Effects of Coriolis Force on Storm Surge along West Coast of Japan Sea

Soo Youl Kim, Yoshiharu Matsumi
Department of Management of Social Systems and Civil Engineering, Tottori University, Tottori, Tottori, Japan

Tomohiro Yasuda, Hajime Mase
Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan

ABSTRACT
The present study shows that an asymmetrical meteorological field of pressure and wind reproduced by the mesoscale weather forecast model in a storm surge simulation is able to account for the highest surge elevation with a time-lag of 15 hours after making landfall of Typhoon Songda in 2004. It was found that Coriolis force in the momentum equations is a predominant factor of the highest surge elevation. This study also evaluates the effect of river discharges; however, there is insignificant contribution to the skew storm surge.

KEY WORDS: empirical typhoon model; mesoscale weather forecast model; storm surge; Coriolis force

INTRODUCTION
In Japan the highest storm surge elevations occur simultaneously with landfall of typhoons along the coasts of the Pacific Ocean, while the highest surges occur 10 ~ 15 hours after landfall for the Sanin Coast of the Japan Sea, especially, at Sakai Minato shown in Figs. 1a and 1b. The highest surge was, for instance, observed at Sakai Minato by Typhoon Songda (9th ~ 15th September 2004) which was located off the deep water near 40ºN. The abnormal surge elevations were measured at Sakai Minato during several typhoon events. From the measurements, characteristics of such the time-lagged highest surge along the Sanin Coast may be involved in a typhoon event:
1) typhoons are located off the coasts of the Japan Sea; and
2) typhoons are influenced by topography before making landfall or passing along the Sanin Coast.

While the numerous studies have been carried out for the storm surge in the Pacific Ocean, understanding of the storm surges with a time lag on the Sanin Coast in the Japan Sea is poor relatively. Yamashita et al. (2008) studied the storm event in the central Japan Sea in February 2008 using an atmosphere-ocean coupled model and observed tidal data. However, they did not take the delayed storm surge into consideration in the study.

Numerous studies have been carried out for estimating wind and pressure fields of a typhoon including several empirical typhoon models based on observed data (e.g., Fujita T, 1952; Schloemer, 1954; Fujii and Mitsuta, 1986). In general, the wind field is estimated based on the pressure gradient and accurate estimation is extremely complicated. To overcome the complication of empirical typhoon model, various solutions are proposed. Kawai et al. (2007) indicated that the wind and pressure fields in the Seto Inland Sea are more accurately reproduced by the PSU/NCAR mesoscale model (known as MM5) than empirical typhoon models. Yasuda et al. (2008, 2009ab) carried out for storm surge simulations in the Seto Inland Sea using meteorological forcing reproduced by the Weather Research and Forecasting model (WRF) developed by Skamarock et al. (2008) with 4 dimensional data assimilation and different nesting schemes.

In the present study, we represent the important factor of Coriolis force in the highest surge level at Sakai Minato in the Sanin Coast of Japan Sea due to Typhoon Songda. We will show that although the empirical typhoon model consisting of pressure gradient (Schloemer, 1954) and gradient wind speed formulae (Fujii and Mitsuta, 1986) has well simulated meteorological fields along the open coasts of the Pacific Ocean, the model estimated wind speeds are overestimated in comparison with the observed ones along the coast of the Japan Sea. In addition, a grade of typhoons changes from typhoon to tropical depression when the typhoon passes over 40ºN in deep water of the Japan Sea. But the empirical typhoon model includes no effects of topography on meteorological profiles and the change of the typhoon intensity. It is found that the wind and pressure fields due to Typhoon Songda are more accurately reproduced by the WRF than the empirical typhoon model. The effect of data assimilation in the meteorological field estimation of WRF was examined based on the conditions of different 4 dimensional data assimilation and nesting schemes. Finally, it is found that the effect of river discharge is small on the time-lagged highest surge elevation.

DESCRIPTION OF NUMERICAL MODEL
Coupled Model of Surge, Wave and Tide
To simulate the storm surge at Sakai Minato in the Sanin Coast of Japan Sea during Typhoon Songda, the coupled model of surge, waves and tides (named SuWAT) developed by Kim et al. (2008, 2010), was employed. In the present study, the tide was not considered since its variation is relatively small in the Japan Sea. Here we briefly describe the model. SuWAT is capable of containing multiple nested domains.