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# Impact of the interaction of surge, wave and tide on a storm surge on the north coast of Vietnam

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**Abstract**

In the present paper, the interaction of surge, wave and tide on the north coast of Vietnamis assessed using a coupled model of surge, wave and tide. A series of storm surge simulations for Typhoons Frankie (1996) andWashi (2005) are carried out, considering the effects of the tide and the wave that combines a wave dependent drag and wave-induced radiation stress to find out a predominant factor in the storm surge generation. Typhoon Frankieis landfalled at the low tide while TyphoonWashi landfalled at the high tide. The results indicate that the effect of the wave is crucial to the storm surge simulation. In particular, the wave induced-surge improves the accuracy of the storm surge level up to 30 %. It also shows that the surge induced by wave radiation stress is dependant with the space resolution, and the finest resolution is improved and in close agreement with the observation. On the other hand, the influence of the tide is ignorable for the case of Typhoon Frankie and considerable in the case of Typhoon Washi.


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*Keywords: Typhoon; storm surge; a coupled model of surge; wave and tide; interaction of surge*

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## 1. Introduction

To assess storm surges, there are two conventional types of physics-based numerical models: a decoupled model of storm surge, and a coupled model of surge, wave and tide. In the last three decades, coupled models have been paid attention to, especially focusing on the interaction of surge, wave and tide. Several studies have introduced wind stress as a function of waves (*e.g.*, Janssen[1,2]). Since then, a number of studies that examined wave-induced stress that is directly obtained in coupled models of surge and wave showed the significant improvements of the model results while comparing with observation data (*e.g.*, Funakoshi, Hagen, and Bacopoulos[3]; Kim, Yasuda, and Mase[4]; Zhang and Li[5]). Wave setup driven by a force of the divergence of radiation stress in the nearshore has also been studied with coupled models of surge and wave (*e.g.*, Bertin *et al.*[6]; Kim, Yasuda, and Mase[7]; Mastenbroek, Burgers, and Janssen[8]). It was found that the wave setup induced by the force of the radiation stress is substantial in the peak surge level during Typhoon Anita 1970 (*e.g.*, Kim, Yasuda, and Mase[7]). It was investigated that the tide-surge interaction is not negligible when estimating local surge levels (*e.g.*, Chen, Wang, and Zhao[9]; Choi, Eum, and Woo[10]; Kim, Yasuda, and Mase[4]). Besides the interaction of tide, wave and surge, topographic characteristics (*e.g.*, bed slope) also plays an important role in the increase or decrease of wave setup, runup and wind driven surge (*e.g.,* Dietrich *et al.*[11]; Kennedy *et al.*[12]).

For several decades, climate change impact studies have focused on storm surge studies in Vietnam (*e.g.*, Ninh[13]; Sao[14]; Thuy[15]). Conventional ways of two (or three) dimensional nonlinear shallow water equations have been used. In other words, in those studies other factors such as tides and waves were not taken into account in the storm surge model. Recently, the effect of waves on storm surge has been investigated in Vietnam. Hien *et al.*[16] showed that the wave setup induced by the force of the divergence of radiation stress is significant in the storm surge on the coast of Haiphong using empirical formula. Thuy *et al.*[17] found that the Typhoon Kalmaegi (2014) surge was significantly influenced by the waves on the Haiphong coast in Vietnam, obtained from numerical simulations using a coupled model of surge, wave and tide.

In the present study, the primary factors affecting storm surge on the north coast of Vietnam are quantitatively investigated using a coupled model of surge, wave and tide. In the study area, the tidal cycles are *diurnal* and the maximum tidal range is up to 3.6 m. Therefore, the tide is also taken into account in the simulation. The study highlights that coupling processes between surge and wave are critical to the prediction of storm surge on the north coast of Vietnam and only using a coupled model of surge, wave and tide (*e.g.*, SuWAT developed by Kim et al. [4]) is able to accurately estimate storm surges. A series of storm surge simulations are conducted for Frankie (1996) and Washi (2005) that consider the interaction of surge, wave and tide.

## 2. Method

To analyze the storm surge in the study area, the coupled model of surge, wave and tide (called SuWAT), developed by Kim, Yasuda, and Mase[4] was used. SuWAT is capable of doing parallel computations for an arbitrary number of domains using the Message Passing Interface (MPI). In the present study, three modules of surge, wave and tide are integrated into SuWAT as shown in Figure 1 that reveals the information of the flow among the modules and the domains. The tidal module provides only boundary conditions to the surge modules in the outermost domain. Coupling parameters include open boundary values, internal exchange among modules and domains in a machine. The calculations are sequentially carried out from the higher level domain to the lower level; the rest of the lower level domains wait for the completion of the higher level domain at a time step. This modeling system has been implemented and verified in other studies (*e.g.*, Kim, Yasuda, and Mase[7]; Kim *et al.*[18,19]; Mase *et al.*[20]).

### *2.1. Surge module*

The surge module solves the depth averaged nonlinear shallow water equations using the staggered Arakawa C grid in space and the leap frog scheme in time. The explicit finite difference scheme is used with the upwind method: