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著者(和文)	Islam Md. Rezuanul
Author(English)	Md. Rezuanul Islam
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THESIS OUTLINE

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学生氏名： Student's Name	Islam Md. Rezuanul	指導教員（主）： Academic Supervisor(main)	高木泰士
		指導教員（副）： Academic Supervisor(sub)	

Thesis Outline

Thesis title: Data-driven storm surge analysis and improving early warning

Storm surge associated with tropical cyclone (TC) has a long history of causing catastrophic damage and many deaths along low-elevation coastal zones. When quantifying natural disasters such as TC, weather forecasting has often employed categorization-based statistical approaches (i.e., index/scale) for promoting public understating. For example, TC wind intensity-based categorization of storm surge index (i.e., Saffir-Simpson Hurricane Scale (SSHS)) has been a useful means of early warning and informing potential impacts for decades. However, storm surge information was removed from SSHS after Hurricane Katrina (2005) and Ike (2008) because they had caused extreme storm surges than those predicted. Afterward, a range of different indices for estimating storm surge potential have been proposed. However, a new practical index overcoming the SSHS has yet to been put in place for inoperational use.

The improved indices are not comprehensive enough to reflect the severity of a surge event precisely. For example, the influence of TC forward speed and coastal geometry are not considered in those existing indices. Another known limitation in the existing indices is that none have been examined in many TC basins except for the Atlantic Ocean. Because they require some of the variables relevant to TC structures (i.e., the radius of 64-kt wind, radius of max wind), which are only available in the Atlantic TC best track/forecasting database. Considering storm surge is an extremely life-threatening hazard, there is a pressing need for an alternative means to represent TC surge potential and threats more effectively.

This study investigated 42 years (1978-2019) of tidal records and landfall TC best tracks in Japan and demonstrated that TC forward speed is significantly correlated with maximum storm surge height. Fast-moving TCs tend to amplify the storm surge along open coastlines (Pearson correlation coefficient, $R = 0.62$) but reduce it in semi-enclosed bays ($R = -0.52$). The negative correlation contrasts with the general perception that the coincidence of TC wind speed and forward speed vectors generates a larger storm surge. Coastal geometry was also confirmed as an influential factor for the correlation between storm surge and TC forward speed.

Spatial and temporal change analyses of storm surge were conducted by taking Tokyo Bay as a case study of a highly vulnerable coastal area. The numerical analysis demonstrates that the slow passage of a large and intense TC transiting parallel to the longitudinal axis of the Bay, making landfall 25 km southwest, is most likely to cause a hazardous storm surge scenario in the upper-bay area. In addition, the temporal change analysis suggests that landfall TC wind intensity and size have become stronger and larger in the recent 20 years (2000-2019) than the previous 20 years (1980-1999). These changes corresponded to increasing storm surge magnitudes (+41% per decade) over the last 40 years (1980-2019). The increased occurrence frequency of TCs with more northeastward tracks is another factor that may have contributed to the increased surge hazards around Tokyo.

Considering the salient TC meteorological parameters, including forward speed and size, this study

proposes a new storm surge hazard potential index (SSHPI) for estimating TC-induced peak surge levels at a given coast. The SSHPI incorporates parameters that are often readily available at real-time: intensity in 10-minute maximum wind speed, radius of 50-kt wind, forward speed, coastal geometry, and bathymetry information. By incorporating forward speed and coastal geometry information in the proposed index, significant improvements in surge prediction could be achieved compared to other existing surge indices.

A retrospective analysis of SSHPI using data from 1978-2019 in Japan suggests that this index captures historical events reasonably well. In particular, it explains ~66% of the observed variance and ~74% for those induced by TCs whose landfall intensity was larger than 79-kt. Furthermore, the performance of SSHPI is not influenced by the type of coastal geometry (open coasts or semi-enclosed bays). The SSHPI was also applied to detect historical storm surge changes in eastern Japan, including Tokyo. It suggests that surge hazard potential has increased more than three times in the recent 20 years (2000-2019) than the previous 20 years (1980-1999), which is well-matched with surge change analysis (R2 = 0.68). As SSHPI utilizes the most common and readily available surge sensitive variables, it can be applied to any oceanic basin beyond Japan. This new index is expected to have a great potential to provide reliable early warning information without expensive numerical computations, leading to improving public awareness of storm surge hazards.