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IMPACT ASSESSMENT OF CLIMATE CHANGE ON SANDY BEACH AT URADOME COAST, JAPAN

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Abstract

IPCC Fifth Assessment Report (AR5) reported that the future environment for coastal area such as sea level, winds, waves and surges will change significantly. The coastal management needs to project the beach profile change in the future. Generally, the beach profile under the climate change is projected using Bruun's rule (1962). The Bruun's rule parameterized the cross section of shoreline change only as a function of sea level rise. However, dynamic movement of longshore and cross-shore sediment transport affects the bathymetry change. Therefore, this study investigated the beach profile change due to the influence of sea level rise and wave characteristics under the climate change using the 3D morphological simulations at Uradome Coast in Japan. The local changes in wave height and wave direction based on the future wave climate projection were considered and their biases were corrected. The beach profile change due to change of wave characteristic in future climate was estimated to be the same or more than that caused by sea level rise.

Key words: climate change, wave characteristic change, sea level rise, beach profile change, morphodynamics, artificial reef

1. Introduction

The influence of climate change on coastal area due to sea level rise and wind wave characteristics has been studied intensively recently. Regarding to recent studies, Hemer et al. (2013) reported that extreme wave heights are predicted to increase, but the mean wave heights are predicted to decrease in the Western North Pacific in the future climate (Figure 1). Change of wave characteristics is very important to predict the beach topographic change. There are two expected wave characteristic changes in the future climate. One is wave height and another is wave direction (e.g. Mori et al., 2010). It is also important to discuss about changes of wind seas and swells in the future climate condition.

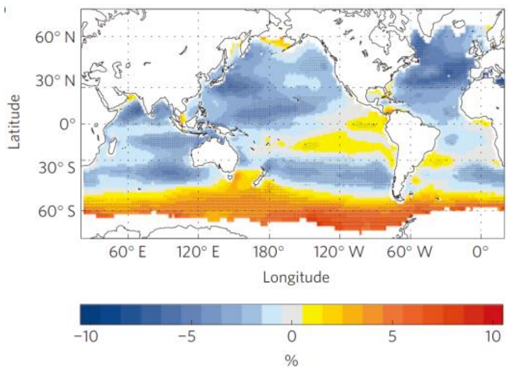

Figure 1. Future changes in the mean wave height (Hemer et al., IPCC-AR5, WGI, Chapter 13)

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Generally, the beach profile under the climate change is projected using Bruun's rule (1962). The Bruun's rule parameterized the shoreline change only as a function of sea level rise. Number of studies have considered only due to sea level rise but few studies consider the change of wave characteristics. In actual dynamic movement of longshore and cross-shore sediment affects the bathymetry change. Therefore, it is important to consider the change of wave characteristics. In this study, the influence of sea level rise and wave characteristics associated with climate change on morphological change is considered using the numerical simulations. The beach profile changes under the climate change at Uradome coast in Tottori prefecture facing to the Sea of Japan are evaluated in this study. There is no effects of swells in the Sea of Japan. Thus we discuss effects of wind sea changes on the beach morphology.

2. Area of Target: Uradome Coast in Japan

Uradome Coast is located at eastern part of Tottori Prefecture and the coast is surrounded by peninsula and port. The coast is 2 km pocket beach, facing the Sea of Japan, as shown in Figure 2. At the Uradome Coast, beach erosion has been started around 1960, and sea walls constructed to protect the port. Also the tow artificial reefs were constructed as an erosion measure like Figure 2. However, the huge artificial reefs caused the scouring of the surrounding area of the reefs. Also, the beach nourishment has been conducted since 2001. In the beach nourishment project, the sand at the deposition area was removed, and the sand was transferred to the erosion area. Then the sand was injected there. The dredging and injection points are shown in Figure 3, and the volume of beach nourishment are shown in Figure4. The legend of Figure 4 shows dredging points. The sand volume per year is normally 40,000m^3.

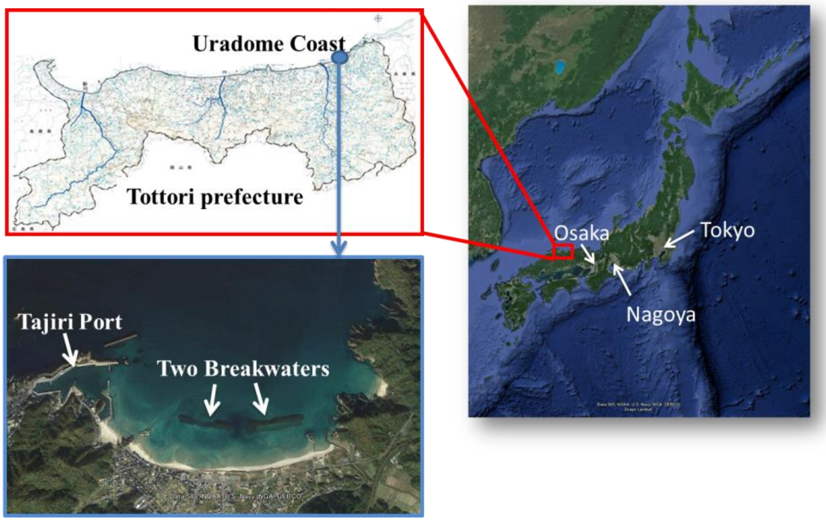


Figure 2. Location of Uradome Coast, Japan

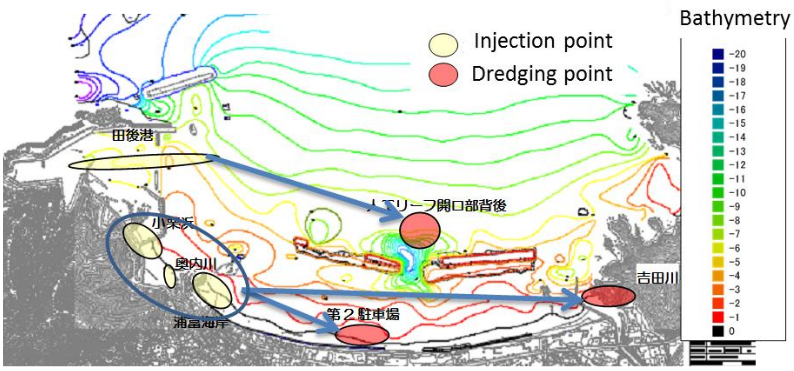


Figure 3. Dredging points and injection points for beach nourishment

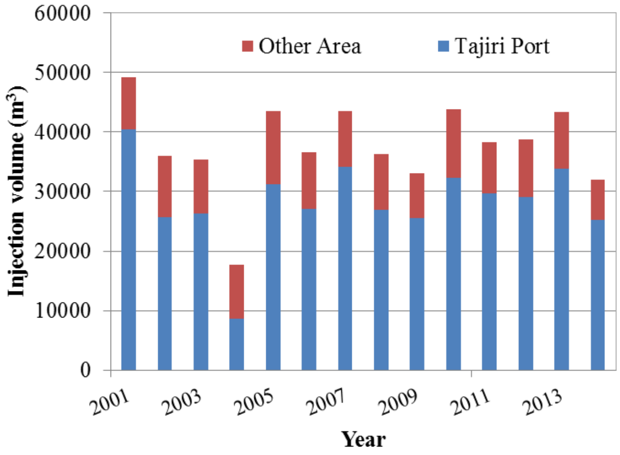


Figure 4. Injection volume for beach nourishment

The seasonal significant wave height and direction that was observed by NOWPHAS (Nationwide Ocean Wave information network for Ports and HArbourS) at Tottori (35º33'N, 134º10'E, water depth 30.1m) between 1995 and 2013 are shown in Figure 5. The broken line in the figure shows the average inclination of the coastline. From Figure 5, the seasonal change is confirmed in the wave height. The wave from NNW in winter (from December to February) are higher, whereas those in summer (from June to August) are quiet, and the main wave direction is NNE. The bathymetry change occurs mainly in the winter due to large energy. However, the wave in winter is almost perpendicular to the coastline. It is guessed the bathymetry change of alongshore is originally small. Therefore, evaluation of the beach change around coastal structures is important to coastal measurement.

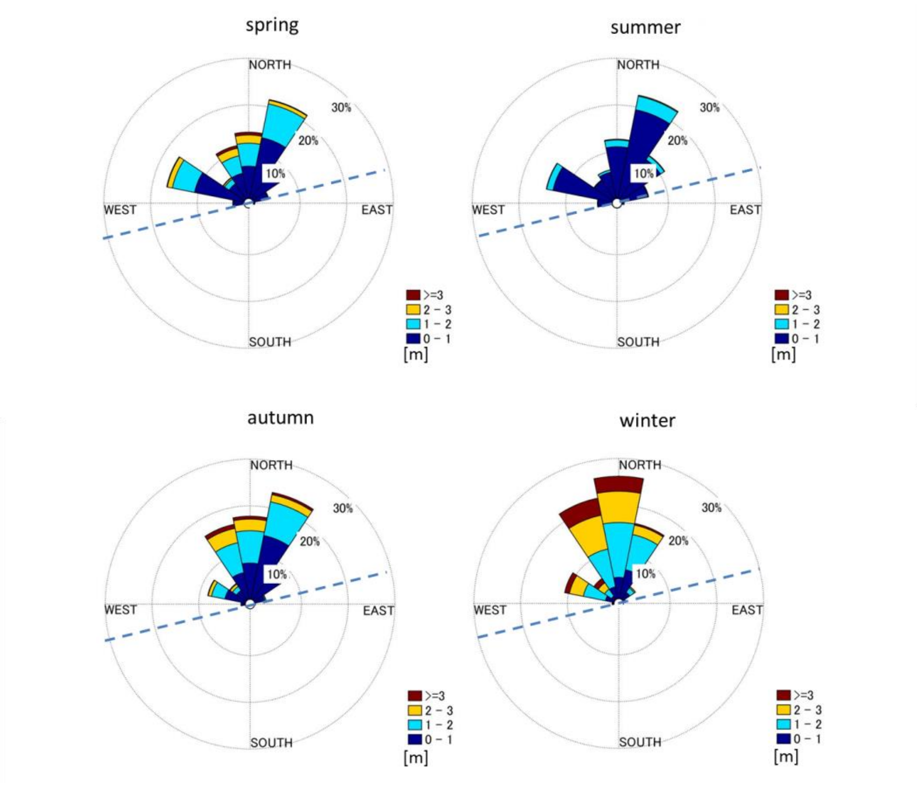
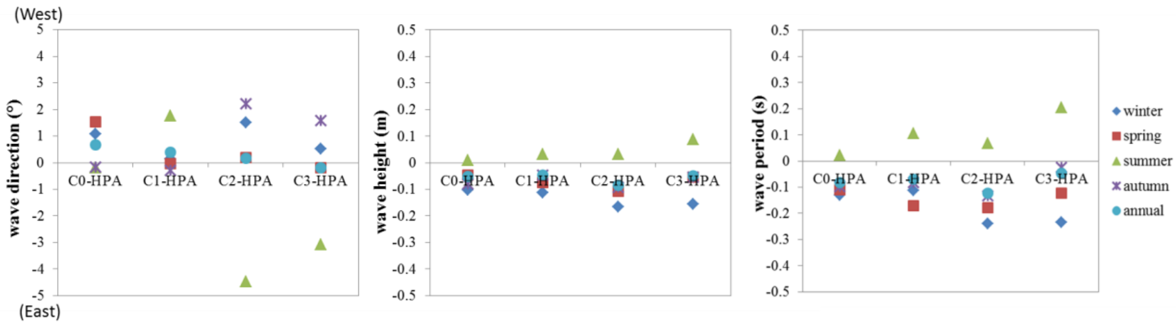


Figure 5. The seasonal characteristics of significant wave height and direction (1995-2013)

3. Future change of wave characteristics

The wave conditions in present and future climate were analyzed based on future climate projection under different SST distributions at the end of this century. The data set was created by Shimura et al. (2015) using the result of MRI-AGCM3.2 developed by the Japanese Meteorological Research Institute for IPCC AR5. The period for the present climate is 1979-2009 and for the future climate is 2075-2099. The future changes of wave characteristics are shown in Figure 6. HPA indicates the present condition and C0 to C3 indicates the different SST distributions. Wave direction is defined a positive anticlockwise. The wave directions are expected to change from -5 to 3 degrees in the future condition. However, the wave height and period were not changed significantly. The wave height and period will change about 3~5 % in comparison with the present climate condition. In this study, the future conditions are established by adding the above results.



(a) Wave direction (b) Wave height (c) Wave period

Figure 6. Future change of wave characteristics change based on the simulation by Shimura et al. (2015)

4. Analysis of Morphological Change

4.1 *Numerical Model*

A morphological change modeling presented by Kuroiwa et al. (2012) is used to project future change of coastal bathymetry considering both sea level rise and wave characteristics associated with climate change. The governing equations of numerical model are the depth integrated Euler equation together with sediment transport model. The morphological change model considers both suspended and bedload sediments considering wave-induced current. The model consists of three modules, which are computations of (1) wave, (2) nearshore current and (3) sediment transport rate. The computational flow is shown in Figure7.

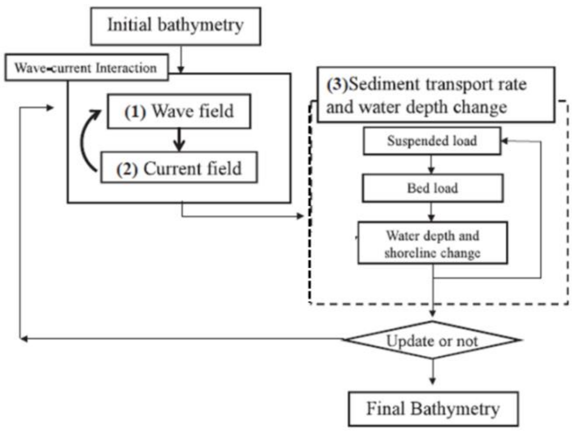


Figure 7. Computational flow chart of bathymetry simulation

4.2 *Wave conditions*

The wave conditions reproduced for bathymetry change calculation are from Oct. 1st 2007 to Mar. 31st 2008 as shown in Figure 8. The wave conditions were arranged the wave data sets observed Tottori Port by NOWPHAS. The detailed value of the wave height, period and direction are shown in Table 1. The period of 122 days are corresponds to half year from Oct. 1st 2007 to Mar. 31st 2008. Because the significant wave height less than 1.0m does not contribute morphodynamics. Also a series of numerical simulations in future condition are shown in Table 2. The change of wave characteristics in Table 2 is added to the wave condition of Table 1 as the future wave conditions.

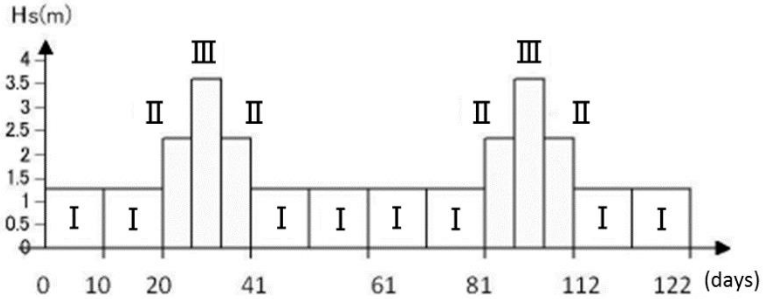


Figure 8. Time series of input significant wave height (from Oct. 1st 2007 to Mar. 31st 2008)

Table 1. Wave conditions (from Oct. 1st 2007 to Mar. 31st 2008)

Wave Number	H_s(m)	T_s(s)	α (°)	Wave direction	Wave action (days)
Ⅰ	1.43	6.65	-7.79	N	10
Ⅱ	2.3	7.1	16.0	NNW	7.5
Ⅲ	3.7	9.7	15.1	NNW	5

Table 2. Simulations case in future conditions

case	wave	period	direction
W01	+0.2m	-	-
W02	-0.2m	-	-
T01	-	+0.3s	-
T02	-	-0.3s	-
WD01	-	-	+5°
WD02	-	-	-5°
WWD	+0.2cm	-	-5°

5. Results and Discussion

To calibrate and validate the morphological change model for observed data, the numerical simulations were carried out and compared with the data by bottom sounding. The initial bathymetry is shown in Figure 9. The period is from Oct. 1st 2007 to Mar. 31st 2008.The computed bathymetry and wave current distributions without future wave changes are shown in Figure 10. Arrows indicate the flow velocity (the cross-sectional average) at each wave action in Table 1, and the color bar indicates deposition (red) and erosion (blue). It is confirmed that a strong flow occurs due to water depth of crown of the artificial reef. And the flow toward the offshore between artificial reefs (red circle) and the westward flow towards the port (blue circle) are getting stronger as the wave height increases.

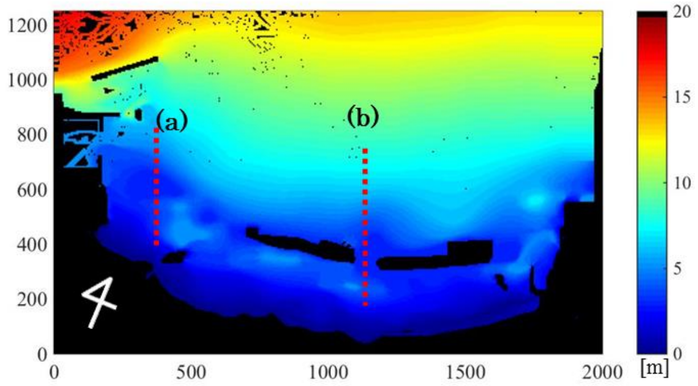


Figure 9. Initial bathymetry for computation at 1st, October in 2007

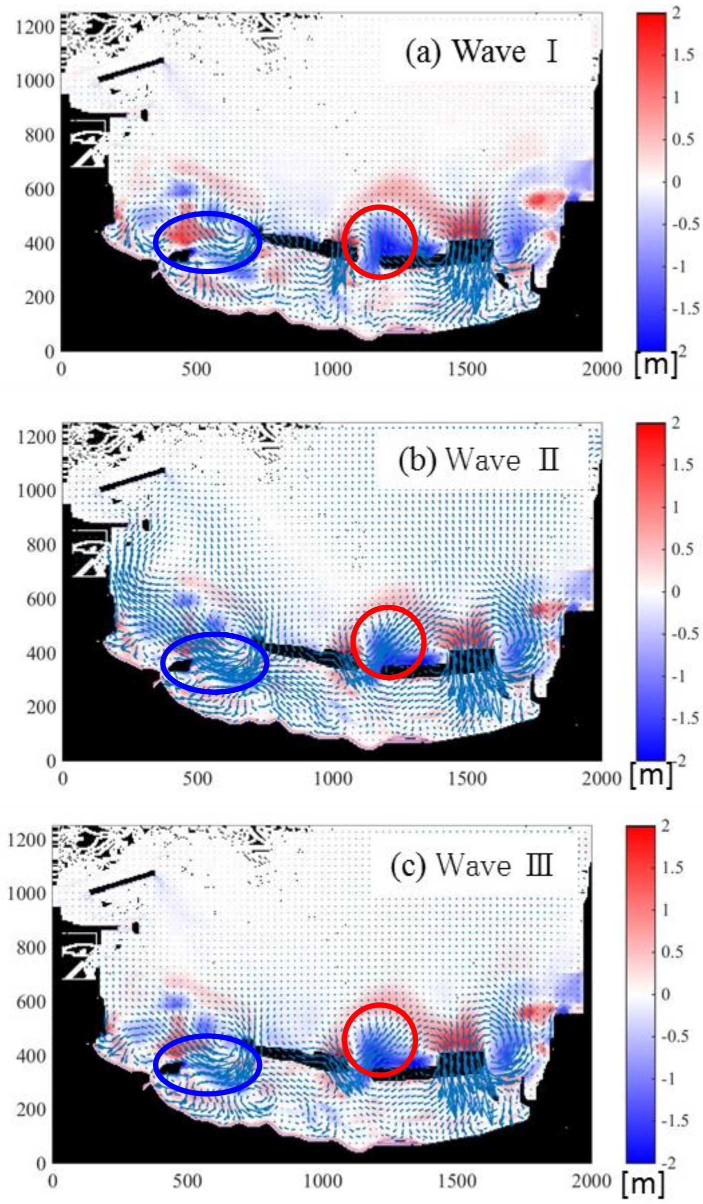


Figure 10. Computed bathymetry after six months (Mar. 31st 2008) and wave current distributions

Figure 11 shows the results of computed bathymetry under future climate condition with wave direction changed by 5 degrees in the east-westward. Arrows indicate the flow velocity in the case of Wave II. It cannot be confirmed the difference between Figure 11(a) and (b). Then the difference of topographic change between changed and unchanged wave direction is shown in Figure 12. From Figure 12 (a), it can be confirmed the deposition around port (blue circle) and the erosion between artificial reefs (red circle) in the case of changed wave direction eastward. On the other hand, the flow toward the west is stronger at west end of artificial reef in the case of changed wave direction westward like red circle in Figure 11(b). Therefore, the deposition near the port is decreased (red circle in Figure 12(b)) and the erosion between artificial reefs is relieved (blue circle in Figure 12(b)). The computation results of changed wave height for future climate are shown in Figure 13. The erosion trend around artificial reef is increased with changed wave height by +20cm. In the case of -20cm wave height, the trend shows opposite. Also, the topographic change with the changed wave period could not be almost confirmed. Figure 14 shows the bathymetry change when the wave characteristics are changed complexly. The wave characteristics changed wave height +20cm and wave direction -5 degrees (eastward). The further erosion can be confirmed around the artificial reed and the deposition around the port is increased. Furthermore the beach profile change with only sea level rise of 20cm is shown in Figure 15. Compared between Figure 13(a) and Figure 15, the beach profile change due to wave characteristics in future climate is estimated to be the same or more than that caused by sea level rise only. Finally the sectional views of alongshore distance 400m (Line of (a) in Figure 9) and 1165m (Line of (b) in Figure 9) are shown in Figure 16. Black dashed line indicates the present condition, blue colors indicate the future condition of changed wave direction, the green line is the future condition of wave height, black line is case of sea level rise and red line indicates the future condition of changed wave height and direction. The erosion and deposition trends are increased respectively under wave characteristics change with wave direction changes to eastward or wave height increases. The wave direction changed to westward caused relief of the trend.

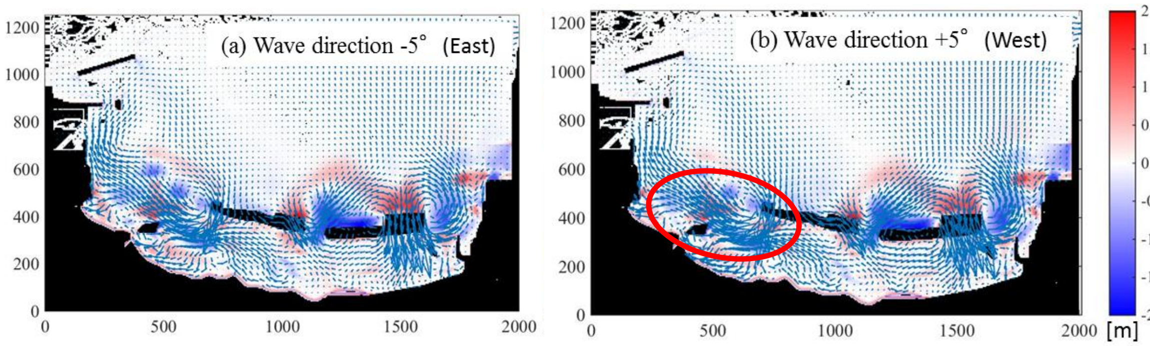


Figure 11. The computed bathymetry under future climate condition
with wave direction changed by 5 degrees

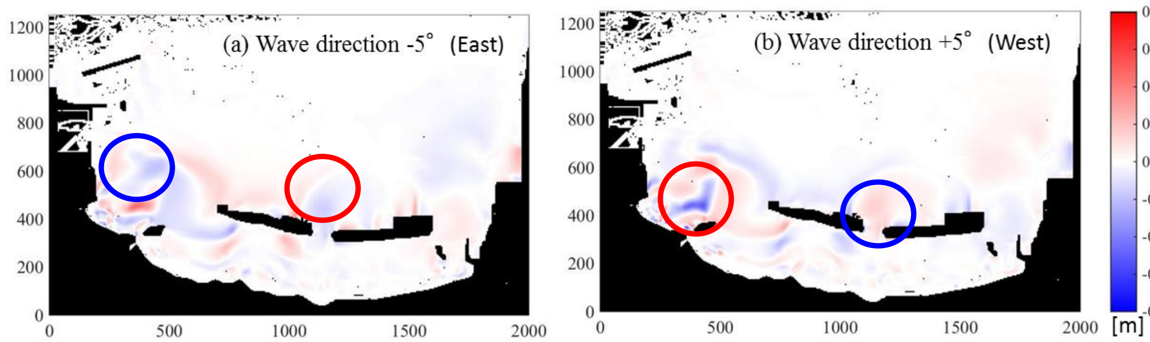


Figure 12. The difference of topographic change between changed wave direction case
and unchanged case

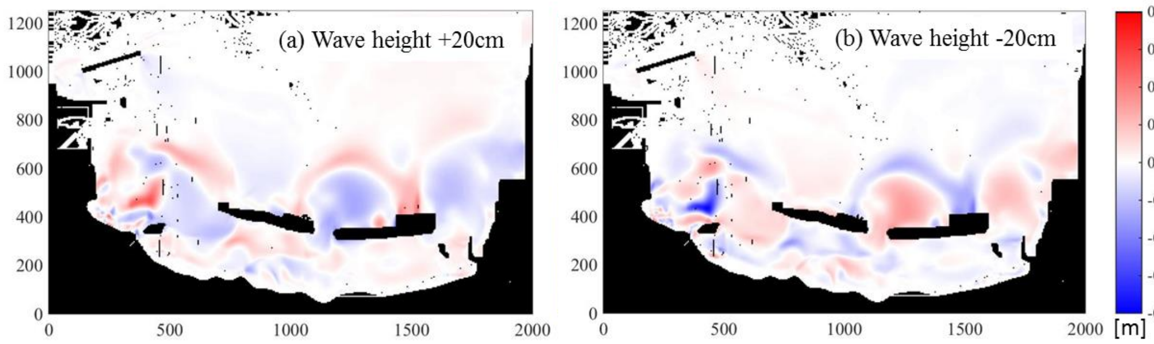


Figure 13. The difference of topographic change between changed wave height case and unchanged case

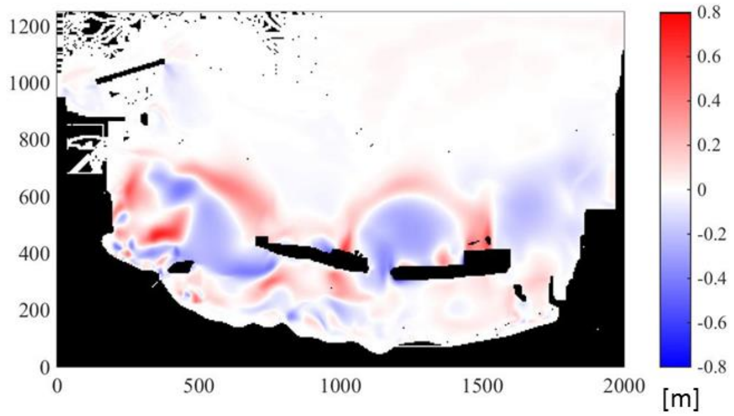


Figure 14. The difference of topographic change between changed wave height case and unchanged case

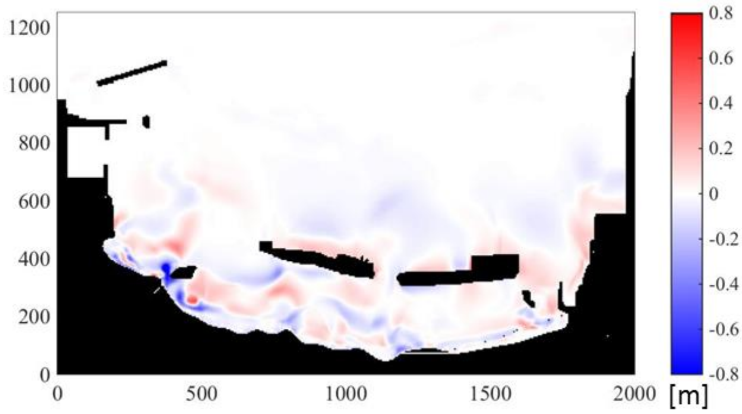
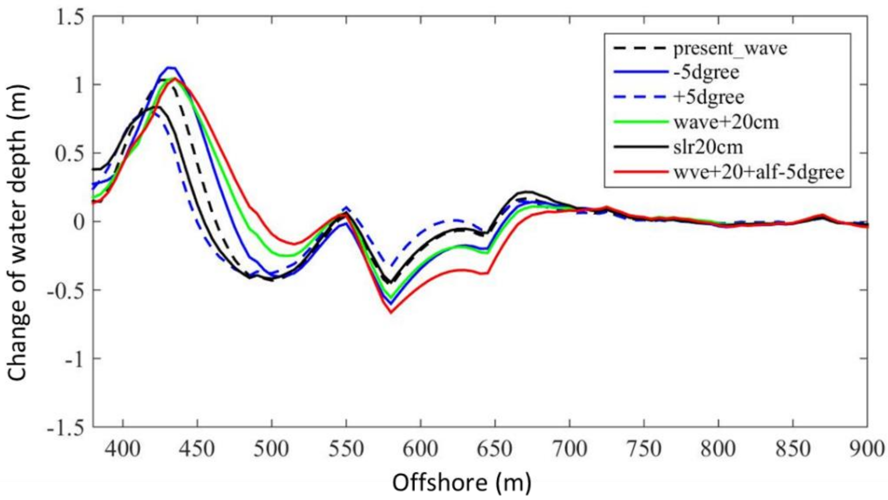
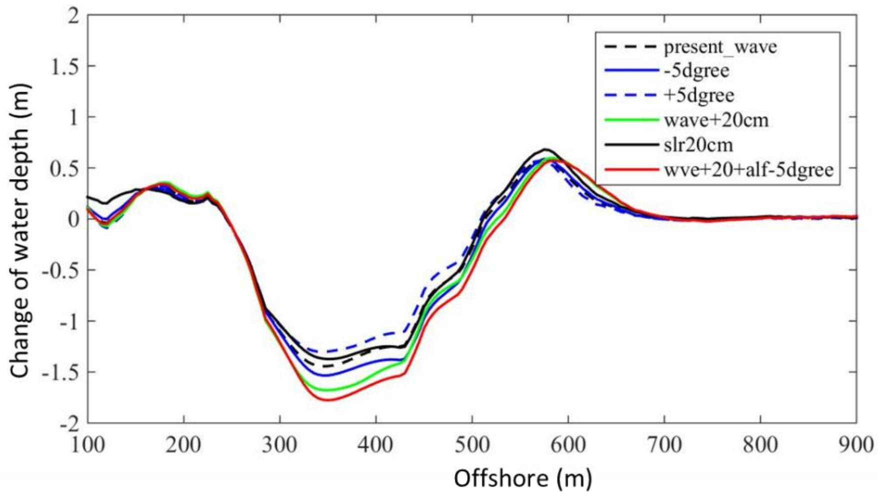


Figure 15. The beach profile change with sea level rise



(a) Alongshore distance 400m



(b) Alongshore distance 1165m

Figure 16. The sectional view of beach profile change with future climate condition

6. Conclusions

In this study, the beach profile change under the future climate condition such as wave characteristics change and sea level rise was investigated using a morphological change model at Uradome Coast of Japan. The obtained results are summarized as below.

- The future changes of wave characteristics were about 0.2m in wave height, 0.3s in wave period and 5 degrees in wave direction at the target site in the Sea of Japan.
- The erosion and deposition trends are increased respectively when the wave direction changes to eastward or wave height increases. The wave direction changed to westward caused relief of the trend.
- The beach profile change due to change of wave characteristic in future climate condition is estimated to be the same or more than magnitude that which might be caused by sea level rise.

Acknowledgements

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