Storm Surges and High Waves due to Typhoons in Three Major Bays of Japan in the Future Climate
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ABSTRACT
This study estimated future changes in storm surges and high waves under +4K warmer conditions (compared with the pre-industrial period) by numerical simulations because their assessments are necessary to evaluate their risks on the ports of Japan. The simulation results showed that the future storm surges and high waves had dispersion related to sea surface temperature warming patterns and the future changes were different for bays. Additionally, the future changes in storm surges were different with those in wave heights. The results can contribute to conducting climate change adaptation measures in port areas.

KEY WORDS: Future climate; storm surges; waves; typhoons; climate change; stochastic typhoon model.

INTRODUCTION
Storm surges in a closed sea area with shallow depth tend to be larger than those in an open sea area. The three major bays in Japan (Tokyo Bay, Ise Bay, and Osaka Bay, see Fig. 2), which have hinterlands with a high density of population and property, are more closed and shallower than other sea areas facing onto oceans. Therefore, there is a high risk of flooding due to storm surges on the ports in the three major bays because ports generally have broader coastal land.

In Japan, typhoons mainly cause storm surges and high waves. Typhoon Vera in 1959 caused catastrophic damage to coastal areas around Ise Bay, which collapsed coastal dikes, flooded the land for 30 km from the coast and for 120 days, and consequently took approximately 5,000 lives away. Since this event, Typhoon Vera has been used as a scenario typhoon in the design of port and shore protection facilities or for making hazard maps. In recent years, Typhoon Jebi in 2018 and Typhoon Faxai in 2019 caused storm surge and wave disasters on the coast of Osaka and Tokyo Bays, respectively (Mori et al., 2019; Kawai et al., 2020; Suzuki et al, 2020).

Climate change is expected to impact the behaviors of typhoons, such as their frequency, intensity, translation speed, and track. The Intergovernmental Panel on Climate Change (IPCC) reported that typhoons would be fewer in number but stronger in intensity over the globe (AR5, 2013). Besides, the frequency of extreme typhoons is likely to increase due to increasing air temperature, sea surface temperature (SST), and ocean heat storage (Murakami et al., 2012).

Considering such circumstances, climate change impacts on storm surges and high waves due to typhoons are significant concerns for sustainable development in the ports of Japan. Therefore, it is essential to evaluate the risks of storm surges and high waves due to typhoons in the future climate and to conduct climate change adaptation measures in port areas. The assessment of future changes in storm surges and high waves is necessary to evaluate those risks.

In this study, we estimated storm surges and high waves due to typhoons in the future climate by conducting numerical simulations. The simulations were conducted for port areas along the three major bays of Japan under six different future sea surface temperature conditions (ΔSST) of RCP8.5 socio-economic reference scenario in Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor, Stouffer, and Meehl, 2012). Based on the comparison between extreme values of storm surges and waves in the future climate and those in the present climate, the future changes of the extreme values were evaluated.

COMPUTATIONAL METHODS AND CONFIGURATION

In this study, we projected the storm surges and high waves due to typhoons in the future climate according to the computational flow shown in Fig. 1. In this section, we will describe the computational method and configuration of each procedure in this flow chart.

Computational Configuration for Typhoons

Stochastic typhoon model

Stochastic typhoon model (STM) is a means to statistically calculate the sequential developments of typhoons from given statistical parameters of typhoons such as track, minimum sea level pressure, and translation speed. Using the STM allows for generating many artificial typhoon data and statistical analyses of various factors with respect to typhoon data.

To obtain typhoon data in the future climate, we used a STM developed by Nakajo et al. (2014) and Umeda et al (2019). The statistical