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INFLUENCE OF CLIMATE CHANGE ON STORM SURGES IN THE ARIAKE SEA

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ABSTRACT: The influence of climate change on storm surges in the Ariake Sea was evaluated using the stochastic typhoon model. The Ariake Sea is located in the middle of Kyushu Island, Japan and has been attacked by severe typhoons many times. There are many lowland coastal farmlands along the coastline of the Ariake Sea as a result of many reclamation projects since ancient times. These coastal farmlands are at risk of even more severe storm surges due to typhoons caused by climate change. The deviations of tides due to storm surges were simulated by an experimental typhoon model employing the Myers model. The stochastic typhoon model generated the tracks and attributes of typhoons over the next 2,000 years. Meanwhile, the tracks of typhoons in the case of the climate after climate change were generated by shifting the start points of typhoons 0.9 degrees further north and 1.9 degrees further east. The number of typhoons after climate change was set to 0.79 times that of typhoons in the present climate. These changes in the tracks and number of typhoons in the future were decided according to the results of numerical simulations of climate change using the AGCM model based on the A1B scenario. The non-exceedance probabilities of the year-maximum anomaly rise were compared to evaluate the change due to climate change. The simulation suggested that the height of the year-maximum anomaly rise due to storm surges in the future climate will be similar to or slightly lower than the present height.

Keywords: Climate change, storm surge, stochastic typhoon model, coastal farmlands

INTRODUCTION

The Ariake Sea is located in the middle of Kyushu Island of Japan, and its coastal areas have been developed by successive reclamation projects since ancient times. Storm surges or floods have repeatedly attacked these lowland reclaimed areas, which are excellent agricultural areas. Countermeasures against storm surges are required because Kyushu is often hit by typhoons. Furthermore, the sea level is expected to rise and typhoons to become stronger due to climate change in coastal zones around the world. Therefore, it is important to estimate the storm surges that may attack the Ariake Sea in future. However, it is difficult to estimate future typhoons based on limited observation data because only about ten typhoons approach Japan every year, and only two reach the land. Hatano and Kuwata (1987) developed a stochastic typhoon model that generates typhoons for arbitrary years based on the statistics and attributes of past typhoons, to compensate for the limited typhoon observation data. Storm surge simulations using the stochastic typhoon model were carried out by Hashimoto et al. (2003) and Kawai et al. (2007), while many other researchers have evaluated the influence of climate change on storm surges. Nevertheless, there have been few evaluations of storm surges using the stochastic typhoon model for the Ariake Sea, because most studies have focused on the important bays with large cities nearby.

The anomaly rise due to storm surges under the present climate and future climate in the Ariake Sea was simulated using typhoons generated by the stochastic typhoon model.

MATERIALS AND METHODS

Analysis area

The analysis area is shown in Fig. 1. The Ariake Sea is an inner bay 20 km wide and 80 km long, with an average depth of about 20 m. The tidal range at the innermost area of the Ariake Sea reaches almost 6 m, the largest in Japan, due to its geographical shape. Tidal flats in the coastal area of the Ariake Sea have continued forming due to the large tidal range, and have been converted into coastal farmlands by many land reclamation projects since more than 1,000 years ago.

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Fig. 1 Location of the Ariake Sea

The Yatsushiro Sea, which is located near the Ariake Sea, was damaged by storm surge flooding caused by Typhoon Bart in 1999.

Stochastic typhoon model

Typhoons that passed through the region bounded by longitude 120–150 degrees east and by latitude 23–39 degrees north, in the best track (BT) data were extracted to build the stochastic typhoon model. The period of the BT data was 55 years from 1951 to 2005. The region was divided into grids of 1.5 degree, and the statistics values of typhoon attributes were calculated in each grid. These attributes were latitude, longitude, typhoon direction and velocity, central pressure, and number of formed typhoons. The radius of influence of a typhoon was estimated by the equation proposed by Kato (2005). In addition, the extracted typhoons were sorted by their month of generation into five periods (June to July, August, September, October, and November to next May), and the statistics value of the attributes were calculated in each period, with reference to Kawai et al. (2006).

The attributes of a typhoon at an arbitrary time (T_i) are given by Equation (1) using a value of one time step behind. The time variation and deviation are calculated by Equations (2) and (3), respectively.

$$T_i = T_{i-1} + \Delta T_i \tag{1}$$

$$\Delta T_i = \Delta S(x_i, y_i) + Z_i \tag{2}$$

$$Z_i = \sum_{m=1}^{n} A_m Z_{i-m} + v_i \tag{3}$$

where, T_i: attributes at an arbitrary time, ΔT_i: time variation of the attributes, $\Delta S(x_i,y_i)$: spatial field average of time variation of attributes at the typhoon center (x_i,y_i), Z_i: deviation, A_m: autoregression coefficient, and v_i: random component following a normal distribution. Here, n means autoregressive order, and n=8 was employed in the simulation.

Future typhoons

The tracks of future typhoons, under the climate after climate change, were generated with reference to Yasuda et al. (2011). The start points of typhoons are shifted 0.9 degrees further north and 1.9 degrees further east. The number of future typhoons is 0.79 times that of typhoons in the present climate. These changes of tracks and number of future typhoons were decided according to the results of numerical simulations of climate change by the AGCM model based on the A1B scenario.

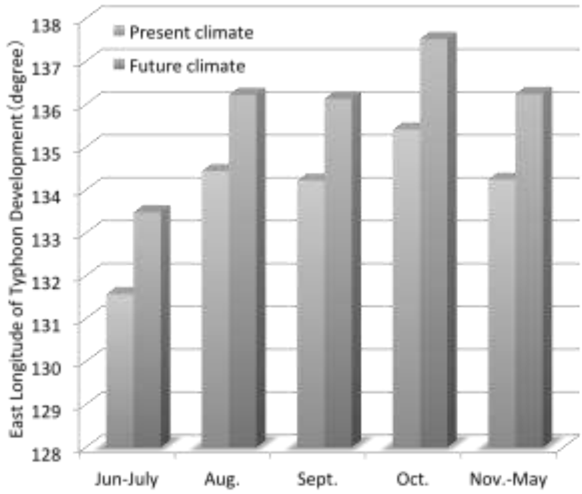

Fig. 2 East longitude of points where typhoons developed

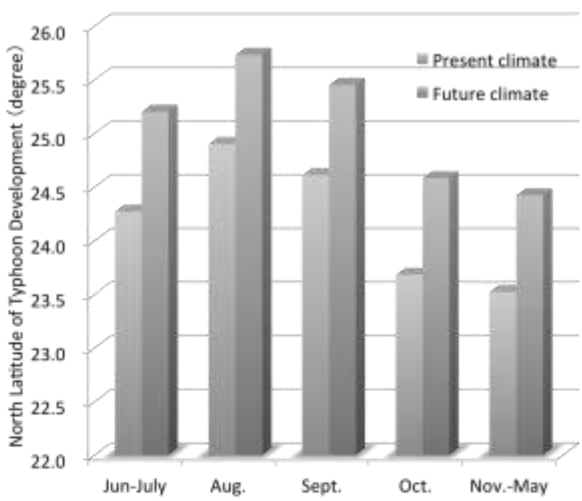

Fig. 3 North latitude of points where typhoons developed

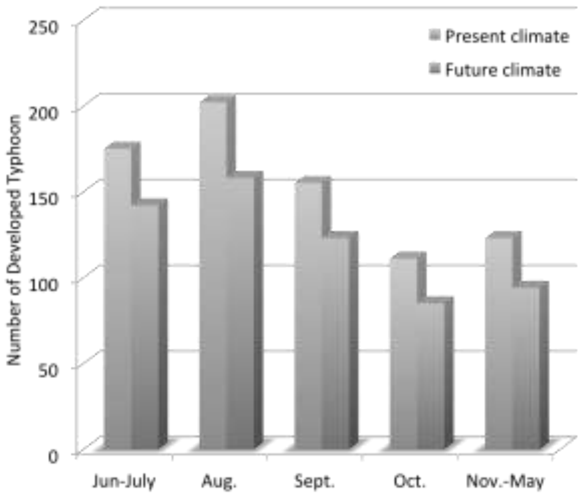

Fig. 4 Number of typhoons generated by the stochastic typhoon model

To confirm the stochastic typhoon model under the future climate, generated typhoons for 50 years were compared. The location and number of typhoons under the present climate and the future climate are compared in Figs. 2-4.

Model for storm surge analysis

An experimental surge model that estimates the distribution of pressure using the Myers equation simulated anomaly rises due to each typhoon that had been generated by the stochastic typhoon model. Here, values used for the correction coefficient of sea wind (C_1) and wind distribution (C_2) were C_1=0.7 and C_2=0.7, respectively, based on a simulation of the reappearance of the storm surge caused by Typhoon Bart in 1999.

A two-dimensional non-linear shallow water model was used for the storm surge simulation. The drag coefficient at the sea surface (C_d) was evaluated by Honda-Mitsuyasu's equation. However, Yokota et al. (2011) pointed out that Honda-Mitsuyasu's equation tends to over-estimate C_d in the region of high wind velocity, because the equation was obtained assuming a wind velocity of less than 25 m/s. Therefore, a constant C_d value as shown in Equation (4) was employed for wind velocity over 30 m/s, with reference to Kinashi et al. (2012), in the simulation.

$$C_d = \begin{cases} (1 - 1.890 \times U_{10} \times 10^{-2}) \times 1.28 \times 10^{-3} \\ \qquad\qquad (U_{10} \le 8.0\text{m/s}) \\ (1 + 1.078 \times U_{10} \times 10^{-1}) \times 5.81 \times 10^{-3} \\ \qquad\qquad (8.0 < U_{10} \le 30.0\text{m/s}) \\ 0.0246 \qquad (30.0\text{m/s} < U_{10}) \end{cases} \tag{4}$$

where, C_d: drag coefficient at the sea surface, and U_{10}: wind velocity at 10 m above the sea surface.

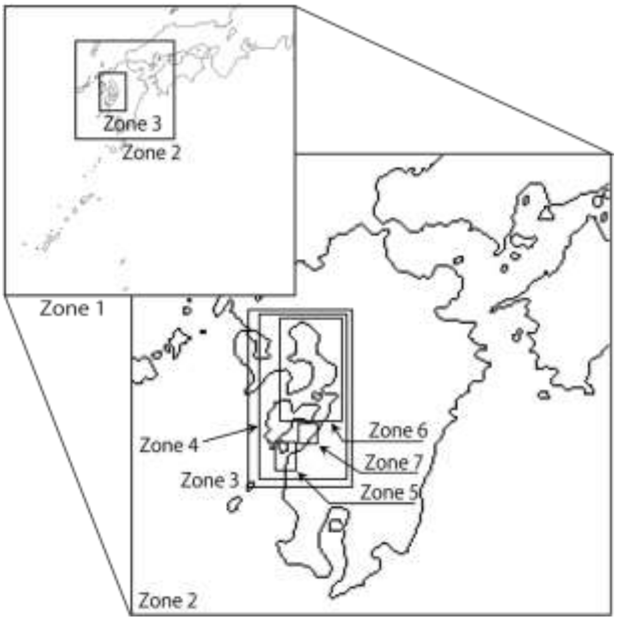

Fig. 5 Analysis area of the storm surge simulation

Table 1 Grid size in each zone illustrated in Fig. 1

Zone	Number of grids	Grid size (m)
1	74 × 75	16,200
2	81 × 81	5,400
3	57 × 93	1,800
4	132 × 246	600
5	96 × 135	200
6	255 × 438	200
7	81 × 96	200

The analysis area of the storm surge simulation is shown in Fig. 5. The grid size in each zone of the analysis area is shown in Table 1. The grid size was gradually made smaller by nesting, and was 200 m in the region including the Ariake Sea.

RESULTS AND DISCUSSION

Typhoons for 2,000 years were generated by the stochastic typhoon model, and the anomaly rise was simulated by putting the obtained attributes of typhoons into the surge model. The number of typhoons under the present climate and under the future climate that were obtained by the stochastic typhoon model was 28,181 and 21,842, respectively. However, typhoons for which the anomaly rise did not reach 0.05 m were excluded from the calculation of non-exceedance probability. Hence, 24,878 and 14,895 typhoons were employed in the calculation for the present climate and the future climate, respectively. A non-exceedance probability of the year-maximum anomaly rise in the Ariake Sea was calculated from the simulated anomaly rise. The locations of points for which the non-exceedance probability was evaluated are shown in Fig. 6.

Figure 7 shows the frequency distribution of the minimum central pressure of typhoons at Okinohata. Figure 8 shows the region of pressure of less than 990 hPa at the same location. Figure 7 shows that the number of typhoons under the future climate was half of that under the present climate at each pressure, and the distribution of frequency under the present climate and that under the future climate were similar in the high-pressure region of over 970 hPa. On the other hand, the frequency of appearance of lower-pressure typhoons between 940 and 955 hPa was similar in both climates. It is not clear in Fig. 8, but the lowest pressure of typhoons that appeared under both climates was the same.

The frequency distribution of wind velocity at Okinohata is shown in Fig. 9. The frequency of velocity under the future climate is half of that under the present climate, and the tendency of frequency in both climates was the same. The maximum wind velocity in the present climate and in the future climate was 44 m/s and 40 m/s, respectively.

Fig. 6 Locations of points at which the non-exceedance probability of the year-maximum anomaly rise was evaluated

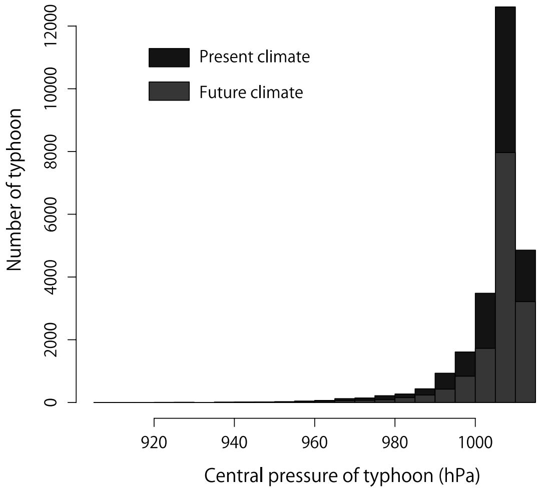

Fig. 7 Frequency distribution of central pressure of typhoons generated by the stochastic typhoon model (all typhoons)

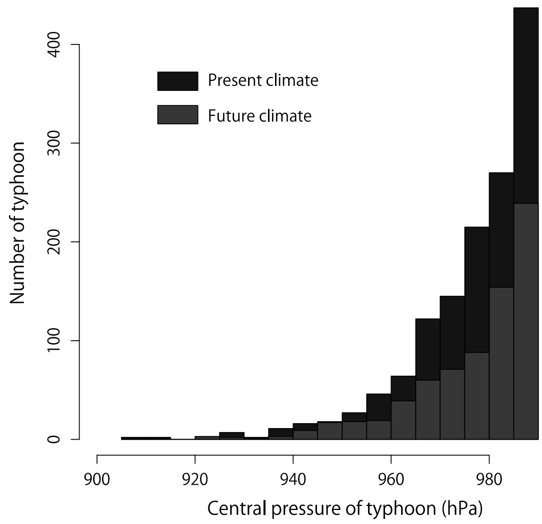

Fig. 8 Frequency distribution of central pressure of typhoons generated by the stochastic typhoon model (low-pressure typhoons)

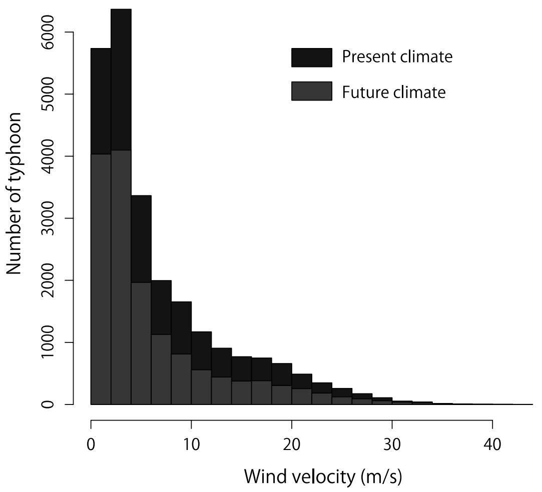

Fig. 9 Frequency distribution of wind velocity at Okinohata

The non-exceedance probabilities of the year-maximum anomaly rise at the main coasts are shown in Figs. 10-13. The anomaly rise shown in these figures does not include the amount of sea level rise.

Okinohata is located at the innermost part of the Ariake Sea and has the highest tidal range in the coastal area. Ariake and Kawachi are located near major coastal farmlands that were developed by national land reclamation projects. Furthermore, Kumamoto has a major city in the hinterland of the coast.

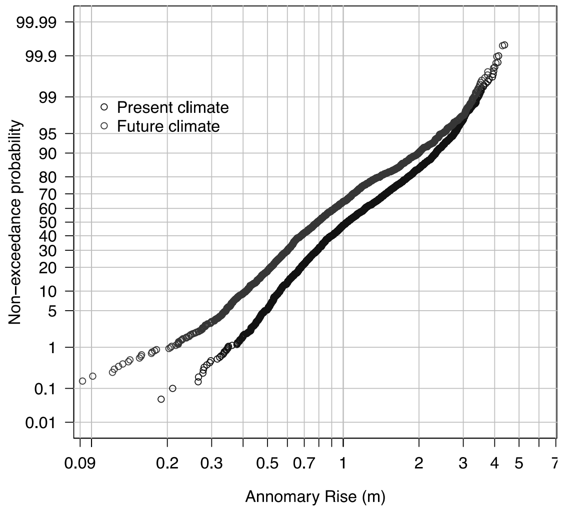

Fig. 10 Non-exceedance probability of year-maximum anomaly rise at Okinohata

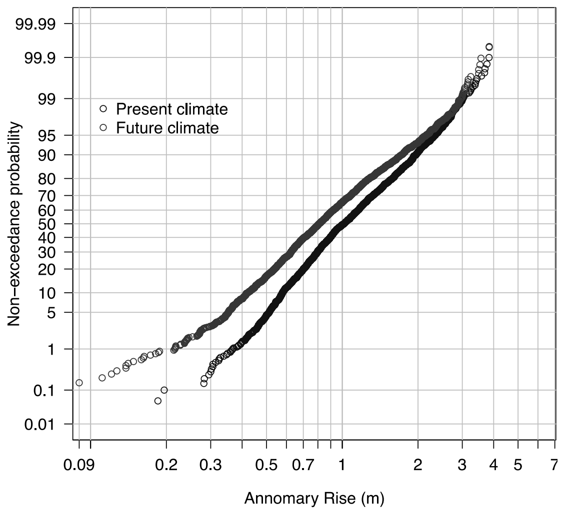

Fig. 11 Non-exceedance probability of year-maximum anomaly rise at Ariake

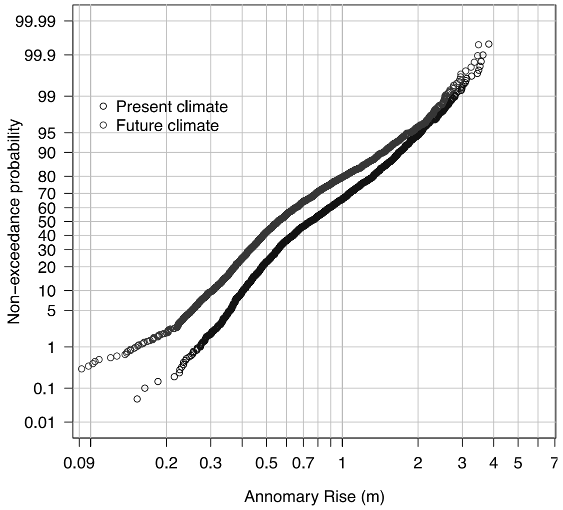

Fig. 12 Non-exceedance probability of year-maximum anomaly rise at Kawachi

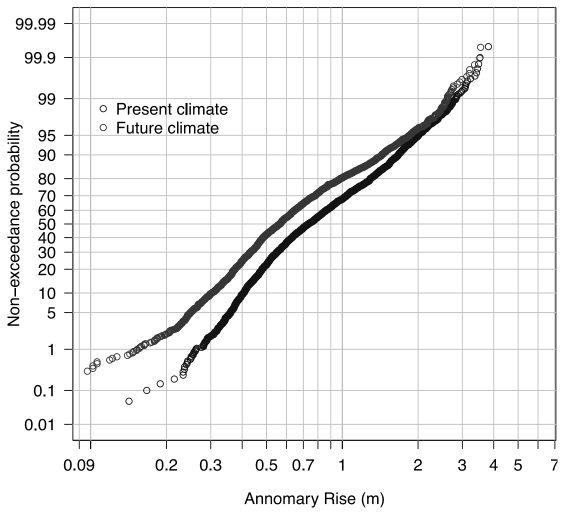

Fig. 13 Non-exceedance probability of year-maximum anomaly rise at Kumamoto

Figure 10 shows the non-exceedance probability at Okinohata. A difference of anomaly rise between the present climate and the future climate is not clear in the region of anomaly rise higher than 3.0 m, whereas the anomaly rise under the future climate is lower than that of the present climate. The anomaly rises at other locations indicate the same tendency as that of Okinohata.

The simulation showed that the height of the year-maximum anomaly rise due to storm surges in the future climate will be similar to or slightly lower than the present height.

REFERENCES

Hashimoto N., Kawaguchi K., Kawai H., Matsuura K. and Ichikawa M. (2003). Modification of Probabilistic Typhoon Model for Rational Design of

Maritime Structures. Proc. of Coastal Engineering, JSCE, 50: 176-180. (in Japanese)

Hatano M. and Kuwata Y. (1987). Evaluation of Concurrent Characteristics of Rainfall and Storm Surge by a Stochastic Typhoon Model. Journal of JSCE, 387/II-8: 237-246. (in Japanese with English abstract)

Kato F. (2005). Study on Risk Assessment of Storm Surge Flood. Technical Note of National Institute for Land and Infrastructure Management, 275:1-108. (in Japanese with English abstract)

Kawai H., Hashimoto N. and Matsuura K. (2007). Estimation of Extreme Value and Duration of Storm Surge in Bays by Using Stochastic Typhoon Model. Annual J. of Coastal Engineering, JSCE, 54: 301-305. (in Japanese with English abstract)

Kinashi, Y., Yamashiro, M., Himeno, S., Yokota M. and Hashimoto N. (2012). Numerical Study on Storm Surge in the Ariake Sea Based on future Climate Projection by MRI-AGCM3.2S. Journal of JSCE, Ser. B2 (Coastal Engineering), 68(2): I_201-I_205. (in Japanese with English abstract)

Yasuda M., Ando K., Mori N. and Mase H. (2009) Prediction and Stochastic Modeling of Future Typhoon Characteristics based on AGCM Projections under Global Warming Scenario. Journal of JSCE, Ser. B2 (Coastal Engineering), 65(1): 1281-1285. (in Japanese with English abstract)

Yokota M., Hashimoto N., Tanaka Y. and Kodama M. (2011) Dependence Property of the Distance from the Strong Wind Area to the Wave Observation Station in the Inverse Estimation of Sea Surface Drag Coefficient. Journal of JSCE, Ser. B3 (Civil Eng. in the Ocean), 67(2): I_903-I_907. (in Japanese with English abstract)