ASSESSMENT OF COMPOUND FLOODING FOR ISE BAY, JAPAN USING TYPHOON TRACK ENSEMBLE EXPERIMENTS

Masaya Toyoda, Toyohashi University of Technology, toyoda@ace.tut.ac.jp
Nobuhito Mori, Kyoto University, mori@oceanwave.jp
Sooyoul Kim, Kumamoto University,sooyoulkim@kumamoto-u.ac.jp
Jun Yoshino, Gifu University, yoshino.jun.d2@f.gifu-u.ac.jp

1. INTRODUCTION

Recent typhoon cases have clearly demonstrated the danger of compound flooding by large storm surges associated with intensified typhoons and floods from upstream. Integrated numerical models that solve for typhoons, storm surges, and floods in a unified manner are required to assess compound flooding properly. Although several studies on compound flooding have been reported (e.g., Yin et al.2021), few examples of coupled numerical models solve atmosphere, river, storm surge, and wave phenomena in a unified manner with high accuracy. Most previous studies applied parametric wind and pressure models for typhoon meteorological fields, which never reproduced precipitation fields caused by typhoons. In addition, many previous studies focused on large rivers in the estuarine areas. However, they did not evaluate those in coastal areas, including small and medium-sized rivers, at high risk of inundation. Therefore, a comprehensive assessment method of typhoon disasters is needed using a integrated numerical model that solves these multi-hazards on different temporal and spatial scales in an integrated manner.

The authors have developed a coupled wave and storm surge model that can account for storm surge run-up to rivers (Toyoda et al., 2021). The coupled model accurately reproduced the river run-up of storm surges in the Yodo and Ina Rivers in Japan induced by Typhoon Jebi (2018), including flood flows from upstream of the rivers. On the other hand, the previous study did not discuss the relationship between typhoon tracks and the risk of compound flooding, and targeted only large rivers.

In this study, risk assessment for compound flooding caused by storm surge and high-river discharge is conducted by applying a typhoon track ensemble experiment of Typhoon Hagibis (2019). Furthermore, the target area is set to Ise Bay, and including small and medium sized rivers, which has the most significant low-lying wide area below the mean sea surface level in Japan.

2. COMPUTATIONAL SETTINGS

(1) High-resolution Typhoon Model (HTM)

In this study, the results of the path ensemble experiment by Yoshino et al. (2021) are used as the typhoon conditions (Fig.1). The initial and boundary conditions were modified by sliding the meteorological field of Typhoon Hagibis (2019) in 0.05-degree increments from east to west using a dynamical meteorological model (HTM). In addition, in the previous study, 60 typhoon cases were generated for the present and future climate conditions, respectively. This study selected 20 cases that caused large storm surges and flooding in Ise Bay from the present climate results. Horizontal resolutions from the HTM are 9 km and 3 km, and rainfall distribution, wind speed, and pressure distribution are used. The output interval is set to 15-min.

(2)River discharge and storm surge

The rainfall-runoff inundation model RRI (Sayama et al., 2012) is used to represent the increase in river discharge due to rainfall. This model can simulate the whole water system flow based on rainfall distribution and topographic data. In this study, J-Flw Dir (Yamazaki et al., 2018) is used for topographic data (resolution: 30 m), and the rainfall output from the meteorological model is used for input conditions. Ibi, Kiso, Nikko, Shin, Shonai, and Tenpaku Rivers in Ise Bay are the target river basins. RRI is applied to each river to obtain a time series of the river discharges at the river mouth that is used for river boundary conditions in SuWAT (Fig.1).

The storm surge was calculated using a coupled model of surge, wave, and tide (SuWAT) developed by Kim et al. (2015). The SuWAT model is based on a nonlinear shallow water equation considering atmospheric pressure-driven surge, wind stress, and wave radiation stress. Six domains nesting were used with spatial resolutions of 7290 m (D1) to 30 m (D6). The storm surge model considered the wave-induced forces from the radiation stress in the momentum. The calculation period was from 0:00 UTC on October 10, 2019, to 0:00 UTC on October 13, 2019. In addition, a 24-h spin-up calculation was conducted. The simulation period was from 0:00 UTC on October 10, 2019, to 0:00 UTC on October 13, 2019. River boundary conditions was given by converting the constantly changing discharges calculated from the RRI into water levels according to the river channel topography (river width and water depth) in SuWAT (Fig.1). Here, the coupling between RRI and SuWAT is one way from RRI to SuWAT. Note that astronomical tide is not included.

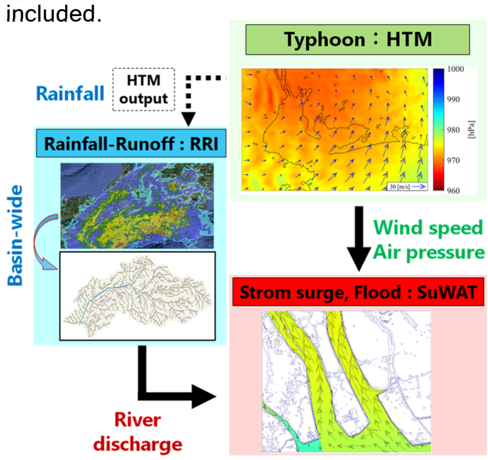

Fig.1 Simulation flow in this study

3. RESULTS AND DISCUSSION

First, we discuss the 20 cases of typhoon tracks, which are the input meteorological fields for this study, and the maximum storm surge for each case (Fig.2). The most westerly track is the typhoon passes about 200 km away from Ise Bay (red). The most easterly track is the typhoon passes east of Ise Bay (blue). The central pressure of the typhoon at landfall is approximately 950 hPa in all cases. Historical disaster event in Ise Bay has shown that typhoons tracks making landfall on the Kii Peninsula shown in green to light blue tend to cause more severe storm surges. The maximum storm surge at the Port of Nagoya was 2.55 m in C12 (black bold).

Next, the compound flooding risk is discussed for each river (Fig.3). Cross-sections were established in SuWAT to calculate the amount of river run up by storm surge for each river, with the setting that the cross-section passing from the sea to the river was set as a positive value. The colored bars in the figure represent the flow into the estuary due to storm surge. The black dots at the top of the bars represent the total surge and discharge (TSD), which is the sum of the flow amount from the storm surge and the upstream discharge simultaneously. The maximum inflow case from the sea differed for each river: The Ibi and Kiso Rivers in the western part of the bay were in C14, The Shin and Shonai Rivers near the Port of Nagoya tidal station were in C12, and the Nikko and Tenpaku Rivers on the east and west of the Shinkawa River were in C2. In all cases, the flood peaks had not yet reached the time of maximum storm surge inflow due to the extended flood arrival time for large rivers (1000 km^2), such as the Ibi, Kiso, and Shonai Rivers. In the Kiso River, which has the largest watershed, there was no increase in flow during the simulation period. In contrast, in the Nikko, Shin, and Tenpaku Rivers, peak flows were observed at or near the time of maximum inflow due to the storm surge in some cases. This is consistent with previous studies, indicating that the difference between the peak times of storm surge and high-river flow tends to be short in small and medium-sized rivers. In particular, C18 in the Shin River (purple) and C17 in the Tenpaku River (light blue) show significant inflows due to the storm surge and large river discharge from upstream. Furthermore, these cases are not the largest in terms of storm surge or river discharge. However, they are the largest in terms of TSD. These results indicate that even when both storm surge and river discharge are not exceptionally large, their combination can create a hazardous situation.

4. CONCLUSION

In this study, a risk assessment of compound flooding caused by storm surge and high-river flow was conducted for Ise Bay, Japan, utilizing a dynamic approach. The results of a typhoon track ensemble experiment involving a total of 20 different typhoon tracks revealed that both storm surge and high-river flow tend to be more significant in the typhoon tracks that move northward along the west side of Ise Bay. Furthermore, it was observed that substantial storm surges run-up from the estuaries of each river tended to coincide with the arrival of high-river flows from upstream in small and medium-sized rivers. Similar simulations will be conducted under various conditions in further studies, such as different typhoon cases and considering the impact of astronomical tides.

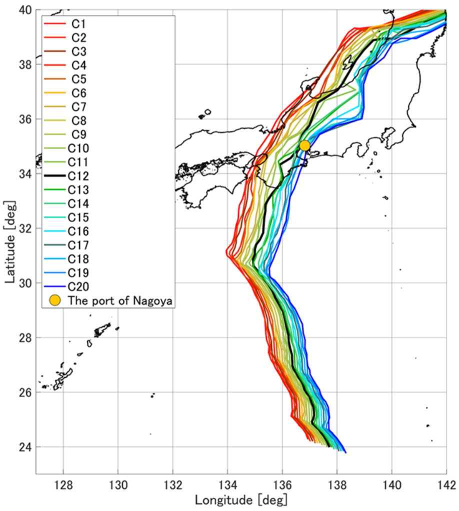

Fig.2 Typhoon track of track ensemble experiments. Each color indicates each track, and the Black bold line means the worst storm surge case. Orange plot indicates the port of Nagoya.

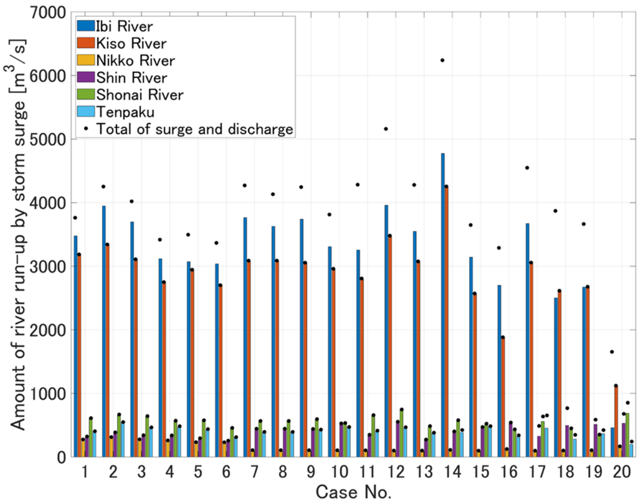

Fig.3 Results of amount of storm surge run-up (bar graph) and total water (each black plot) in each case. Each color indicates each river (blue, red, yellow, purple, gree, light blue indicate Ibi, Kiso, Nikko, Shin, Shonai, and Tenpaku Rivers, respectively.)

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