Can indications of climate change impacts be detected from recent phenomena in Japanese coasts?

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Abstract

The IPCC 4th assessment report (2007) reveals the global warming caused by human actions. The current situation will change gradually; however, it will accelerate gradually to a situation never experienced before. This implies a collapse of the preconditions for disaster prevention work. Our final aim is to establish an adaptation methodology for the coastal prevention policy in Japan. The purpose of this study is to determine climate change signs and effects. First, wind changes between the future climate and present climate are analyzed by earth simulator results. Second, the wave climate historical change is re-analyzed for the data of five observation stations around the Japanese coast. We suggest the growth of wave climate in recent years and prove its relation with climate change by a comparison between the present and future wind outlines using the earth simulator.

Introduction
The disaster prevention planner of strategies for adaptation to climate change should take into account that the relative condition on field will change completely. Most studies rely on present assumptions; however, they focus on different target conditions. These studies do not consider changes in conditions.

Most disaster risk management programs have been evaluated using return periods, the largest record, or other historical theories. The current situation is expected to change and accelerate gradually. This will lead to a collapse of the preconditions of empirical methods.

Kawai et al. (2007) have simulated future risk using a stochastic typhoon model for an increase in the storm surge risk. Using the Bruun rule (1962), Mimura et al. (1997) have estimated the beach erosion scale by a rise in sea level induced by global warming. In Japan, beach erosion is almost completely caused by an interruption of alongshore sediment transportation. A change in coastal topography is caused by cross-shore sediment transportation and along shore sediment transportation. Along shore sediment transportation is induced by incident angle of waves caused by wind.

Our final aim is to establish an adaptation methodology for the coastal prevention policy in Japan. The purpose of this study is to determine the key elements for this adaptation as the beginning of a chapter on beach change. The prediction of changes to the future and the historical changes of wave climate observation data are compared.

**Total energy of characterized regions by MRI-GCM20 results**

MRI-GCM20 is a global climate model in the form of a 20 km mesh (MRI-GCM20) developed by the Meteorological Research Institute in Japan. The sea surface temperature (SST) is provided by Meteorological Research Institute Coupled GCM Version 2.3 (one of atmosphere-ocean coupled models). The experiment is performed for 20 years since both 1978 as the present climate hindcast and 2080 as the future climate forecast. The calculation time step is 6 min, and data are recorded every 6 h. The future climate is applied to the A1B scenario of the IPCC SRES. We use sea/land surface wind for wave generation.

We divide the surrounding area of Japan into 6 regions as wave generating areas that attack coasts (Figure 1). These regions are divided by island chains and peninsulas. Its outer frame comprises the lat. 45°N line, lat. 20°N line, long. 120°E line, and long. 155°E line for the generation of long waves. As Japanese islands are located along lat. 35°N and long. 140°E, the
regions are mainly divided using these lines. Regions I and II are cut off by the long, 28°E line passing through the Korean Peninsula and Okinawa mainland. Region III is the main region comprising major typhoon routes strongly attacking west Japan. Region IV covers the Sea of Japan.

The regional potentials for wave generation are determined by the total wind strength in every region. Figure 2 shows the spectra of the total wind speed for each region.

![Figure 1. Location of regions and stations](link)

![Figure 2. Total wave spectra of regions](link)
Region IV shows a slight increment around the 180-day period. This region experiences strong periodic wind in the winter season; however, it is almost calm in the summer season. The 180-day period shows the presence of periodic wind in the winter. This increment suggests that this wind will become stronger in the future. Region VI also shows an increment in long periods. These spectra show the characteristics of and changes in the wind fields; therefore, they suggest that the wave climate will change as well.

**Spectra of winds extracted at MRI-GCM20 grid stations**

In the Fig. 1, the five stations denoted by stars are the grid points nearest to the actual wave observation stations. We select 6 GCM20 grid points to detect the local wind change. These denoted by dots show the location of each region and are 500 km or 200 km away from four actual wave observation stations.

The wave growth is caused and limited by the fetch and duration of blowing of wind. Though the data of one point are insufficient to understand the total wave climate, the wind data of each observation indicate the capability of wave generation and growth. The data indicate a change.

Figure 3a shows the wind spectra at “Sumiyoshi” station and St.Ss500S located 500 km to the south of this station. These stations belong to region III. There are no significant differences between the present and future climate at St.Ss500S; however, the inshore station “Sumiyoshi” indicates wave growth over a longer period.

Figure 3c shows the wind spectra at T60NNW located 60 km to the north-northwest and T200NNW located 200 km to the north-northwest of the “Tanaka” observation station. They are located in region IV. In these spectra, there are 2 zones with a considerable difference between the present and the future climate for the longer period. The first zone comprises a period around equal to or greater than 60 days (left side). This zone indicates strong wind in the future. The next one is between around the 60-day period and 14-day period. This zone indicates a weak wind in the future. This suggests that the periodic wind of the winter season that is characteristic to this domain will change in the future. If this change in spectrum shape indicates an energy shift to the longer period in the future climate, it will lead to a higher potential of stronger winter waves caused by an increment in the basic blowing duration.

Figure 3d shows the wind spectra at the “Kashima” station and St.K500SE located 500 km to the southeast of
Kashima. These spectra show an increment in the longer period, similar to the results shown in Fig. 3b. In particular, at St.K500SE, the maximum increment in the longer period is approximately 1.7 times. This station indicates a profile change similar to St.Ss500S and St.Sg500S.

Figure 3. Wind spectra at MRI-GCM20 grids of stations

Typhoon tracking extracted by MRI-GCM20

Coasts along the Pacific Ocean are affected by the typhoon. The typhoon tracks employed in this study are extracted by MRI-GCM20 using the methods and criteria by Oouchi et al. (2006). Figure 4 shows the location distribution every 6 h for the six regions on the annual cycle series for 20 years. The left-hand-side graphs in Fig. 4 are plotted by the latitude of every region, and those on the right-hand side are plotted by the maximum wind speed at sea level.

Regions III and V, which are near the region of origin of the typhoon, show a decrease in the number of typhoon tracking points. The number of tracking points remains almost constant in region VI. The rate of tracking points in region VI is approximately 10.7% of all the tracking points in the present climate. This rate grows to approximately 13.8% in the future climate. The typhoon sojourn time in region VI is expected to increase from 4.6% to 5.3% in all regions for 20 years by considering the existing duration of the typhoon. Then, typhoons that progress to higher-latitude regions (IV and VI) are expected to increase.

The maximum wind speed at sea level is shown on the right-hand side of Fig. 4. The maximum wind speeds in regions I,
III, and V for 20 years are estimated to increase to 10.1m/s, 6.8m/s and 11m/s. In region II, both the mean and maximum of the maximum wind speed are expected to reduce in the future. Region VI, in which the number of tracking points does not change, shows a 1.7 m/s increase in the mean and a 1.7 m/s decrease in the maximum.

Figure 4. Typhoons attacking the regions simulated using MRI-GCM20
Location by latitude (left) and wind velocity (right)

Chronological analysis of wave height-period coupling frequency data at actual observation stations

The River Bureau of the Ministry of Land, Infrastructure, Transport and Tourism of Japan has acquired wave climate data from 32 observation stations at coasts (as of 2004). In this study, we select three observation stations and one port observatory. The four stations are located along the Pacific Ocean; Kashima port to the north (NOWPHAS data 1973–2004, NOWPHAS: Nationwide Ocean Wave information network for Ports and Harbors by Port Airport Research Institute), Suruga, and Sumiyoshi (closed in 2005). Another is located along the Sea of Japan.

In Japan, the main statistical results of the wave climate as continuous archives are determined from the wave
height-period coupling frequency table. The lengthening of the wave period would cause an increment in the wave runup to the beach. This is an important element for the sand transportation on the beach.

To evaluate wave height and period as a couple, we use energy averaged waves and total wave energy. The energy averaged wave height is used as the representative wave in the contour line change model, as suggested by Tanaka et al. (1982).

\[
T_m = \frac{\sum n_k T_k}{\sum n_k}, \quad T_m H_{em}^2 = \frac{\sum \sum (n_{kj}T_kH_j^2)}{\sum \sum n_{kj}}
\]

\(H_{em}\): energy averaged wave, \(T_m\): mean period,
\(j\): height ranks, \(k\): period ranks, \(n\): wave number

Figure 5 shows the annual total wave energy (E), energy averaged wave height (H), average wave period (T), data number (N), and El Nino southern oscillation (ENSO) terms. As this data are observed with respect to every hour, the data number is limited to 8760 in a year. The annual total energy includes missing observed terms. The dashed straight lines denote the regression lines since 1990. If the data number is less than 2000 in a year, the regression is calculated during years showing stable trends because of reliability. Sasaki et al. (2005) have attempted to obtain the relation between the summer extreme wave height and the ENSO. The wave height observed near the coast is not related to the ENSO.

All stations show a growth of the total incoming energy. The figures are classified into three types by trends of the energy averaged wave height. The first trend type shows an increment in both the energy wave height and annual total energy. The Tanaka (region IV) and Suruga (region III) stations are classified into this type. Even if the only changing factor is the wave height, it is sufficient to indicate coastal change. A change in the wave height induces refraction, diffraction, wave breaking, and sand transportation. In this situation, the coastal prevention policy will have to be re-planned because of the probability of major changes in waves eroding the beach.

The second type has a stable energy averaged wave height and increments in the total energy. The Kashima port (region VI) is classified into this type. The coastal prevention policy would have to be revised because the wave characteristics do not change drastically; however, some large waves are extremely strong.

The third type shows a decrease in the energy averaged wave height and increase in the total energy. The Sumiyoshi station (region III) is classified into this type. In this situation, although the coasts would probably appear calm on more days, large waves in low frequent would extend larger.
Figure 5. Inter-annual change of energy averaged wave height \( H \) (m), averaged wave period \( T \) (s), annual total wave energy \( E \) (m\(^2\)/s)(includes missing terms), acquired data number \( N \) and ENSO terms

Figure 6. Pair months total energy of Top 10 waves

Analysis of top 10 waves

The observation data shown in figure 5 reveal that the wave climate has become severe. The River Bureau has maintained observational data of the annual top 10 wave height events since the beginning of archiving. Figure 6 shows the total wave energy recorded in the annual top 10 waves over a two-month period. Typhoons and periodic wind in winter are seasonal climate phenomena. Then, we separate a year into two seasons with three two-month sets. The two seasons are the cold season and warm season. The cold season comprises pair sets of December and January, February and March, and October and November. The warm season comprises pair sets of April and May, June and July, and August and September.

The Sumiyoshi and Suruga stations have shown
increments in the June and July set during the warm season since around 1997. This may suggest that the typhoon season on wave climate comes to visit early.

**Discussions and conclusion**

Now, we try to interpret the recently observed climate change by simulation results. The increase in the annual total wave energy at the Tanaka observation station, which is included in the first trend type shown in Fig. 5, could be caused by an increase in the periodic wind in winter. This trend has also been predicted in Fig. 3c. Further, Figure 7 shows the averaged wind speed and direction for the cold season in the present and future obtained by MRI-GCM20 results. The counter line of 4m/s wind speed comes to expand to Pacific over Japan like tongue shape. The counter in the Sea of Japan closes to Japanese main land. Although the Suruga station is also classified into the first trend type, this station, which is influenced by the typhoon shown in Fig. 6, would be effective for tracing the typhoon characteristic trends shown in Fig. 4. Similarly, the Kashima port shows a growth in annual energy due to the typhoon shown in Fig. 4. These Pacific station trends are induced by a stochastically occurring typhoon that is expected to strengthen. Further, the southwest coast of Hokkaido, for example, Kojouhama, would be attacked by a more severe inundation force in winter (Fig. 7). The observation data of Kojouhama show increments in winter. The Sumiyoshi station located in region III shows a trend opposite to the Suruga station. In fact, the total typhoon energy increases and affects the station.

**Figure 7. Wind field by predicted seasonal average in cold season**
On the basis of these observations, it may be said that the increments in the annual total wave energy and energy averaged wave height are influenced by global warming. The wave climate appears to have been already influenced by global warming. However, this judgment may be inaccurate. We should re-analyze more observed data and continue to collect data. We should simulate wave climate directly by using wind fields or the wind in the next-generation high-resolution climate model.

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Reference


