

## Estimation of the damage cost on compound water related disaster in Japan using 2D non-uniform flow model

YUKAKO TANAKA<sup>1</sup>, SO KAZAMA<sup>2</sup>, DAISUKE KOMORI<sup>3</sup>, MASAHIRO AKIMA<sup>2</sup>

1. School of Engineering, Tohoku University, Sendai, Japan, yukako.tanaka.s5@dc.tohoku.ac.jp
2. Graduate School of Engineering, Tohoku University, Sendai, Japan
3. Graduate School of Environmental Studies, Tohoku University, Sendai, Japan

### Abstract

This study runs the simulation of a compound disaster involving flood and storm surge and evaluates the damage cost for the disaster in Japan. The tide level and daily rainfall, which cause the compound disasters, are calculated by means of frequency analysis for annual minimum atmospheric pressure. 2D non-uniform flow model expressing the inundation depth is carried out using the tide level and daily rainfall distribution interpolated as input data. Damage cost is estimated using the inundation depth by each land use. The total damage cost in whole Japan with 50-year return period of compound disaster is 75 trillion JPY.

**Key Words:** Flood, Storm surge, Inundation, Frequency analysis, High-risk area

### 1. INTRODUCTION

During recent years, many people are interested in climate change and adaptation associated with global warming. For example, crucial fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC AR5) mentioned that flood and storm surge will be more serious in lower zones caused by sea level [1].

In Japan, it is estimated that risk of flood will increase due to the changes in precipitation pattern. According to the regional climate model of the Meteorological Research Institute - Japan Meteorological Agency, 100-year return period of precipitation in 2100 will increase by 20 percent nationally compared to the current figure, which may lead to an increase in future flood risk in Japan [2]. Tezuka *et al.* evaluated future flood damage cost in whole Japan quantitatively and estimated the annual expected flood damage cost in 2100 in Japan which showed from 1.10 to 1.36 times compared to the current condition [3]. Statistics of the Japan Meteorological Agency, Environment and Maritime showed that a mean sea level of Japan coast rose by 1.1 mm per year between 1971 and 2010, 2.8 mm per year between 1993 and 2010 [4]. Udo *et al.* estimated that a mean sea level of Japan coast rise nearly 0.3 m in the end of 21<sup>st</sup> century [5]. Misawa *et al.* estimated that the annual expected storm surge damage cost in 2100 would increase 6.2 times compared to the current condition due to the sea level rise [6]. ADB (Asian Development Bank) predicted that annual expected damage of water - related disaster would be increased by nearly 900 billion JPY (≒ 9 billion USD) for Japan by 2050 under the effect of these climate change [7].

Many flood and storm surge events have occurred in Japan. The damage cost of Ise Bay Typhoon in 1959, which brought flood and storm surge on the same day, was

estimated approximately 550 billion JPY in whole Japan [8]. Moreover, Oouchi *et al.* estimated that the frequency of intense typhoon whose maximum wind speed was more than 45 m/s increase in the experiment with a forcing higher sea surface temperature and increasing greenhouse-gas concentration compared to current climate condition [9]. It is anticipated that intense typhoon would be formed stronger and it would bring flood and storm surge on the same time in Japan because of higher sea temperature. Therefore, it is important for Japan to evaluate quantitatively the damage of flood and storm surge disaster.

Although many studies have done on impacts on each flood and storm surge, few studies have done on a compound disaster involving these two events. Misawa *et al.*, evaluated that the probability of simultaneous incidence of flood and storm surge and estimated the damage cost of these two disasters in whole Japan [6]. However, this study estimated the damage cost of compound disaster only in whole Japan and didn't examine the characteristic of each region. Akima *et al.*, estimated the damage cost on flood and storm surge in compound disaster that two disasters happened at the same time with one square kilometer mesh [10]. However, this study overvalued the inundation depth of compound disaster because they estimated the inundation depth of flood and storm surge on the condition that highest tide level stay constant so far as the storm surge flooding calculation and the difference between the tide level and the ground elevation was regarded as the inundation depth of storm surge.

To understand the impact of compound disaster, we try to calculate the inundation depth which is more similar to the actual phenomenon by taking into time series variation of tide level, and to estimate the damage cost in Japan for the compound disaster.

## 2. METHODOLOGY

The flood and storm surge were compounded because these disasters could happen in the same place as low pressure occurred. Flood and storm surge coincide as the compound disaster are selected considering damage in lower areas in Japan. We focus on low atmospheric pressure at typhoon because almost compound disasters selected are derived typhoon.

### 2.1 RAINFALL DATA

The magnitude of the daily rainfall which cause compound disasters calculated from the relationship between annual minimum atmospheric pressure and daily rainfall, which was developed by Akima *et al.*, was used [10].

In this data, it was assumed that probability of compound disaster could be represented in probability of yearly minimum low atmospheric pressure. First, the data of yearly minimum atmospheric pressure and daily rainfall of before and after day at the observation day for each observation station were observed. Second, the linear regression equations of yearly minimum atmospheric pressure and daily rainfall were estimated by the least-square method from these data. Next, 50-years and 100-years return periods of the low atmospheric pressure for each observation station were calculated by means of the generalized extreme value (GEV) probability distribution function with the probability weight moment (PWM) method. Finally, the daily rainfall 50-years and 100-years return periods of compound disaster, were obtained by the substituting 50-years and 100-years return periods of low atmosphere pressure to the above-mentioned linear regression equation. The daily rainfall data from 143 rain gauges throughout Japan over 51 years, and the atmospheric pressure data for each

observation station are used for analyses on the daily rainfall. **Fig 1** shows the observation stations of the daily rainfall and the atmospheric pressure in this study.

We distribute spatially the daily rainfall of all stations by means of Inverse Distance Weight (IDW) method.

## 2.2 TIDE LEVEL DATA

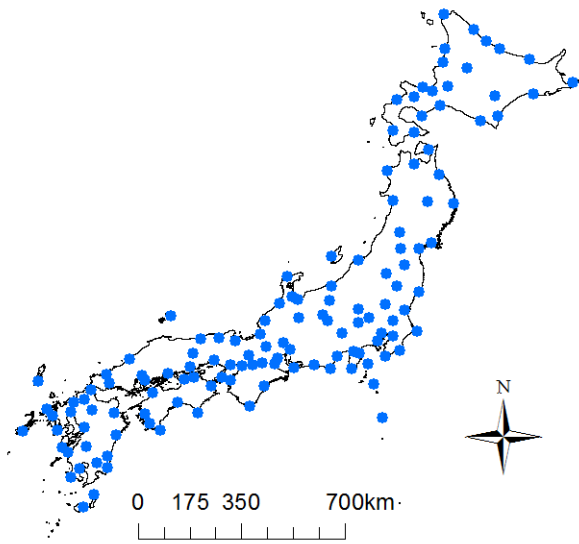
The magnitude of the tide level deviation by compound disasters calculated from the relationship between annual minimum atmospheric pressure and tide level deviation, which was developed by Akima *et al.*, was used <sup>[10]</sup>.

In this data, it was assumed that probability of compound disaster can be represented in probability of yearly minimum low atmospheric pressure. Firstly, the data of yearly minimum atmospheric pressure and the highest tide level deviation of before and after day at the observation day for each observation station were observed. Secondly, the linear regression equations of yearly minimum atmospheric pressure and the highest tide level deviation were estimated by the same method as above from these data. Next, 50-years and 100-years return periods of the low atmospheric pressure for each observation station were calculated by the same means of frequency analysis as above. Finally, the tide level deviation of 50-years and 100-years return periods of compound disaster were obtained by substituting 50-years and 100-years return periods of low atmosphere pressure to the above-mentioned linear regression equation. The tide level data from 59 tide-gauge stations throughout Japan over 16 years, and the atmospheric pressure data for each observation station are used for analyses on the tide level deviation. **Fig 2** shows the observation stations of the tide level in this study.

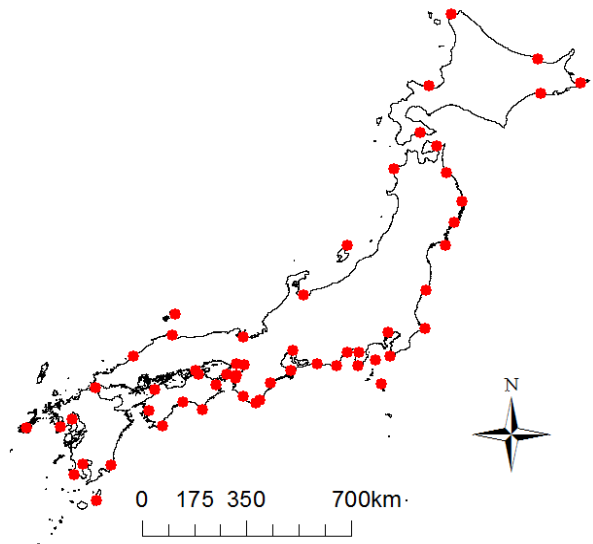
To calculate the inundation depth taking into account time series variation of tide level, we try to make longitudinal tide level deviation data. Firstly, as a model case we focus on the Shiranui Typhoon which actually brought flood and storm surge at the same time. The data of hourly tide level deviation of 24 hours around the time in which the highest one was recorded for the nearest observation station to the inundation area were observed. Secondly, variation pattern of tide level deviation, as shown in **Fig.3**, are obtained by calculating the ratio between the highest tide level deviation and tide level deviation on each hour from these data. Finally, the time series tide level deviation which cause 50-years and 100-years return periods of compound disaster are obtained by substituting 50-years and 100-years return periods of tide level deviation to peak of the above-mentioned variation pattern.

In order to eliminate the tidal fluctuation, the tide level causing 50-years or 100-years return periods of compound disasters are calculated as the sum of the 50-years or 100-years return periods of time series tide level deviation and the mean sea level corresponded to observation station. In this calculation, the time of the highest tide level deviation is set at 0~96 hours after the flood inundation analysis started and 17 types of tide level data are made. In one example, **Fig 4** shows the tide level causing 50-years return period of compound disaster in which the highest tide level deviation is set at 12 hours later at Hachinohe observation station.

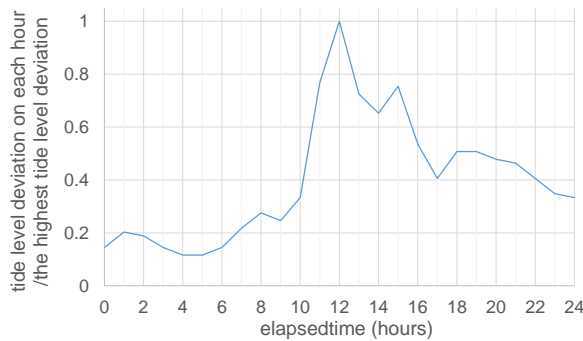
We interpolated spatially the tide level of all stations by means of Inverse Distance Weight (IDW) method.



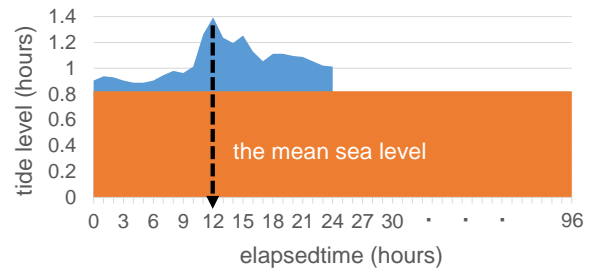
**Fig 1. Observation stations of rainfall and atmospheric pressure**



**Fig 2. Observation stations of tide level**



**Fig 3. Variation pattern of tide level deviation**



**Fig 4. The tide level causing 50-year return period of compound disaster at Hachinohe observation station (the highest tide level deviation is set at 12 hours later)**

### 2.3 ESTIMATION OF THE DAMAGE COST ON COMPOUND DISASTER

In order to discuss the risk of compound disaster involving flood and storm surge in Japan, we estimated the damage of 50-years and 100-years return periods of the compound disaster. Flood simulation expressing the inundation depth is computed using daily rainfall distribution and tide level data on coastline as input data in Japan [11]. In this computation, 2D non-uniform flow model which can distinguish river channel and floodplain and calculate the flow of raging flood water as two dimensional flow was used. Damage cost is estimated using inundation depth calculated by the above method and prices per unit of area calculated by each land use developed by the flood control economy investigation manual published by the MLIT [12]. In this method potential damage cost can be estimated because flood inundation analysis is done without any consideration for river levees or sea defenses.

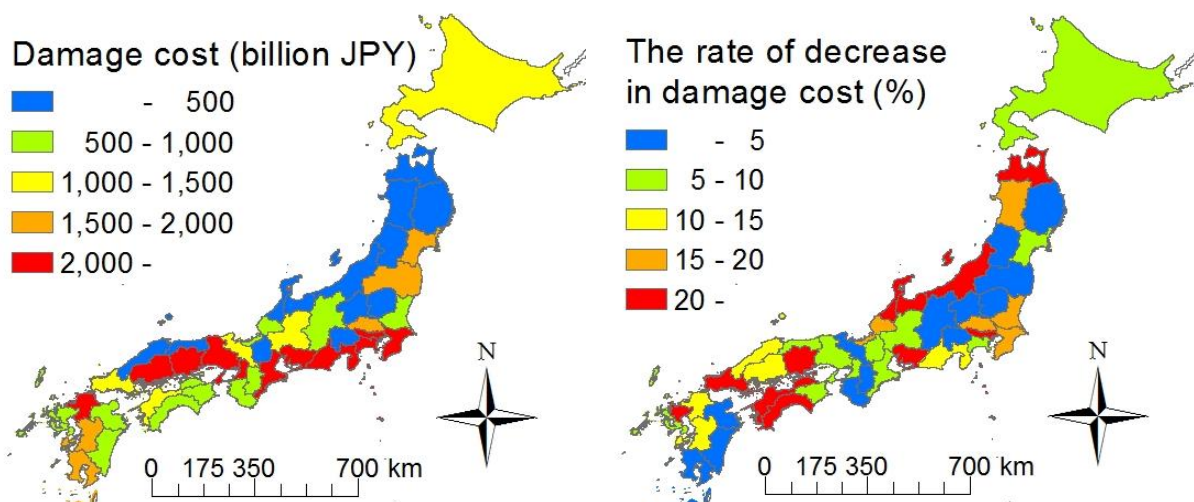
Inundation depth and damage cost distribution in whole Japan were calculated with one square kilometer mesh, with a land use inventory having 11 classifications including rice field, farmland, building site, golf course, main road site, forest, wasteland, other site, river and lakes, beach and sea area is used for the damage cost estimation.

### 3. RESULTS

#### 3.1 THE DAMAGE ON FLOOD COINCIDEING WITH STORM SURGE AT THE SAME TIME

Total amount of the potential damage cost in whole Japan for 50-years return period of compound disaster involving flood and storm surge is 75 trillion JPY. The damage cost by the Ise Bay Typhoon in 1959, which actually bought a compound disaster in Japan, shows good agreement with this study estimation proposed [8]. **Fig 5** shows the spatial damage distribution of 50-years return period of compound disaster. The compound disaster damage costs of Tokyo, Aichi, and Osaka prefecture are higher than any other prefecture and the amount of damage cost in the three prefectures accounts for 32% of the total cost in Japan. Asset values of these prefectures are higher and most of high asset areas locate on low elevation areas compared with the others. The damage costs of flood and storm surge in the part of the compound disaster are 49 trillion JPY and 32 trillion JPY, respectively. The damage cost of the compound disaster on flood and storm surge is lower than the sum of the flood and storm surge independently. This was caused by the different time of the highest water level for different disasters.

The damage cost of compound disaster in this study is smaller by 15.2% than that estimated by Akima *et al.* [10]. This difference could be caused by the difference in infiltration of tidal waves to the land. In their study the inundation depth of storm surge was calculated as the difference between the tide level and the ground elevation regarded. However, in this study the inundation depth of storm surge is calculated in 2D non-uniform flow model using tide level distribution interpolated on coastline as input data. **Fig 6** shows the spatial distribution of the rate of decrease in the damage cost for 50-years return period of compound disaster. The rates of decrease in the compound disaster damage costs of Niigata, Ishikawa, Kochi, and Kagawa prefecture are higher than any other prefecture. In these prefectures, most of their areas locate on low land areas compared with the others and each of their commercial districts is also centered on the area. Asset values of Tokyo, Aichi, and Osaka prefecture are higher and most of their areas locate on low altitude areas along large rivers which can swell greatly with the heavy rains flow through these prefectures ,so that storm surge couldn't contribute to compound disaster a lot.

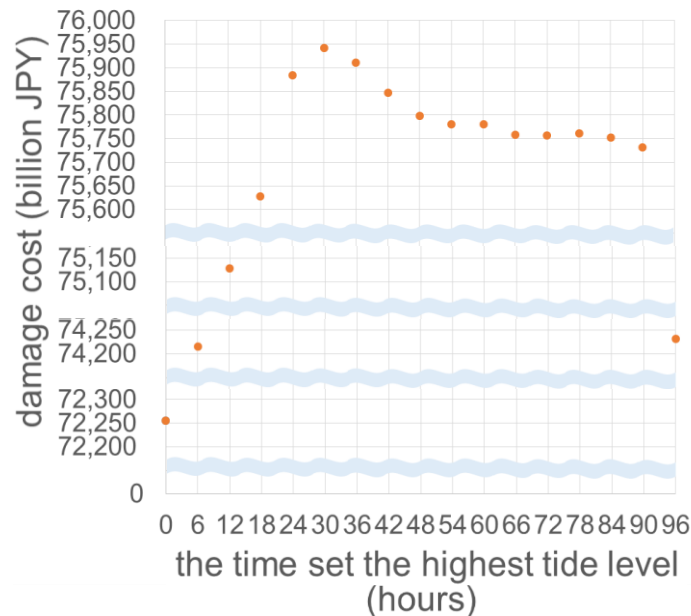


**Fig 5. The damage cost distribution of compound disaster**

**Fig 6. The rate of decrease in damage cost distribution of compound disaster**

### 3.2 THE DAMAGE ON FLOOD AND STORM SURGE BROUGHT WITH A TIME DIFFERENCE

As shown in Fig.7, total amount of the potential damage cost in whole Japan for 50-years return period of compound disaster reaches a peak on the condition that the time of the highest tide level deviation is set at 30 hours after the flood inundation analysis started. The difference in the damage cost caused by the difference in the time of the highest tide level deviation is at most 3.7 trillion JPY.



**Fig 7. The difference in the damage cost caused by the difference in the time of the highest tide level**

### 4. CONCLUSIONS

We evaluate quantitatively the damage cost of compound disaster which is more similar to the actual phenomenon by taking into account time series variation of tide level, and extract high-risk area in Japan. Additionally, we evaluated the difference in the damage cost caused by the difference of the peak time of the inundation depth of flood and it of storm surge.

Based on the above findings, we draw the following conclusions:

- 1) In whole Japan the potential damage cost of compound disaster of flood and storm surge was 75 trillion JPY.
- 2) There were many prefectures whose the damage cost of compound disaster was overvalued in the old flood inundation analysis.
- 3) The difference in the damage cost of compound disaster caused by the difference in the time of the highest tide level was at most 3.7 trillion JPY.

Considering the adaptation method against global warming, it takes many times and high costs to raise the flood control level in whole Japan [13]. Therefore, it is important to extract the higher risk areas and choose the appropriate measures for the areas [13]. Considering the adaptation method against water disasters, it is useful to estimate quantitatively the spatial disaster damage cost. Especially, considering the adaptation method against compound disaster, the hazards, which are the rainfall and tide level, cause compound disaster based on the regional characteristics are needed to take

into account. Although the probability of compound disaster is low, it may bring enormous damage once occurrence. Therefore, it is important to construct the adaptation method for the compound disaster in mind in high-risk areas. Results show where government should invest intensively in disaster prevention by infrastructure in high-risk area to raise resistance to water disasters in Japan. In this study the inundation depth of compound disaster is quantitatively calculated in each area, and it can support considering city design based on the regional characteristics. Results show in considering the adaptation method against global warming, time series variation of tide level and the difference in the time it takes for the inundation depth of flood or storm surge to reach their peak need to be taken into account. Our result can contribute to flood control design and the efficient adaptation method against water disasters.

### Acknowledgements

This research was supported by the Environment Research and Technology Development Fund (S-14) of the Ministry of the Environment, Japan and the Social Implementation Program on Climate Change Adaptation Technology (SI-CAT) of MEXT, Japan and Advancing Co-design of Integrated Strategies with Adaptation to Climate Change (ADAP-T) of JST/JICA, SATREPS.

### References

- [1] Ministry of Economy, Trade and Industry, the Japan Meteorological Agency, the Ministry of the Environment, (2013): IPCC(AR5) Synthesis Report Summary for Policymakers, pp.1-pp.29.
- [2] Wada K, Murase K, Tomisawa Y, (2005): Research on assessment of change in precipitation characteristic according to global warming and flood and water shortage risk. *Japan Society of Civil Engineers paper NO. 796/II-72*, pp 23–37.
- [3] Shoya TEZUKA, Keisuke ONO, So KAZAMA, Daisuke KOMORI, (2014): Flood damage estimations based on extreme precipitation and discharge and variation in the future, *JSCE J Hydraulic Engineering*, 70(4), pp.501-pp.506.
- [4] Japan Meteorological Agency: Long-term change trend of Japan coastal sea level, [http://www.data.jma.go.jp/kaiyou/shindan/a\\_1/sl\\_trend/sl\\_trend.html](http://www.data.jma.go.jp/kaiyou/shindan/a_1/sl_trend/sl_trend.html), 2015.
- [5] Keiko UDO, Yuriko TAKEDA, Jun YOSHIDA, Akira MANO, (2013): Future protections of Beach erosion in Japan using sea level change data of the MIROC5 model, *JSCE Environmental Research*, 69(5), pp.239-pp.247.
- [6] Koki MISAWA, So KAZAMA, Takeshi SUZUKI, Keiko UDO, Shoya TEZUKA, (2014): Estimation of compound disasters of flood and storm surge under climate change, *JSCE Environmental Research*, 70(5), pp.95-pp.100.
- [7] Michael I, Westphal Gordon A, Hughes Jorn Brommelhorster, (2013): Economics of Climate Change in East Asia., chapter2, pp.28-57.
- [8] Cabinet Office(2008): Ise Bay Typhoon report, [http://www.bousai.go.jp/kyoiku/kyokun/kyoukunnokeishou/rep/1959--isewanTYPHOON/pdf/03\\_mokuji.pdf](http://www.bousai.go.jp/kyoiku/kyokun/kyoukunnokeishou/rep/1959--isewanTYPHOON/pdf/03_mokuji.pdf).
- [9] Kazuyoshi OOUCHI, Jun YOSHIMURA, Hiromasa YOSHIMURA, Ryo MIZUTA, Shoji KUSUNOKI, Akira NODA, (2006): Tropical Cyclone Climatology in a Global-Warming Climate as Simulated in a 20 km-Mesh Global Atmospheric Model:

Frequency and Wind Intensity Analyses, Journal of the Meteorological Society of Japan, Vol. 84, No. 2, pp. 259--276.

[10] Masahiro AKIMA So KAZAMA, Daisuke KOMORI, (2016): Estimation of potential damage cost on flood and storm surge disasters under same return period, JSCE J Hydraulic Engineering, 72(4), pp.1\_1267-pp.1\_1272.

[11] Soichiro MACHIDA, Seiki KAWAGOE, So KAZAMA, Masaki SAWAMOTO, Hiromune YOKOKI, Kazuya YASUHARA, (2007): EVALUATION OF FLOOD DAMAGES FOR CLIMAIE CHANGE, Proceedings of the Symposium on Global Environment, Vol.15, pp.155-pp.160.

[12] Ministry of Land, Infrastrucure, Transport and Tourism (MLIT), (2005), The flood control economy investigation manual (proposed).

[13] Kiyoshi M, (2014): NIKKEI CONSTRUCTION, “Public Works Reform to Approach Global Warming”, Nikkei Business Publications Inc..