Coastal Flooding Processes Caused by Slow-moving Tropical Cyclones

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BACKGROUND AND RESEARCH NEEDS

Examples of Recent Slow-moving Tropical Cyclones

Ongoing climate change appears to modify the characteristics of recent tropical cyclones (TCs) and coastal disaster processes caused by them. In particular, some slow-moving TCs and even stalled ones have triggered devastating coastal hazards. In 2018, Hurricane Harvey strayed back and forth over the Gulf of Mexico, which caused prolonged flood damage over the Texas coasts (Blake & Zelinsky, 2018). In 2019, Hurricane Dorian, moving at a speed of 5-7 km/h, destroyed the Bahamas (Avila et al., 2020). Since high-intensity TCs exhibit strong gradient winds, their net wind speeds remain substantial even when these TCs move at a slow speed (Inagaki et al., 2021). This can result in more severe and prolonged damage caused by slow-moving TCs compared to those with typical translation speeds.

Would TCs Be Slower under Future Climate?

Climate change affects global thermal circulation systems, such as ocean currents and air streams, consequently altering the translation of TCs. A weakening of ocean currents in the North Atlantic (including the Gulf of Mexico) was pointed out recently (Ditlevsen & Ditlevsen, 2023), which would make growing concern that the sustained high sea surface temperature would cause an increase in hurricane intensity and possible slowed-down of translation speeds. In Japan, typhoons are typically accelerated by westerly just before landfall, leading to their weakening. However, due to the anticipated northern shift of summer westerly under the future climate, future typhoons would approach the Japanese archipelago at a slower speed than present ones without significant weakening (Yamaguchi et al., 2020).

Previous Studies

Taking these concerns into account, the authors previously developed a numerical model using WRF (Skamarick et al., 2021) and SWAN (The SWAN Team, 2023), and investigated the development of wind waves around the Japanese coastal zone (Inagaki et al., 2021). Under the situation where a large typhoon moves at a speed of 3-7 km/h, the significant wave height H_s over 4 meters persisted along the coastal areas for more than a day, even in coastal regions (see **Figure 1**).

OBJECTIVES

In the present study, the authors focused on the effect of slow translation speeds of typhoons on coastal flooding caused by a storm surge and wave overtopping. The wind-induced set-up under different translation speeds of a typhoon was investigated using a numerical model. Furthermore, the modification in wave parameters such as frequency spectrum and wave set-up were also examined to understand better the potential risks to coastal communities caused by slow-moving typhoons.

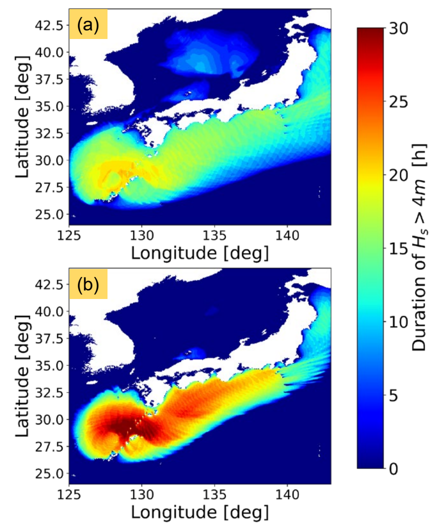

Figure 1. *Duration over which H_s is greater than 4m in the case of Typhoon Trami in 2018.* ***(a)*** *the original translation speed.* ***(b)*** *the case for reducing the translation speed to 50%. The figures were recreated based on Inagaki et al., 2021.*

METHODOLOGY

The present study examined variations in surging situations by modifying the translation speed of historical typhoons that passed through the Japanese archipelago. Calculations of meteorological forcing and adjustments to wind speeds in accordance with changing translation speeds were conducted by following the methodology of Inagaki et al., 2021. The modified wind forcings were then input into the FVCOM-SWAVE model (version 4.1, Chen et al., 2003) (see **Figure 2**). Also, for the simplicity of topographical effects, the analysis was first performed at Shiono-Misaki, which is open to the Pacific Ocean (see **Figure 3**). As a limitation of the proposed model, the changes in the thermodynamic processes of typhoons associated with the variations in translation speeds were not included.

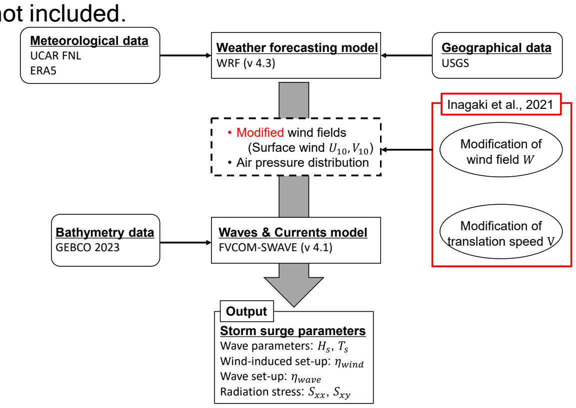

Figure 2. *Description of the proposed numerical model.*

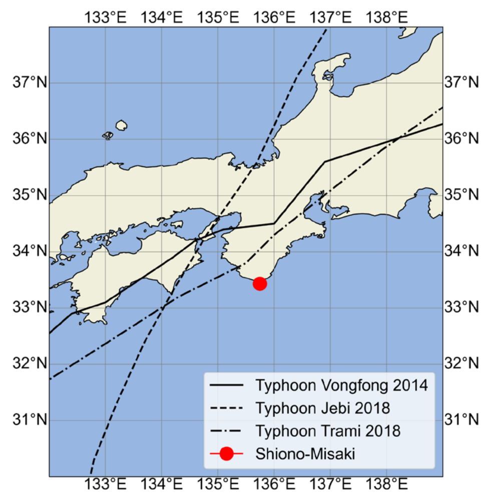

Figure 3. *The location of Shiono-Misaki and tracks of the target typhoons.*

RESULTS & DISCUSSIONS

Reducing the translation speed to 30% resulted in an approximately 10% increase in the significant wave period, T_s , compared to the original translation speed. Furthermore, a slight shift in the frequency spectrum distribution towards longer periods was observed. Additionally, the water surface deviation due to the wind-induced set-up was 20-40% higher than at the original translation speed, indicating that the energy supply duration from the air is sufficient to push seawater towards the land (see **Figure 4**). According to these results, it can be suggested that slow-moving typhoons could result in an increased risk of storm surges and high-energy waves. A more detailed analysis such as wave set-up is needed to better understand the risk of coastal flooding.

Furthermore, it is worth noting that the present findings were obtained exclusively from Shiono-Misaki, which is open to the sea. The presence of more intricate geographical features, such as a gulf or bay, could yield different results in terms of the modification of wave characteristics caused by the change in typhoon wind situations.

From the perspective of coastal community resilience, it becomes increasingly important to address engineering concerns such as the long-term stability of coastal structures and their foundations or ship mooring. Proposing engineering indicators or developing retrofitting design guidelines could be a direction for further research that would be built upon the present findings.

CONCLUSIONS

The motivation for the present study stemmed from concerns regarding potential coastal flooding processes caused by slow-moving tropical cyclones. The analysis of the Pacific coast of Japan using the proposed numerical model revealed that a slower-moving typhoon could result in increased storm surge risks. More holistic case studies focusing on geographical and topographical features would be required to understand the general behavior of waves associated with the modification of typhoon wind situations. A series of studies could contribute to future coastal disaster prevention and mitigation endeavors.

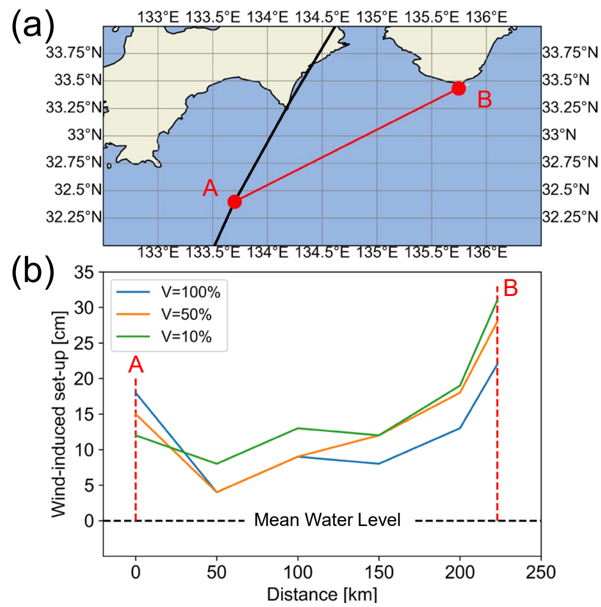

Figure 4. *Wind-induced set-up caused by different translation speeds for the case of Typhoon Jebi in 2018.* ***(a).*** *Location of the typhoon center and Shiono-Misaki.* ***(b).*** *Profile of the wind-induced set-up along the cross-section A-B described in* ***Figure 4-(a)****. The percentile represents the ratio to the original translation speed.*

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