WAVE HEIGHT AND WAVE ENERGY MAPPING IN MALAYSIAN SEAS USING SATELLITE ALTIMETRY DATA

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DEDICATION

I dedicate this work to my beloved Mother, Father, Sisters, Brother, Ayah Cik, and All My Best Friends

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ABSTRACT

In recent development of water base renewable energy, Malaysia is one of country which are active on this matter. In order to assess an area for wave energy mapping and development, the wave climate or seasonal wave mapping must be defined. Acquiring an accurate and reliable wave climate data is one of the crucial step in the assessment of wave energy resources. Using satellite altimeter have resolve two main problems with conventional wave measurements, which are spatial distribution of data and the accuracy for wave height data. Using altimeter technology, wave period are derive and the estimation of wave power in Malaysian seas can be accurately estimate. The Radar Altimeter Database System located at Global Navigation Satellite System and Geodynamics Laboratory Universiti Teknologi Malaysia, was used to extract the significant wave height and wind speed data. Validation was carried out for wave height and wave period using in-situ measurement. According to validation results, altimeter derived data is closely consistent with buoy data and correlation coefficient for European Remote Sensing Satellite 2 and Envisat are 0.9587 and 0.982 respectively for wave height and 0.750 respectively for wave period from Envisat. The monthly averages of altimetry significant wave height and wave energy starting from January 1993 to December 2011 were mapped in this study. The results shows Northeast Monsoon clearly have the most significant effect on Malaysian seas. The Southwest monsoon have very minimal effect on Malaysian seas. Average wave height during Northeast Monsoon were around 1.5m to 2.2m for the open seas and 0.6m to 0.8m for closed sea area. The results also shows that during Southwest monsoon most of Malaysian seas only have less than 1m of wave height except on certain places near the coast of Borneo. The average of wave power during Northeast Monsoon were round 8kW/m to 15kW/m for open seas and less than 5kW/m for sheltered sea area.

ABSTRAK

Perkembangan terbaru dalam bidang tenaga boleh diperbaharui berasaskan air, Malaysia adalah salah satu negara yang aktif dalam hal ini. Untuk menilai dan memetakan tenaga ombak, iklim ombak atau pemetaan ombak bermusim perlu dibuat. Memperolehi data iklim ombak yang tepat dan boleh dipercayai adalah langkah yang penting dalam penilaian sumber tenaga ombak. Satelit altimeter telah menyelesaikan dua masalah utama ukuran ombak konvensional, iaitu masalah taburan data spatial dan ketepatan data ketinggian ombak. Dengan teknologi altimeter, tempoh ombak diterbitkan dan anggaran kuasa ombak di laut Malaysia boleh dibuat dengan tepat. Sistem Pangkalan data Radar Altimeter di Makmal Sistem Navigasi Satelit dan Geodinamik Universiti Teknologi Malaysia, telah digunakan untuk menyari data ketinggian ombak dan kelajuan angin yang ketara. Pengesahan data dilakukan dengan menggunakan pengukuran secara terus. Merujuk keputusan pengesahan, data terbitan altimeter hampir konsisten dengan data boya dan nilai pekali korelasi untuk Satelit Penderiaan Jauh Eropah 2 dan Envisat, masing-masing adalah 0.9587 dan 0.982 untuk ketinggian ombak dan 0.750 bagi tempoh ombak Envisat. Purata ketinggian ombak dan tenaga ombak yang ketara dari altimeter bermula dari Januari 1993 hingga Disember 2011 telah dipetakan. Monsun Timur Laut dengan jelas mempunyai kesan yang paling ketara, tidak seperti Monsun Barat Daya yang mempunyai kesan yang sangat minimum ke atas laut Malaysia. Ketinggian purata ombak pada Monsun Timur Laut diantara 1.5m sehingga 2.2m untuk laut terbuka dan 0.6m sehingga 0.8m bagi laut tertutup. Sementara itu pada Monsun Barat Daya, laut Malaysia hanya mempunyai ketinggian ombak kurang daripada 1m kecuali pada tempat-tempat tertentu berhampiran pantai Borneo. Purata kuasa ombak pada tempoh Monsun Barat Daya adalah dalam lingkungan 8kW/m ke 15kW/m bagi laut terbuka manakala kurang daripada 5kW/m bagi kawasan laut terlindung.

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LIST OF SYMBOLS

a	-	Constant of 3.6231
b	-	Constant of 0.0754
c	-	Constant of 0.1943
d	-	Constant of -0.0188
e	-	Constant of 0.0000
f	-	Constant of 0.1991
c	-	Speed of the radar pulse
g	-	Local acceleration of gravity
ζ	-	Pseudo wave age
H	-	Wave height
Hs	-	Significant wave height
kW/m	-	Kilo watt per metre
L	-	Ocean wave length
m	-	Metre
mss	-	Mean square slope
m_4	-	dispersion relationship
P	-	Power
$\mathrm{P_i}$	-	Power per unit
$R_{corrected}$	-	Corrected range
R_{obs}	-	Observed range
t	-	Travel time
SWH	-	Significant wave height
T	-	Period
T	-	Peak period
Ta	-	Estimate wave period
T_z	-	Altimeter wave period

U	-	Wind speed
Δh_{wet}	-	Wet troposphere correction
$R_{corrected}$	-	corrected range
R_{obs}	-	observed range
ΔR_{ssb}	-	Sea-state bias correction
ΔR_{wet}	-	Wet tropospheric correction
ΔR_{dry}	-	Dry tropospheric correction
ΔR_{iono}	-	Ionospheric correction
ρ	-	Water specific weight
λ	-	Latitude/wave length
ϕ	-	Longitude
σ^{0}	-	Geometrical Optics approximation

LIST OF ABBREVIATIONS

AUNP	-	Asean-EU University Network Program
AVISO	-	Archiving, Validation and Interpretation of Satellite Oceanographic data
CNES	-	Centre National d'Etudes Spatiales
DEOS	-	Delft Institute for Earth-Oriented Space Research
DORIS	-	Delft Object-oriented Radar Interferometric Software
DORIS	-	Doppler Orbitography and Radiopositioning Integrated by Satellite
EC	-	European Committee
EnviSat	-	Environmental Satellite
EUMETSAT	-	European Organisation for the Exploitation of Meteorological Satellites
ERS-1	-	European Remote Sensing Satellite 1
ERS-2	-	European Remote Sensing Satellite 1
IDW	-	Inverse Distance Weighted
GEOS-3	-	Geodynamics Explorer Ocean Satellite 3
GMT	-	Generic Mapping Tool
GNSS	-	Global Navigation Satellite System
GPS	-	Global Positioning System
IGS	-	International GNSS Service
InSAR	-	Interferometic Synthetic Aperture Radar
ITRF	-	International Terrestrial Reference Frame
MATLAB	-	Matrix Laboratory
MMD	-	Malaysian Meteorological Department
MSS	-	Mean Sea Surface
NASA	-	National Aeronautics and Space Administration
NCEP	-	National Centre for Environmental Prediction

NCO	-	NetCDF Operator
NEONET	-	Netherlands Earth Observation NETwork
NOAA	-	National Oceanic and Atmospheric Administration
PO.DAAC	-	Physical Oceanography Distributed Active Archive Center
Radar	-	Radio detection and ranging
RADS	-	Radar Altimeter Database System
RINEX	-	Receiver Independent Exchange
SAR	-	Synthetic Aperture Radar
SCS	-	South China Sea
SEAMERGES	-	South-East Asia Mastering Environmental Research with Geodetic Space Technique
SEASAT	-	Sea Satellite
SLR	-	Satellite Laser Ranging
SWH	-	Significant Wave Height
TOPEX	-	Topography Experiment
T/P	-	TOPEX/POSEIDON
USO	-	Ultra-Stable Oscillator
UTM	-	Universiti Teknologi Malaysia
VOS	-	Visual Observation Ship
WEC	-	Wave Energy Converter
WGS84	-	World Geodetic System 1984
WH	-	Wave Height
WS	-	Wind Speed

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CHAPTER 1

INTRODUCTION

1.1 Study Background

Geographically, Malaysia is surrounded by water; the South China Sea, the Malacca Strait, the Sulu Sea and the Celebes Sea. Peninsular Malaysia is bordered by the South China Sea on the east side and by the Malacca Strait on the west coast. Sabah and Sarawak which are located on the north and northwest side of the Borneo Island border by the South China Sea along its northwest coast, and by the Sulu Sea and Celebes Sea in the northeast section of Sabah. During recent decades, marine operation activities in Malaysian Seas such as offshore oil operations, ship building, offshore structural industries and fisheries have been growing rapidly and have played an important role in the development of the Malaysian economy.

Due to these facts, the energy needed to be supplied to these industries is also growing tremendously. The ocean holds a tremendous amount of untapped energy and it is not surprising that the oil crisis of the 1970s increased interest in ocean energy, relatively only a few people have heard of it as a viable energy alternative. In fact, while hydroelectric dams are currently the only well known, mass producing water-based energy, but the ocean also has the potential to be a highly exploitable water-based energy source.

Ocean energy comes in a variety of forms such as marine currents, tidal currents, geothermal vents, ocean thermal and waves. All are concentrated forms of solar or gravitational energy to some extent. Moreover, wave energy provides 15-20 times more available energy per square meter than either wind or solar (Jennifer Vining, 2005**)**. The most commercially viable resources studied so far are ocean currents and waves.

Ocean waves arise from the transfer of energy from the sun to wind and then water. Solar energy creates wind which then blows over the ocean, converting wind energy to wave energy. Once converted, this wave energy can travel thousands of miles with little energy loss. Most importantly, waves are a regular source of power with an intensity that can be accurately predicted several days before their arrival. Furthermore, wave energy is more predictable than wind or solar energy.

In order to assess an area for wave energy mapping and development, the wave climate or seasonal wave mapping must be defined. The wave climate describes an area's wave height distribution. Our knowledge of the wave climate is basically derived from instrumented buoys or ships and from visual observations from merchant ships. Instrumented ships and buoys provide us with very useful information but poor spatial distribution. But the instrumented buoys are very expensive and limited in terms of their distribution. On the other hand, visual observations provide better spatial distributions and cost effective. But it has the biggest disadvantage, with visual estimates it means the quality of the data are questionable in term of accuracy and consistency because they are not measurements, but are just visual observations from the ship (Gulev *et al*., 2003). The spatial data distributions are also limited by using VOS (visual observation ship) data because they only give us data that are along their main route. For navigation purposes maybe they are very useful, but for scientific purpose they are inadequate. An example of the coverage of visual observation is shown in Figure 1.1, showing poor spatial coverage.

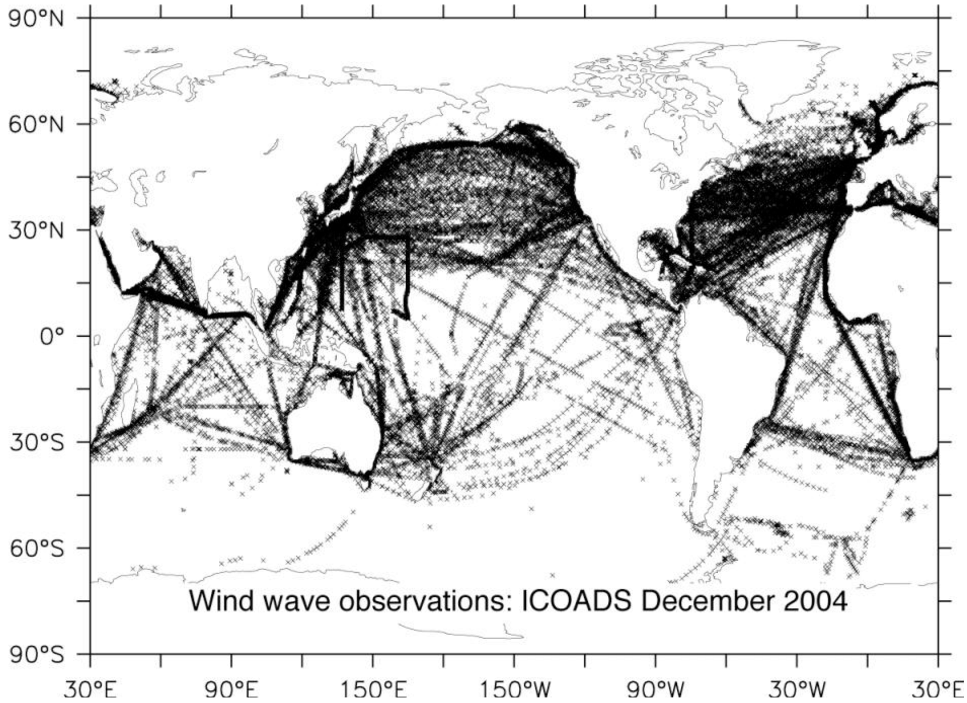

Figure 1.1: The coverage of visual wave observations from voluntary observing ships in December 2004. (Gulev *et al.*, 2003)

In Malaysia, Malaysian Meteorology Department (MMD) collects data based on voluntary observations from ships (VOS), which suffer from poor accuracy and spatial coverage. To overcome these problems, we must use a technology that can give us good spatial data coverage, yet good accuracy data. Currently, the technology that can give us all these advantages 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 (Andersen and Scharroo, 2011).

The aim of this research is to monitor and assess the wave energy in Malaysian seas. For these purposes significant wave height and wind speed data from satellite altimeter need to be extracted using Radar Altimeter Database System (RADS). Using data from six satellite missions TOPEX, ERS-2, ERS-1, JASON-1, JASON-2, and ENVISAT from the year 1993 until the year 2011. After the data extraction process, the next process is benchmarking the data with in-situ measurement from the buoy. This is to make sure our data are good in terms of accuracy and quality. Validation of wave height and wave period data in this study is by using in-situ measurement from offshore buoy provided by oil and gas company. Wave and wind data were used to derive wave period and wave energy in the Malaysian Seas. The study is focus on the South China Sea, the Malacca Strait, the Sulu Sea and the Celebes Sea area. All the altimeter data processing will be extracted from the Radar Altimeter Database System (RADS), developed by Delft University in the frame of the SEAMERGES project, an EU funded project (AUNP).

1.2 Problem Statement

To assess and harness wave energy, accurate data with comprehensive coverage is important. At present, readily available wave data are supplied by Malaysian meteorology department (MMD). MMD data is based on voluntary observations from ships (VOS), which are limited in term of the coverage and of course, the accuracy is questionable for scientific purposes. Usually VOS only covered the path of the ship, it means that those path that are not on their route will have no data. To overcome this problem, measurements from instrumental such as buoy are needed for high accuracy data, but unfortunately those instruments are very high in cost and we cannot afford to deploy them all around our waters. We need an alternative method that have good coverage of the Malaysian ocean and yet still capable producing good accuracy, especially for the scientific purposes. According to Marcus Mueller *et al.*, 2008 satellite technology offers the best potential for accurate measurement of wave height, velocity and direction, including both global and localised effects. Using altimeter technology, full data coverage for the Malaysian oceans can be attained, which means we can solve the spatial data problem provided by VOS. Furthermore, these data will be benchmarked with buoy data for the data accuracy validation. Also, by using those data mapping for the long term, the wave height climate around Malaysian seas and derivation of wave period estimation for Malaysian seas can be completed. The wave height and wave period estimation derived around Malaysian seas will be validated with buoy data. The second main output of this study is mapping of wave power for Malaysian seas, which is based on validated data (wave height and period).

1.3 Objectives

In pursuit the aim of this research, the following objectives will be addressed:

i. To derive and validate significant wave height data from satellite altimeter for Malaysian seas
ii. To derive and validate wave period based on wave height and wind speed data from satellite altimeter
iii. To produce wave height mapping and wave energy mapping in Malaysian seas.

1.4 Scope of the Study

The scopes of this study are described as follows:-.

i. Study area

The areas of wave height and wave energy study are selected from the Malaysian Sea region: South China Sea, Malacca Strait, Sulu Sea and Celebes Sea

ii. Satellite altimetry data

Wave height data and wind speed will be derived from six satellite missions: TOPEX, ERS-2, ERS-1, JASON-1, JASON-2, and ENVISAT from the year 1993 until the year 2011. The data will be extracted in the range area of $95° E \leq \lambda \leq 125° E$ and $0° N \leq \varphi \leq 15° N$, from January 1993 until December 2011.

iii. Ground Truth Data

Ground truth data will be used to verify the accuracy of wave height derived using altimeter technology. Due to the limited ground truth data, verification will only cover for a few areas based on the availability of data. Usually for wave height verification, an offshore buoy data will be used. In this study, we will get the data from an oil and gas company.

iv. Software

a) Radar Altimeter Database System (RADS)

Altimetry data from six satellite missions will be extracted and derived by the Radar Altimeter Database System (RADS). Two kinds of altimeter data will be extracted and processed that are significant wave height and wind speed by using the RADS software.

b) MATLAB Software

MATLAB programming will be developed to grid and calculate the average of significant wave height, wave period and ocean wave energy. We will also use this software to produce a map of wave height, wave period and wave energy by using it m-map function.

v. Data Analysis

The analysis will be focused on:

a) Mapping of average wave height data (1993-2011) during the monsoon transition period as listed below to see the wave height climatology/variation

- Southwest monsoon season (June -September)

- First inter-monsoon season (April -May)
- Northeast monsoon season (November - March)
- Second inter-monsoon season (October)

b) Producing Joint Annual Probability Distribution of wave period for the respective areas, this is very important in deriving wave energy and also the most important criteria for marine/offshore engineers.

c) Mapping the wave energy on a monthly basis throughout the eighteen years over Malaysian seas and assessment of the wave energy can be done.

1.5 Significance of the study

This study aims to demonstrate the potential of space-based technique by using satellite altimetry mission to extract, retrieve and derived wave height, wind speed, wave period and wave energy. This method will offer the best opportunity to overcome the weaknesses of the available measurement methods and will improve our knowledge about renewable energy and ocean wave energy at Malaysian Seas.

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 periods in the open oceans 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.

Ocean energy conversion has been of interest for many years. Recent developments of renewable energy devices and the concern over global warming have renewed the interest on the topic. Moreover, wave energy provides 15-20 times more available energy per square meter than either wind or solar. The most commercially viable resource studied so far are ocean currents and waves. Therefore this research is to monitor and assess the ocean wave energy in Malaysian seas and hopefully it will be able to help our country in developing renewable energy potential and devices.

1.6 Thesis outline

The thesis is focusing on mapping the wave height data for Malaysian seas and mapping of wave energy for Malaysian seas using satellite altimeter data. All five chapters in this thesis are focusing on the introduction of study, review of the study, methods on how the data are processed, results of the study and some few recommendations for a future studies. The five chapters are as follows:

Chapter 1 introduces the research outline, research objectives, research aim and also a general structure of study methodology in this thesis.

Chapter 2 review studies associate with mapping and deriving wave height and energy around the world from other researchers. This is very important to have a knowledge and overview of past and recent study on this particular studies. It also important to study a various method and outcome from other researchers to strengthen our study on Malaysian seas.

Chapter 3 shows the methodology of the study. It describes on how the data are process and mapped and also calculation involve in deriving wave energy from satellite altimeter. This chapter show a detail processing of satellite altimeter acquired from RADS compare to a simple and general methodology in chapter 1.

Chapter 4 shows all the results of the studies comprising mapping of wave height and wave energy for Malaysian seas. The mapping are divided into monthly mapping for each type (wave height and energy)

Chapter 5 is the final chapter in this thesis. It summarize the results of this studies and few recommendation are made to enhance future studies on this particular studies.

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