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Satellite-based wave data and wave energy resource assessment for South China Sea

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ABSTRACT

Wave energy has the potential to valuably contribute to the coastal states renewable energy mix. However, lack of data sources hinders the effort to deliberately assess this resource. This paper presents an assessment of wave energy resources in the South China Sea (Malaysian Exclusive Economic Zone) using satellite altimeter. Radar Altimeter Database System (RADS) provides data of significant wave height and wind speed from several satellite altimeters. The data were extracted for a space resolution of 0.25° × 0.25°, and within the time range from January 2001 to December 2010 and space range of 1.5°N − 10.0°N, 95.0°E − 116.0°E. For this study, fifteen 2° × 2° zones were considered around the east coast of Peninsular Malaysia and the coast of East Malaysia. The 10-year-data were validated with buoy measurements and presented as the probability distribution of wave height and wave period. The results indicate that bulk of the waves had peak period between 5s and 7s and significant wave height between 0.5 m and 1.5 m. The data were then used to calculate the theoretical available wave energy and power in the study areas. The results show that the average wave energy density of Malaysian seas facing the South China Sea is in the range of 1.41 kW/m to 7.92 kW/m, while the energy storage varies from 7.10 MW h/m to 69.41 MW h/m. This study also demonstrates the ability of satellite altimeter to provide an accurate and reliable data for more comprehensive and realistic estimate of the energy potential. The ability of satellite altimeter to provide wave data for all sea zones will enable more accurate identification of potential locations for wave energy development in Malaysia.

1. Introduction

Malaysia has adopted the Five-Fuel Diversification Strategy energy mix implemented since 1999. According to this strategy, five main sources, namely natural gas, coal, oil, hydro and renewable energy contributed to the energy mix in Malaysia. In 2012, the energy supply mix was roughly 46% natural gas, 32% oil, and 19% coal and coke, and 3% hydro [1]. The Malaysian Prime Minister, Najib Razak, during his keynote address at the official opening of the third International Greentech and Eco Products Exhibition and Conference Malaysia (IGEM 2012) stated that, the government targeted to have 5.5% share of renewable energy in the total energy mix in installed capacity by 2015.

The potential renewable energy sources in Malaysia include solar energy, wind energy and ocean energy. Ocean energy consists of wave energy, tidal energy, salinity gradient and Ocean Thermal Energy Conversion (OTEC). Ocean energy has a number of significant advantages includes source-predictability, abundance, high load factor and low environmental impact and availability compared to other renewable energy sources. The wave energy is rightly regarded as one of the renewable energy sources with the greatest potential to replace conventional energy sources. According to Zubaidah in Ref. [2], out of the ocean-related sources of waves, tides and currents, the one with some potential is perhaps wave energy off-shore the east coast of Malaysia.

Numerous studies have established the wave energy resource assessments in various region, for example in Baltic Sea [3], Hawaiian Islands [4] and Indian shelf seas [5]. Many countries around the world also have evaluated the potential of the wave energy resource in their coastlines including China [6], Korea [7], French [8], Australia [9], England [10] and the United States [11]. In

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addition, atlas of global wave energy resource assessment were also presented [12,13]. The assessments were carried out using wave climate data from buoy, satellite altimeter, numerical wave hind casts model or a combination of these sources.

The wave climate data play a key role in the assessment of wave energy resources. Thus, acquiring an accurate and reliable wave climate data is one of the crucial steps in the assessment. Previously, visual observations from merchant ships and buoys have provided us with very useful information on the wave climate with better spatial distributions despite not giving full global coverage. However, several studies questioned the quality and consistency of these visual estimations [14–16]. Maulud et al. [17] and Wan Nik et al. in Ref. [18] assessed the potential of wave energy resources in Malaysia using buoy measurements data. Both studies identified that the wave energy has a potential to valuably contribute towards Malaysian renewable energy mix.

Maulud et al. in Ref. [17] developed a mapping of Malaysian seas using Geographical Information System (GIS) based on wave data from Malaysian Meteorological Department (MMD) to assess the potential wave energy location in Malaysia. In their study, they identified a high potential location for wave energy off Sabah in the Northern portion of East Malaysia. On the other hand, Wan Nik et al. in Ref. [18] used field survey or in-situ measurements to assess the wave power potential along the east coast of Peninsular Malaysia. Their study based on one and two-hourly buoy datasets acquired from acoustic wave and current (AWAC) instruments deployed by Universiti Malaysia Terengganu (UMT) and Malaysian Meteorology Department (MMD). Their results indicated that Terengganu coast of Peninsular Malaysia could provide a source of low wave power varies in the range of 0.1 kW/m to 6.49 kW/m.

However, a recent survey on the potential of marine renewable energy in Malaysia by Yaakob and Koh in Ref. [19] suggested that the data from Malaysian Meteorological Department (MMD) is incomplete and inaccurate with limited coverage. Thus, the mapping developed by Maulud et al. in Ref. [17] does not accurately portray the true picture of Malaysian seas. Their estimate of the wave power density between 13 kW/m to 160 kW/m is also unacceptable as it is too high for Malaysian sea conditions. The buoy data as in Ref. [18] also have limited spatial and temporal coverage [20] and only applicable to the particular area of interest. This measuring system also are not widely available and does not have a worldwide evenly distributed cover, mainly due to high costs and difficulty related to harsh sea environment [21]. Nevertheless, the buoy measurements data are usually used to validate the performance of other wave measurements such as satellite altimeter and wave model.

An alternative approach of using satellite altimeter in oceanography and marine field is capable to offer more accurate and reliable data with a good comprehensive coverage. However, due to small area of the earth's surface at low and mid latitude, the wave data can only be imaged once every few days with a single satellite, hence, lack in temporal resolution. The satellite measurements are also quite intermittent compared to 3 hour in situ or buoy measurements. Krogstad and Barstow in Ref. [22] addressed that the 3 hour in-situ buoy measurements is unnecessarily dense to determine the long term distribution of significant wave height, $\boldsymbol{H_s}$. Even so, satellite altimeter is ideal for detail resource mapping due to its high spatial resolution [23]. Barstow et al. in Ref. [24] used two years of altimeter data to construct a global map of the available wave energy resources in deep water. They succeeded in generating reasonable estimates of the spatial variations of mean wave energy despite the relatively short record length [21].

Besides, satellite altimeter data provided more comprehensive data of wave height and wave period for all sea zones [25]. Numerous studies have assessed the accuracy of satellite altimeter measurements by comparing them with oceanic in-situ measurements from buoy stations around the globe [26–29]. Aziz et al. in Ref. [30] showed that the altimeter wave height is accurate and has excellence coverage and frequency of occurrence as compare to buoy measurement data in the South China Sea. Fairly little research on validation and application of altimeter has been conducted in the South China Sea, particularly around Malaysian seas. Thus, this paper highlights the application of satellite altimeter in the assessment of wave energy resource in Malaysia.

2. Area of interest and wave data

Fifteen $2° \times 2°$ zones around the east coast of peninsular Malaysia and the coast of East Malaysia (Sabah and Sarawak basin) were considered in this study, as shown in Fig. 1. All selected zones are located within the Exclusive Economic Zone (EEZ) of Malaysia. Zone A to E are located in the east coast of Peninsular Malaysia facing the South China Sea, while Zone F to O are located around the coast of East Malaysia. The South China Sea possesses great potential of wave energy. These zones are exposes to the Northeast Monsoon season in the month of November to January each year. During this monsoon season, wave heights are larger attributable to the stronger wind speed and larger wind fetch. According to Muzathik et al. in Ref. [31], the intensity of the wave energy fluctuates seasonally in this zone, with the highest energy density occur during the northeast monsoon season.

2.1. Satellite altimeter

Since the launch of Geostat in 1985, satellite altimeter has been used to explore the ocean dynamics and provided global coverage of sea level [32,33], ocean current [34,35], wave height, and wind speed [20]. Satellite altimeter is a nadir-pointing instrument designed to measure precisely the time a radiated pulse takes to travel to the surface and return. Fig. 2 illustrates the schematic representation of satellite measurements. The angles $\boldsymbol{\theta}$ and $\boldsymbol{\theta}'$ are the antenna pointing angle and incidence angle. $\boldsymbol{R}$ is the satellite altitude above the nadir point while $\boldsymbol{R_\theta}$ is the slant range of radar measurement at pointing angle $\boldsymbol{\theta}$ and $\boldsymbol{A_f}$ is the antenna footprint area [36]. Theoretically, radar altimeters on board the satellite will permanently transmit a short pulse of microwave radiation with known power towards the sea surface. Interaction between the sea surface and the microwave direction will reflect part of the signal to the satellite altimeter to precisely measure the travel time between the satellite and the sea surface.

Radar Altimeter Database System (RADS) established the data from satellite altimeter in a harmonized, validated and cross-calibrated sea level database. The database is consistent with accuracy, correctness, format, and reference system parameters. It also enables users to extract the data from several present and past satellite altimeter missions such as Envisat, Topex/Poseidon (T/P), Jason-1, Jason-2 etc. In this study, the wave data were retrieved from combination of multi satellite altimeters including Envisat, ERS-2, Jason-1, Jason-2, and Topex/Poseidon (T/P). These altimeters have provided us with good quality measurements for the past several decades [27]. Multi-mission processing allows more along-track data for model assimilation, higher resolution and better resilience thus providing high precision altimeter data. The data were extracted from Radar Altimeter Database System (RADS) located in the Global Navigation Satellite System (GNSS) and Geodynamics Laboratory, Universiti Teknologi Malaysia.

The RADS data were retrieved with each mission have been updated with most up-to-date correction [37] for a space resolution of $0.25° \times 0.25°$, within the time range from January 2001 to December 2010 and space range of 1.5°N – 10.0°N, 95.0°E –