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A shallow water model for computing water level due to tide and surge along the coast of Bangladesh using nested numerical schemes

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Highlights

- Investigation of tide generating forces for the purpose of increasing accuracy in water levels.
- Offshore islands of the whole coastal belt along with coastal bending were incorporated.
- Nested numerical schemes were exercised to save computer memory space.
- Appropriate tidal regime over the model domain was generated by forcing the sea level to be oscillatory with the constituent M_2.
- Impacts of tide generating forces, offshore islands, river discharge and grid resolution on water levels were tested and water levels were found to be influenced by them.

Abstract

A vertically integrated shallow water model is developed for computing water levels due to the nonlinear interaction of tide and surge associated with some storms that hit the coast of Bangladesh. Emphasis is given on the investigation of tide generating forces for the purpose of increasing accuracy in water levels due to a storm. Offshore islands of the whole coastal belt along with the complex land–sea interface is modeled via stair step because of the application of a rectangular grid. Nested numerical schemes are exercised in this study to save computational cost. Appropriate tidal regime over the model domain is generated by forcing the sea level to be oscillatory with the constituent M_2 along the southern open boundary of the parent model omitting wind stress and tide generating forces. The previously generated tidal regime is introduced as the initial state of the sea for the nonlinear interaction of tide and surge. The model is applied to estimate water levels at different coastal and island locations of Bangladesh associated with the two recent storms AILA and SIDR that hit the coast of Bangladesh. The results simulated by the model are found to be satisfactory with observed data and reported results obtained through various investigations.

Keywords: Tide generating force; Non-linear interaction; AILA; SIDR; Finite difference method

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1. Introduction

Bangladesh is one of the most cyclone prone countries in the world, where most of the cyclone affected areas are concentrated. Every year during cyclones, the surge levels associated with cyclonic storms along the coast of the country become high even for a less intense storm and a lot of devastation takes place. The factors responsible behind the facts are extreme bending of the coastline, shallowness of water, offshore islands, huge discharge through the Meghna and other rivers, low lying islands etc. (see e.g., Roy [18], Debsarma [3], Rahman et al. [14–16], Paul and Ismail [11,12]). Moreover, the head of the Bay of Bengal is a large tidal range (difference between high and low tides) area with the highest range around the Sandwip island [19]. Therefore, the water level due to the tide–surge interaction becomes significantly high if a storm approaches the coast during a high tide period. Many analyses and prediction of water levels during storm surges taking into account some of the factors mentioned above have been made for this region of interest [12].

The first nonlinear tide–surge interaction model due to Johns and Ali [6] for the Bay of Bengal was conducted including the major rivers Ganga, Brahmaputra and Meghna and offshore islands, where the model was a stair step. In a stair step model, the coastal and island boundaries are approximated along the nearest finite difference grid lines. Therefore, accurate representation of the boundaries highly depends on grid resolution. Since the investigation was conducted without considering very fine resolution of grids, the coastal and island boundaries representation was somewhat different from reality. To incorporate these facts into account accurately, Roy [17] developed the model of Johns and Ali [6] by nesting a fine mesh model into a coarser parent model extending up to 15°N latitude in the Bay of Bengal. This study incorporated only two major offshore islands Sandwip and Hatiya of Meghna estuarine region accurately through proper stair step representation in the fine mesh model. It is to be pointed out here that the coast of Bangladesh is thickly populated with low lying big and small islands and the islands may affect surge levels in the region of interest. Considering the facts into account, Rahman et al. [14,15] investigated storm surge problem to incorporate coastal complexities closely, whereas Rahman et al. [16] investigated the same problem in polar coordinates for computational efficiency. But the studies [14–16] were used to predict water levels due to pure surge only. With a view to rectifying this problem, Paul and Ismail [12] investigated storm surge problem interacting tide and surge nonlinearly as well as incorporating coastal complexities of Meghna estuarine region and found water levels to be influenced by the factors mentioned.

Though a considerable number of studies have been carried out, so far, for the coast of Bangladesh, unfortunately, no attempt has been taken into account to develop an efficient model suitable for operational forecasting purpose for this region till now. One of the major problems for numerical modeling of storm surge along the coast of Bangladesh lies with the fact that fine resolution is required near the coast to incorporate its complexities. On the other hand, according to As-Salek and Yasuda [1], "owing to a high tidal range of about 4.5 m with a semidiurnal astronomical tide in the Meghna estuary, a difference of arrival time of the peak storm surge can lead to a great change in the maximum water levels". Murty et al. [10] reviewed the storm surge problem in the Bay of Bengal and concluded that "on the oceanographic side, a major difficulty lies in the interaction of surge and tide, a thorough understanding of both being necessary for accurate forecasting of the magnitude and time of peak water level". Thus high tidal range along the Meghna estuarine area is another factor that should be taken into account properly to predict water levels accurately due to the interaction of tide and surge. Again, according to Vatvani et al. [21], numerical treatment of tidal motion in coastal seas, prescription of tidal forcing along open boundaries is sufficient in generating the appropriate and accurate tidal motion in the model. However, for models of larger seashore, with sections of the deep ocean or large closed basins, the contribution of tide generating forces (TGFs) on the water motion can no longer be neglected.

In the present study, we intend to investigate the storm surge problem along the coast of Bangladesh extending the body forces with TGFs to enable accurate prediction of water levels due to the nonlinear interaction of tide and surge incorporating the coastal complexities accurately in the numerical schemes.

The present work thus is an improvement on that of the works by Rahman et al. [14–16] who derived storm surge models to predict only pure surge incorporating coastal complexities properly, and over all of the studies, conducted along the region of interest, with regard to the inclusion of TGFs.

The rest of the paper is organized as follows. Section 2 deals with the theoretical foundation. Details of numerical procedure is described in Section 3. History about the storms used in the study for the validation of the model is given in Section 4. Result discussion and validity of the model are presented in Section 5 and conclusion along with future opinioning is given in Section 6.