

Monthly Variations of Global Wave Climate due to Global Warming

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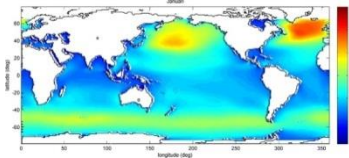
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Graphical abstract



Abstract

Over recent years, ocean wave climate change due to global warming has attracted a lot of attention not only coastal and offshore engineer but also stakeholders in the marine industry. There is a wide range of application in ocean environment that require information on ocean wave climate data, such as ships design, design of offshore platforms and coastal structures or naval industry. In this research, monthly variation in significant wave height is studied using MRI-AGCM3.2 wind climate data for 25 year period from 1979-2003. The 25 year significant wave height simulation derived from JMA/MRI-AGCM wind climate data. The JMA/MRI-AGCM climate data were input into WAM model. The results showed that the monthly variability of significant wave height in the Northern Hemisphere is greater than in the Southern Hemisphere. Meanwhile, most of the equatorial regions are in calm condition all year.

Keywords: Wave climate; global warming; wave height

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1.0 INTRODUCTION

The ocean climate is affected by increasing temperatures in many different ways. A static side-effect of global warming is for example the thermal expansion of the oceans resulting in rising sea levels. Effects of this phenomenon can already be seen in many coastal regions where coastal erosion and inundations are common problems. According to the Intergovernmental Panel on Climate Change (2007), the sea-level has risen by 1.7 ± 0.3 mm/year since the second half of the 19th century and the rate seems to have increased during the last decade.

The dynamic side-effects of the warming climate are the expected changes of the behavior of ocean waves, storm surges and other extreme events [2]. Reports of increased extreme climate in many parts of the world make the importance of understanding and assessing the effects of climate change greater than ever before. The number of coastal and marine activities and applications which are dependent on reliable and long-information about wind term and wave climate are also constantly increasing, and with that the necessity of predictions and forecasts of future development.

Since, there is a wide range of application in marine environment that require information on ocean wave climate data, such as ships design, design of offshore platforms and coastal structures or naval industry [6], [10]. The priority of climate change research in ocean environment should consider to the wave climate change as well as sea level rise or other impact of

climate change. Because, understanding the properties of waves and their potential changes are the major knowledge for management in coastal and offshore activities [9].

There have been several researches to develop long term global wave climatologist. Some initial researches have been made to obtain global climatologist by using remote sensing data [11], [12], [13]. Another study to obtain global climatologist by using reanalysis winds data, such as the study of Cox and Swail, (2001) involved a wave hindcast of the North Atlantic Ocean and covered a 40 year period. These included the global hindcast carried out by Caires and Swail (2004) within period 1984-2000 by using ERA-40 datasets.

The aim of this present study is to analyze the monthly variability of global significant wave height for the 25 year period 1979-2003 due to the effect of climate change. The wave simulations are analyzed on a global scale with the main focus directed at the evolution of the average wave fields, under the influence of climate change. The wave predictions that are used for the analysis is modeled by the numerical model of WAM (WAVE Model).

2.0 DATA

The present study is based on wind field datasets from the JMA/MRI-AGCM3.2 in order to simulate global wave climate for the periods 1979-2003. The AGCM3.2 is the most recent version

of a model created by the Meteorological Research Institute (MRI) in collaboration with the Japan Meteorological Agency (JMA) intended for climate simulations as well as weather predictions [7]. The model can, for example, give information on possible future changes of tropical cyclones, the East Asian Monsoon, extreme events and other changes induced by global warming [8].

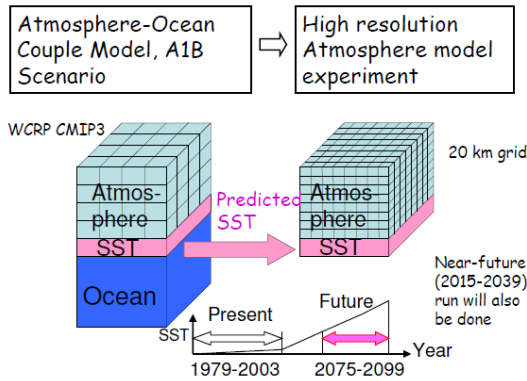


Figure 1 Kakushin program time slice experiment (adopted from Kitoh et al., 2009)

Model projections of global climate change (global climate projections) was designed by MRI-JMA Japan or better known as 20 km of high-resolution MRI-JMA AGCM. This model is a model of a single atmosphere AGCM based on the A1B scenario and the model is designed especially for Kakushin program [4] as shown in Figure 1.

Kakushin Program is climate prediction research project and one of its objectives is to predict extreme weather conditions in East Asia region and especially in Japan. This program is supported by the Government of Japan. Input data to the model AGCM is Sea Surface Temperature (SST), the average warming of SST and related oceanic climate conditions [4].

3.0 WAM MODEL

The numerical model used in this study is the third-generation wave prediction system, called WAM (WAVE Model) [5]. This model originally was developed by Europe-based Wave Model Development and Implementation group [14]. 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 [3].

WAM calculates the evolution of the wave energy spectrum by an explicit method, without any prior assumptions about its shape. It represents the physics of wave evolution in accordance with present day knowledge for the full set of degrees of freedom of the two-dimensional surface wave spectrum. It solves the action density balance equation, expressed in terms of wave energy, for the case of steady depths and currents. In deep water, the energy balance equation reads

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

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 white capping, 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 wind climate data from JMA/MRI-AGCM3.2.

4.0 VALIDATION MODEL

For the validation process, the modeled wind and wave climate were validated by the long-term measured data records at three locations in the northern Pacific Ocean (three NOAA buoys). The three buoys used for the validation are: a NOMAD buoy in the Gulf of Alaska known as station 46001 and two buoys, stations 51002 and 51003, located in south of Hawaii (www.ndbc.noaa.gov). Ratios for the statistical parameters describing comparison of wind speed and wave height of the model and NDBC buoy data is presented in Table 1.

Table 1 Comparison of statistical parameters between modeled and observed wind speed, U_{10} , and significant wave height, H_s , distributions

Station	U_{10}		H_s	
	Mean	Range 10-90 perc	Mean	Range 10-90 perc
46001	1.262	0.929	0.968	1.151
51002	1.043	0.845	0.987	0.625
51003	1.100	0.769	1.013	0.749
Average	1.135	0.847	0.989	0.842

This comparison shows that there are notable differences between the measured and modeled data series for 25 year period. Based on the averaged differences over the three locations, it is seen that the mean value of significant wave height is estimated very accurately by the model, with an underestimation of only 1%. The mean wind speed on the other hand, is overestimated by 13.5%. The range between the 10th and 90th percentile are underestimated by the models for both wind speed and significant wave height, This is consistent with the appearance of the more narrow distributions for the modeled values as presented in Figure 2.

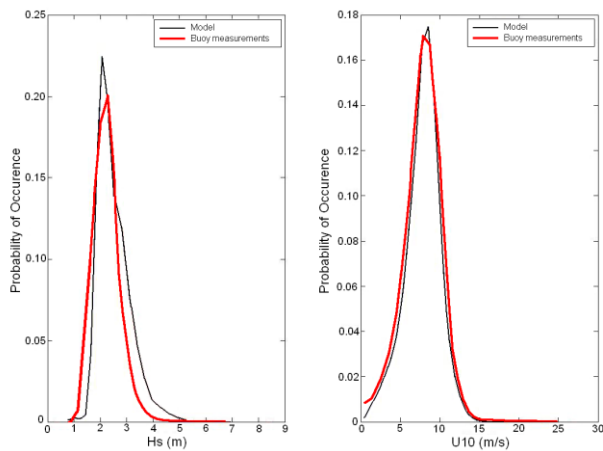


Figure 2 Probability density plots for significant wave height, H_s , and wind speed at 10 m height, U_{10} , for modeled values and observations from NOAA buoy station 51002 located South of Hawaii in the Pacific Ocean

5.0 RESULTS

The monthly averaged values of significant wave height for 25 years are presented in Figure 3. From the analysis of the monthly variation showed that the average of significant wave height each month always changes depending on the latitude and region. The maximum value of averages significant wave height occurs at higher latitude in each hemisphere.

From Figure 3, it is clearly seen that the Southern Hemisphere experienced intense wave conditions all around the year. The west coast of the Southern Hemisphere (particularly in Australia and South America) has a severe wave condition than in the east part of the Southern Hemisphere. Added, during July until September, the peak of averaged significant wave height takes place in the Southern Hemisphere.

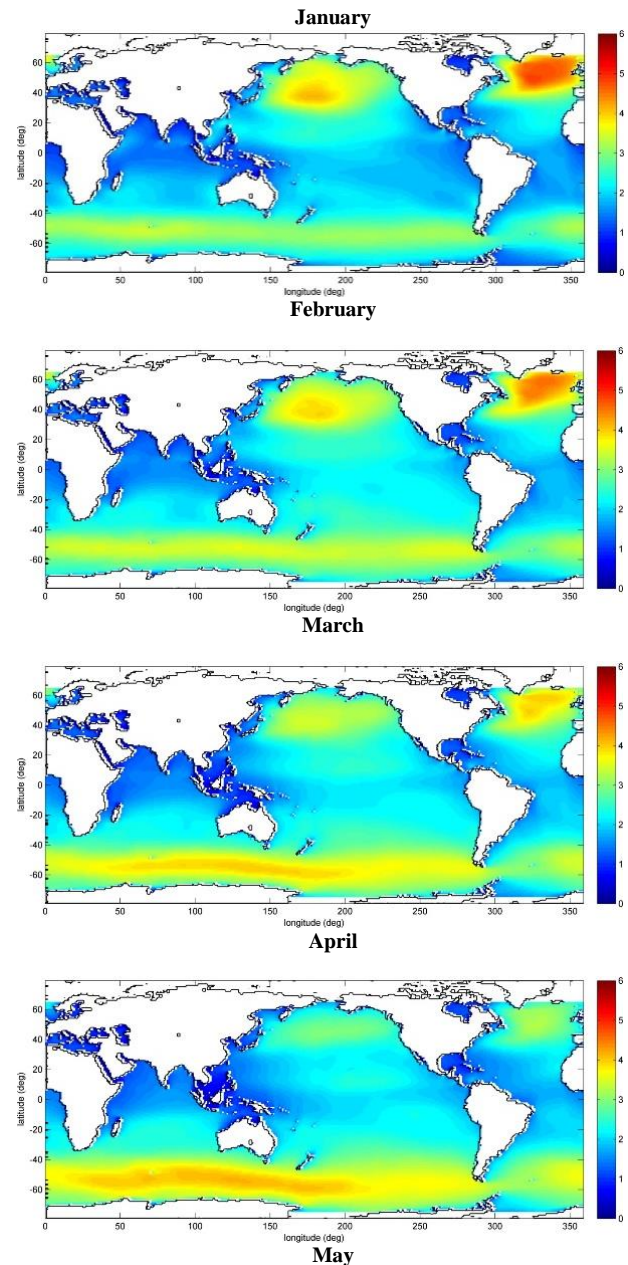
Meanwhile, in the part of Northern Hemisphere, the averaged significant wave height has more monthly variability. The highest wave conditions are observed in the North Pacific and North Atlantic Oceans during January. The maximum averaged monthly significant wave height occurs in North Atlantic Oceans with value of H_s around 5.0 m during January. In the meantime, during June-August, the Northern Hemisphere experiences lower waves with value of significant wave height around 2.0 m. At the same time, in June-August, the Southern Hemisphere experiences the maximum wave conditions. In October, the North Pacific and North Atlantic Oceans wave climate condition has again increased.

In contrast to the high latitude in each hemisphere, there is little monthly variability in the equatorial regions. Figure 3 shows that the monthly averaged of significant wave height in the equatorial regions is in calm condition, starting from January to December. Overall, the global wave climate conditions show the monthly averaged of significant wave height decrease from high latitude to the equator regions.

6.0 CONCLUSION

This study describes the simulation of 25 years global significant wave height derived from the Japan Meteorological

Agency/Meteorological Research Institute (JMA/MRI)-AGCM3.2 wind climate data. The wind climate data were input into ocean wave model WAM with a global grid of space 1° in latitude by 1° in longitude. The analysis of global wave climate showed that the monthly variability of significant wave height in the Northern Hemisphere is greater than in the Southern Hemisphere. Meanwhile, most of the equatorial regions are in calm condition all year.



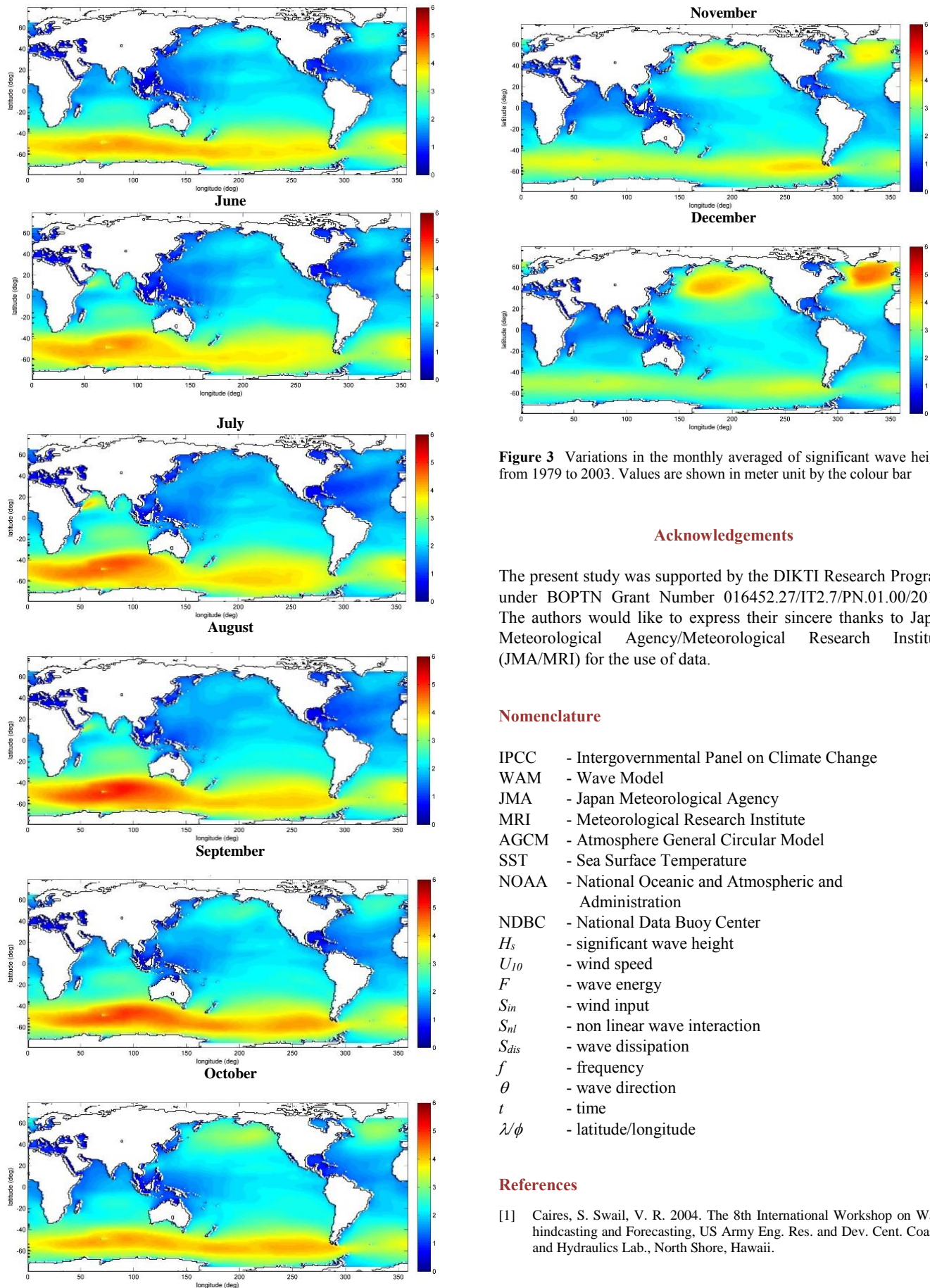


Figure 3 Variations in the monthly averaged of significant wave height from 1979 to 2003. Values are shown in meter unit by the colour bar

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Nomenclature

IPCC	- Intergovernmental Panel on Climate Change
WAM	- Wave Model
JMA	- Japan Meteorological Agency
MRI	- Meteorological Research Institute
AGCM	- Atmosphere General Circular Model
SST	- Sea Surface Temperature
NOAA	- National Oceanic and Atmospheric and Administration
NDBC	- National Data Buoy Center
H_s	- significant wave height
U_{10}	- wind speed
F	- wave energy
S_{in}	- wind input
S_{nl}	- non linear wave interaction
S_{dis}	- wave dissipation
f	- frequency
θ	- wave direction
t	- time
λ/ϕ	- latitude/longitude

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