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Maximum potential storm surge under the present and future climates estimated by a coupled TC-ocean model

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Recently, there is growing concern that the average intensity of global tropical cyclones (TCs) is likely to be enhanced by the warmed sea surface in the future climate. According to the IPCC AR4 report, future-climate TCs possibly cause more serious disasters such as high wind, high wave and storm surge. To evaluate the TC-induced disasters with high-resolution grids, 2-dimensional TC models, which are typically based on empirical, statistical and parametric approaches, are used traditionally. However the 2-dimensional TC model is not capable of being applied to the future climate scenarios, because such an empirical approach is not necessarily consistent with TCs under the future climate scenarios. Therefore it is necessary to substantially revise the traditional methods and to improve our understandings of the maximum potential storm surge spawned by future-climate TCs.

In this study, we develop a fully dynamic algorithm for estimating the potential maximum storm surge under the present and future climates. The algorithm mainly consists of two essential components: 1) dynamic TC initialization and 2) dynamic storm surge estimation. The first component is aimed at initializing atmospheric conditions dynamically for an atmospheric model using the TCPV bogussing scheme, which is based on the combination of an axisymmetric TC model and an Ertel's potential vorticity inversion technique. The axisymmetric TC model, developed by Emanuel (1985), is intended to dynamically estimate the axisymmetric potential vorticity structure inside of a well-developed TC reaching to the maximum potential intensity under the present and future climate conditions. The Ertel's potential vorticity inversion, developed by Davis and Emanuel (1991), is used to inversely convert from the obtained potential vorticity fields to the initial atmospheric fields (wind vector, temperature, and geopotential height), which can be estimated to satisfy both of the dynamic and thermodynamic equilibriums. The TCPV bogussing scheme can arbitrarily control initial positions of TCs, resulting in controlling TC tracks in the atmospheric model, and is able to be adapted to a variety of situations in any region and in any climate by reasonably modifying the mean and/or anomalous potential vorticity fields in TC environment. The second component is aimed at dynamically simulating the storm surge height using a coupled TC-ocean model, which is based on MM5 (Dudhia, 1993) and CCM (Murakami et al., 2004). Initializing many TCs with many slightly different positions, the coupled model enables us to evaluate the maximum potential storm surge induced by a well-developed and worst-hit TC striking the target area.

A number of numerical experiments are conducted at 9km resolution, in which Typhoon Vera (1959) reaching a maximum potential intensity of about 910hPa (SST= 29.0 degree C) is initialized with many slightly different positions. Results indicate that the maximum potential storm surge at the port of Nagoya proves to be +4.5m MSL which exceeds the historical record (+3.5m MSL) brought by Typhoon Vera. On the other hand, to evaluate the climate change impact on storm surge, the Typhoon Vera's environment is modified based on the CMIP3 multi-model ensemble of the SRES A1B emission scenario. The TCPV bogussing scheme shows a maximum potential intensity of about 880hPa (SST=30.2 degree C) under the future-climate environment. The projected maximum storm surge at the port of Nagoya is expected to increase to +6.5m MSL in the late 21st century as a result of the global warming, indicating that the existing coastal facilities are insufficient to meet future needs for disaster prevention (see Figure).

Keywords: tropical cyclone, storm surge, climate change, TCPV bogussing scheme, TC-ocean coupled model

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