SOUTH CHINA SEA OCEAN TIDE SIMULATOR

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ABSTRACT: The work in progress to understand the tidal propagation for the South Asian Seas including Indonesia and Philippines is described using high resolution tidal models forced by equilibrium tide as well as co-oscillating tide at the straits. The tidal harmonics for TOPEX/Poseidon altimetry and at coastal and islands stations are used to give a new set of empirical co-tidal charts for principal constituents and can be used to improve the hydrodynamic tidal models. Some of results delivering tidal predictions over the whole area are presented and discussed for distribution of tides in the South China Sea. Also some of strategy to make real-time barotropic forecast are discussed in detail.

Keywords: Tidal propagation, tide simulator, The South China Sea

INTRODUCTION

The South China Sea (SCS) is a typical marginal sea characterized with the deep basin, shelf break, and shallow shelf (Fig. 1). The presence of many straits and channels further forms a complex topography. The water depth exceeds 5000 m in the deep basin, while shelves show the shallow water depth less than 100 ~ 200 m (Fig. 1). According to Zu et al. (2008), the SCS consists of a deep basin with two continental shelves (about 55% of the total size) along the north and southwest coasts. The northeastern part of the SCS connects to the East China Sea through the Taiwan Strait, and to the Pacific Ocean through the Luzon Strait. In the southern part of the basin, the SCS links with the Java Sea through the Karimata Strait, and with the Sulu Sea through several narrow channels between the Philippine Islands (Fig. 2). The tides in the South China Sea and the Java Sea area have been previously modeled with different interests with varying degree of reproduction (Thuy, 1968; Ye and Robinson, 1983; Roos, 1989; Rahman et al., 1990). As the multiyear altimeter dataset from the TOPEX/POSEIDON mission were available, the improvement of global tidal models by empirical method exclusively using data only (Schrama and Ray, 1994; Mazzega and Berge, 1994), assimilation using data and hydrodynamic modeling (Egbert et al., 1994) and hydrodynamic modeling (Provost et al., 1994) were performed. A model by DHL (Roos, 1989) was focused on coastal zone of the Java Sea with nested grids over the similar model boundary to our present model but its northern boundary was limited to middle part of the South China Sea. Provost et al. (1994) presented tidal results over the present modeling region using a FEM-based global model with reproduction of eight constituents for the removal of tides from T/P altimeter data.

The tidal characteristics of these regions were reported in many studies. According to Fang et al. (1999), the tidal regime, especially the semidiurnal tides, in SCS are complex and the tidal currents may be strong in the shelf but very weak in the deep basin. In addition, the complex and steep bottom topography of the SCS has a great influence on the wind-induced circulation and the distribution, propagation and dissipation of the tidal energy (Egbert and Ray 2000). Egbert and Ray (2000) showed that the higher frequency forcing from the tide should not be neglected in the circulation, mass and energy transport and ecosystem dynamics in the ocean because tidal current is a significant energy sources for mixing.

The aim of this study is to understand the tidal characteristics and propagation for the South Asian Seas covering the South China Sea (SCS). In this study, the on-going work to understand the tidal propagation for the South Asian Seas covering the South China Sea is described using the high resolution tidal model forced by co-oscillating tides at the straits and the equilibrium tide. The tidal harmonics developed by TOPEX/Poseidon altimetry (Matsumoto et al. 2000) are used to give the boundary condition for principal constituents to improve the hydrodynamic tidal model. The results of the tide computations over the whole area are presented and discussed for the distribution of tides in the South China Sea. Also some of strategies to make the real-time barotropic forecast are discussed.

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Numerical Simulation

A modeling technique that converts the model equations to a discrete form and allows the computation over spatially unstructured meshes has been used as a main component of a regional ocean tide simulator that takes advantage of more accurate representations of the coastlines, man-made dikes, coastal structures, and topographic features. Rather than refining the dynamic grid nesting technique to retain the finite difference scheme, we decided instead to adopt a finite element technique that permits more flexibility when fitting regular coastlines and allows bathymetry with elements of an arbitrary size, shape and orientation.

The Hydrodynamic Model

SELF (A Semi-implicit Eulerian–Lagrangian Finite-Element) model originally developed by Zhang and Baptista (1999) has been used which is an open-source community-supported modelling system, based on unstructured grids, designed for the effective simulation of 3D baroclinic circulation. It uses a semi-implicit finite-element Eulerian-Lagrangian algorithm to solve the Navier-Stokes equations (in either hydrostatic or non-hydrostatic form), written to realistically simulate a wide range of physical processes under atmospheric, ocean and river forcings. The high-order, stable and computationally efficient algorithm is used. The hydrostatic version of SELFE solves the 3D shallow-water equations, with Boussinesq approximations, and transport equations for salt and heat. The primary variables that SELFE solves are free-surface elevation, 3D velocity, 3D salinity, and 3D temperature of the water. Details for physical formulation of SELFE are described in Zhang and Baptista (1999). Semi-implicit schemes are applied to all equations; the continuity and momentum equations are solved simultaneously, thus bypassing the most severe stability restrictions (e.g. CFL). A key step in SELFE is to decouple the continuity and momentum equations via the bottom boundary layer. SELFE uses an Eulerian-Lagrangian method (ELM) to treat the advection in the momentum equation, thus further relaxing the numerical stability constraints. The advection terms in the transport equations are treated with either ELM or a finite-volume upwind method (FVUM), the latter being mass conservative.

In SELFE, unstructured triangular grids are used in the horizontal direction, while hybrid vertical coordinates – partly terrain-following S coordinates and partly Z coordinates – are used in the vertical direction. By taking a single vertical layer the 2 dimensional tide computation has been carried out in this study.

We consider a semi-enclosed sea including Java Sea southward, Celebes and Sulu Seas eastward and Ko Phuket – Pulu We westward.

The model domain is considerably large, covering from 100° to 125° east longitude and from 7° south latitude to 25° north latitude. Approximate mesh sizes in the region of interest were set to a few tens of meters enough to resolve the complex bathymetry of the tidal flat area, thus enabling a detailed representation of tidal characteristics in the modeled region.
In this study, the mesh system was recomposed using the conforming Delaunay triangulation (CDT) method and the boundary and topography information. We used GEBCO 30” bathymetry dataset for the depth of model domain. We made the fine mesh for Hong Kong and Cilegon City area, Indonesia, where POSCO, Korea will construct an integrated steel mill. The mesh size in the above two regions is 50 ~ 100 m. The model grid size of Zu et al. (2008) is about 10 km, and that of Fang et al. (1999) is 0.25 degree (about 27 km). Compared with two previous studies, it can be said that our model is based on high resolution. Fig. 3 shows the overall mesh system and the refined mesh in Hong Kong and Cilegon City. By allocating a single layer the vertical direction, the barotropic simulation of tides was performed. That is, we used the 2D model.

The tidal boundary condition for water elevation was determined from 8 major tidal constituents of the Japanese NAOTIDE database (Matsumoto et al. 2000) developed by assimilating TOPEX/Poseidon altimeter data. The realtime ocean tide simulation for the SCS was performed using nodal factor and equilibrium arguments. The time step was set to 400 seconds. The length of model run was 60 days starting from January 1st, 2009 and the initial part of 30 days was discarded. Harmonic analysis for 8 tidal constituents was performed during 1 month as a preliminary phase of constructing the realtime ocean tide model.

MODEL VERIFICATION

Tidal elevation amplitude and phase were calculated by the harmonic decomposition from the elevation results for the last part of 30 ~ 60 days in the simulation. The model verification was carried out by comparing the amplitude and phase at 118 tide stations from Fang et al. (1999) and University of Hawaiian Sea Level Center. The locations of these stations are shown in Fig. 2. Fang et al. (1999) commented that the tide data were obtained from several sources and hence the quality of these data varies significantly. For instance, the harmonic constants at some stations were obtained from the observation for only 1 or 2 days. The comparison was performed using the RMSE (Root Mean Square Error) for 4 tidal constituents and the stations of outliers are excluded. The absolute value of the ratio between the distance with the mean and the standard deviation over 2 was used in determining the outliers. The stations of outlier are indicated in white symbols. A total of 94 data were compared with simulation. Figure 4 shows the comparison charts for the amplitude of 4 major constituents and Figure 5 shows the phase comparison. Table 1 shows the RMSE excluding outliers of 4 tidal constituents and including outliers in brackets.
Fig. 4 Comparison of amplitude of 4 major constituents between calculations and observations

Fig. 5 Comparison of phase of 4 major constituents between calculations and observations
Amplitudes of 4 constituents were calculated showing the slight difference from observations, while phases are reasonably calculated in general. However, the verification for the phase of $S_2$ tide is the worst, which is the same as results of Fang et al. (1999). It is because that can be partially caused by the errors existing in the observed phase-lags due to small amplitudes. Also, the discrepancies in all verifications are attributed to insufficient model resolution.

Fig. 6 Reproduced tidal distributions of $M_2$, $S_2$, $K_1$ and $O_1$ constituents for the modeled region (solid lines for co-phase (degree) and dashed lines for Co-amplitude (cm)). Co-phase indicates Greenwich phase-lag (G).
Fig. 7 Model-produced cotidal chart for $M_2$ (left) and $K_1$ (right) constituent by Fang et al. (1999). Solid line: phase-lag (degree), dashed line: amplitude (cm). Co-phase indicates local time phase-lag (G).

(a) $M_2$ Amplitude (cm)  (b) $M_2$ Phase (degree)

(c) $K_1$ Amplitude (cm)  (d) $K_1$ Phase (degree)

Fig. 8 Empirical co-tidal chart using T/P-J altimetry for $M_2$ (left) and $K_1$ (right) constituent by Wang (2008). Co-phase indicates Greenwich phase-lag (G).
RESULTS AND DISCUSSION

Fig. 6 shows the reproduced tidal distributions of major constituents, \( M_2 \), \( S_2 \), \( K_1 \) and \( O_1 \) in the modeled region. In addition to the simulated tidal chart, tidal charts of \( M_2 \) and \( K_1 \) constituents derived from Fang et al., (1999) and Wang (2008) were presented for the comparison (Fig. 7 and 8). The tidal distributions of 4 major constituents are similar to the previous studies. The simulated amplitude of the semi-diurnal tide \( M_2 \) is generally small (less than 3 m) in the model area. The largest \( M_2 \) tide amplitude is simulated in the Taiwan Strait and the relatively large amplitudes are found in the south of Guangdong around Leizhou Peninsula and the northwest coast of Kalimantan, south of the Indo-China Peninsula, and around the western and southern parts of the Malay Peninsula. The amphidromic points are shown in the shelves including Gulf of Thailand.

The \( S_2 \) tidal chart is similar to \( M_2 \) tidal chart. The highest amplitudes of \( S_2 \) tide are observed near the positions showing the highest \( M_2 \) amplitude. In the case of \( S_2 \) tide, the high values are predominantly observed in the southeast coast of Kalimantan and Celebes Sea.

The K1 and O1 tidal charts show the amphidromic points in Gulf of Thailand and the K1 and O1 tidal amplitudes are larger than \( S_2 \) tide. The tidal amplitudes of semi-diurnal tide \( M_2 \) and \( S_2 \) are high in the eastern part of Leizhou Peninsula, while those of K1 and O1 tides are high in the western part of Leizhou Peninsula. Fang et al. (1999) reported that the amplification of semi-diurnal tides in the shelf sea east of the Leizhou Peninsula is much greater than that of diurnal tides. This pattern was described by Cao and Fang (1990) by means of the theory of Clarke and Battisti (1981). Generally, the tidal amplitude of K1 is higher than that of \( S_2 \), and is high in Sunda Shelf and Karimata Strait. Both K1 and O1 tidal charts show the degenerate amphidromic system centered at the middle of Vietnam coast. This figure is also exhibited in Fang et al. (1999). In addition, the amphidromic system is simulated in Gulf of Thailand.

REAL-TIME BAROTROPIC FORECAST ON SCS

In addition to comparison of tidal elevation amplitude and phase, we compared the simulated time series of water level during September 2009 with observations obtained from Hawaiian Sea Level Center (Fig. 9). The typhoon Ketsana passed through the South China Sea from east to west (Fig. 10 from http://agora.ex.nii.ac.jp/digital-typhoon). The wind data from ECMWF was prepared to surface boundary input during 2 month. Fig. 9 shows the time series of the observation, tidal prediction and the calculation of real-time barotropic forecasting structure for the last part of 49–62 days of the simulation.

Fig. 9 Water elevations of observation of Hawaiian Sea Level Center at five stations, tide prediction without meteorological force, and the calculation based on the regional real-time barotropic forecasting system.
Some differences are found, however generally the simulations are agreed well with observations. The peak positive surge at 28th Sep. in st.74 is underestimated but the negative surge at 29th Sep. in st.76 is represented very well. The differences are attributed to disagreement between the observation stations and calculation grid points, the mismatch of bottom friction coefficient, and the effect of shallow water depths.

CONCLUSIONS

The first step for the construction of the regional real-time ocean tide prediction was fulfilled by using the fine FEM model. The verification of the model was made through the comparison between the reasonably-simulated co-tidal chart for principal constituents, time-series of water level and the measurements.

The current study essentially aims at creating the real-time barotropic tide/waterlevel forecast system via the short term meteorological forecast for the South China Sea in connection with the next generation hydrographic survey for the new geodetic vertical datum correction and also for the navigational purpose. The long-term simulation for 18.6 years, moon's full synodic period was necessary to achieve this goal. The future works are oriented toward the long-term simulation based on a efficient modeling system with fine mesh system and large region, and considerable amounts of data storage and a large volume of computational results.

ACKNOWLEDGEMENTS

The study was supported by the project for the development of the marine environmental impact prediction system following the disastrous events funded by KIOST. The simulation was performed at the Supercomputing Center at Korea Institute of Science and Technology Information (KISTI).

REFERENCES


