

Projection of Ocean Wave Climate Change Based on Numerical Simulations

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ABSTRACT

This study aims to analyze global wave climates of present and future time by using the WAM model. The analysis is performed based on wind climate data from the JMA/MRI-AGCM3.2 climate change projection. We analyze two 6-hourly wind data sets, covering two periods: the present climate ranging from 1979-2003 and future climate extending from 2075-2099. These wind data are used to implement the WAM model for producing the outputs of wave characteristics. Subsequently, the outputs from each period were used to study global wave climate in the future. The analysis showed that the wave climate is strongly dependent on the geographical position of regions from mid to high latitude and low latitude. This includes regions where the climate induced changes for present to future climate. The largest increases of significant wave height which reached approximately 5% occur in the southern parts of the Indian, Pacific and Atlantic Oceans and in the Antarctic Ocean. The decreases in the same magnitude around 5% occur especially in the North Atlantic Ocean.

KEY WORDS: *Climate Change, Wind Climate, Wave Climate, WAM*

1.0 INTRODUCTION

Waves and the general conditions of the oceans affect coastal regions and marine activities on a daily basis and bring impacts for all over the world. It is increasingly apparent that human activity is affecting not only the atmospheric climate, but also the characteristics of our oceans. As the composition of the atmosphere changes and the concentration of green-house gases increases, the whole environment gets the impacts.

The ocean climate is affected by the increasing temperatures in many different ways. A static side-effect of global warming, for example, causes thermal expansion in the oceans which raises sea levels. The effects of this phenomenon can already be seen in many coastal regions, where coastal erosion and inundations are becoming the common problems. According to IPCC (2007) the sea-level has risen for 1.7 ± 0.3 mm/year since the second half of the 19th century. This rising rate seems to have increased during the last decade as reported by Church and White, (2006).

The dynamic side-effects of the warming climate are predictable changes of the behavior of ocean waves, storm surges and other extreme events (IPCC, 2007). Reports on the increasing extreme climate in many parts of the world highlight the importance of understanding and assessing the effects of climate change. Today, these reports put more concern on the effect of climate greater than in the past. The numbers of coastal and marine activities which are dependent on reliable and long-term information about wind term and wave climate are also constantly increasing. Therefore, studies on predicting and forecasting future development are required. There have been numerous studies performed to assess the effects of future climate change. These studies analyze both, the static effects such as sea level rise and the dynamic side-effects. These effects include the change of wave climates. A large part of these studies focuses on the development of future extreme events, such as tropical storms and cyclones (Caires., et al., (2006), Weisse and von Storch (2009),

Murakami et al. (2011), Kitoh et al (2009)). However, there are still very few studies conducted on the global scale effects of climate change on ocean waves.

One of these studies is presented by Mori et al. (2010). Mori et al. (2010) used the wind fields simulated by MRI/JMA-AGCM3.1 to model the past, close future and future average and extreme wave in the SWAN model. After comparing the averaged values of the significant wave height over the periods of 1979-2003, 2015-2031 and 2075-2099, Mori et al. (2010) find that the changes in wave climate over the observed time indicate a strong latitude dependency. The findings show that the mean wave heights will increase both in the mid-latitudes areas and in the Antarctic Ocean, while the equatorial region and the coastal areas in Japan will experience decreasing average wave heights. However, in the proximity of the Japanese islands, this area is predicted to experience increasing magnitudes of extreme waves because of tropical cyclones.

Another study analyzing the future development of significant wave height is conducted by Wang et al. (2004). They apply a statistical model to the output of the CGCM2 (Canadian Centre for Climate Modelling and Analysis) coupled atmosphere-ocean model for three different emission scenarios. Their analysis was limited to the future wave fields of the North Atlantic Ocean. It is found that the monthly wave height in the north-east Atlantic Ocean and in the south-western North Atlantic will increase towards the end of the 21st. It is projected that the mid-latitudes will experience some decreases.

The aim of this present study is to evaluate the effects of climate change and compare wave climates between simulations for the present and the future climate. The wave simulations are analyzed on the basis of a global scale, with the main focus on observing the evolution of the average wave fields, which is affected by the changing climate. The wave predictions that are used for the analysis is modeled by WAM numerical wave model and using input wind fields from JMA/MRI-AGCM3.2. JMA/MRI-AGCM3.2 is an Atmospheric General Circulation Model, from which the second version was recently developed through the collaboration between Japanese Meteorological Agency, JMA and Meteorological Research Institute, MRI.

2.0 WIND CLIMATE DATA

This study projected future wind fields by adopting JMA/MRI-AGCM3.2. It is used as the input for developing WAM model to simulate wave fields within the periods of 1979-2003 and 2075-2099. The AGCM3.2 is the most recent version of the model developed by Meteorological Research Institute (MRI) in collaboration with Japanese Meteorological Agency (JMA). This model is designed for simulating climate and predicting weather (Mizuta, et al., 2006). The model can, for example, provide information on possible future changes of tropical cyclones, the East Asian Monsoon, extreme events and other changes induced by global warming (Mizuta, et al., 2011).

JMA/MRI-AGCM3.1 was the previous version of JMA/MRI-AGCM3.2. It was the first climate model that could stand long-time integration while being able to conserve mass and simulate realistic high-resolution global climate. This model can simulate global climate with a horizontal grid size of around 20 km, a grid size which is normally only employed for Regional Circulation

Models (RCMs) (Mizuta, et al., 2011). One advantage with a high-resolution global model is that problems with lateral boundary conditions can be avoided. Moreover, the AGCM provides information on regions that cannot be provided by a RCM simulation (Mizuta, et al., 2006). The MRI-AGCM3.2 were simulated under Special Report on Emissions Scenarios (SRES) A1B for the IPCC Fifth Assessment Report (AR5) in which computations were covering two periods: the present climate ranging from 1979-2003 and future climate extending from 2075-2099. (Kitoh et al., 2009).

The first version of the model, 3.1, was developed from JMA operational numerical weather prediction model. This model was constructed based on observed Sea Surface Temperature (SST). In the second version, 3.2, only smaller changes, including new parameterization schemes, were made in order to increase the accuracy of the model performance (Mizuta, et al., 2011). As reported by Mizuta et al (2011), the results of the experiments showed that the AGCM, especially the current version, 3.2, can simulate the global climate in a realistic manner. After comparing the models standard deviations and correlation coefficients to those of an observed climatology, it is found that most variables were better in the AGCM3.2.

3.0 WAM MODEL

The numerical model used in this study is the third-generation wave prediction system, called WAM model (WAMDI Group, 1988, Komen et al., 1994). The model was developed with the purpose of operational prediction of waves over the whole globe, making it well suited for this global climate study (Janssen, et al, 1994). The WAM model is based on the following energy balance equation read as follows:

$$\frac{\partial}{\partial t} F + (\cos \phi)^{-1} \frac{\partial}{\partial \phi} (\phi \cos \phi F) + \frac{\partial}{\partial \lambda} (\lambda F) + \frac{\partial}{\partial \theta} (\theta F) = S_{tot} \quad (1)$$

where $F(f, \theta, \phi, \lambda, t)$ is the wave spectrum described by the frequency f and the wave direction θ as function of latitude and longitude on the spherical earth and S is the source term given by

$$S_{tot} = S_{in} + S_{nl} + S_{dis} \quad (2)$$

where the terms on the right hand side represent the physics of wind input, nonlinear wave-wave interaction and dissipation due to whitecapping, respectively

In this study, WAM model operates on regular longitude/latitude global grid with a fixed resolution of 1 degree, extending from 75° south to 65° north. The spectral domain is discretized in 25 frequency bins from 0.041 Hz to 0.411 Hz, and in the direction-space, a full circle is used with resolution of 15°. WAM model is run in deep water mode and bottom friction is disregarded. WAM model is run in every 6 hours using sea surface wind field at 10 m height above the sea surface from JMA/MRI-AGCM3.2.

4.0 RESULTS

The following chapter presents the results of the global analysis and the comparison between present and future wave climates. The aim of this assessment is to give an overview on the spatial patterns related to the global distribution of significant wave height, and to evaluate and locate possible changes between the present and future climate.

Figure 1 presents the period averaged distribution of significant wave height numerically modeled by WAM model. The top part represents the present period and the bottom part presents the future climate. Figure 1 clearly illustrates a strong latitude dependence of the distribution of the average significant

wave height distribution. The largest significant wave height (approximately 5 m and above) occurs in the high-latitude regions. These regions extend approximately within the range of 40°N-60°N and 40°S-70°S respectively. These regions include the Southern Indian, Pacific and Atlantic Oceans as well as in the Antarctic Ocean. The average significant wave height in the mid-latitude regions, both north and south, are slightly smaller than in the high latitude regions. They range from 1-1.5 m. The calmest averaged wind conditions are found in the equatorial region: e.g. around the Indonesian archipelago and of the west coastal region of Central America.

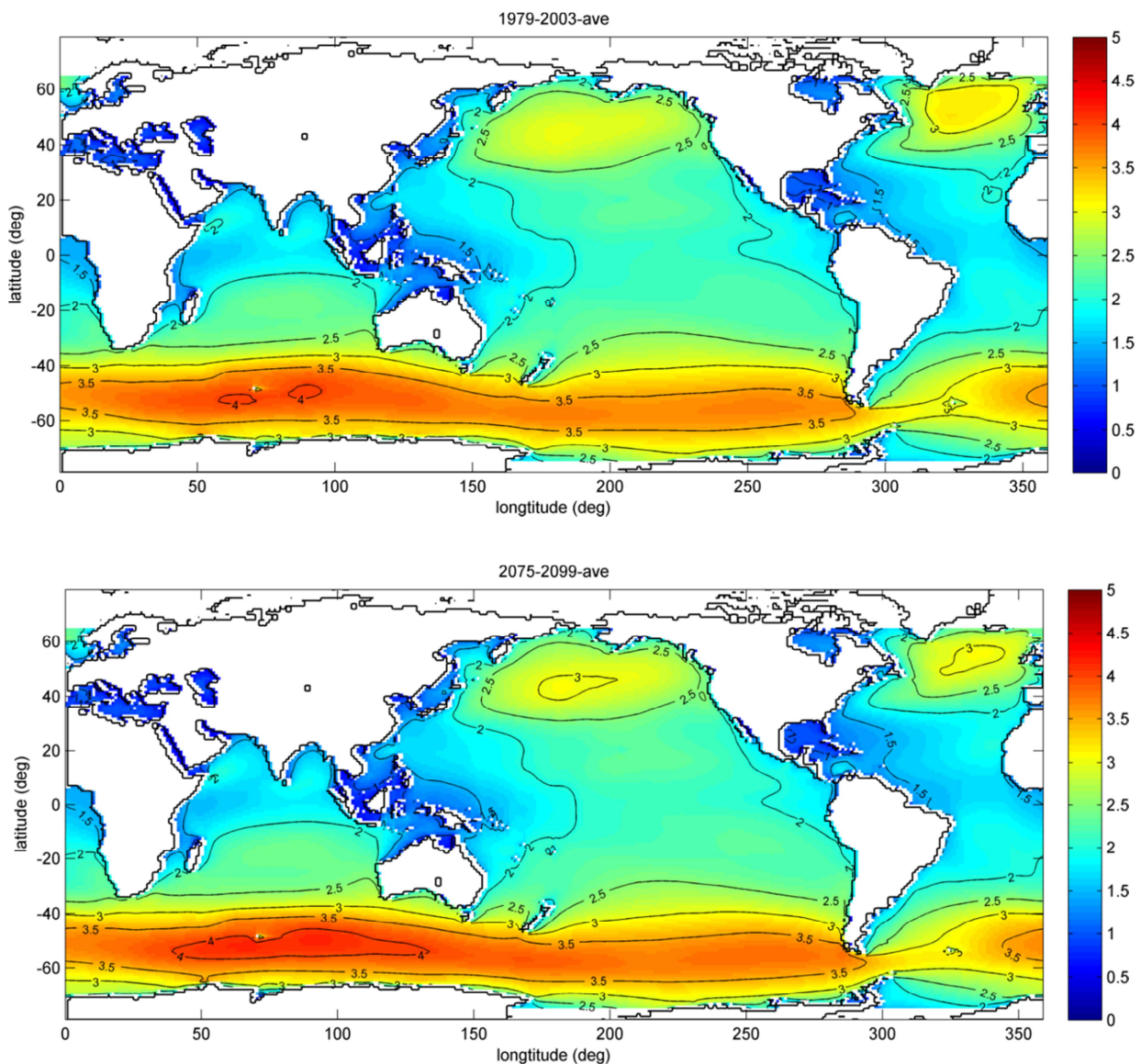


Figure 1: Global distribution of significant wave height (m), simulated by the WAM model. The result is based on the 25-year average for the periods 1979-2003 (top) and 2075-2099 (bottom).

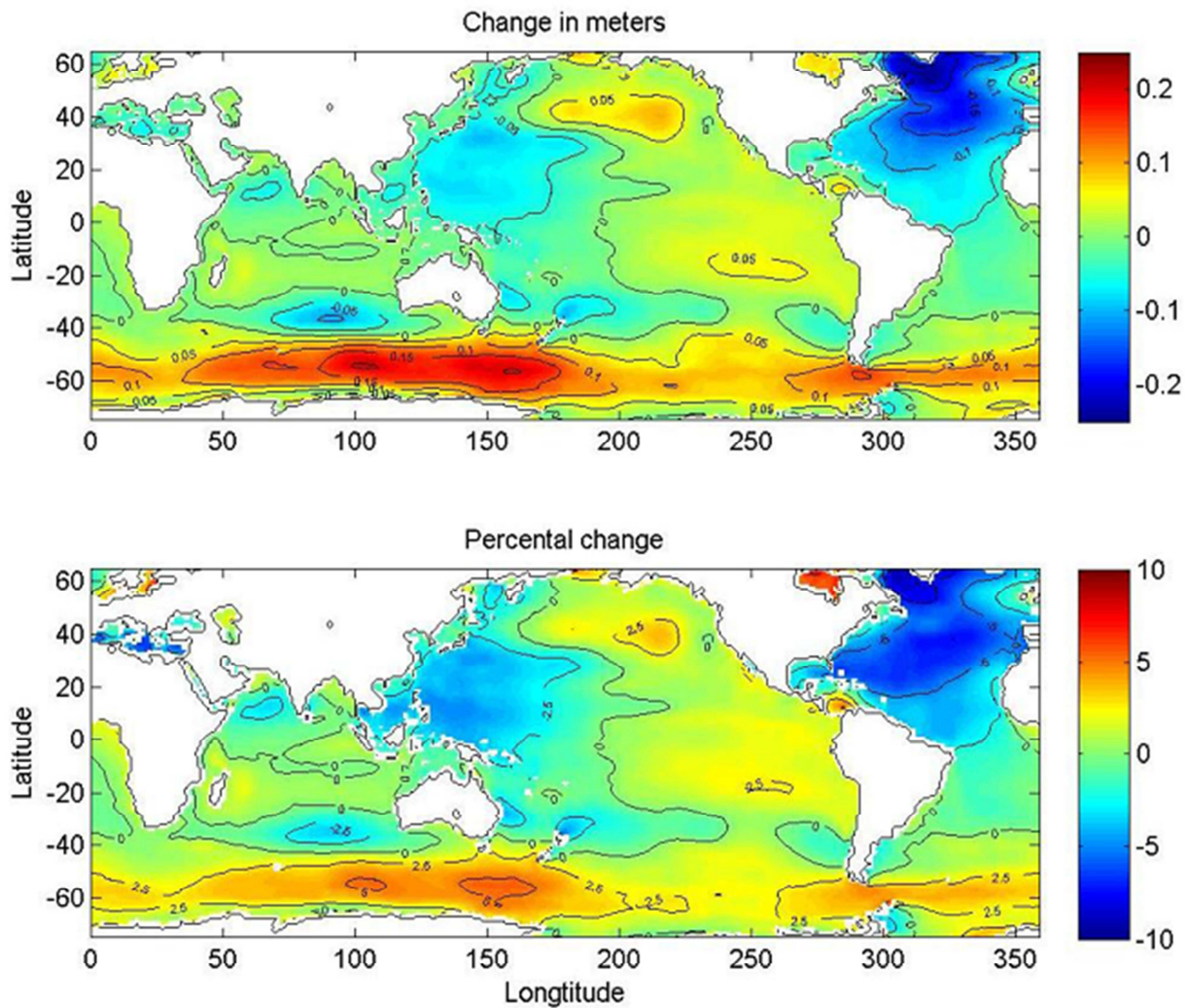


Figure 2: Change of the 25-year average of global significant wave height between climate simulations during present period (1979-2003) and future period (2075-2099). The upper figure shows the change, which is measured in meters, and the lower figure is the normalized change between the two periods, measured in percentage.

Figure 2 shows that the overall spatial distribution pattern of the averaged significant wave height from the climate simulation of the present period is relatively similar to the overall spatial distribution of the future period. However, the magnitudes of the averaged significant wave height change in many places between the two periods. To explain these quantitative transformations of the wave climate, the change between the two periods is plotted and represented in Figure 2. The change is measured, both in meters (the upper figure) and percentages (the bottom figure).

The largest increases occur in the Southern Atlantic, Indian and parts of the Pacific Ocean and in the Antarctic Ocean. In these regions, the changes in average significant wave height for the local scope increases up to 5%, and 2.5% and it is widely spreaded (relating to changes of average wave height of 0.1-0.2

m). Compared to the change in wind speed, the areas where large increases occur considerably more extensive. It is also found that the large area of significantly lower future wave heights includes the North Atlantic Ocean. A greater part of this region shows decreases of 5% and above.

Interestingly, the north western region of the Pacific Ocean, the tropical cyclone intense area off the coastal region of Japan, shows a significant decrease in the mean significant wave height. This is relevant to the earlier discussion, which mentions that tropical storms are likely to increase in the region, in warmer climate in the future. Therefore, it is important to highlight the fundamental differences of the processes for creating the daily average climate and the processes behind extreme events. Thus,

these phenomena should always be analyzed and evaluated separately.

5.0 CONCLUSION

This study presented projected future changes in global wave climate fields derived from the wind field output of JMA/MRI-AGCM3.2 model. The wave fields are numerically modeled by WAM model for a resolution of 1 degree. This study aims to give an overview of forthcoming changes in wave climate from present to future which focuses on the effects of climate change. The results shows that there is no unanimous trend in the increasing or decreasing wave height since the evolution of the wave climate is very strongly related to location. The regions which experience significant future changes of wave climate are found to be in the mid- to high latitudes. This significant increases reaches 5%, in the Southern Hemisphere and local regions of the northern Pacific Ocean. The decreases in the same magnitude occurs especially in North Atlantic Ocean. Large parts of the world appear to be unaffected by the projected climate change. Therefore, It is important to remember that this analysis is mostly limited to the average wave climate. This study does not taken into account the possible changes in the events which are outside the range of normal climate conditions.

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