PREDICITON OF INUNDATION DISASTER DUE TO STORM SURGE UNDER GLOBAL WARMING

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This study clarifies the characteristics of the disaster risks induced under the scenarios of global warming. In this study, the sea level rise and typhoon intensity based on the scenarios of A1FI and A1B produced by IPCC 4th Assessment Report are considered for the conditions of storm surge disaster in future climate. They are predicted for the target years of 2040 and 2060 as the middle term as well as of 2100 as the long term target. On these conditions of sea level and typhoon intensity, a newest model of storm surge inundation is employed for estimation of inundation area and asset damage. in the coastal and hinterland area in the Ise Bay. Several disaster risks induced by storm surge are estimated quantitatively.

Keywords: Global warming, IPCC, inundation disaster, storm surge

Introduction

Population and assets are concentrated in the urban area behind the coastline in Japan. For example, Tokyo, Nagoya, and Osaka, when storm surge inundations occur, serious damage to the coastal area will be induced. The risks of these storm surge induced disaster, which suffers the population and asset value, are expected to increase with the sea level rise and the increase of typhoon intensity owing to global warming.

"the sea level rise" and "the increase of typhoon intensity" caused by global warming are predicted by the IPCC 4th and 5th Assessment Reports. If the sea level rise and typhoon intensity continue to increase, there is a high possibility of serious damage occurring to human lives and property due to storm surge. And it is possible to estimate these risks of damage by using numerical simulations.

Therefore, in this research, the damage risk of storm surge inundation triggered by global warming is estimated by using numerical simulations, and the features of damage risk occurring under various global warming scenarios are clarified. Therefore, in this study, a numerical simulation is applied to estimate the several disaster risks in the hinterland of Ise Bay due to storm surge inundation. And the features of damage risk occurring under various global warming scenarios are clarified.

In this study, two subjects are expressed. The First Subject is “Estimate of the sea level rise and the increase of typhoon intensity caused by global warming”. The Second Subject is “Estimate of the risk of damage due to storm surge inundation caused by global warming”.

ESTIMATE OF THE SEA LEVEL RISE AND THE INCREASE OF TYPHOON INTENSITY CAUSED BY GLOBAL WARMING

The IPCC 4th and IPCC 5th Assessment Reports

The Intergovernmental Panel on Climate Change (IPCC) 4th Report was published in 2007, and IPCC 5th Report was published in 2013. From these Reports, Predicted values of the sea level rise, increase in land surface temperature and sea surface temperature (SST) caused by global warming can be obtained. In the worst case climate change scenario, the maximum increase in sea level in 2100, which is approximately 90 years from now, is predicted to be 0.59 m in the IPCC 4th Report and 0.82 m in the IPCC 5th Report. This study is based on the IPCC 4th Report. Two scenarios among those that assume rapid economic growth are used in this study. These are scenario A1FI, which is a fossil-fuel intensive (FI) scenario and represents the worst case for climate change, scenario A1B, which is characterized by a balanced emphasis on all energy sources. A1FI scenario is the worst case in climate change scenario, and A1B scenario is the balanced emphasis on all energy sources.

Estimate of sea level rise caused by global warming

At first, prediction of sea level rise caused by global warming will be expressed. The IPCC 4th Report predicts the sea level rise and typhoon intensity increase under the influence of global warming.

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The sea level rise in 2100 is projected to be 0.18 m to 0.59m. The maximum rise is 0.48 m under A1B scenario and 0.59 m under A1FI scenario. These values are taken as the simulation conditions of sea level rise in this study.

There are unknowns regarding future trends in sea level variations. Therefore, following the method of the NRC-1 model in a paper by the USACE (U.S. Army Corps of Engineers), we adopted a method in which the sea level variation under the present climate, which is obtained by an analysis of sea level data, and the predicted 0.59 m sea level rise in the IPCC 4th Report are joined by a projection curve. Fig. 1 is based on the model produced by the NRC Report. This equation express the projection curve (Eq. 1).

$$E(t) = a(t-2000) + b(t-2000)^2 \qquad (1)$$

The start year of the prediction is 2000. "t" is given by the number of elapsed years from 2000 and expresses the year for which the prediction is made. The coefficient "a" is related to the sea level rise at present. In this study, the tide level data observed in Ise Bay is analyzed. From the results, the tendency of tide level rising cannot be clarified. Therefore, the coefficient “a” is determined 0.0. The coefficient "b" is related to the sea level rise in the future. When "t" is 100 years, coefficient "b" determined 0.59 m and 0.48 m based on the IPCC 4th Report. The sea level rise caused by global warming can be estimated for any years by using this equation. For example 2040, 2060.Here, the results of an analysis by the Japanese Meteorological Agency have revealed that vertical variations with a maximum amplitude on the order of 6 cm and a period of several decades appear in the variation of mean sea level over time. That is, sea levels actually fluctuate around the predicted values, as shown in the figure. However, no method for predicting short-term changes in sea level has been established. Therefore, in this research, this short-term fluctuation is not reflected in the predicted values.

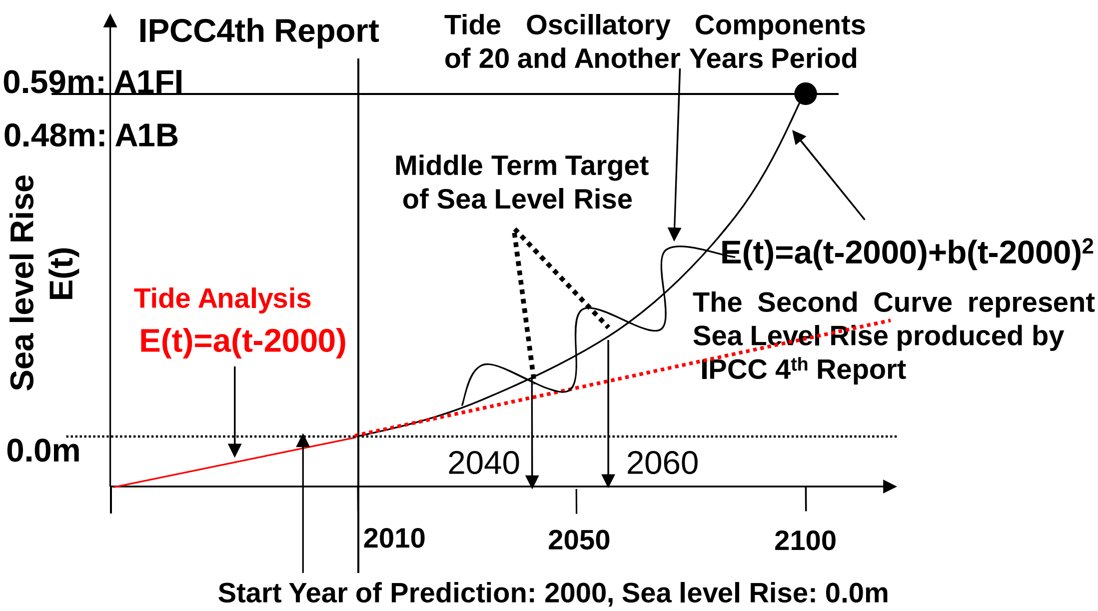
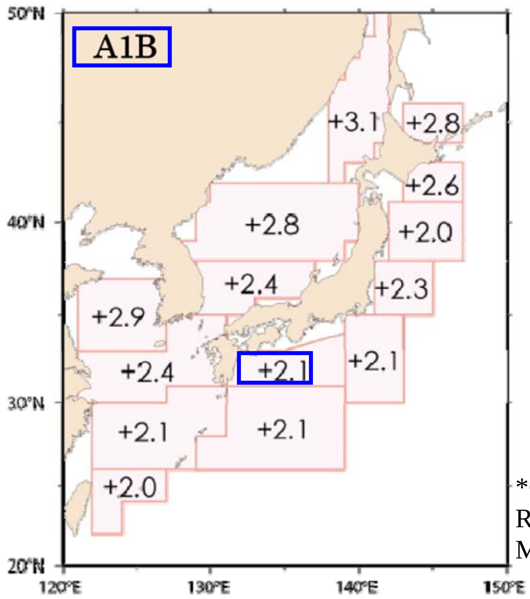


Figure 1. Estimate of sea level rise caused by global warming.

Estimate of typhoon intensity caused by global warming

At second, prediction of typhoon intensity caused by global warming will be expressed. The typhoon intensity increase is projected for the central atmospheric pressure depth of typhoon (CPT), which represents a decrease of atmospheric pressure from 1,010hPa. According to Knutson and Tuleya (2004), when the radiative forcing increases, the center pressure of the typhoon decreases to 14% and the wind speed over the sea surface to 6%. It was possible to estimate the decrease in CPT of typhoons in 2100 in comparison with 2000 as the baseline year by applying this relationship to the predicted values of radiative forcing under each scenario given in the IPCC 4th Report. In this study, the typhoon intensity is estimated using these diagrams (Fig. 2).



B1	:	1.8℃	(1.1～2.9℃)
A1T	:	2.4℃	(1.4～3.8℃)
B2	:	2.4℃	(1.4～3.8℃)
A1B	:	2.8℃	(1.7～4.4℃)
A2	:	3.4℃	(2.0～5.4℃)
A1FI	:	4.0℃	(2.4～6.4℃)

*IPCC Fourth Assessment Report, Report of Working Group I, Summary for Policy Makers (published version), excerpted from the Japanese Ministry of the Environment website version of May 22, 2007

*Global Warming Prediction Information, Vol. 7, Reference materials, excerpted from the Japanese Meteorological Agency website

II.3.11: Total Radiative Forcing (Wm^{-2}) from GHG plus direct and indirect aerosol effects as used in the Simple Model SRES Projections

Year	A1B	A1T	A1FI	A2	B1	B2	IS92a
1990	1.03	1.03	1.03	1.03	1.03	1.03	1.03
2000	1.33	1.33	1.33	1.33	1.33	1.33	1.31
2010	1.65	1.85	1.69	1.74	1.73	1.82	1.63
2020	2.16	2.48	2.17	2.04	2.15	2.36	2.00
2030	2.84	3.07	2.78	2.56	2.56	2.81	2.40
2040	3.61	3.76	3.67	3.22	2.93	3.26	2.82
2050	4.16	4.31	4.83	3.89	3.30	3.70	3.25
2060	4.79	4.73	5.99	4.71	3.65	4.11	3.76
2070	5.28	4.97	7.02	5.56	3.92	4.52	4.24
2080	5.62	5.11	7.89	6.40	4.09	4.92	4.74
2090	5.86	5.12	8.59	7.22	4.18	5.32	5.26
2100	6.05	5.07	9.14	8.07	4.19	5.71	5.79

*Knutson and Tuleya (2004)

Figure 2. Estimate of typhoon intensity caused by global warming.

It is possible to estimate sea surface temperature (SST) for the seas near Japan under the A1FI scenario based on the ratio of SST by JMA (Japan Metrological Agency) and the land surface temperature by the IPCC 4th results under the A1B scenario. However, because the SST based on the JMA was values that were published for scenarios A1B and B1, the SST for scenario A1FI was obtained by analogy, based on the relationship with the land surface temperature under the respective scenarios obtained from the IPCC 4th Report. The assumption in this case was that variations in SST and land surface temperature are closely related and their changes are linear. Accordingly, it is possible to estimate SST for the seas near Japan under scenario A1FI by using the ratio of SST and the land surface temperature under scenario A1B. The rate of decrease in the CPT of typhoons was then estimated from the results of the research by Knutson and Tuleya (2004) and global warming based on the above-mentioned resources. As a result, a rate of decrease of 14.7% was obtained for scenario A1B and 24.8% was obtained for A1FI (Eq. 2). Where, C: concentration of carbon dioxide before change, C_0: concentration of carbon dioxide.

$$R_f = 5.35x\ln(C/C_0) = 5.35\ln(2.2) = 4.2W/m^2$$
$$P_d = 14(\%)/4.2(W/m^2)\times(9.14(W/m^2) - 1.69(W/m^2)) = 24.8\% \quad (2)$$
$$CPT = 950hPa - 60hPa\times 0.248 = 935hPa\,(\text{atmospheric pressure decrease}: 15hPa)$$

Where, R_f = Radiative forcing, P_d = Atmospheric pressure decrease rate, CPT = the central atmospheric pressure depth of typhoon at Ise Bay. Fig. 3 shows the projection curve of CPT from 2010 to 2100. In this study, the present year defines 2010 and the prediction is performed in 2040 and 2060 as the middle term target as well as in 2100 as the long term target. By this diagram, it is possible to estimate the decrease of CPT in any years.

Also, Table 1 shows the simulation conditions of sea level rise and typhoon intensities under the scenarios of A1FI and A1B based on the IPCC 4th Report.

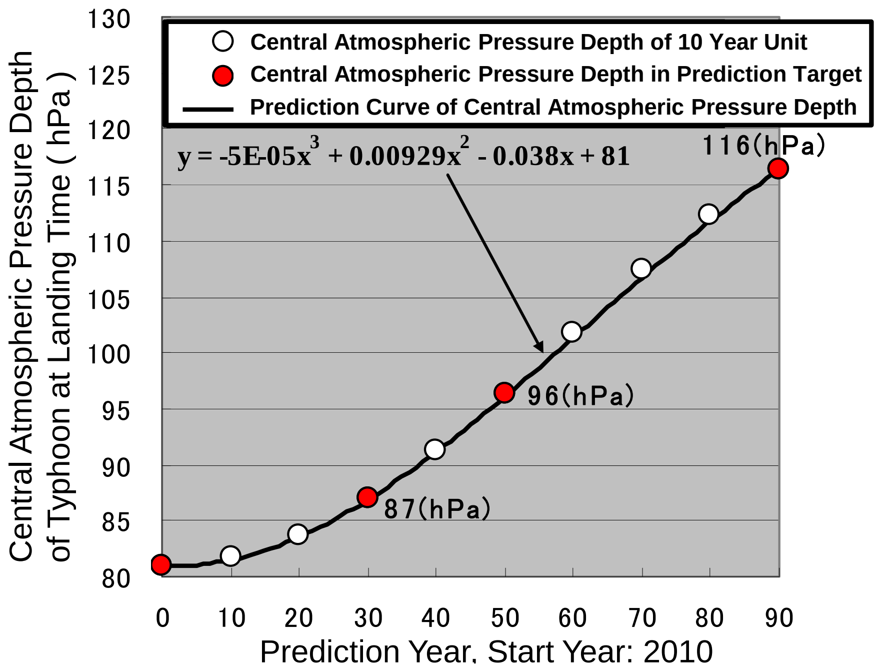


Figure 3. The projection curve of CPT from 2010 to 2100.

Table 1. The simulation conditions of sea level rise and typhoon intensity				
Global Warming Scenario	Prediction Target / Condition	2040	2060	2100
A1FI	Typhoon Intensity (※)	1.07	1.19	1.44
	Sea Level Rise (cm)	9.4	21.2	59.0
	Tide Level over Mean Sea (m)	1.314	1.432	1.810
A1B	Typhoon Intensity (※)	1.05	1.14	1.36
	Sea Level Rise (cm)	7.7	17.3	48.0
	Tide Level over Mean Sea (m)	1.297	1.393	1.700

(※) The Ratio with Typhoon Intensity in 2010 (Present)

Typhoon Intensity: Central Atmospheric Pressure Depth of Typhoon at Landing Time in 2010

ESTIMATE OF THE RISK OF DAMAGE DUE TO STORM SURGE INUNDATION CAUSED BY GLOBAL WARMING

The domain of test estimation

The test estimation is performed in Ise Bay of Japan. The Noubi Plain has the hinterland below mean sea level. It is damaged with extremely inundation. In fact, the Typhoon Vera named Ise Bay Typhoon struck this area in 1959 and caused to large inundation damage. As the scale of the Ise Bay Typhoon at landfall, the central pressure is 935 hPa, and CPT is 75 hPa. At present, coastal dikes are constructed to prevent for damage against the storm surge and high wave due to Typhoon Vera. However, if the sea level rises and typhoon intensity increases, storm surge and wave height will exceed the design conditions. And it is possible for storm surge inundation damage to occur again.

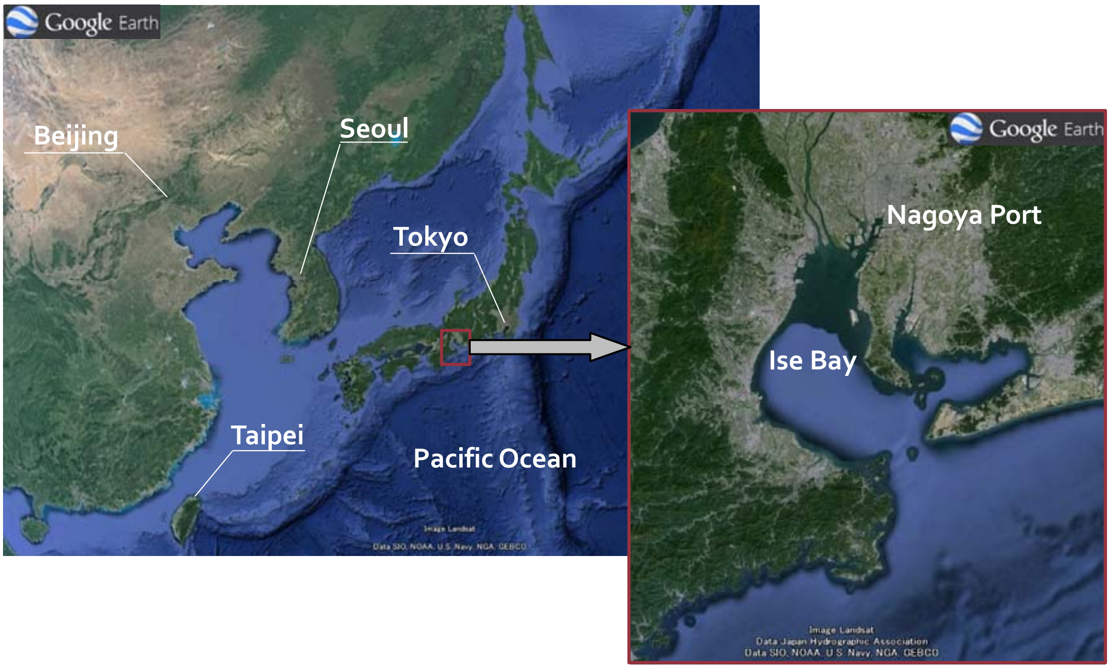


Figure 4. The domain of test estimation.

The simulation of storm surge

The risk of damage due to storm surge inundation is calculated by using numerical simulations. The input conditions of numerical simulations are “the sea level rise” and “the typhoon intensity” under global warming scenarios. The simulation of storm surge is carried out by using numerical models of wave hindcasting, wave transformation, storm surge and inundation. Details of the storm surge model can be found in Shibaki et al. (2004). The model combines wave and storm surge simulations. The simulation of storm surge inundation incorporates the process of wave overtopping and water overflow over the dikes on the coastline. In this model, overflow rate is estimated by using Honma’s formula and wave overtopping rate is estimated by using Goda’s diagram. A newest estimation method of flow rate combined with wave overtopping and water overflow is employed. The simulation of storm surge inundation is performed in the hinterland area in the Ise Bay, which is located in the center of the southern coast of Japan. In this study, 100 m grids are employed for the finest grid size which covers the coastal sea and the hinterland. The simulation area for the storm surge and the wave hindcasting is arranged based on the typhoon track. Fig. 5 shows the target area for the inundation simulations. The 100m grid size is adapted for the inundation simulation area. The red line presents the track of Ise Bay Typhoon. In this study, this track is used as a route for the design typhoon under the global warming scenarios. Also, the initial sea level is asuumed with H.W.L. (high water level) plus sea level rise caused by global warming.

According to Compare with the inundation area by using numerical simulations and distributions of population and asset, the risks of damage due to storm surge inundation are estimated under global warming scenarios.

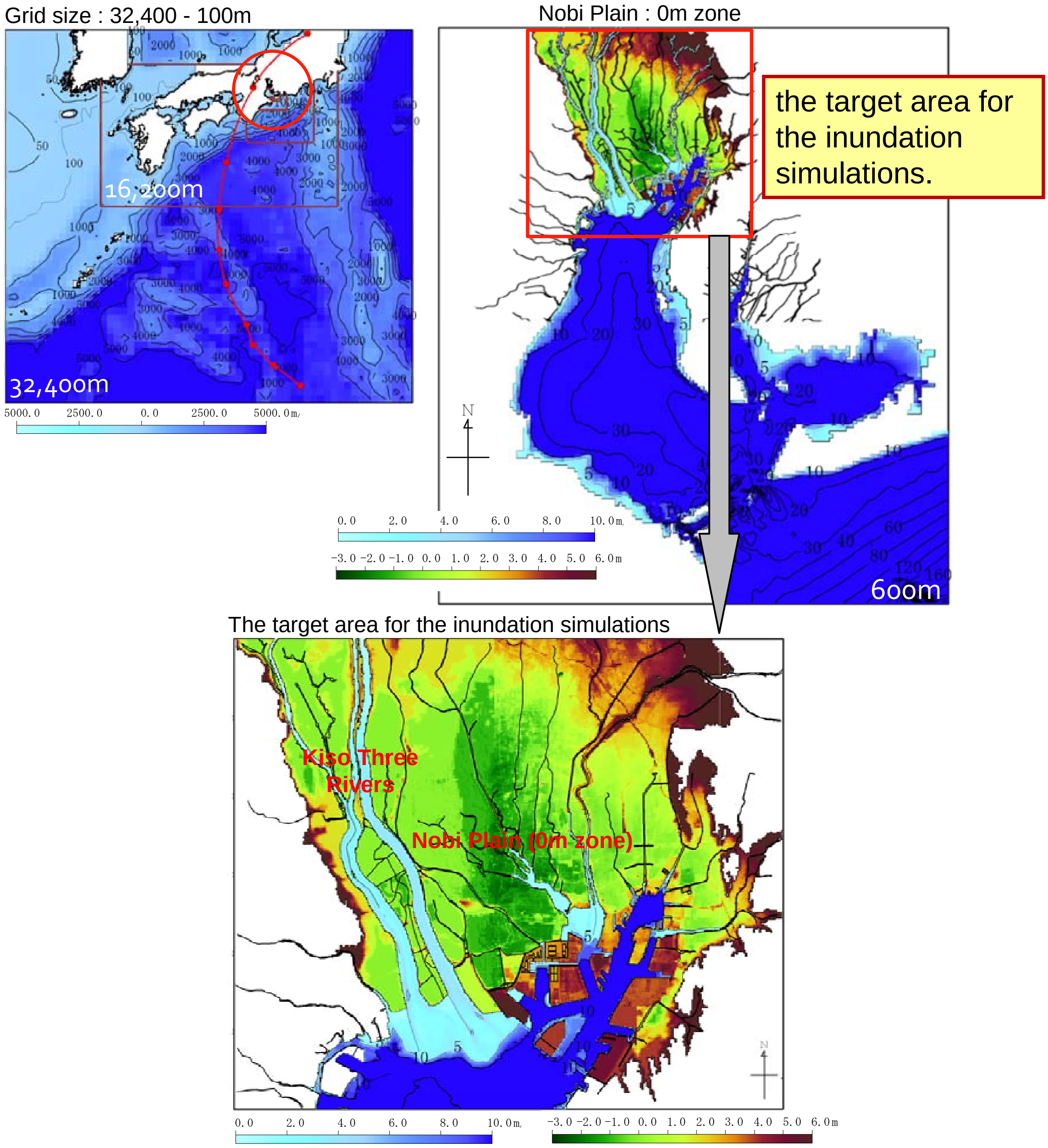


Figure 5. The simulation area for the storm surge and the wave hindcasting.

The results of predictions of inundation (A1FI , A1B)

Fig. 6 show the results of predictions of inundation under A1FI and A1B scenario. The prediction years are 2040, 2060, and 2100. The results of inundation area under A1FI scenario, Central Nagoya has a high concentration of assets. The inundation area will extend to Nagoya in 2100. The Inundation depth will reach to 2 m nearly. The results of inundation area under A1B scenario, the tendency of the inundation area is the same under the A1FI scenario. However, the inundation depth under the A1B scenario is less than the A1FI scenario. These figures confirm the fact that overflow and wave overtopping will occur, resulting in extensive inundation of the hinterland, as a result of tide levels and wave heights that exceed planning conditions due to global warming. Central Nagoya has a high concentration of assets. The predicted inundation range will extend to that area in 2040 under scenario A1FI and in 2060 under scenario A1B, and as a result, property damage will increase rapidly. Moreover, even assuming the inundation range does not increase, the inundation depth will increase, resulting in an increase in inundation above floor level and an accompanying increase in the cost of damage.

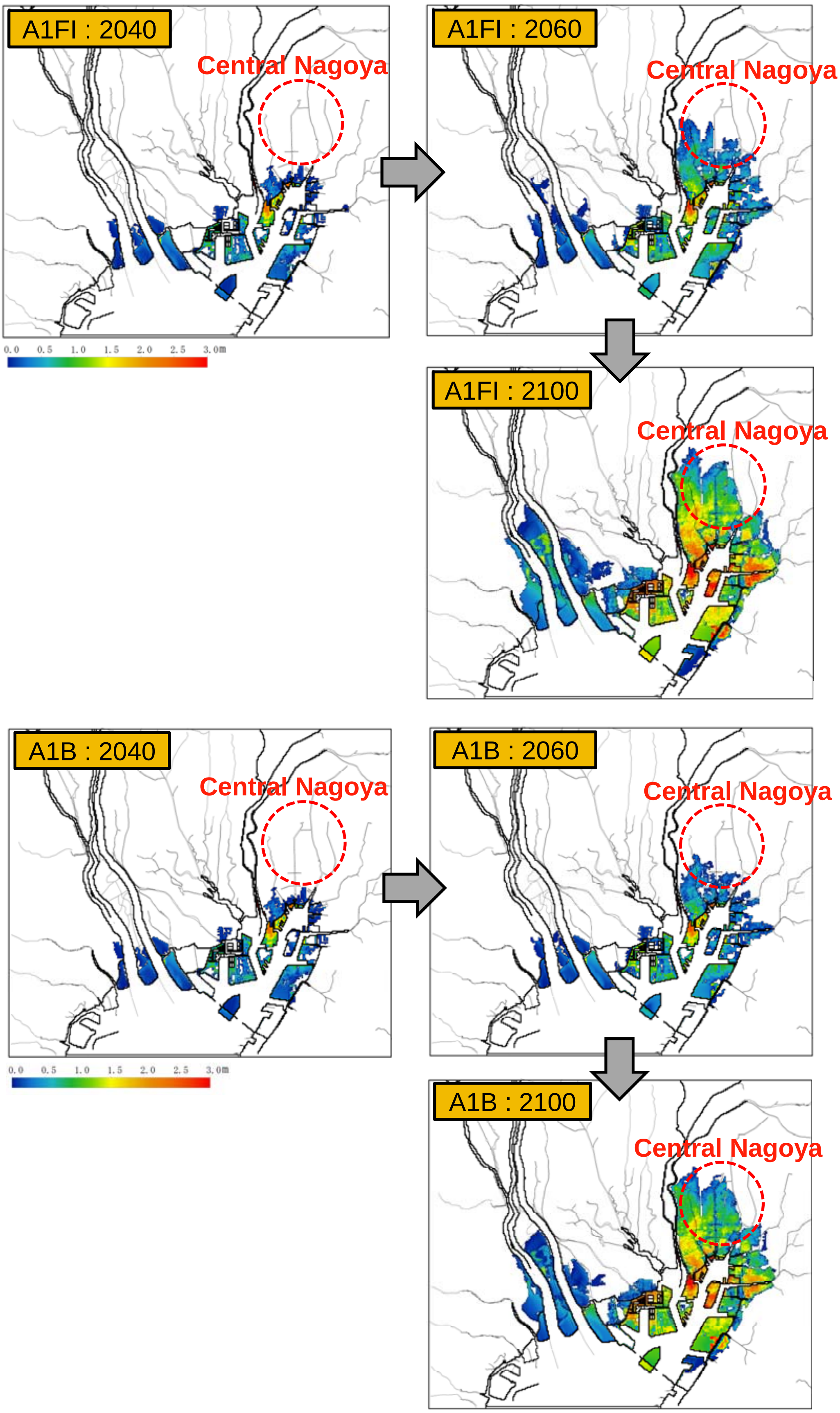


Figure 6. The results of predictions of inundation(A1FI, A1B).

The results of predictions of inundation (A1FI, A1B)

Inundation areas and asset damages are estimated based on the results of inundation simulations. The estimation method of the several disaster risks in the hinterland is based on the counting of suffering population and asset damage in the inundation area. Total assets consist of houses, business establishments and public accommodations. The distribution of population and asset is arranged with 100m grids (Fig. 7). As the asset distribution, the total floor area, number of general households, number of farming fishing households, number of employees of businesses, area of agricultural fields, areas of terminals and warehouses and amount of goods in open air storage belonging to ports, and the respective values of those assets were reduced to data form. These grid data are used for estimation of asset damage. There is higher population density and concentration of assets in the Central Nagoya area.

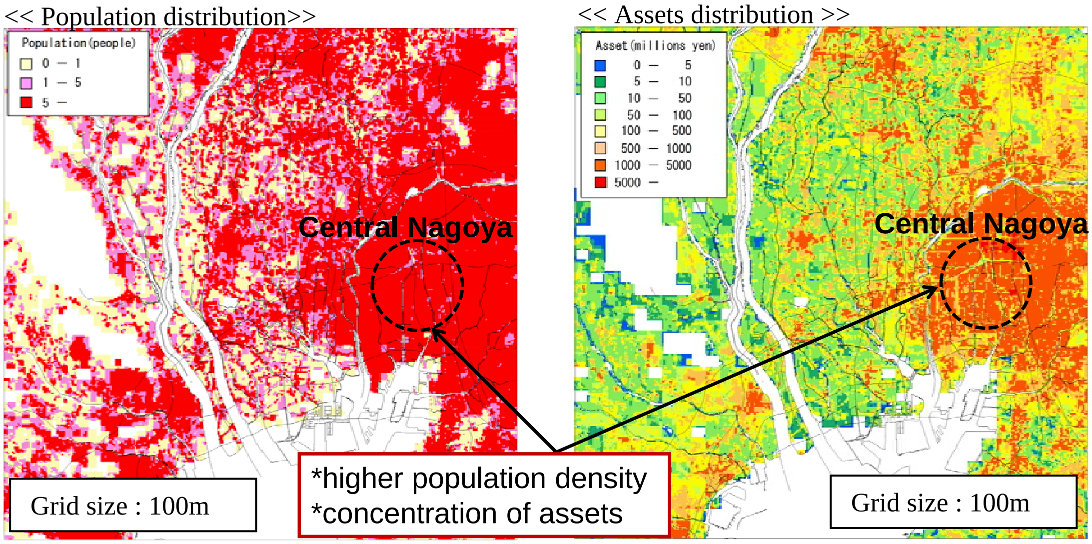


Figure 7. The population and asset distribution data.

Fig. 8 shows the predicted inundation areas and asset damage from 2010 to 2100 under the scenarios of A1FI and A1B. While the inundation area increases gradually, the asset damage increases rapidly after 2040 or 2060 depending on the scenarios. It is because the majority of assets are located in the inland area at some distance from the coastline. The inundation area increases gradually, there are not large differences between inundation areas under A1B and A1FI scenario. The asset damage increases rapidly from 2040 under the A1FI scenario and from 2060 under the A1B scenario. According to spread of the inundation areas in the Central Nagoya, the asset damage increase under A1FI scenario in 2040 and under the conditions of A1B in 2060. Central Nagoya has high concentration of assets. Acoording to the results, property damage will increase rapidly in the future.

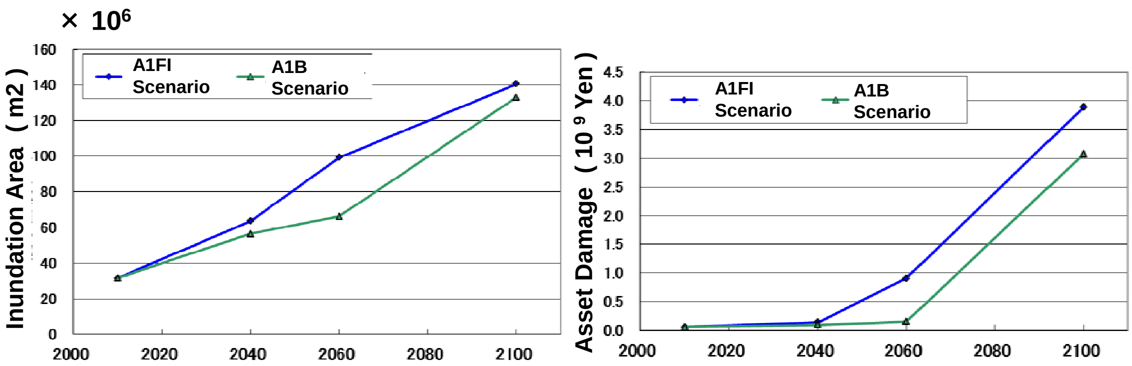


Figure 8. The inundation area and the prediction of asset damage.

CONCLUSIONS

The inundation disaster risk due to storm surge under the scenarios of global warming is researched. The conditions of Climate Change are the scenarios of A1FI and A1B produced by IPCC 4th Report. The sea level rise and typhoon intensity increase are considered for the conditions of storm surge disaster in future climate. They are predicted for the target years of 2040 and 2060 as the middle term as well as of 2100 as the long term target. On these conditions of sea level and typhoon intensity, the storm surge inundation simulations are performed. A newest model of storm surge inundation, which incorporates the estimation of flow rate combined with wave overtopping and water overflow over the coastal structures, is employed for estimation of inundation area and asset damage in the coastal and hinterland area in the Ise Bay. Several disaster risks induced by storm surge are estimated quantitatively.

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