HISTORICAL WAVE CLIMATE HINDCASTS BASED ON JRA-55

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Abstract

This study examined long-term wave hindcasts forced by JRA-55 reanalysis released by Japan Meteorological Agency. The wave hindcasts were performed by new version of WAVEWATCHIII with two different configurations, ST2 and ST4 forced by sea surface winds of JRA-55. The mean and extreme significant wave heights show good agreement with observed data by buoys and satellite altimeter. The results of wave hindcasts based on JRA-55 performs better than existing wave reanalysis as ERA-40 and ERA-interim. The extreme value analysis for wave heights are agree with observed data in the mid-latitude except active tropical cyclone regions.

Key words: global warming, climate change, sea surface wind, ocean wave

1. Introduction

Study of ocean wind waves in stormy condition and swells is important for coastal, ocean, and environmental engineering. The long-term wave hindcast has been conducted in coastal engineering and is getting popular to apply it for engineering design purpose. The use of wave hindcast data instead of observation data has both negative and positive impacts. The wave hindcast can simulate more than 25-40 years and gives spatial distributions of wave climate information over a regional scale or the global scale. The long-term atmospheric analysis has been carried out (e.g., NCEP/NCAR, ECMWF ERA-40/Interim) and apply them to the long-term wave hindcast Cox and Swail (2001); Caires and Sterl (2005). The accuracy of long-term wave hindcast strongly depends on the accuracy of sea surface winds of atmospheric analysis. However, the wave hindcast has systematic error, bias, needs to verify its accuracy.

On the other hand, future projections and impact assessments for coastal environments and hazards have been studied based on the global model projections. The Fifth Assessment Report (AR5) of IPCC discussed mean wave climate change in the working group I (WGI) IPCC (2013). The average changes and their width vary significantly by season and sea area. The mean wave height is going to decrease in the Western North Pacific (WNP) in the future climate condition Mori et al. (2010); Hemer et al. (2013); Shimura et al. (2015). The mean wave height significantly increases (up to approximately 0.4 m) in the center of the Northern Pacific in DJF Shimura et al. (2015). The change width is approximately 7.5% of the mean wave height in the present condition. In addition, the projected changes of mean wave height in the WNP is similar range of projection of sea level rise (SLR) but they have different spatial distributions. Thus it is important to discuss the combination of mean wave height change and SLR in the regional impact assessment.

The historical wave climate changes reported by both numerical and field data analysis. For example, the annual maximum wave height was increased 5 cm/year in the Western North Atlantic (WNA) but was

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decreased in the North Sea Wang and Swail (2002). The wave hindcasts in the Atlantic Ocean show more significant wave height increase in the region off the Canadian coast and the northwest of Ireland but less significant change in the North Sea and in the region off the Scandinavian coast.

The long-term wave hindcast is useful for climate study and it also useful for engineering purpose. Although it is possible to simulate the historical long-term wave climate based on the atmospheric analysis, the homogeneity of atmospheric analysis is necessary to estimate trends of historical change Chawla et al. (2013). In addition, the accuracy of extremes (e.g. tropical cyclones) is also needed to know for the application to coastal engineering design. JRA-55 Ebita et al. (2011); Kobayashi et al. (2015) released by Japan Meteorological Agency which performed 55 years atmospheric reanalysis from 1958 to 2012 over the globe. Additionally, JRA-55 implemented typhoon information by boughs scheme since 1958. It is interesting for coastal engineering that the latest reanalysis data can be useful for long-term hindcast of wave field.

This study examined long-term wave hindcasts forced by JRA-55 reanalysis released by Japan Meteorological Agency. The wave hindcasts were performed by new version of WAVEWATCHIII 4.18 with two different configurations, ST2 and ST4 forced by sea surface winds of JRA-55. The results of wave hindcasts based on JRA-55 analyse with observed data and show the accuracy both mean and extreme wave conditions.

2. Outline of hindcast

The long-term wave hindcast was carried out using WAVEWATCH III (ver. 4.18) forced by wind speeds at 10 m height U_{10} of JRA-55Kobayashi et al. (2015). JRA-55 covers the globe and assimilated from 1958 to 2012. Two set of source term combinations were used for the computation. One is Tolman and Chalikov (1996) (denotes ST2 hereafter) and another is Ardhuin et al. (2009) (denotes ST4 hereafter). The combination of ST2 was used WAVEWATCH III ver.3.x and the ST4 is tuned for S_{in} and S_{ds} by Ardhuin et al. (2009).

The time integration of the wave hindcast was the same to JRA-55, 1958-2012, and it gave the same spatial coordinate and resolution. The bathymetry was given by ETOPO5 and assumed deep-water condition if water depth is deeper than 300 m. The spatial discretization was about 60 km and directional spectra were discretized 29 bins in frequency domain and 30 in direction. The ice coverage was considered based on COBE-SST2 which was also used in JRA-55.

The accuracy of U_{10} in JRA-55 and the significant wave heights and periods H_s and T_s were verified by the long-term buoy data by JMA and NOAA. The long-term buoy data by JMA and NOAA were chosen relatively deep water conditions (deeper than 50 m) and observed longer than 20 years. Totally 6 buoys in JMA and 31 buoys in NOAA's NDBC (National Data Buoy Center) were selected for validation of wave hindcast. The spatial distribution of characteristics wave heights were compared with ERA-40/Interim. The results of wave hindcasts performed in here denotes JRA-55-Wave hereafter for simplicity.

3. Accuracy of wave hindcast

The accuracy of monthly mean significant wave heights H_s^m, annual maximum significant wave heights $\langle H_s^{max} \rangle$(denotes extreme wave height) and monthly mean significant wave periods T_s^mwere validated by the observed data. Figure 2 shows the spatial distributions period averaged significant wave height for JRA-55-wave and ERA, respectively. Although the spatial distributions of JRA-55-wave (ST4) and ERA are similar, $H_s^m$of ERA small in the middle to high latitude and location distributions such as the lower latitude in the Western North Pacific (WNP) are also different. This is due to weaker global circulation and related wind speeds U_{10} in ERA in comparison with JRA-55-wave.

The example of comparison of $H_s^m$and $\langle H_s^{max} \rangle$between JRA-55-wave and buoy data is shown in Figure

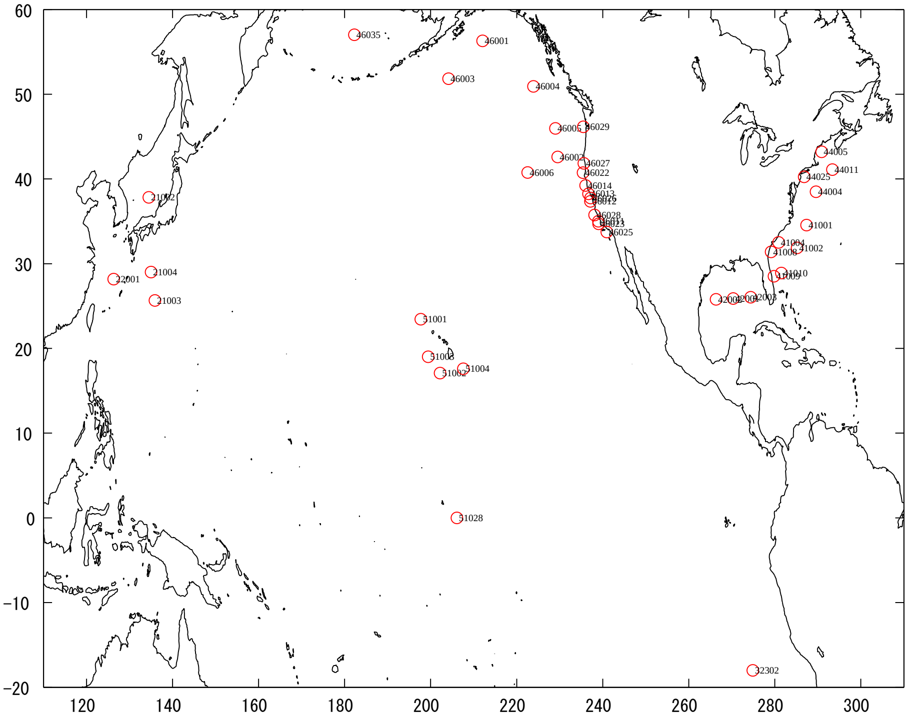
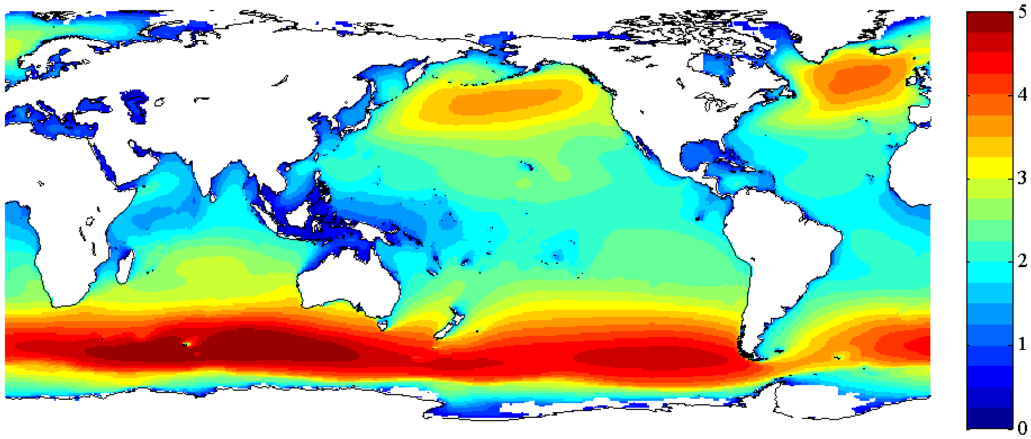


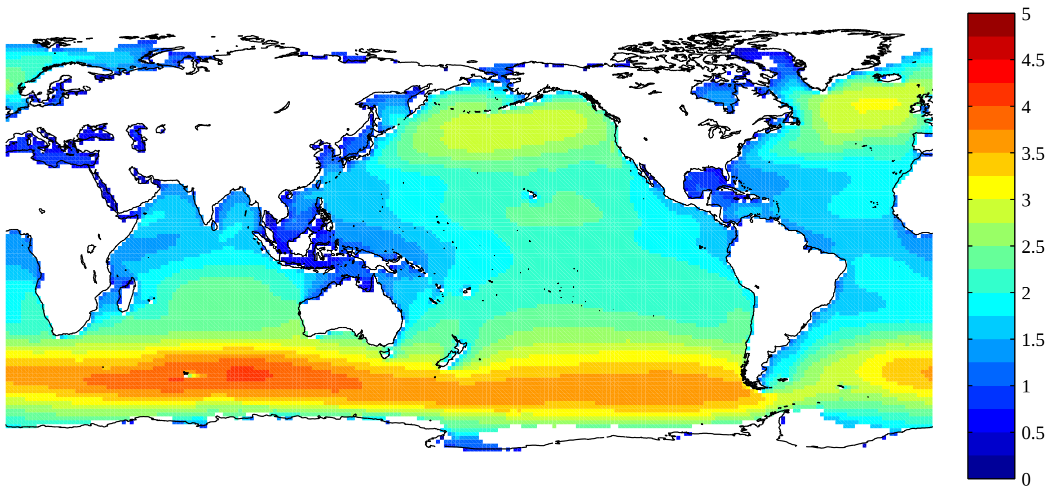
Figure 1: Locations of buoy for validation

3. The comparison of two different locations, off coast of Alaska in the Pacific side and off coast of Hawaii, are shown to discuss about the mean and extreme wave climate hindcast. The time series of H_s^mindicate the underestimation of ERA to buoy data. However, JRA-55-wave gives good agreement with the buoy data. The differences between ST4 and ST2 are not significant but can shows small differences at Alaska. The time series of $\langle H_s^{max}\rangle$indicates similar tendency to H_s^m. Although JRA-55-wave is not perfectly matched with the buoy data, the results of ERA underestimated and annual variation is also different. These characteristics of differences between the model and buoy data can be observed the most of locations. The mean RMS error for $\langle H_s^m\rangle$over 37 buoys is 0.25 m by JRA-55-wave (ST4) and is improved in comparison with ERA dataset. The model bias depends on the region. The values of $\langle H_s^m\rangle$by JRA-55-wave and ERA underestimate in the Pacific Ocean and Atlantic Ocean. However, $\langle H_s^m\rangle$over estimates by JRA-55-wave but underestimate by ERA in the Western North Pacific. The improvement of model bias by JRA-55-wave in comparison with ERA is consistent to ERA both the mean and Scatter Index over the globe. The significant improvement of model bias by JRA-55-wave can be found due to tropical cyclone related regions in the middle latitude both the Northern and Southern hemisphere.

The extreme value analysis was performed to examine the accuracy of extreme wave heights. Figure 4 shows an example of extreme wave height distributions based on the annual maximum significant wave heights at the same location shown in Figure 3. The extreme distribution of $\langle H_s^{max}\rangle$ JRA-55-wave shows better agreement up to 10 years return values with buoy data respect to ERA dataset. The extreme wave heights by JRA-55-wave gives reasonable agreement with the buoy data except middle latitude. The main reasons of bias for extreme wave heights are less accuracy of tropical cyclone in the analysis and sensitivity of tropical cyclone track due to low resolution of wave modeling (60 km in here). The JRA-55-wave (ST4) gives slightly better agreement with the buoy data in comparison with ST2. However, the deviation between ST4 and ST2 starts 3-10 years return value.



(a) JRA-55 (ST4)



(b) ERA

Figure 2: Comparison of period averaged significant wave height $\langle\langle H_s^m \rangle\rangle$ between JRA-55-wave and ERA-40 (unit:m)

4. Characteristics of historical wave climate

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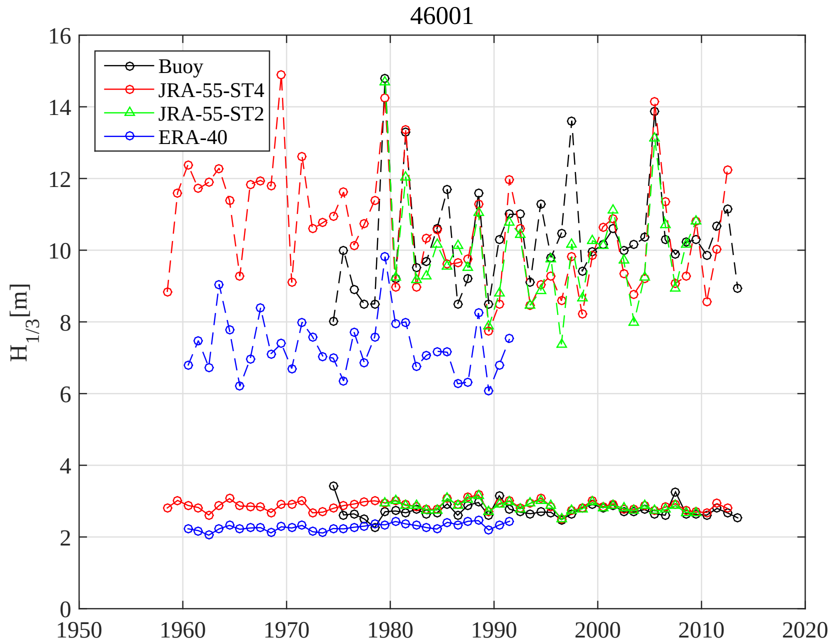
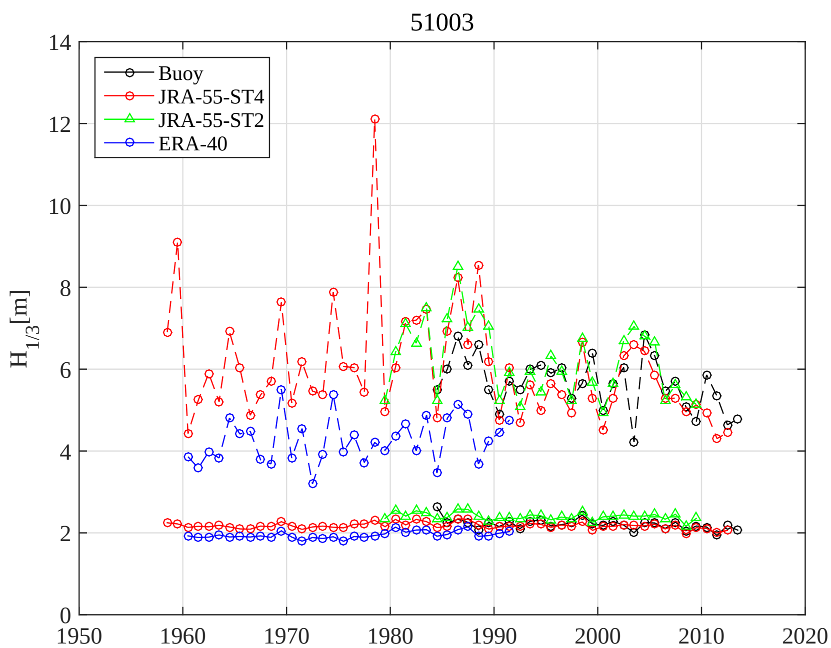
There are many studies of future projection of wave climate change since IPCC AR5. The future projections of global wave climate under global warming scenarios have been carried out and the decrease or increase in wave heights differed depending on the oceans until the end of this century (e.g., Hemer et al., 2013). Several research groups have deployed dynamical approaches for global wave climate projection (e.g., Mori et al., 2013; Shimura et al., 2015). However, there is a few global studies to discuss historical wave climate changes due to lack of homogeneous atmospheric analysis. It is important to know the historical

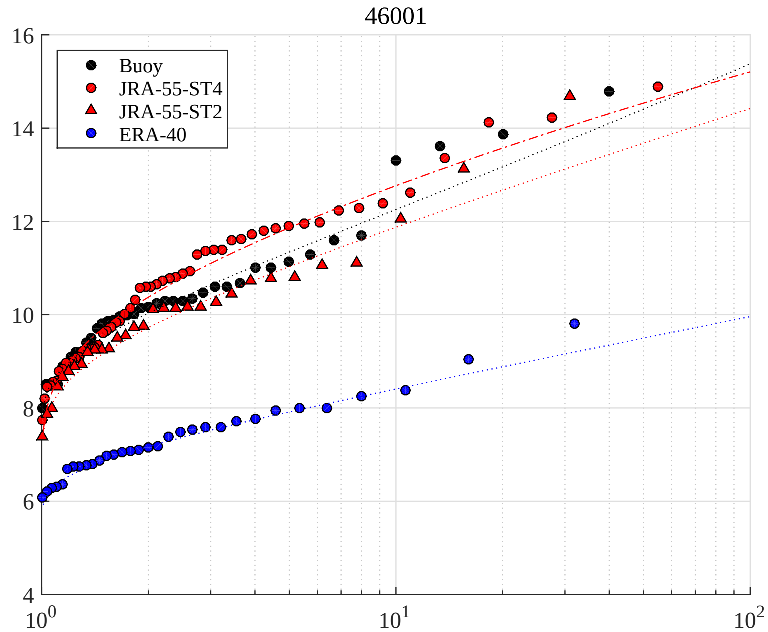


(a) NDBC buoy #46001: off coast of Alaska

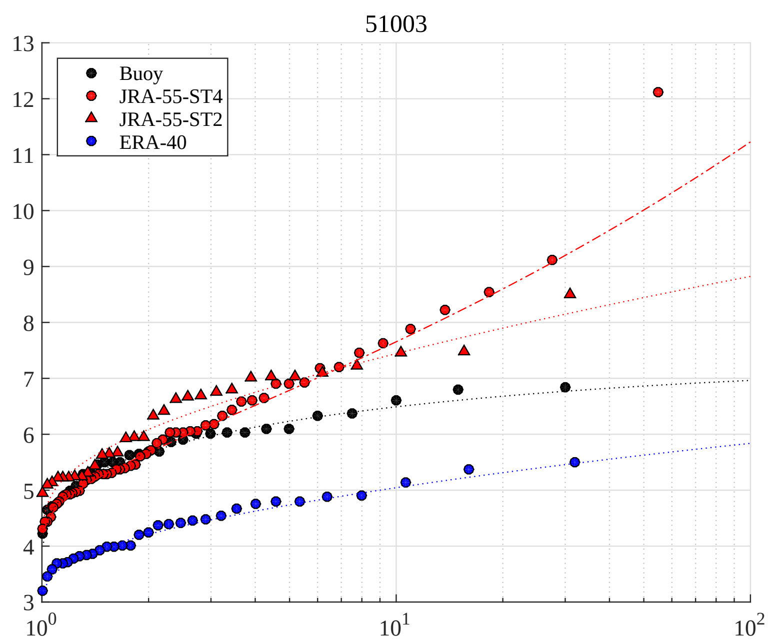


(b) NDBC buoy #51003: off coast of Hawaii

Figure 3: Comparison of annual mean significant wave height $\langle H_s^m \rangle$ and annual maximum significant wave height $\langle H_s^{max} \rangle$between the model and buoy data (solid line: $\langle H_s^{max} \rangle$, dashed line: $\langle H_s^m \rangle$, black circle: buoy data, red circle: JRA-55-wave (ST4), green triangle: JRA-55-wave (ST2) and blue circle: ERA)



(a) NDBC buoy #46001: off coast of Alaska



(b) NDBC buoy #51003: off coast of Hawaii

Figure 4: Comparison of extreme value distribution based on annual maximum significant wave height $\langle H_s^{max} \rangle$between the model and buoy data at NDBC buoy #46001: off coast of Alaska (horizontal axis: years, black circle: buoy data, red circle: JRA-55-wave (ST4), green triangle: JRA-55-wave (ST2) and blue circle: ERA, lines: correspond extreme value distribution)

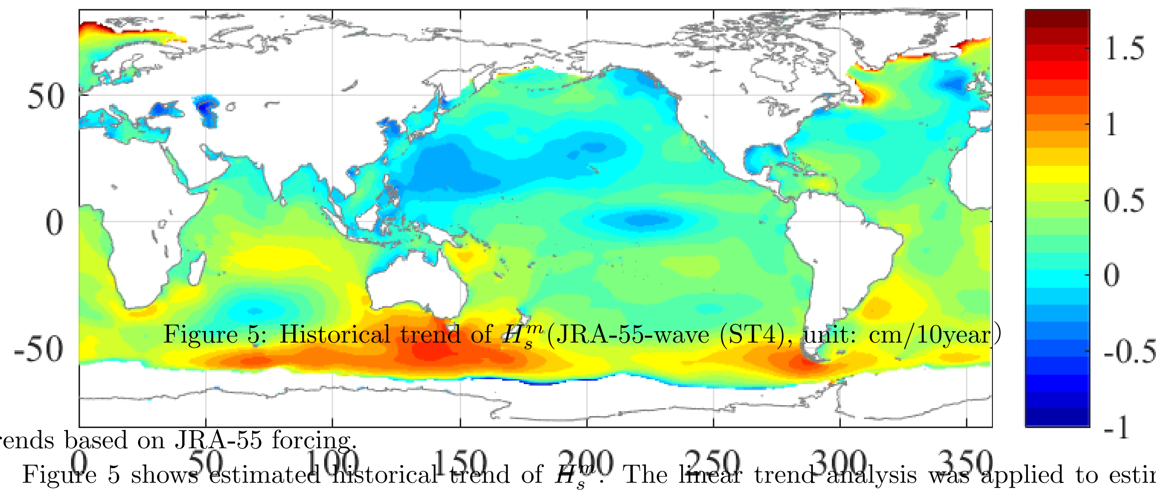


Figure 5: Historical trend of H_s^m(JRA-55-wave (ST4), unit: cm/10year)

trends based on JRA-55 forcing.

Figure 5 shows estimated historical trend of H_s^m. The linear trend analysis was applied to estimate historical trends, although there is no significant difference between the linear and quadric approximation for historical H_s^m. The estimated historical trends in H_s^m show ± 2 mm/year and is the same magnitude of historical sea level change. The historical mean wave heights have been increased in the Antarctic Ocean but have been decreased in the North Pacific Ocean and the North Atlantic Ocean. The spatial distribution of historical H_s^m trends is similar to future change of mean wave heightMori et al. (2010); Hemer et al. (2013); Shimura et al. (2015), although the magnitudes are different. Therefore, the future projected wave climate change is occurred in the present climate and is expected to accelerate in the future climate condition due to green house gas emission.

5. Conclusion

The 55 year global wave hindcast was examined using WAVEWATCHIII (denotes WW3) forced by U10 of JRA-55. The accuracy of wind sea and swell is verified by two different source term configurations of WW3. The mean and annual maximum wave height and periods were verified by the long-term observation data.

First, the values of mean and extreme wave height were compared with long-term buoy observation data. Although ERA-40 shows negative bias, the present wave dataset shows better performance both mean and annual variation. The extreme value analysis for annual maximum wave height was conducted to verify long-term return value. There is still significant bias of extreme value in the range of a few meters for 50 year return period but the present wave dataset indicates significant improvement in comparison with ERA-40. The averaged errors of simulated annual maximum Hs to all buoy data indicate significant improvement in comparison with ERA-40. The historical global wave climate characteristics were analyzed based on the present wave dataset. The historical trends of mean wave height change were analyzed. The estimated historical wave climate change is agree with buoy data and indicates decrease trends over the Northwestern Pacific and the North Atlantic. The estimated global wave climate trend shows good agreement with the future changes of wave climate change.

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