Wave energy resource assessment for Southeast Asia

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Abstract:
Wind-generated ocean waves have the potential of contributing a significant amount of renewable energy. The conversion of ocean waves into sustainable electrical power has been increasingly concerned and the need for wave energy resource assessment therefore becomes essential. This paper explores the wave energy potential of Southeast Asia (SEA) by applying numerical wind-wave modelling. In particular, the spectral wave model with SEA domain and resolutions between 1° and 100m was run for one-year period. The boundary conditions were obtained from another spectral wave model with the coarser mesh of Indo-Western Pacific domain, comprising of the Indian Ocean and part of western Pacific Ocean ranges between 20° to 140° E and 60° S to 35° N. The modelling output presents the map of annual mean wave power of the region and it reveals that wave power is highest in the western side of Sumatra island, the Andaman Sea part offshore of Myanmar, followed by the South China Sea area between Vietnam and the Philippines. Within the Singapore Strait, wave energy is found to be strongest in the southeast, and showing the greatest magnitude during northeast monsoon.

Keywords: *Ocean renewable energy; Singapore; Southeast Asia; Wave energy; wind-wave simulation*

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1. Introduction

Wave energy resource estimation is a necessary step in identifying areas suitable for siting wave energy converters (WECs) and also in selecting the appropriate WEC for a site. Wave information can obtained though measurement or numerical wind-wave model simulations. Measurements techniques are either direct, e.g. wave buoys, or indirect, e.g. satellite altimeter. Direct measurements are not widely available – buoys are sparsely located or clustered on particular coastlines and ships' visual observations are limited to shipping lanes (Hemer and Griffin, 2010). Satellite altimeter and Synthetic Aperture Radar (SAR) data has been shown to give accurate wave data. However, this data is temporally sparse, as dictated by the repeat cycle of each satellite. Numerical wave models take wind fields and use them to force wave fields based on the physics of wave generation, propagation and decay. The directional spectra are computed at the nodes of a grid covering the region of study, with the spectral or, more commonly, the integrated height period and direction parameters stored at regular intervals. The so-called third generation models now in most common use are WAM and WAVEWATCH III offshore along with SWAN for more accuracy closer to shore (Pontes and Bruck, 2008; WAMDI Group, 1988). The correctness of model results is dependent on the input wind data. It is therefore common to improve the accuracy by calibrating results against measured wave data.

As in Fig. 1, the corresponding correlation coefficients between model data and the Topex/Poseiden satellite data are generally high, suggesting a good level of accuracy. However, the correlations in the Southeast Asia (SEA) region are low, as is the wave power. The lower correlation is due to lower wave heights and less variation in wave conditions but also because the 0.5° resolution cannot properly represent some of the small island geographical features. For this reason, it is important to map the wave resource of the area on a far higher resolution than has been carried so far. The Tropical Marine Science Institute (TMSI) at National University of Singapore and the Energy Research Institute at Nanyang Technological University have been jointly modelling weather within SEA using simulated wind fields produced using the Weather Research and Forecasting (WRF) model as input into MIKE 21 SW, a spectral wave model developed by DHI Water & Environment (DHI, 2012). The wind-wave model has been run for one year period, including the whole of the SEA region, along with areas of ocean that feed into the local wave conditions. In addition, very high resolution mesh has been nested for Singapore waters.

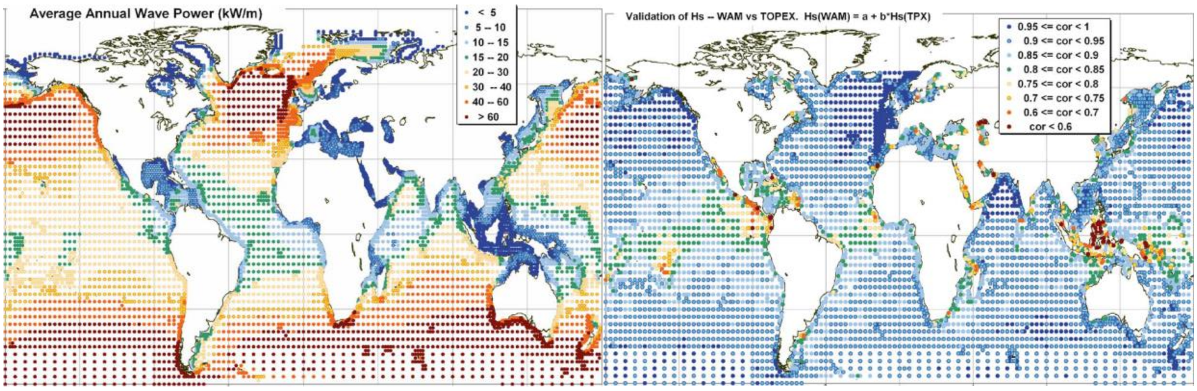

Fig. 1: Average annual wave power (left) and correlation coefficient between model and satellite data (right)

2. Methodology

MIKE 21 SW, the spectral wave model developed by DHI Water & Environment is used to simulate the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas. The model has been widely used in wind-wave modelling research (Aboobacker et al., 2013). Two domains were considered for the wind-wave simulations.

(i) Indo-Western Pacific (IWP) domain: It consists of the Indian Ocean and part of western Pacific Ocean ranges between 20° to 140° E and 60° S to 35°. The flexible mesh in this domain ranges between 1.5° and 0.75°.

(ii) Southeast Asia (SEA) domain: It consists of the South China Sea (SCS), Malacca Strait (MS) and Singapore Strait (SS) ranges between 90° to 130° E and 7° S to 35° N. The flexible mesh in this domain ranges between 1° to 100m. The finest resolutions are in the SS (between 3km and 100m) focusing the Tanah Merah region along the Singapore coast.

The primary aim of the IWP model is to obtain the boundary conditions for the SEA model, both run consequently. The boundary parameters are significant wave height (Hs), peak wave period (Tp), mean wave direction (MWD) and directional standard deviation (DSD).

Bathymetry data have been considered from various sources and interpolated to the triangulated flexible mesh with various resolutions to generate the model bathymetry for wind-wave computations.

Wind-wave parameters have been computed in the IWP and SEA models forced by National Centers for Environmental Prediction (NCEP) and WRF modelled winds, respectively.

3. Results and Discussions

3.1 Maps of annual results:

Modelling results provide wave height and period, which are then used to compute the wave power and energy. The calculation method assumes omnidirectional waves, not considering only the amount of energy orthogonal to the line. Fig. 2 reveals that annual mean wave energy is highest in the western side of Sumatra island, the Andaman Sea part offshore of Myanmar, followed by the

South China Sea area between Vietnam and the Philippines. Fig. 3 display the maps of annual mean wave energy, together with the total annual energy per unit crest within a buffer area covering 2 km from the coastline of Singapore. It can be seen from Fig. 3 that the area producing greatest wave energy in Singapore Strait is in the southeast of the island. Higher energy swells and wind waves in the area are propagating from South China Sea, where they have better conditions to grow (larger depth and fetch). The total annual wave energy within the buffer area is estimated to be approximately 47.2 GWh. The resource maps also suggest that WEC devices for Singapore should probably be located on the southeastern sites of candidate locations like Raffles' Light House, Semakau, Sebarok, St. John's Sentosa, and along East Coast Park (ECP) (where Tanah Merah Ferry Terminal is located). The presence of breakwaters along ECP supports the findings that the wave climate in the southeastern side of Singapore is relatively stronger than the southwestern part of the island.

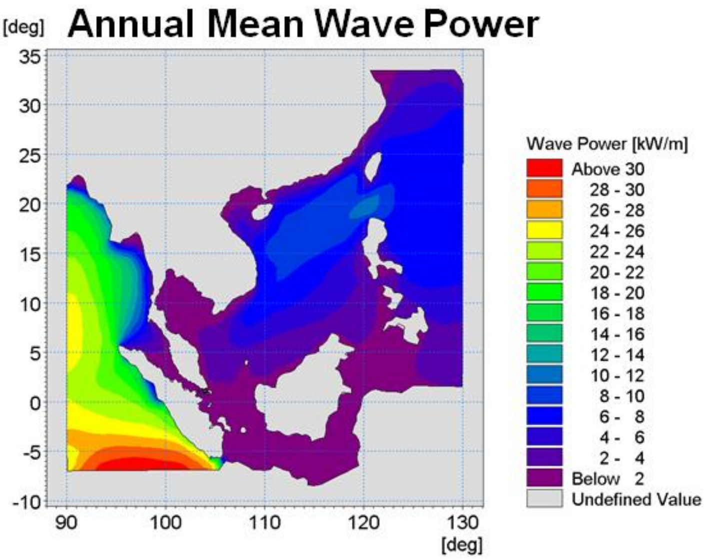

Fig. 2 Annual mean wave energy of Southeast Asia

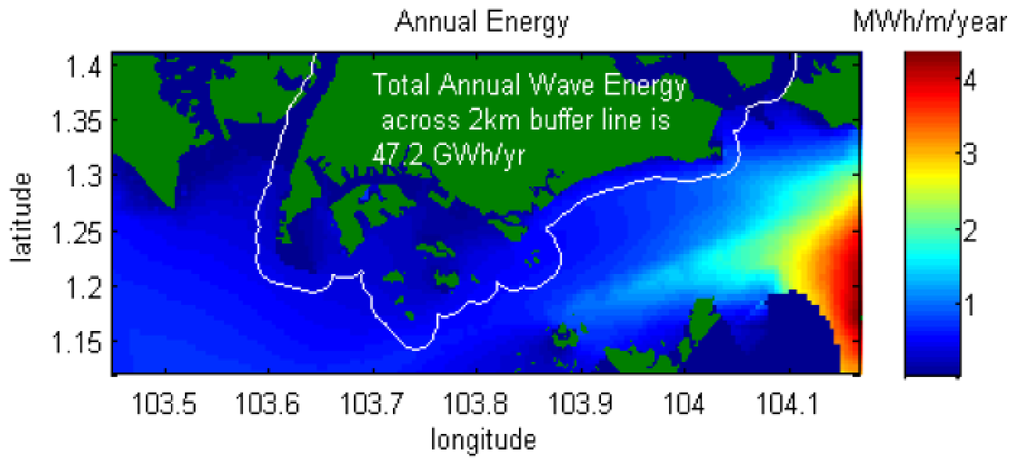

Fig. 3 Annual wave energy per unit crest map and total wave energy across Singapore coast buffer line

3.2 Seasonal distribution of wave power:

Singapore has two monsoon seasons. The wind is north-east during December-March (north-east monsoon, NE) and southwest during June-September (south-west monsoon, SW). Fig. 4 and Fig. 5 depict the seasonal wave power per unit crest with direction arrows shown. Figure 4 illustrates that the most energetic waves are corresponding to north-east monsoon, when wind-waves in eastern part of Singapore region are composed of swells propagating from the southern SCS (predominantly easterlies) and wind-seas in the Singapore Strait (north-easterlies).

During the other monsoon, wave energy is significantly smaller being limited by fetch and shallow depth.

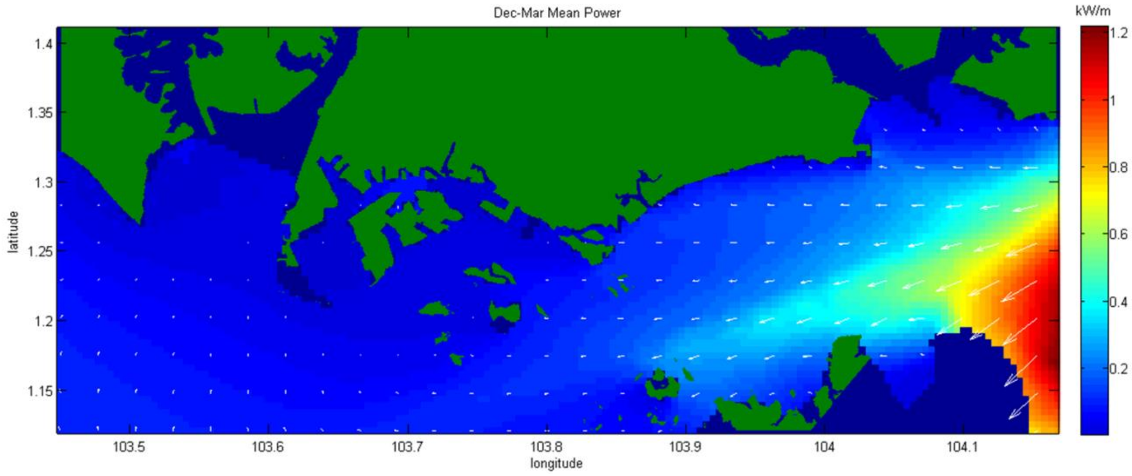

Fig. 4 Waver power per unit crest with direction arrows over north-east monsoon season (December to March)

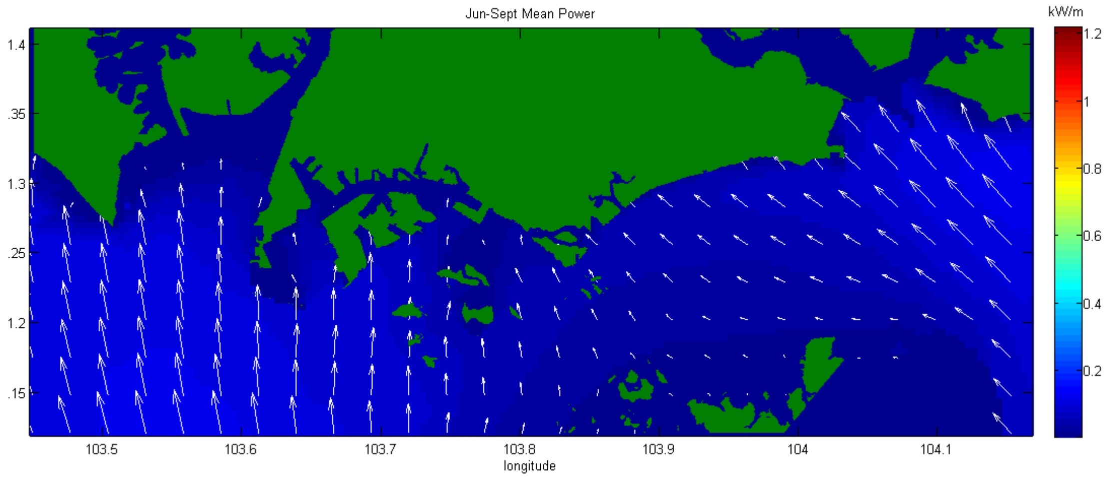

Fig. 5 Wave power per unit crest with direction arrows over south-west monsoon season

References

Aboobacker, V.M., Rashmi, R., Vethamony, P., and Menon, H.B. 2011a. On the dominance of pre-existing swells over wind seas off Goa, west coast of India. Continental Shelf Research 31: 1701-1712.

DHI. 2012. MIKE 21 Spectral Waves FM User Manual. DHI Water & Environment, 122 pp.

Hemer, M.A. and Griffin, D.A. 2010. The wave energy resource along Australia's Southern margin. Journal of Renewable and Sustainable Energy, Vol. 2(4).

Pontes, M. T. and Bruck, M. E. (2008). Using Remote Sensed Data for Wave Energy Resource. Proc. 27th International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2008) 6: 751-759.

The WAMDI Group. 1988. The WAM model - third generation ocean wave prediction model. Journal of Physical Oceanography 18: 1775-1810.