Wave Energy Resource in the Western Part of Japan

T. Okamoto[1], H. Lee[2], Y. Higo[3], and S. Inada[4]

[1] Graduate School for International Development and Cooperation
Hiroshima University, 1-5-1 Kagamiyama
Higashi-Hiroshima, Hiroshima, Japan
E-mail: tokamoto@hiroshima-u.ac.jp

[2] Graduate School for International Development and Cooperation
Hiroshima University, 1-5-1 Kagamiyama
Higashi-Hiroshima, Hiroshima, Japan
E-mail: lee.hansoo@gmail.com

[3] Graduate School for International Development and Cooperation
Hiroshima University, 1-5-1 Kagamiyama
Higashi-Hiroshima, Hiroshima, Japan
E-mail: yhigo@hiroshima-u.ac.jp

[4] Graduate School for International Development and Cooperation
Hiroshima University, 1-5-1 Kagamiyama
Higashi-Hiroshima, Hiroshima, Japan
E-mail: m111691@hiroshima-u.ac.jp

Abstract

Numerical simulation is conducted for 40 years period to find the wave resource distribution along the Japanese coast in regional scale. Three level nested domain is constructed in WAVEWATCH III to carry out the regional scale simulation and 40 years record from NCEP/NCAR reanalysis data is utilized for input. Calculation result is compared with GPS buoy data for model validation.

40 years average of wave energy flux is calculated from the model output and it is found that most of the coastline in the western part of Japanese main islands is exposed to the wave with 4-7kW/m of energy. The most energetic wave found off the coast of western part of Japanese main islands is about 10kW/m. Small islands off south of Japanese main islands have the highest potential in the region, where the energy level reaches to 15kW/m.

Keywords: Wave climate, Numerical simulation, WW3, NCEP/NCAR reanalysis

1. Introduction

Recent trend of global warming requires to introduce low carbon emission technologies into whole the society. Energy sector, as one of major CO2 emission sources, has been adapting many low carbon technologies for this purpose. Utilization of renewable energy is the one of the adaptation measures to reduce the carbon emission because it achieves zero emission at the site. Increasing trend of oil price in last ten years brings the energy security concern and makes renewable energy to be more feasible.

In Japan, the national energy policy has aimed at the heavy dependency on the nuclear power generation for decades, mainly because of the energy security perspective. On top of that, the reduction of CO2 emission from the energy sector was also planned to be achieved by increasing the share of the nuclear power generation. Thus, the utilization of renewable energy did not get the higher priority in energy industry and the share of renewable energy in power generation remains low comparing to European countries. The industry predicted the share of renewable energy sources excluding hydro-power generation would be only 2% by 2019 following to this policy [1].

However, the fatal accident at Fukushima Daiichi Nuclear Power Plant forced to discard the nuclear dependent policy and the government had to start revising the national energy plan earlier than it was planned. It is expected that the new policy emphasizes the utilization of renewable energy, based on the white paper published in the last fall. So, the situation will be changed.

The development activity of wave power generation in Japan was started in 1970's as a reaction of the Oil Crisis, similar to the other countries. And it was once leading the world; Kaimei, the first grid-connected prototype deployed to offshore in 1978. However, because of the low priority in the political and strategic plan, there has been notable project for a decade.

Another reason that the wave power generation development in Japan was stalled is perhaps the relatively low wave energy around Japanese islands. Global scale estimation indicates that the wave energy around Japanese islands is mostly about 15-20kw/m [2], so less than a half of European Atlantic coast.

In [2], the regional estimations are also available for several countries but the date is not available for Japan. Recent report [3] issued in 2010 by a governmental agency estimates the energy potential still based on coarse estimations published more than 20 years ago. This also indicates that R&D activity for wave power generation in Japan is not very active recently.

Therefore, the wave climate data around Japan is only available either through global scale model results like [2] and [4] or coarse estimations of old researches [3]. So, this study tries to find the wave energy resource around Japan with regional scale. 40 years numerical simulation was conducted to find out the wave energy distribution around Japan. Offshore buoy data was utilized for the model validation. The result was analysed to characterize the wave climate around Japan.

2. Numerical model

WAVEWATCH III (WW3) [5] is the third wave generation model developed by NOAA/NCEP. WW3 solves the random phase spectral action density balance equation for wavenumber-direction spectra. With new version of WW3, it includes the source term for shallow water waves, so it has a capability to calculate shallow water region. It is claimed that the accuracy for the shallow water calculation is not excellent. But in this work, the calculation domain covers only up to relatively shallow water zone, so it is decided to use WW3 for all the calculation domains.

The calculation domain is nested three levels. The first domain covers the north-western Pacific Ocean (100E-170W, 0N-60N) and the grid size is 0.6 degree both in the latitude and longitude. The second domain covers the western part of Japan, which is from 125E to 145E and from 25N to 38N with 0.2 degree grid spacing as shown in Fig. 1. The third domain is determined to cover where the wave has relatively high energy, estimating from the previous results [2] and [3], namely Kanto area (around Tokyo) and Izu islands (small islands off south of Tokyo). The grid size of the third domain is 0.05 degree

But at the time of writing this paper, the calculation of the third domain has not been completed. Thus, only the second domain result is discussed in this paper and the third domain result will be shown at the conference.

NCEP/NCAR re-analysis data is used for the wind data as input. The duration of calculation is 40 years, from 1971 to 2011. The time interval of each calculation domain was set to 3600, 900, 300 sec for Domain 1, 2, and 3 respectively.

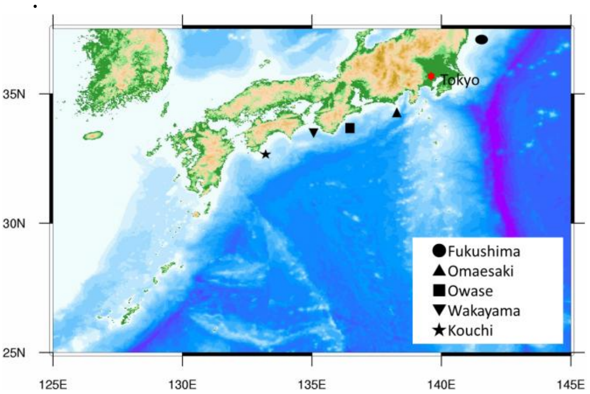

Figure 1: Calculation domain 2 and buoy locations

3. Model Validation

For model validation, buoy data is retrieved from NOWPHAS database maintained by the Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan. MLIT deployed GPS buoys off Japanese coast recently and the data from 2009 is available. They are located relatively deep area, such as in the range of 120m to 350m.

The depth range of GPS buoys is slightly deeper than the anticipated deploying location of offshore wave energy devices but in the similar range. Five GPS buoys located within the Domain 2 were selected for the model validation; Kouchi, Wakayama, Owase, Omaesaki, and Fukusima (from west to east as shown in Fig. 1).

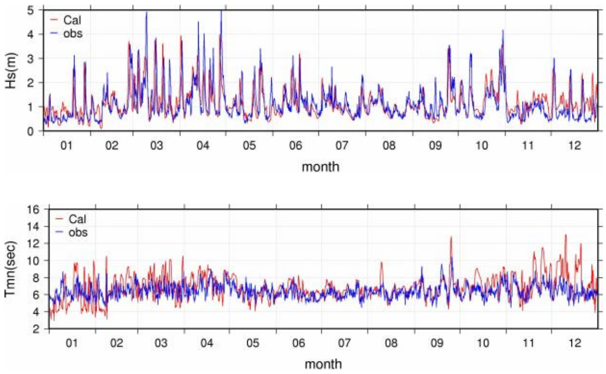

Figure 2: Comparison of measured and calculated time series at Owase buoy location (Upper: Significant wave height, Lower: Mean wave period)

Model validation was made with the buoy data and the result of Domain 2. The buoy data is recorded from 2009 with the time interval of two hours. The output of numerical simulation was recorded with the time interval of three hours for Domain 2. Therefore, the comparison was made six hours each, such as four times per day.

The Comparison was made for one year period of 2010. Fig. 2 displays the comparison of significant wave height and mean wave period of whole one year period at Owase station. Averages of the significant wave height (H_s) and the mean wave period (T_m) are shown in Table 1. Root mean squared error, correlation coefficient, and bias are also calculated and shown in Table 2.

	H_s (m)		Std. Dev.	
	Calc.	Obser.	Calc.	Obser.
Kouchi	1.24	1.50	0.581	0.783
Wakayama	1.13	1.29	0.589	0.663
Owase	1.15	1.12	0.586	0.692
Omaesaki	1.08	1.71	0.576	0.812
Fukushima	1.30	1.69	0.645	0.813

	T_m (s)		Std. Dev.	
	Calc.	Obser.	Calc.	Obser.
Kouchi	6.64	6.50	1.290	1.038
Wakayama	6.62	5.72	1.350	0.757
Owase	6.89	6.40	1.443	0.820
Omaesaki	7.04	5.60	1.423	0.590
Fukushima	7.54	6.47	1.512	0.926

Table 1: Averaged values and standard deviations of significant wave height (upper panel) and mean wave period (lower panel)

Buoy	RMSE	Corr.	BIAS
Kouchi	0.654	0.651	0.301
Wakayama	0.674	0.457	0.329
Owase	0.570	0.614	0.136
Omaesaki	0.992	0.427	0.808
Fukushima	0.737	0.653	0.358

Buoy	RMSE	Corr.	BIAS
Kouchi	1.332	0.368	0.335
Wakayama	1.523	0.427	0.705
Owase	1.437	0.396	0.135
Omaesaki	2.027	0.208	1.444
Fukushima	1.703	0.491	0.783

Table 2: RMSE, Correlation coefficient, bias of significant wave height (upper panel) and mean wave period (lower panel)

As shown in Table 1 and 2, calculation results at Omaesaki and Fukushima stations have relatively poor correlation to the measured data comparing to the other stations. The water depths at Omaesaki and Fukushima station are shallower than the others; it is about 120m for Omaesaki and Fukushima while the others are located at deeper than 200m. This result implies that the capability of WW3 to handle shallow region is not very good as pointed out, although the wave can be classified as deep water wave for the given water depth and wave period.

The calculated wave height is slightly smaller than the measured one. The standard deviation of calculated wave height is slightly smaller than the measured one. It can be concluded that high wave heights during storm condition are underestimated by the model. In this calculation, the local wind generation due to low pressure system is not included. Therefore, the wind speed is weaker during the stormy conditions. This probably explains that the calculated results have smaller wave height than the measured one.

The wave period calculation is slightly problematic. It seems to be similar to the case of significant wave height but very low correlation values were obtained and the standard deviations are much bigger than the observed ones for all stations. As shown in Fig. 2, the wave period fluctuates larger than the observation except during the summer period. This tendency can be seen in all cases, especially in Omaesaki data, and clearly contributes the high standard deviation value and low correlation value. The reason of high fluctuation and why it happens except summer season are currently unknown.

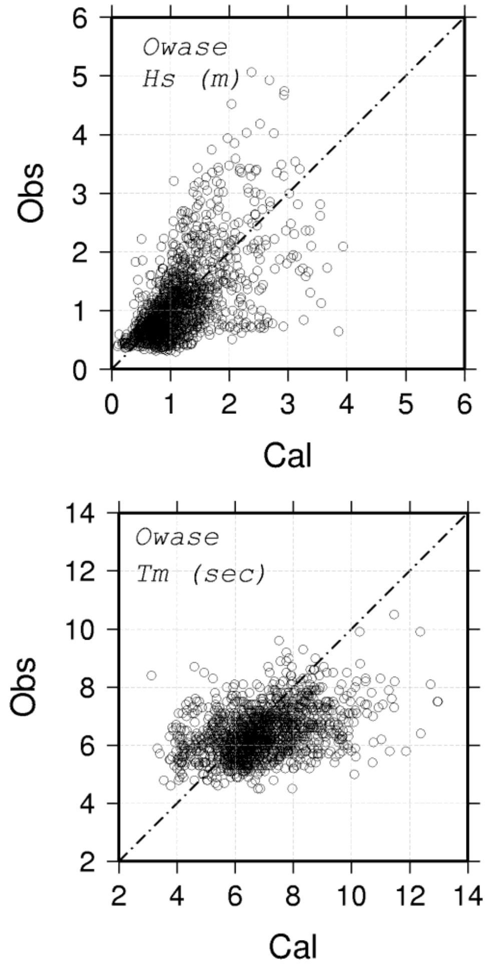

Figure 3: Comparison of measured and calculated values at Owase buoy station (Upper: Significant wave height, Lower: Mean wave period)

The scattered diagram between the calculated values and observed values were made to see the relation between them. Although it does not converge very well, the relation between the calculated and observed value for the significant wave height seems to be able to be related by the simple linear regression line with realistic numbers. However for the wave period, it is very difficult to make a regression analysis them because of the large fluctuation in the calculated result.

4. Results

The wave energy flux is calculated for the area around Japanese islands. The simplified equation for deep water wave is used in this calculation since the water depth is deeper than 100m and the wave period is shorter than 8 sec for most of the calculation nodes. The wave energy flux for deep water wave is given as;

$$P = 0.49 H_{m0}^{2} T_{-10}$$

where H_{mo} is the significant wave height, T_{-10} is the energy period.

Fig. 4 displays the 40 year average of wave energy flux in the whole section of Domain 2. It shows relatively high wave energy, larger than 20kW/m, is observed in the east of Japanese islands. This is the south-western edge of high energy area in the northern Pacific Ocean. But it is far from the land.

Japan is located in the western edge of the Pacific Ocean. So, there is not enough fetch for wave to grown up by the westerly wind. The energy level is, therefore, lower than the eastern end of ocean in general. In adding to that, the western part of Japan is sheltered from the swell coming from north-eastern direction, which originated in the middle of northern Pacific Ocean and therefore having high wave energy, because of the orientation of coastline. Therefore, the very low energy is observed along the coast.

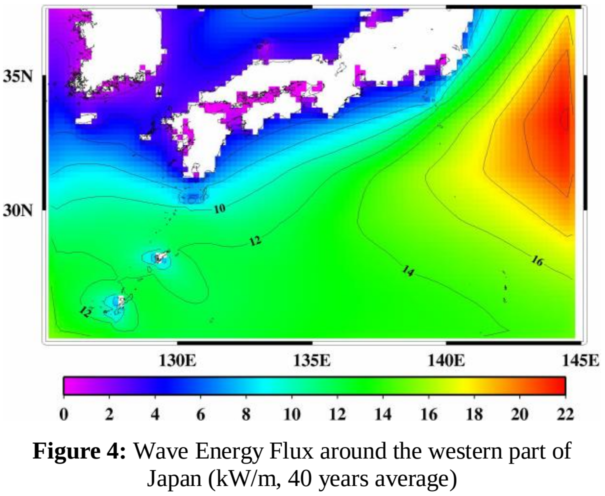

Figure 4: Wave Energy Flux around the western part of Japan (kW/m, 40 years average)

Fig. 5 is the close-up of Fig. 4, which only displays the wave energy flux around Japanese main islands. The calculation result displays that the most of the coast open to the Pacific Ocean in the western part of Japanese main islands is exposed to the wave with 4-7kW/m in average. This energy level is lower than the existing studies in which it counts about 15-20kW/m [2] and 11-17kW/m or 5-12kW/m [3].

The coast of Sea of Japan receives very low wave energy. Most of the coast receives 2-3kW/m. The eastern part experience 3-4kW/m. This is again lower than the existing studies; 10-15kW/m in [2] and 11kW/m or 3-9kW/m in [3].

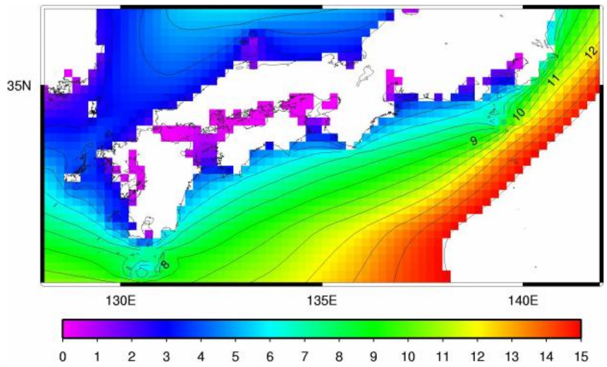

Figure 5: Wave energy flux around the western part of Japanese main islands (kW/m, 40 years average)

In the coastline of main islands, the Pacific eastern shore receives the most energetic waves because of the orientation of coast, which accounts about 10kW/m. Other locations with relatively high potential are the offshore of Shionomisaki, the tip of a peninsula located in the centre of the main island, and the south end of Kyushu Island, the westernmost island among the main islands, where it receives about 7-8 kW/m.

Small islands off the southern coast of main islands have relatively high energy potential. Hachijo-jima Island (off south of Tokyo) and Ogasawara islands (lower right corner in Fig. 4) show the most prominent potential in the western part of Japan. It counts about 15kW/m. But this is also lower than the previous studies. In [2], the energy flux in this area can be read as 20-30kW/m, or maybe 30-40kW/m.

Considering the results obtained here and the comparison between the calculation results and buoy data conducted in the previous section, it seems that the numerical model underestimates the wave height throughout the domain. The possible reason for this underestimation could be the inaccuracy of wind data but further investigation is needed.

5. Summary

The wave energy flux distribution along the western part of main islands of Japan and southern remote islands was calculated by using the 40 years numerical simulation result. For the main islands, the energy flux accounts very low level because of the orientation of the coast.

Remote islands in the south of main islands have more potential than the main island. But this area hits more typhoons than main islands. So, further investigation is needed to find the seasonal variation and extreme conditions.

The energy level obtained in this study is lower than the previous studies. Considering the comparison between the calculation result and measured data, it seems that the model slightly underestimates the wave height. More data analysis is needed to find the cause of inaccuracy.

The calculation result of third domain and the more analysis to characterize the wave climate around Japanese islands will be presented at the conference.

Acknowledgements

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