Typhoon Waves and Storm Surges Modelling based on a Coupled Wave-Current Model in the Bohai Sea

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ABSTRACT

In this study, a coupled FVCOM and SWAVE model was applied to simulate storm surges and extreme waves in the Bohai Sea during two tropical cyclones. The Jelesnianski’s typhoon model was adopted to calculate the spatio-temporal variations of air pressure and wind field in the computational domain. The simulated results reasonably reproduced the extreme waves and surges induced by typhoon events. It was demonstrated that typhoon winds and waves have significant effects on the longshore currents and the vertical distribution of flow velocities in shallow waters in the Bohai Sea.

KEY WORDS: Shallow waters; FVCOM-SWAVE; storm surge; wave-current interaction; wave-induced current

INTRODUCTION

As a potentially disastrous natural phenomenon, storm surge refers to the abnormal rise and fall of the sea surface caused by strong atmospheric disturbances, such as tropical cyclones (typhoons and hurricanes). Storm surge and extreme waves caused by strong winds can lead to widespread flooding of low-lying areas, which may lead to heavy casualties, particularly where there are large populations living near sea level, on islands, or on the flood plains of coastal estuaries (Brown et al., 2007). Therefore, providing accurate numerical predictions of extreme water levels induced by tropical cyclones or temperate cyclones has become essential for disaster prevention and damage mitigation in coastal areas.

In early storm surge models, wind stress force and atmospheric pressure gradients have always been regarded as the primary factors that cause the abnormal rise or fall of sea surface elevation during storm events. Actually, the dynamics of the air and sea interface are much more complicated due to the interactions between winds, ocean waves, and currents near the sea surface (Kim et al., 2008; Zheng et al., 2013). It has been demonstrated that the presence of wind waves has a strong influence on the process of water flux transfer (Delpey et al., 2014), nearshore circulation (Orescanin et al., 2014), and pollutant and sediment transport (Santoro et al., 2017) in coastal waters. Therefore, many simulations have coupled wind waves and surges to enhance the prediction accuracy regarding the interactions between storm surges and coastal beaches and structures (Dietrich et al., 2011; Ray et al., 2011; Yin et al., 2016). In shallow waters near coastlines, bathymetric features and geometric configurations are complicated. In these areas, wave propagation and wave-breaking zones are dependent on water levels and currents, which subsequently affect radiation stress gradients as wave transformations drive nearshore currents (Wolf, 2009). Furthermore, wind-driven waves are affected by the vertical momentum mixing and bottom friction in shallow waters, which in turn influence currents (Dietrich et al. 2011). When a typhoon arrives, strong wind stress generates enormous wave heights which have an obvious influence on water surface elevations and currents. Therefore, many studies have been carried out to highlight the importance of wind waves to storm surge and have investigated the wave-current interactions of various tropical cyclones in coastal areas. For example, Sun et al. (2013) applied the fully coupled model (FVCOM and SWAVE) to study the influence of current-wave interaction on storm surges using Hurricane Bob as a case study. Ferreira et al. (2014) used the hydrodynamics and the wave model of ADCIRC and SWAN to investigate the impacts of potential changes of land cover on storm surge due to sea-level rise. By coupling the SWAVE wave model and FVCOM ocean model, Grashorn et al. (2015) investigated the hydrodynamics and wave energy conditions during moderate wind and storm scenarios in the southern North Sea. Yin et al. (2017) applied the coupled ADCIRC + SWAN model to study the potential effects of sea level rise and typhoon intensity on storm surge and waves in the Pearl River Estuary, China.

As a coastal country, China has an area of more than 3 million square kilometers of ocean. Many coastal cities in China are threatened by storm surge during typhoon events. The Bohai Sea is a semi-enclosed sea with the highest latitude in China. It is adjacent to the Yellow Sea and composed of Liaodong Bay, Bohai Bay, and Laizhou Bay (Fig. 1). Due to its special geographical location, the Bohai Sea has experienced a relatively high number of storm surge disasters induced by typhoons (Feng et al., 2016). Numerous studies simulating storm surges in the Bohai Sea have been conducted in recent years. Zhao and Jiang (2011) investigated the effects of local coastline change on storm surge induced by cold-air fronts in the Bohai Sea using the FVCOM model. Feng et al. (2012) applied the ADCIRC model to investigate the impact of hurricane paths on storm surge in Bohai Bay. Wang et al. (2018) simulated 32 disastrous storm surge events in the Bohai Sea from 1985...