Simulation of Significant Wave Height Climatology using WaveWatch III

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Abstract
In recent decades, the extreme wave height has become more frequent. High spatial resolution of wave model is inevitable to investigate the impact of monsoon and generate the wave atlas. The significant wave height (SWH) resulting from model estimation has a high correlation with the altimeter data (0.77-0.94), with the highest correlation in Northern Papua, and the lowest in Sulawesi Sea. The maximum SWH in Java Sea is approximately 3-3.5m, occuring in January and February. Generally, the maximum SWH in Southern Java Sea is higher than the maximum wave height in the southern coast of Kalimantan. This tends to increase the flood risk in the north coast of Java, because it coincides with the peak of wet season. When reaching 6m it can cause for example, decreasing fisheries production and preventing commodity flows that use marine transportations.

1. Introduction

For the past 50 years, Greenhouse Gas (GHG) has been caused by human activities. This basic conclusion came from the IPCC (2007) AR4 (Assessment Report 4). Based on the NOAA data, the increase in global CO_2 concentration since 1980 reached 50ppm (Figure 1) with an increasing trend rate.

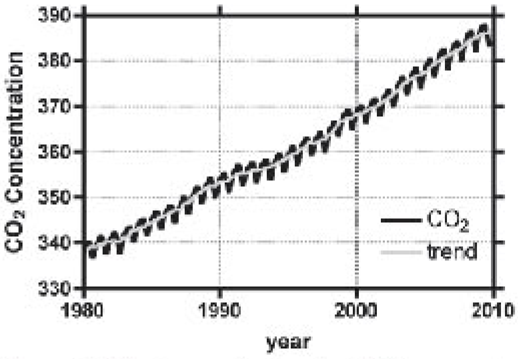

Figure 1: The increasing trend of CO_2 concentration from 1980 to 2009

This has impact on global warming intensity rate, which has been happening since 1900s. The increase in intensity can be shown by the increasing acceleration of sea surface temperature (SST), sea level, and ice melting in both Antarctica and Greenland. Besides giving a direct impact on sea level rise, global warming causes climate change, giving impact to health, agriculture, forestry, and transportation sectors.

A number of extreme weather events in the past few years have also been affected by global warming intensity, with the increasing intensity of El Nino and La Nina (Timmermann et al., 1999 and Timmerman, 2001). Generally, El Nino occurred once every 2-7 years, but since 1970, El Nino and La Nina frequencies became once every 2-4 years (Torrence and Compo, 1999). In addition, during the 1997/1998 El Nino, Indonesia suffered a long dry season, and during the 1999 La Nina, Indonesia suffered high rainfall, causing sea level rise by 20-30cm, and flood in most parts of Indonesia, especially in the coastal zone. Related to the temperature increase, strong tropical cyclone intensity is increasing (Elsner et al., 2008). The average power of tropical cyclone in the Atlantic Ocean is increasing, with an increase of maximum wind speed by $0.4ms^{-1}yr^{-1}$ (Elsner et al., 2008). Webster et al., (2005) explained that global warming causes the high frequency and intensity of the annual strongest cyclone. On the contrary, the number and duration of cyclone events were decreasing in all oceans, except in the last decade, in the northern Atlantic Ocean (Webster et al., 2005). Although the physical mechanism that is causing the decrease in number and duration of cyclone events have not been clear, but it has been predicted to be caused by the more frequent El Nino than the La Nina in the last few decades (Webster et al., 2005 and Elsner et al., 2008). The objective of this research is to find the influence from season to the average significant wave height and maximum significant wave height. A map of *Significant Wave Height* (SWH) using the blended wind data from QuickScat (*Quick Scatterometer*) and NCEP (*National Climate and Environmental Prediction*) Reanalysis II from 2000 to 2008 will be generated.

2. Methods

The fundamental equations that used in the WAVEWATCH III are presented based on the WAVEWATCH III user manual (Tollman, 2009). Further details of the WAVEWATCH III equations and numerical algorithms can be found in Tollman (2009).

2.1 Description

In general, the wave spectrum S is a function of all phase parameters (i.e., wavenumber k, direction θ, intrinsic frequency σ, and absolute frequency ω), space (x) and time (t):

$$S = f(k, \theta, \sigma, \omega; x, t)$$

Equation 1

However, the individual spectral components are assumed to satisfy the linear wave theory and to follow the dispersion relation:

$$\sigma^2 = gk \tanh kd$$

Equation 2

$$\omega = \sigma + k.U$$

Equation 3

where d is the mean water depth and U is the current velocity. However the WAVEWATCH III uses the wavenumber direction (k, θ) as the independent phase variable. In this study, the surface current is not used as the input data, thus the energy of a wave package is conserved. Four time steps are used in WWATCH to reach computational efficiency: (a) a global time step (300 s) for the propagation of the entire solution, (b) a spatial time step (300 s) representing the spatial propagation, (c) a spectral time step (300 s) for intra-spectral propagation, and (d) a source time step (100 s) for the source term integration. On the other hand, the wind friction velocity (u_*) is calculated from the wind speed (W) and the drag coefficient (C_*) by using the formula from Tolman and Chalikov (1996):

$$u_*^2 = C_* W^2$$

Equation 4

$$C_*(W) = 1.2875 \times 10^{-3} \quad W < 7.5 ms^{-1}$$

Equation 5

$$C_*(W) = (0.8 + 0.065W) \times 10^{-3} \quad W \geq 7.5 ms^{-1}$$

Equation 6

2.2 Model Configuration

Increasing global phenomenon such as ENSO, can change the spatial distribution pattern of wave height in Indonesia's seas. Wave modeling was used to investigate the characteristics of significant wave height. The wave model used is the WaveWatch III (WWIII) (Tollman, 2009) by using data input of average wind speed every 6 hours, blended observation result of QuickScat (Quick Scatterometer) with NCEP reanalysis from January 2000 to December 2008. The long-term with high temporal resolutions of wind data input is needed to obtain the high accuracies of the model-estimated wave height. In the WWIII model, the evolution of wave spectrum direction is presented in the amount and direction of wave in the spherical coordinate. Interaction between wind-wave and wave-wave in the terminology of dissipation and friction of ocean's floor are also accounted in this model. This model also used the parameterization of JONSWAP (*Joint North Sea Wave Project*) (Hasselmann et al., 1980). The grid model domain for Indonesia's area was from 90-150°E and from 15°S to 15°N, with a 25km resolution and was nested to the global model with a resolution of 1°x1° Lon/lat, stretches from 0-359°E and from 80°S to 80°N.

2.3 Model Validation

Calculation with the model has its own benefit, which is high spatial resolution, depends on the ability of the computational hardware used. The altimeter data is available in the form of grid, with a resolution of 1°x1° Lon/Lat. The available SWH altimeter data is only for late 2005 to present day, while the calculation of the model can be done using medium resolution wind data of 0.5°x0.5° Lon/Lat, the blended result of QuickScat observation and NCEP Reanalysis II. The comparing of SWH spatial distribution model with altimeter for global domain is shown in Figure 2. The model result showed the height of SWH relatively matches with the altimeter calculation result. In the deep sea, the model estimation result tends to be 50cm to 1m higher than the altimeter observation, while in the shallow sea, the model showed a lower height by 20-50cm.

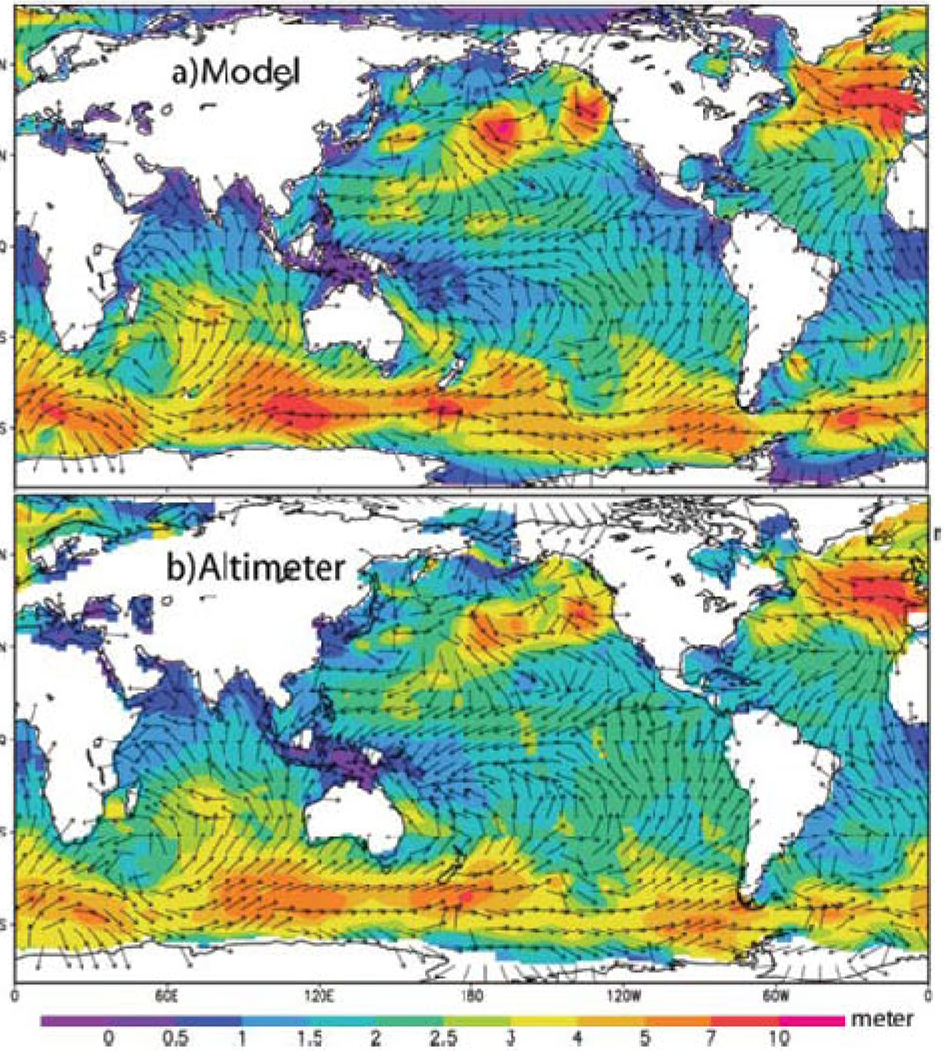

Figure 2: Spatial distribution of significant wave height (SWH)

This may be caused by a low spatial resolution from the global model, which is 1°x1° Lon/Lat.Validation of model result on Indonesia's domain with the altimeter data is shown in Figure 3. Validation between model and altimeter was done using regional average, in Java Sea, western coast of Sumatera, southern coast of Java, Karimata Strait, Sulawesi Sea, and Pacific Ocean in northern Papua. Based on this validation, the WWIII model can be used to estimate wave height in Indonesia's seas. The SWH result from model estimation has high correlation with the altimeter data, and ranges from 0.77 to 0.94, with the highest correlation in Pacific Ocean in northern Papua and the lowest in Sulawesi Sea. The validation result also showed that the SWH model has high accuracy, though tends to be higher for western Sumatera and southern Java, with average over-estimation of 40cm. The model-estimated SWH in Java Sea and Karimata Strait tend to be lower than the altimeter data for SWH <1.5m, and tend to be 30cm to 50cm higher for SWH >1.5m. The model-estimated SWH in Pacific Ocean is relatively the same as the altimeter observation with high correlation.

3. Result and Discussion

3.1 Monthly Average Wave Height

Generally, the estimation result of wave height shows that the wave height in Indonesia's seas is influenced by the seasonal wind. Between November to March, the wave height in Pacific is higher than the wave height in Indian Ocean. Figure 4 shows the average SWH on wet season peaks, December, January, and February. In general, in Pacific Ocean (northern Papua), the SWH reaches 3m or more, while in Indian Ocean (southern Java and western Sumatera), it reaches 2.5m.

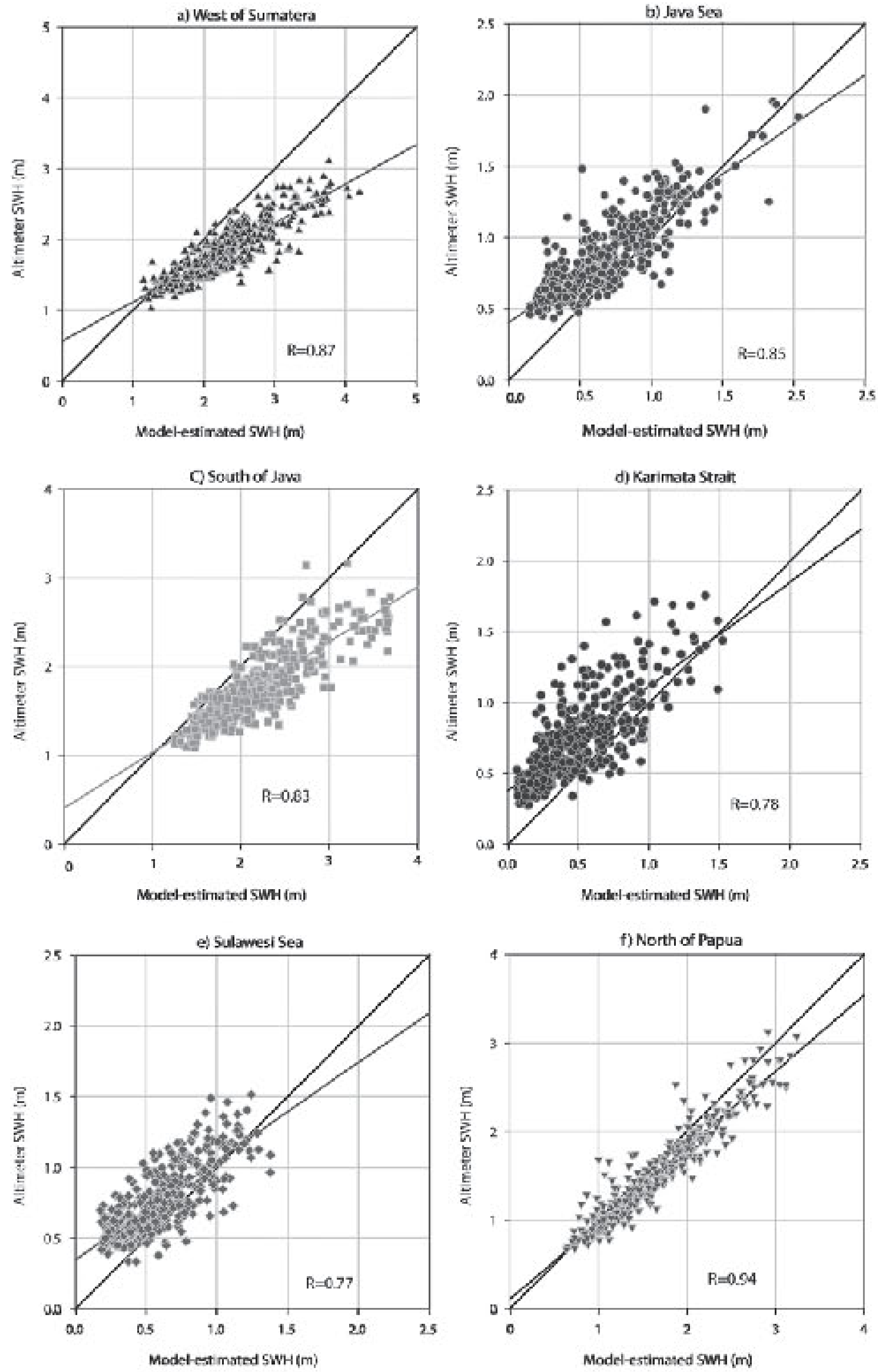

Figure 3: Scatterplot between model-estimated and altimeter for SWH using altimeter data and model in 2007

The wave height in Java Sea only reaches 0.5-1.5m with the highest SWH occurs in February. The wave height in Sulawesi Sea, Karimata Strait, and South China Sea reaches its highest peak in February with a height of 2.5m. The wave height in Banda and Flores Seas reaches its peak in February with a height of around 2m. The average direction of the wave in the northern hemisphere is southward while the southern hemisphere wave is heading north from Indian Ocean. The wave intrution from Indian Ocean is intensified during March, through Lombok Strait, heading to Makassar Strait. The direction of the wave in Java Sea tends to move eastward until Banda Sea, and Flores. On May to September, the wave height in Indian Ocean is higher than the wave height in Pacific Ocean. The average SWH during Australian monsoon peak is shown in Figure 4. In general, the SWH in Indian Ocean reaches 3m or more, while the SWH in Pacific only reaches 2.5m. The wave height in Java Sea is only around 1-1.5m, with the highest SWH occurs in August and September. The wave height in the southern Java Sea tends to be lower than one in northern Java Sea. It is caused by the pressure of the seasonal wind blowing from North to South. The wave height in Sulawesi Sea, Karimata Strait, and southern South China Sea is weakening and only as high as 1.5-2m. The wave height in the Banda and Flores Seas reaches its peak in July and August with a height of around 1.5m. Meanwhile, the average wave direction is moving from northward, the same direction as the seasonal wind. Although in the Pacific Ocean we can still see the southward wave propagation on the first and the end period of the Australian monsoon. The wave direction in Java, Banda, and Flores Sea is heading to west, with the intensified wave intrusion from Indian Ocean through Lombok Strait, until Makassar Strait and Sulawesi Sea.

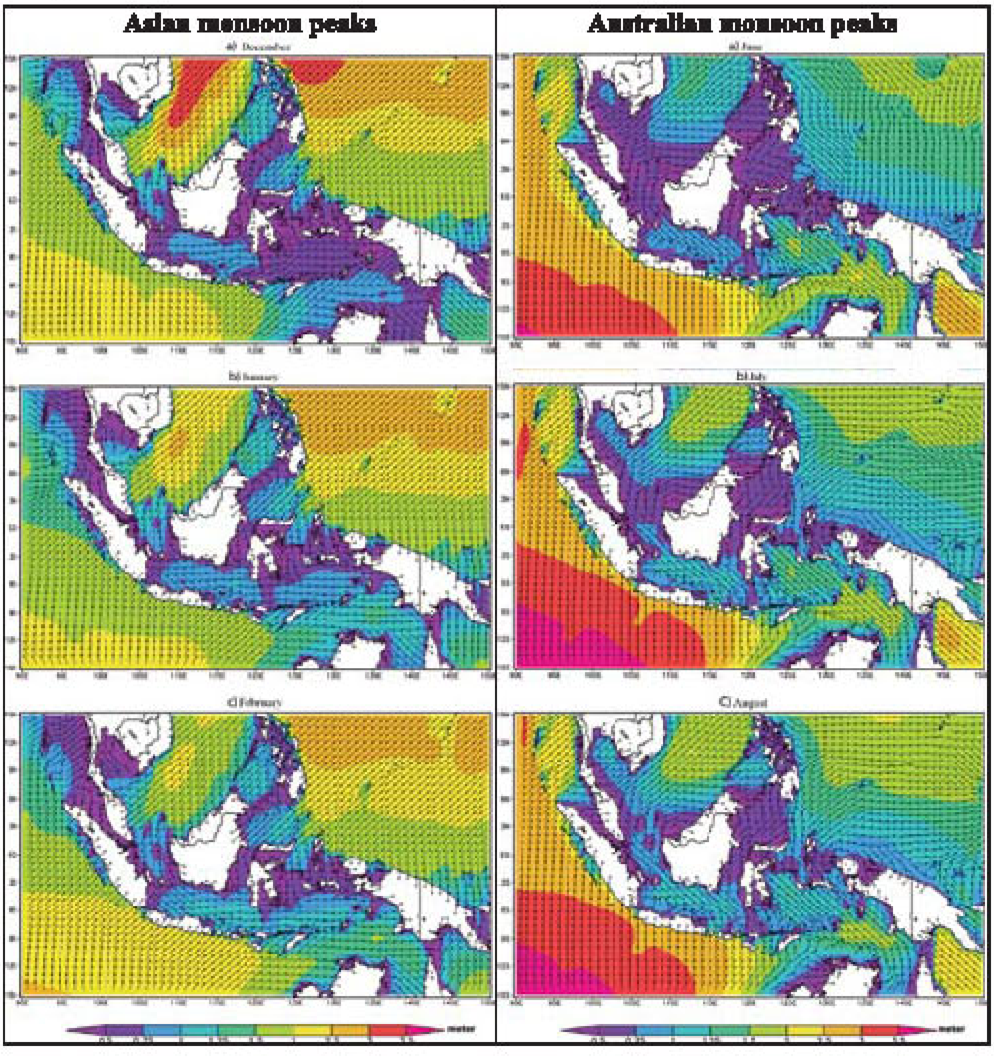

Figure 4: The average SWH on Asian (left) and Australian (right) monsoon peaks from 2000 to 2008

3.2 Extreme Wave

The monthly extreme wave height during Asian monsoon is depicted in Figure 5. It shows that the average maximum wave height in Indonesia's seas reaches 1-6m, with the maximum wave height reaches 6m in Northern Papua (Pacific Ocean). It is shown that the maximum wave height in Pacific Ocean and South China Sea reaches its maximum height on December, with a height of 9-10m, then weakens to around 6-7m, in January and February. The maximum SWH in the Java Sea is around 3-3.5m, especially on January and February with maximum wave height of 3.5m. Generally, it is seen that the maximum SWH in the southern Java Sea (northern coast of Java) is higher than the maximum wave height in the southern coast of Kalimantan. This tendency is increasing the flood risk in the north coast of Java, because it coincides with the peak of wet season. The maximum SWH in the south coast of Java increases from December to February, and reaches to 3.5m. SWH in the southern Karimata Strait tends to be lower with a height of around 3m, while the maximum SWH in the Banda, Flores, and Sulawesi Seas reaches to 2-3.5m. The maximum SWH on Australian monsoon period is shown in Figure 5.

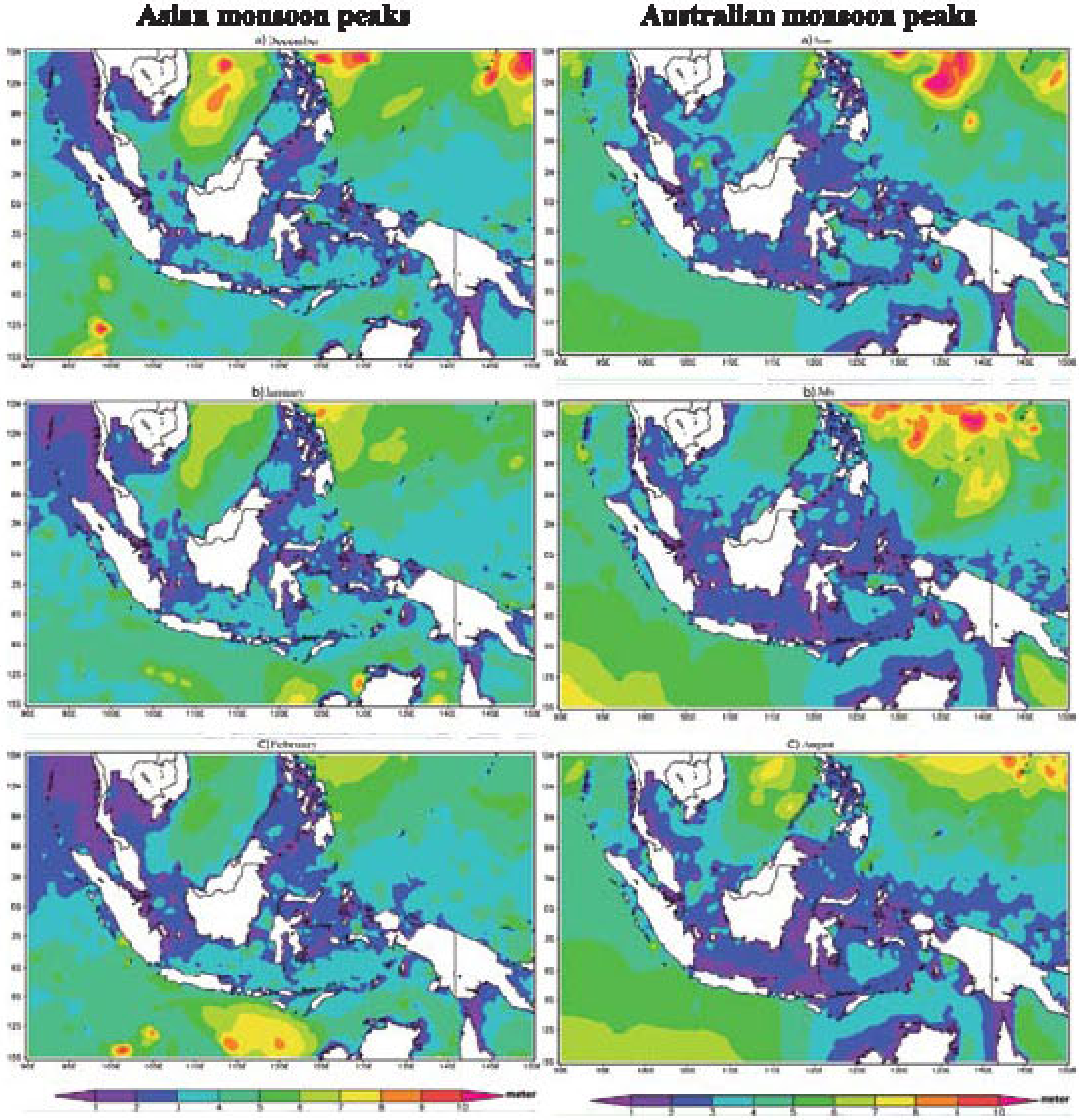

Figure 5: The average maximum SWH on Asian (left) and Australian (right) monsoon peaks from 2000 to 2008

From Figure 5, the decrease in maximum SWH in Java Sea, Banda, Flores, Karimata Strait, and Sulawesi Seas only reaches 1-3m. The average maximum SWH in the Pacific Ocean is higher than the one in Indian Ocean. The wind pressure is causing the maximum wave height in the northern Java Sea higher than SWH in the north coast of Java, with a difference of height reaching 1-2m. In general, the maximum wave height during Australian monsoon period is lower than the maximum wave height during Asian monsoon period. Eventually, these maximum SWH both during Asian and Australian monsoons will prevent the flow of comodity flows that are using marine transportation facility, other than increasing the flood risk in the coastal zone with a low elevation of 0-3m.

4. Conclusion

The SWH within the Indonesian Seas is estimated by using the WaveWatch III. The model spun up from 2000 to 2008 with temporal resolutions of 6-hours. The SWH from the model estimation has a high correlation with height derived from altimeter data (0.77-0.94), with the highest correlation in Pacific Ocean in the northern of Papua, and the lowest in Sulawesi Sea. However, the model tend to over-estimate wave height during the low wind speed. The coupled model between atmospheric and WaveWatch III is inevitable to increasing the accuracies and the model running period. The high extreme waves in locations that reach to 6m can causes impact such as the decreasing of fisheries production and prevent the commodity flows that use marine transportation facility. The high wave on Asian monsoon period (wet season) will increase flood risk, which finally will affect agriculture and health.

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