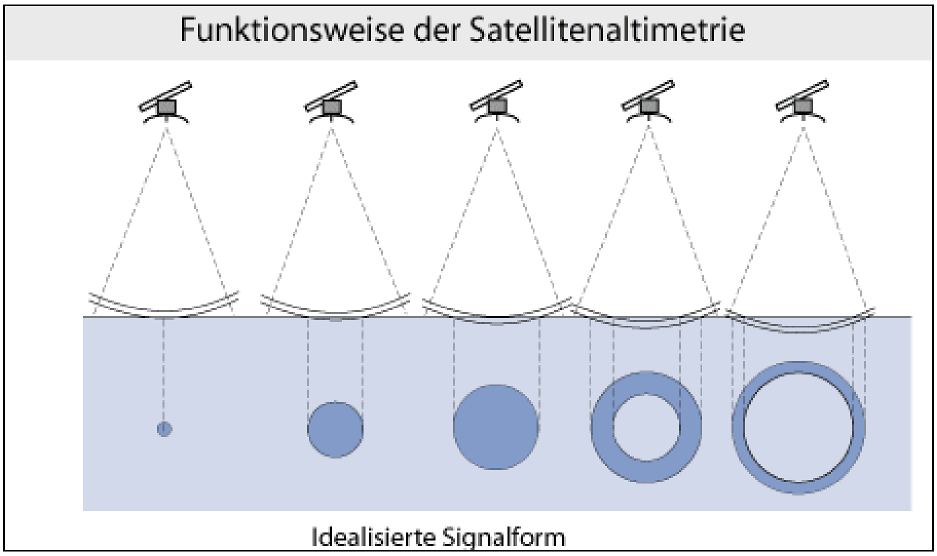

Figure 3: Footprint development (Courtesy of W. Bosch - Satellite Altimetry, ESPACE, 2010)

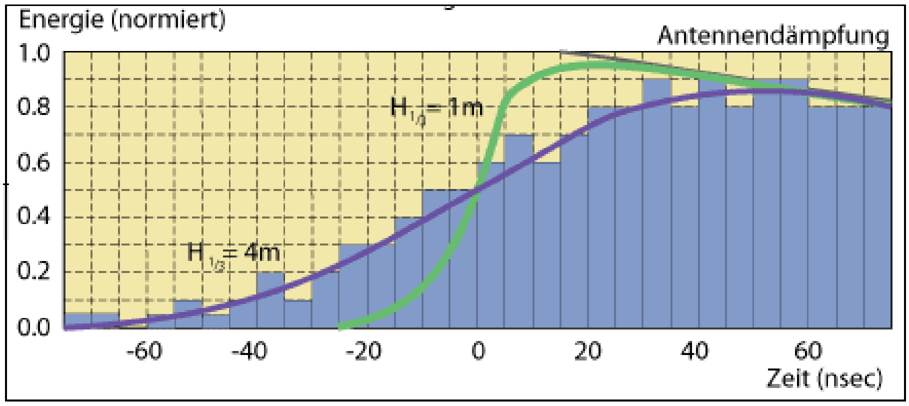

Figure 4: Idealized return echo (Courtesy of W. Bosch - Satellite Altimetry, ESPACE, 2010)

However, the situation is far more complex in practice. Several factors have to take into account for the Corrections of altimeter range measurements such as orbit error (radial component) and instrumental effects such as electronic time delay, clock (oscillator) drift , offset antenna phase centre , centre of gravity , time tagging of observations, Doppler shift error and so on. Another correction to be done is the atmospheric refraction due to ionosphere, troposphere (dry component) and troposphere (wet component). Other component that also can affect the signal is ocean surface such as ocean tides, Earth tides, electromagnetic bias (sea state) and inverted barometer effect. (W. Bosch, 2010). All of the effect and the correction can be refer to Figure 5.

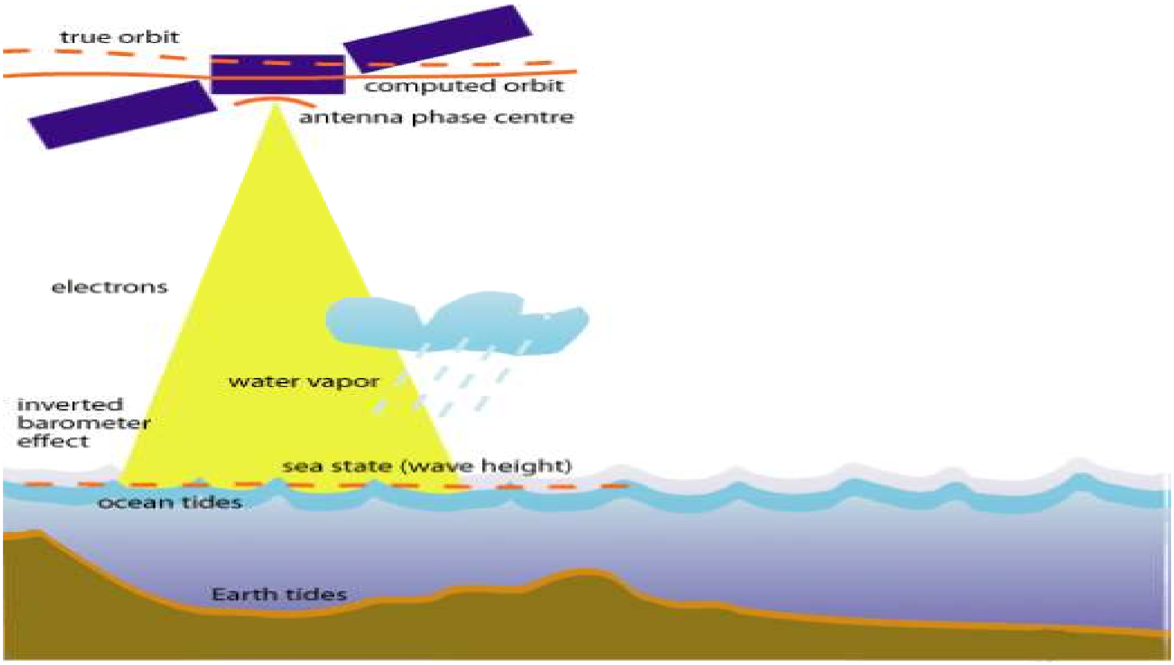

Figure 5: Corrections for altimeter range measurements (Courtesy of W. Bosch - Satellite Altimetry, ESPACE, 2010)

Figure 6 presents the schematic diagram of satellite radar altimeter system and its principle. By using a similar notation to Fu and Cazenave (2001), the corrected range $R_{corrected}$ is related to the observed range R_{obs} as :

$$R_{corrected} = R_{obs} - \Delta R_{dry} - \Delta R_{wet} - \Delta R_{iono} - \Delta R_{ssb}$$

Where,

$R_{obs} = c\ t/2$ is the computed range from the travel time t observed by the on-board ultra-stable oscillator (USO), and c is the speed of the radar pulse neglecting refraction.

$\Delta Rdry$: Dry tropospheric correction

$\Delta Rwet$: Wet tropospheric correction

$\Delta Riono$: Ionospheric correction

$\Delta Rssb$: Sea-state bias correction

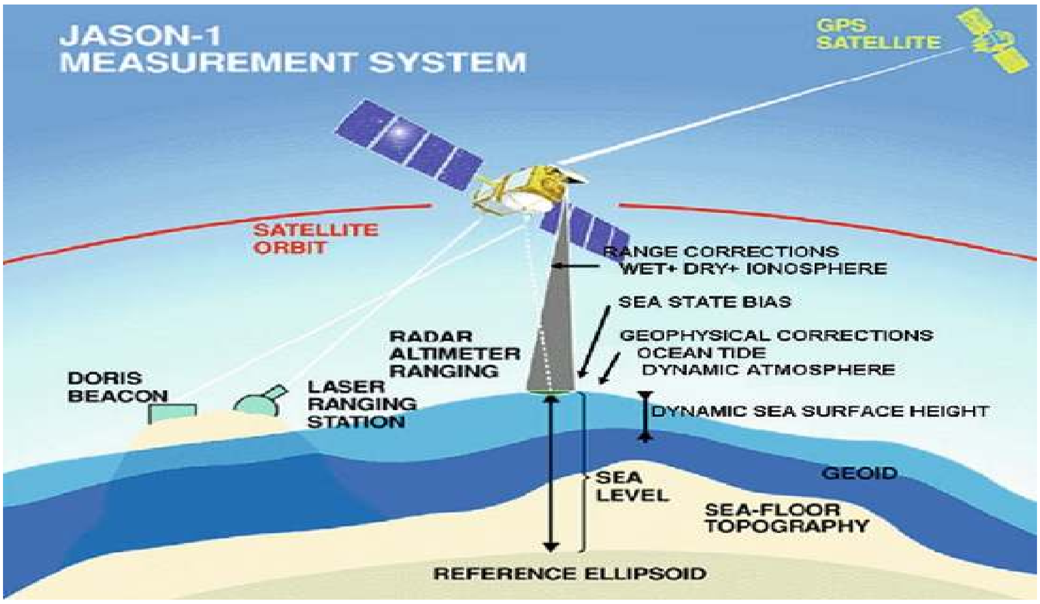

Figure 6: Principle of Satellite Altimeter (Courtesy of AVISO)

Once we have all the data from each of the altimeters (Topex, ERS-2, Jason-1 and Jason-2) we can combine the information to produce climatologies. To ensure we get enough satellite passes our climatologies are monthly average on a 0.25° x 0.25° square grid or around 27.8km x 27.8km.

In order to study the seasonal variation effect, the significant wave height and wave period from January 2000 until December 2008 are averaged based the monsoon season, Northeast Monsoon (November, December, January ,February) , Southwest Monsoon (May, June, July, August) , first Inter-monsoon (March, April) and second Inter-monsoon (September-October).

The seasonality of wave climate around Malaysian seas is derived from monthly gridded altimeter measurements over nine complete years (2000-2008). In a single year, the roughest month may vary (usually between November to February), but on average, December is the roughest month at most locations, especially the open sea such as the South China Sea.

4 DATA VALIDATION

For validation purpose, we receive a set of data from an oil and gas production company. The data set consists of significant wave heights measured at two points in Malaysian sea. The points are located at Sabah waters at 5.83 latitude and 114.39 longitude and at Sarawak waters at 5.15 latitude and 111.82 longitude. In this validation process, the data from Sarawak was chosen because we have better data reading from altimeter satellite at that particular point. The altimeter data was extracted from 0.25X0.25 grid (Figure 7), for almost the same time as the in-situ data (Figure 8).

Figure 7: In-situ data location

ERS2 (12-Jan-1996 03:06:57)	data In-Situ 12-01-1996 3:00:00 AM	ENVISAT (14-Jun-2002 02:36:54)	data In-Situ 14-Jun-2002 03:00
		0.835	0.8
1.59	1.85		
		(14-Jul-2002 14:28:19)	14-07-02 14:00
(11-Feb-1996 14:58:26)	11-02-96 15:00	0.77	0.71
2.7	3.03		
		(18-Aug-2002 14:28:17)	18-08-02 15:00
(16-Feb-1996 03:06:59)	16-02-96 3:00	1.54	1.61
0.5	0.47		
		(05-Jan-2003 14:28:16)	05-01-03 14:00
(02-Nov-1997 14:58:16)	02-11-97 15:00	2.4	2.25
2.182	2.13		
		(10-Jan-2003 02:36:49)	0-Jan-2003 03:00
(07-Nov-1997 03:06:49)	07-11-97 3:00	2.45	2.16
1.69	1.76		
		(14-Feb-2003 02:36:47)	14-02-03 3:00
(07-Dec-1997 14:58:14)	07-12-97 15:00	1.758	1.68
1.24	1.72		
		(21-Mar-2003 02:36:52)	21-02-03 3:00
(12-Dec-1997 03:06:48)	12-12-97 3:00	0.98	0.79
1.735	2.03		
		(20-Apr-2003 14:28:21)	20-04-03 14:00
(27-Mar-1998 03:06:51)	27-03-98 3:00	0.53175	0.32
1.36	1.36		
		(16-Nov-2003 14:28:22)	16-11-03 14:00
(26-Apr-1998 14:58:17)	26-04-98 15:00	1.57	1.52
0.56	0.51		
		(21-Dec-2003 14:28:25)	21-Dec-03
		3.16	2.99
(01-May-1998 03:06:50)	01-05-98 3:00		
0.285	0.34	(26-Dec-2003 02:36:59)	26-12-03 3:00

Figure 8: Wave height data from altimeter satellite and in-situ

From the data, we plotted a correlation graph between the altimeter data and the in-situ data. We obtained a good correlation between these data, we can see from correlation between ERS-2 data and in-situ data (Figure 9), the value of R^2 is 0.925. Meanwhile for Envisat data and in-situ data (Figure 10) the value of R^2 is 0.983. It shows that the altimeter data have a good accuracy and can be trusted especially for the prediction purposes of the wave climatologies.

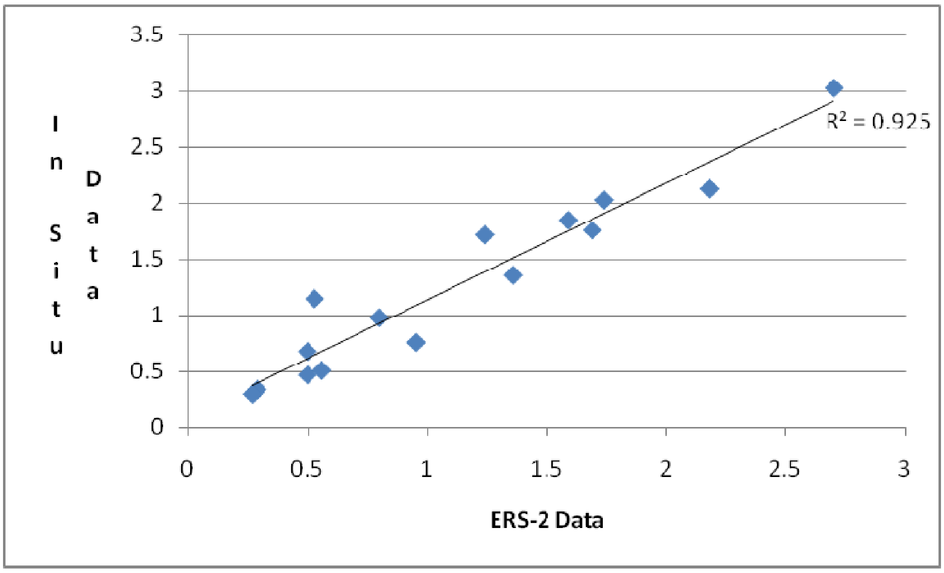

Figure 9: Correlation graph of altimeter data (ERS-2) and in-situ data.

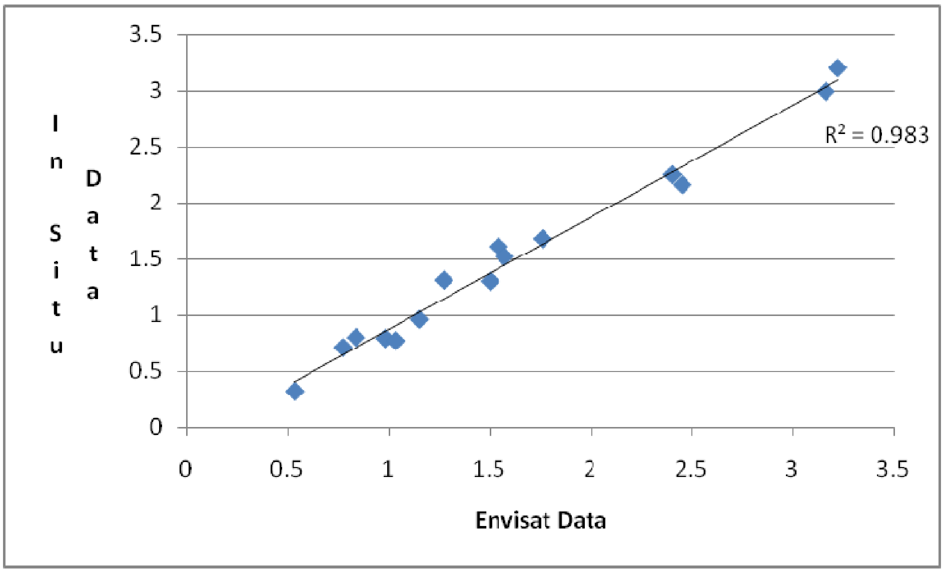

Figure 10: Correlation graph of altimeter data (Envisat) and in-situ data.

4 RESULTS AND DISCUSSION

The average significant wave heights in each monsoon are shown in Figure 11 to Figure 14. In these figures, the South China Sea is the roughest region throughout the year, while more sheltered regions, for example, around Malacca Straits, Sulu Sea and Celebes Sea are relatively calm. The seasonality varies slightly from region to region. For example, the Northeast Monsoon tends to be rougher than the other monsoon season period, for the inter-monsoon it usually calmer than the monsoon period all over the sea.

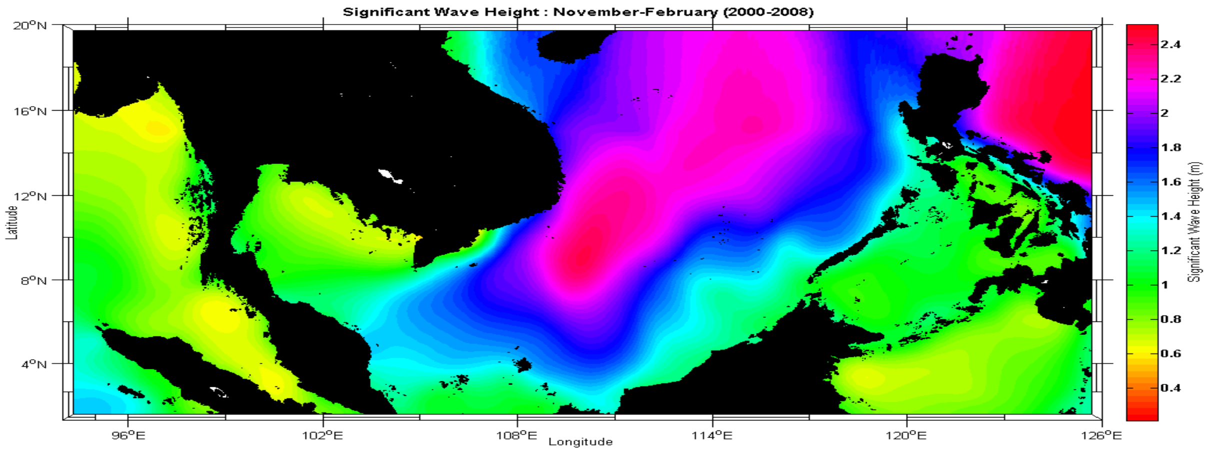

Figure 11: average of SWH during Northeast Monsoon (2000- 2008)

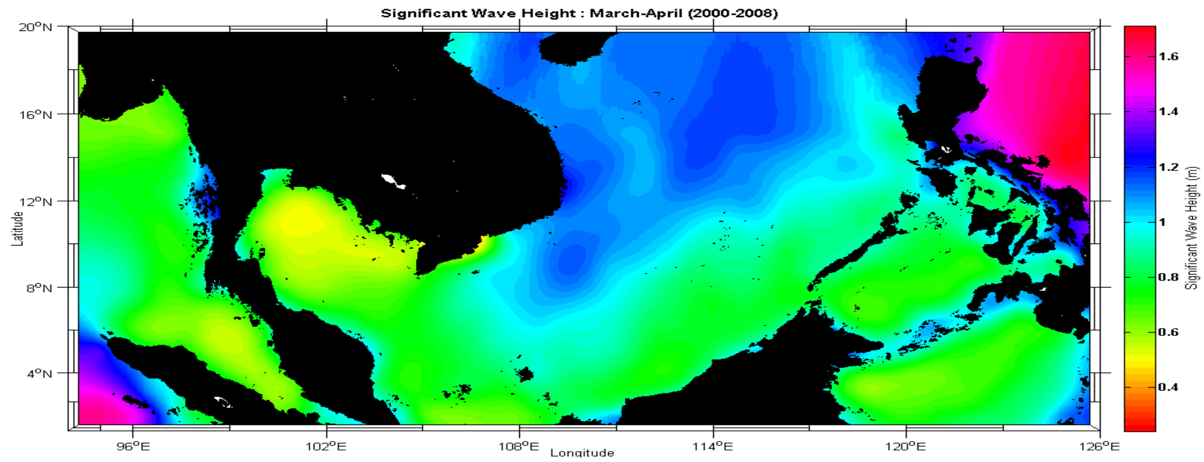

Figure 12: average of SWH during first Inter-monsoon (2000- 2008)

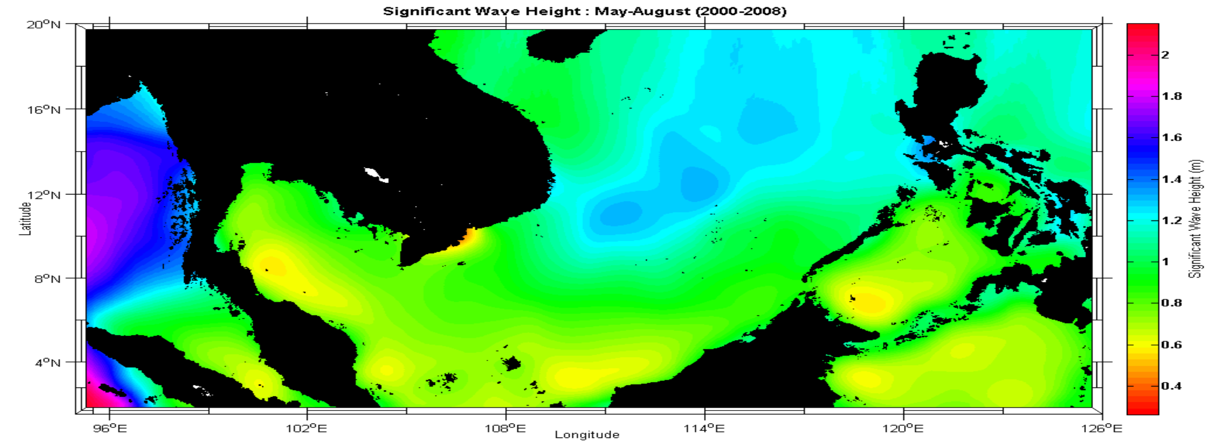

Figure 13: average of SWH during Southwest Monsoon (2000- 2008)

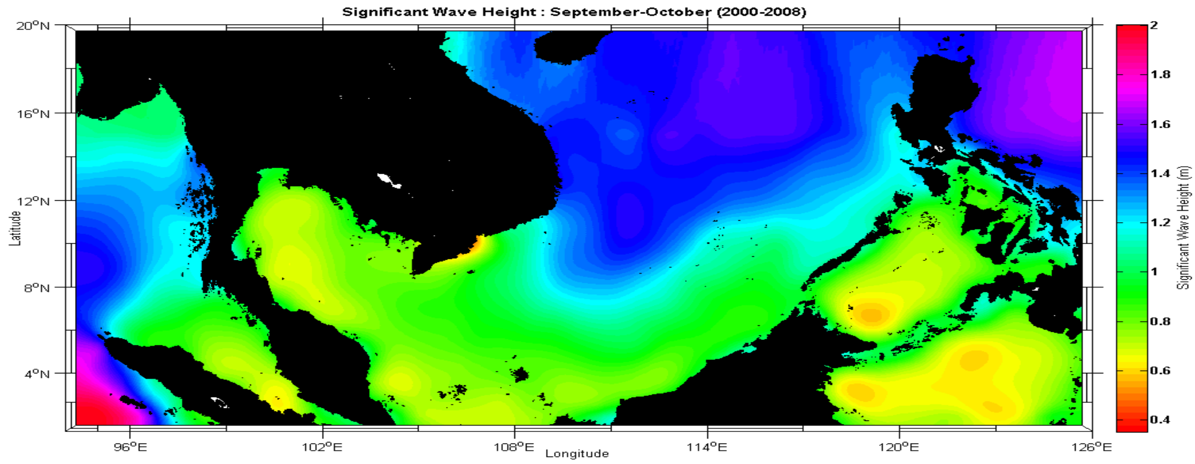

Figure 14: average of SWH during second Inter-monsoon (2000- 2008)

6 Conclusions

RADS technology provides a means as a complementary tool to the traditional wave measuring instruments in measuring long term wave height. In Malaysia region where instruments to measure wave such as buoy are still limited and very rare both in number and geographic distribution. RADS technology is able to facilitate the demand of wave height information on almost every part of the sea area. The comparison between altimeter derive wave height data and ground truth observations showed good agreement so far, and therefore both techniques are competitive. In conclusion, RADS is extremely helpful in both research and education and in operational and commercial exploitation of the radar altimeter data products.

7 Acknowledgements

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References

[1] Andersen, O., B., and Scharroo, R. (2011). Range and Geophysical Corrections in Coastal Regions: And Implications for Mean Sea Surface Determination. In Coastal Altimetry. Springer. doi:10.1007/978-3-642-12796-0.

[2] Challenor, P.G., S. Foale, and D.J. Webb (1990). Seasonal-Changes in the Global Wave Climate Measured by the Geosat Altimeter. International Journal of Remote Sensing, **11**(12), 2205-2213

[3] Chelton, D.B., K.J. Hussey, and M.E. Parke Global (1981). Satellite Measurements of Water-Vapor, Wind-Speed and Wave Height. *Nature*, **294**(5841), 529-532.

[4] Din, A. H. M., Omar, K. M., Naeije, M., and Ses, S. (2012). Long-term Sea Level Change in the Malaysian Seas from Multi-mission Altimetry Data. International Journal of Physical Sciences Vol. 7(10), pp. 1694 - 1712, 2 March, 2012. DOI: 10.5897/IJPS11.1596.

[5] D. J. de Waal *&* P.H.A.J.M. van Gelder 2005 Modelling of extreme wave heights and periods through copulas. Springer.DOI 10.1007/s10687-006-0006-y

[6] David K. Woolf., P. David Cotton and Peter G. Challenor (2003). Measurements Of The OffShore Wave Climate Around the British Isles By Satellite Altimeter. Phil. Trans. R. Soc. Lond. A January 15, 2003 361 1802 27-31;doi:10.1098/rsta.2002.1103 1471-2962 .

[7] Fu, L., and Cazenave , A. (eds.) (2001). Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications. Academic Press. San Diego, California, ISBN 0122695423.

[8] Gulev, S.K., V. Grigorieva, A. Sterl, and D.Woolf (2003). Assessment of the reliability of wave observations from voluntary observing ships: Insights from the validation of a global wind wave climatology based on voluntary observing ship data. *Journal of Geophysical Research: Oceans*, **108**(C7), 3236, doi: 10.1029/2002JC001437

[9] Lucy Mathers. (2005). Altimeter Database System, Exploitation and Extension *(RADSxx)* (Vol. 2005)

[10] Naeije, M., Schrama, E., and Scharroo, R. (2000). The Radar Altimeter Database System project RADS, 487-490.

[11] Oost, W.A., et al.,(2002). New evidence for a relation between wind stress and wave age from measurements during *ASGAMAGE.* Boundary Layer Meteorology.