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MODELING TIDAL CURRENT AROUND MOKPO, THE SOUTH WESTERN COASTAL ZONE OF KOREA

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ABSTRACT: This study provide modeling of tidal circulation around the Mokpo coastal zone (MC) using unstructured triangular horizontal grid by which high resolution is concentrated in the local region that reaches to 100 m. For this simulation, the 3D finite-volume ocean model FVCOM is applied for the numerical simulation. Only the astronomical tidal constituent M2 and its harmonic M4 are considered. By expanding open boundary to the shelf break of the East China Sea, only M2 elevation was specified on the open boundaries, and the generation of M4 tide around MC was observed, which is the representative criteria for the accuracy of the shallow water tide simulation. Around the intertidal zone of MC, wet/dry point treatment method incorporated in FVCOM was also used and tested its applicability in the level of resolution of this model.

Keywords: The yellow sea, shallow water tide, ebb dominance, unstructured grid, FVCOM

INTRODUCTION

Mokpo coastal zone (MC), located in the south-western tip of the Korean Peninsula, is bounded on the west by the Yellow Sea (YS) and on the south by Jeju Strait. The complex ria coastline of the south-western tip of the Korea, surrounded by almost 2000 islands, is encompassed by vast tidal flats, and the water depth of this region is only below 50 m. Mokpo have been traditionally the center of marine transport around South western part of Korea. The narrow channels in this region are oceanic links from YS to the ports around Mokpo. Furthermore, relatively large tidal current speed in this region makes this region as the most important candidate for the tidal current energy production. To describe accurate tidal current of MC enables the detailed prediction of sediment transport or lateral transfer of salt or pollutant which dominate the marine environment of south western coastal zone of Korea.

Because of the complex ria coast and many islands surrounding this area, model requires high resolution for the accurate reproduction of tidal circulation in this area. Shallow water depth and broad intertidal zone intensify the nonlinear effect of shallow water current which induces strong tidal asymmetry. Ebb dominance by basin hypsometry is known for the prominent characteristic of the tidal current in this area. Because M2 is dominant tidal constituent in the YECS, thus the M4 is dominant shallow water tide over the coast of the west coast of Korea. Local overtide generation depends on the nonlinear process in the propagation of M2 tide from offshore and dimensions of the coastal water in which they are generated. Therefore, reproduction of topography with high resolution along with well-description of flooding and drying of broad intertidal zone around many islands and shore determines the success of accurate shallow tide modeling in the study area.

This study describes the numerical test for the accurate simulation of shallow tidal current in MC on some specific horizontal resolution. Model covers entire YS and the current in MC did not simulated separately from the regional model. Triangular unstructured grid enables the element with relatively high resolution in horizontal grid to be only concentrated on the MC. FVCOM (Chen et al. 2003) was selected for the hydrodynamic model, which solves 3D primitive equation using finite volume method. Wet/dry treatment technique provided by FVCOM will be also tested for the simulation of ebb dominance. It will show whether it is appropriate to use wet/dry treatment in the regional scale model covering YS. To minimize the effect of one tidal constituent on tidal deformation of another in the multi-constituent tidal modeling, only the astronomical M2 tide was force on the open boundaries. Reproduction of M2's shallow water harmonics M4 will be considered as the criteria for the successful reproduction of tidal current in this region.

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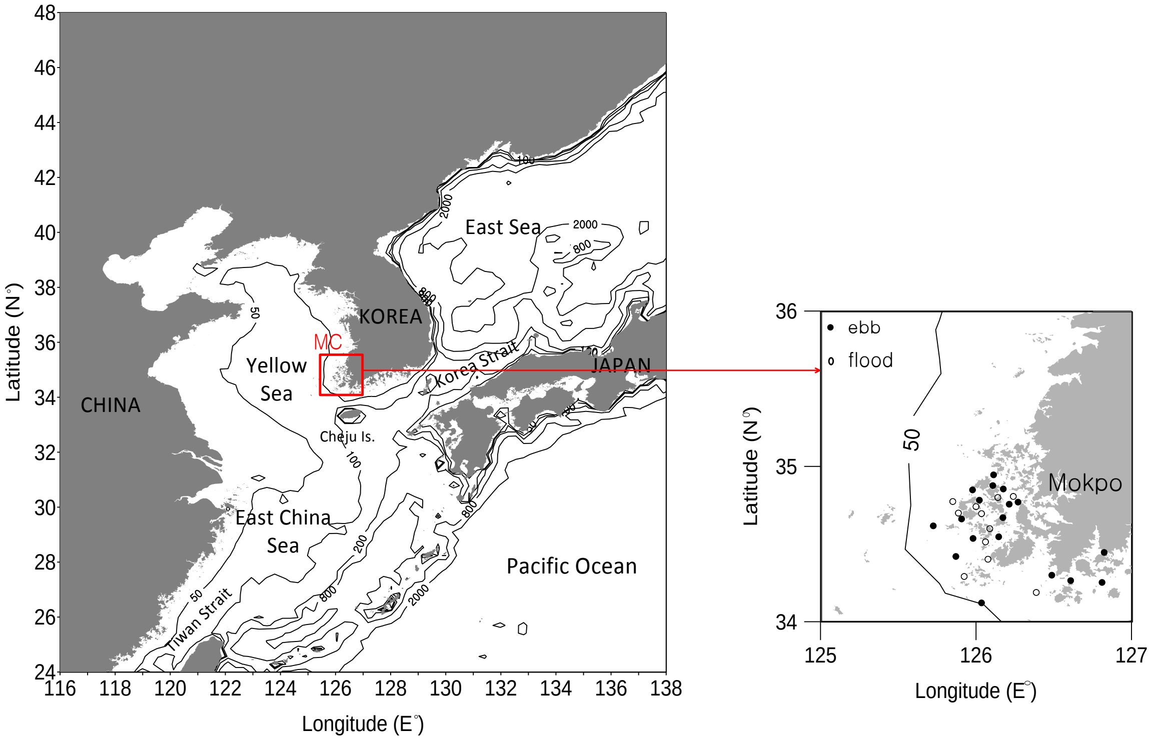

Fig 1. Bathymetry (in meters) and locations of the MC and tidal gauges in WCK selected for the evaluation of modeling accuracy.

MODEL SET-UP

Modeling area and horizontal grid

Because the Mokpo Coastal Zone (MC) occupies small part of the YS, grid nesting from regional model including YS is effective decision for the case of the structured grid modeling. However, nested model around the coastal region usually suffer from disturbances by unexpected numerical instabilities near open boundaries and the nonlinear tidal response near-shore. Especially in the study of shallow water constituent of tidal modeling, extracting open boundary condition of nested grid will be complicated because the lack of the tidal observation near nested boundary. Even when the existing global or regional tidal models are used for the extraction of open boundary condition, these models cannot provide the exact information of the shallow water constituent due to the resolution is not enough to reproduce generation of shallow water constituents. Therefore, the regional model of this study covers entire YS and the most of East China Sea (ECS) shown in Fig. 2, bounded by Taiwan Strait (A), a line of shelf break determined by 200 m isobaths (B), and Korea Strait (C). The open boundary is expanding to the shelf edge of YECS which is advantageous to use offshore co-oscillating tidal condition as boundary forcing.

The unstructured triangular grid in Fig. 2 has a horizontal resolution varying from 0.5 to 1 km in the west coast of Korea except MC region, 3 – 5 km in the East coast of China, and 10 – 30 km in interior of YS and ECS. The minimum size of triangles in MC is about 100 m and the average element size along the coastline of MC is about 400 m. A total number of nodes and elements of horizontal grid are 57,348 and 106,738, respectively, and the element number in MC is 74,734 which is 70% of entire element number. Thus, the effect of decrease in computational time will not be large enough when the MC region is nested from YS and computed independently. An enlarged view of the triangular grid in the MC is shown in Fig. 3, which shows a detailed fit of actual irregular coastline in this region.

For the water depth interpolated to horizontal grid, two sets of bathymetry data were applied; one is 'Skkutopo1min' (Choi et al, 2002) for regional topography and 'KorBathy1s' (Suh, 2008) for the topography of MC with high resolution. First, 'Skkutopo1min' was constructed based on the bathymetric maps provided by NGII (National Geographic Information Institute) of Korea and JODC (Japan Oceanographic Data Center), and referred altitude data of DTED (Digital Terrain Elevation Data) by NGA (National Geospatial- Intelligence Agency). 'KorBathy1s' is based on the 212 digital marine maps around the Korean Peninsula, surveyed by KOHA

(Korea Hydrographic and Oceanographic Administration) and published in 2007.

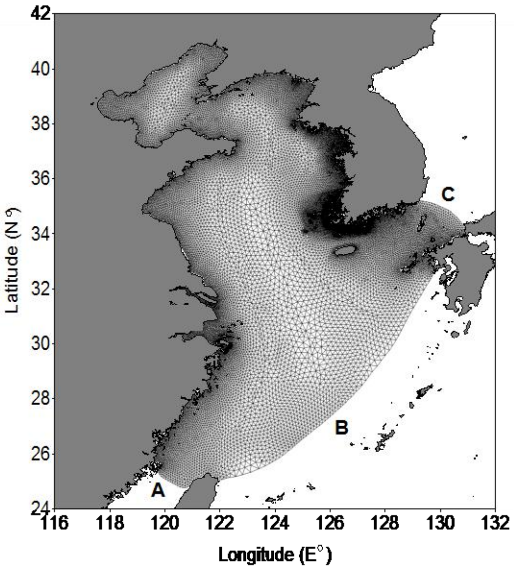

Fig. 2 Horizontal unstructured grid of the entire YECS. Labels A, B, and C indicate the sections of open boundaries where M2 offshore tide was specified.

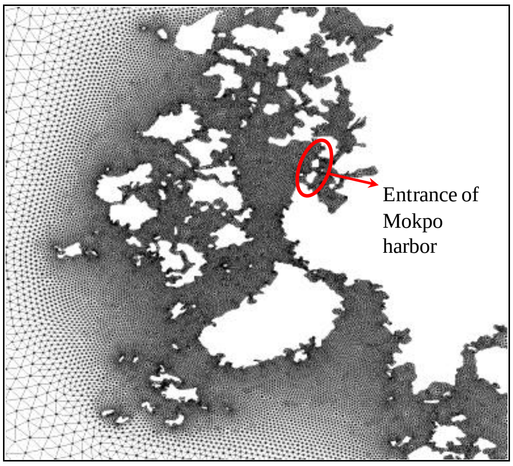

Fig. 3 Enlarged views of the unstructured grids around MC and the position of entrance to Mokpo Harbor.

Open boundary condition

Boundary conditions for tidal model are zero flow velocity normal to the coastline and specified elevations along the open sea. To obtain the open boundary condition of M2 constituent along boundaries A, B, and C, NAO.99Jb (Matsumoto et al., 2000) regional model was used. This model provides the resultant amplitude and phase of ocean tide around Korea and Japan with 1/12° resolution, covering from 110 – 165°E and from 20 – 65°N. NAO.99Jb was nested from NAO.99b. This global model provided open boundary conditions of regional model, and assimilation was performed with both Topex/Poseidon altimeter data and 219 coastal tidal gauge records obtained around Korea and Japan. In the model domain of this study, only M2 tide need to be specified on the open boundary adjacent to offshore.

Objective data

The model was evaluated by comparing its results with observations at the 29 coastal tide gauge sites around the Mokpo coastal zone (MC, inside the square shown in Figure 1). One month data of tidal current around MC was obtained from the 2005 observation of KHOA (Korean Hydrographic and Oceanographic Administration) (KOHA, 2005). The information of observation points are listed in Table 1.

Table 1 Measured tidal current data (KOHA, 2005)

Site	Period	Longitude	Latitude
06JD01	9.14 - 10.16	125.865	34.418
06JD02	9.14 - 10. 8	126.070	34.406
06JD03	9.14 - 10.16	125.918	34.295
06JD04	6.29 - 7.28	126.031	34.118
06SA01	8. 8 - 9. 9	126.108	34.946
06SA02	8. 8 - 9. 7	126.103	34.877
06SA03	9.15 - 10.15	126.171	34.855
06SA04	8. 8 - 9. 7	126.134	34.804
06SA05	8. 8 - 9. 7	126.233	34.811
06SA06	8. 9 - 9.10	126.209	34.756
06SA07	9.15 - 10.15	126.266	34.770
06SA08	8. 8 - 9.10	126.169	34.669
06SA09	8. 9 - 9. 9	125.973	34.849
06SA10	9.15 - 10.15	126.017	34.782
06SA11	8.17 - 9.19	125.993	34.745
06SA12	9.15 - 10.15	126.029	34.700
06SA13	8.17 - 9.19	126.082	34.603
06SA14	9.15 - 10.15	126.141	34.545
06SA15	8. 9 - 9.10	126.054	34.518
06SA16	9.15 - 10.15	125.844	34.778
06SA17	9.14 - 10.15	125.880	34.703
06SA18	9.14 - 10.15	125.902	34.661
06SA19	9.14 - 10.15	125.976	34.535
06SA20	9.14 - 10.17	125.719	34.616
06WD01	6.26 - 8. 4	126.822	34.444
06WD02	6. 1 - 7. 6	126.808	34.250
06WD03	6.27 - 7.28	126.484	34.297
06WD04	6. 2 - 6.27	126.606	34.262
06WD05	6. 2 - 7. 6	126.381	34.192

Among them, 31 records was found out to be ebb dominant point and plotted in solid circles (•), whereas flood dominant observation point was plotted as void ones. KOHA (2005) provided the tidal analysis of the recorded current at those gauges. M2 and M4 current data was extracted for the comparison with modeled tidal current.

RESULTS

FVCOM uses the wet/dry treatment method in which numerical grids consist of wet and dry points with a boundary defined as an interface line between land and water. It has been widely used to simulate the water transport over inter-tidal areas in estuarine models and used in unstructured grid with FVCOM by Zheng et al. (2003). However, using wet/dry treatment in computational modeling requires high quality of bathymetric representation which contains the detailed reproduction description of channel cross-section accompanied by intertidal zone. This requires accurate geometry surveying data and higher grid resolution with great computational efforts. It is necessary to find out that the wet/dry technique can be applied appropriately even in the regional model with minimum 100 m resolution is displaced in the interesting region. The first modeling without wet/dry treatment was performed after artificial deformation of topography. Bathymetry under 5 m water depth was determined as the minimum cutoff depth which means water depth smaller than 5 m was redefined as 5 m. In this bathymetry, bottom roughness effect was tested.

Effect of bottom roughness

Usually, at inlets where cross-sectional area of the channel and the bay area change with the tidal cycle, bottom roughness can contribute to the asymmetry of the channel tidal current. Mota Oliveria (1970) suggests that greater friction moves an inlet system toward flood-dominant behavior because head losses associated with higher friction bring about decrease in natural flushing capacity. Seelig and Sorenson (1978) found that shallower channels are more flood dominant than deeper channels when the friction factor was weakly decrease with increasing channel depth. Speer and Aubrey (1985) and also found via numerical simulations a trend toward flood dominance in shallow channels where friction increases.

In this study, different values of drag coefficient for quadratic friction law were tested to see the response of shallow tidal current in MC. 0.001 and 0.002 tried to be used as a drag coefficient of the quadratic friction law for the bottom stress. Two simulation results using drag coefficient with 0.001 and 0.002 are displayed in Figs. 4 and 5, respectively. In these figures, modeled major axes of tidal ellipse (denoted by Maj.) on each observation point are compared with the observed tidal ellipse for M2 and M4 constituents.

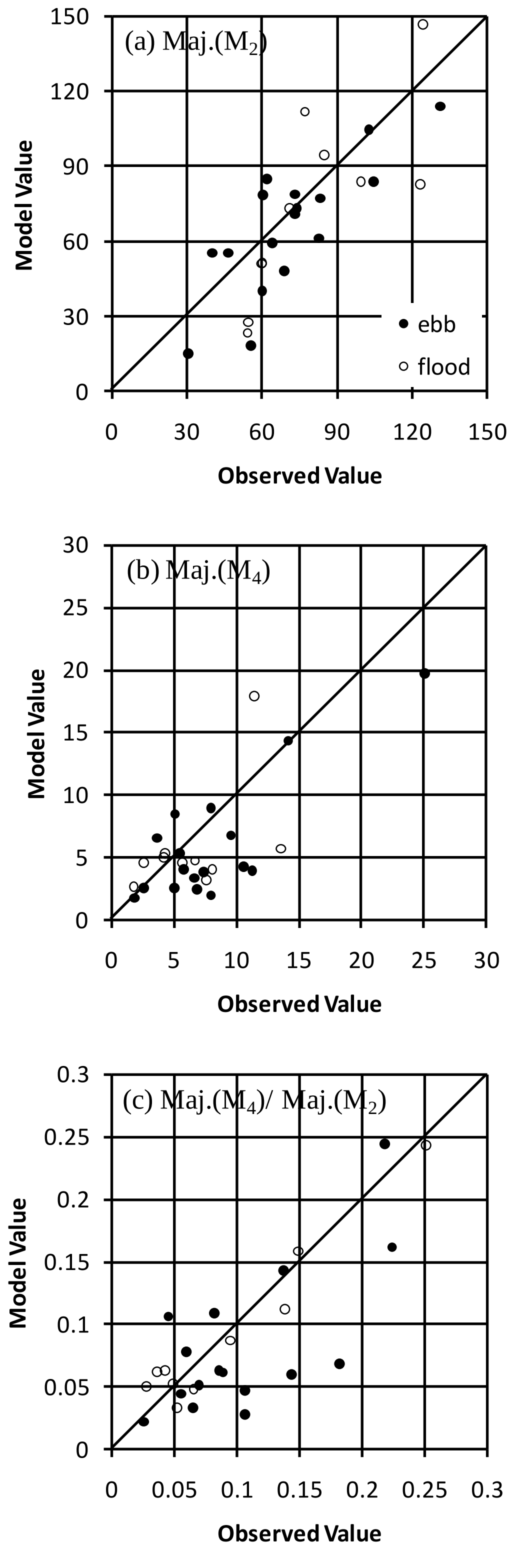

Fig. 4 Comparison between numerical model and observation for C_d = 0.001: (a) tidal current speed in major axis direction of M2 tide (cm/s), (b) and M4 tide (cm/s), (c) and the ratio between them .

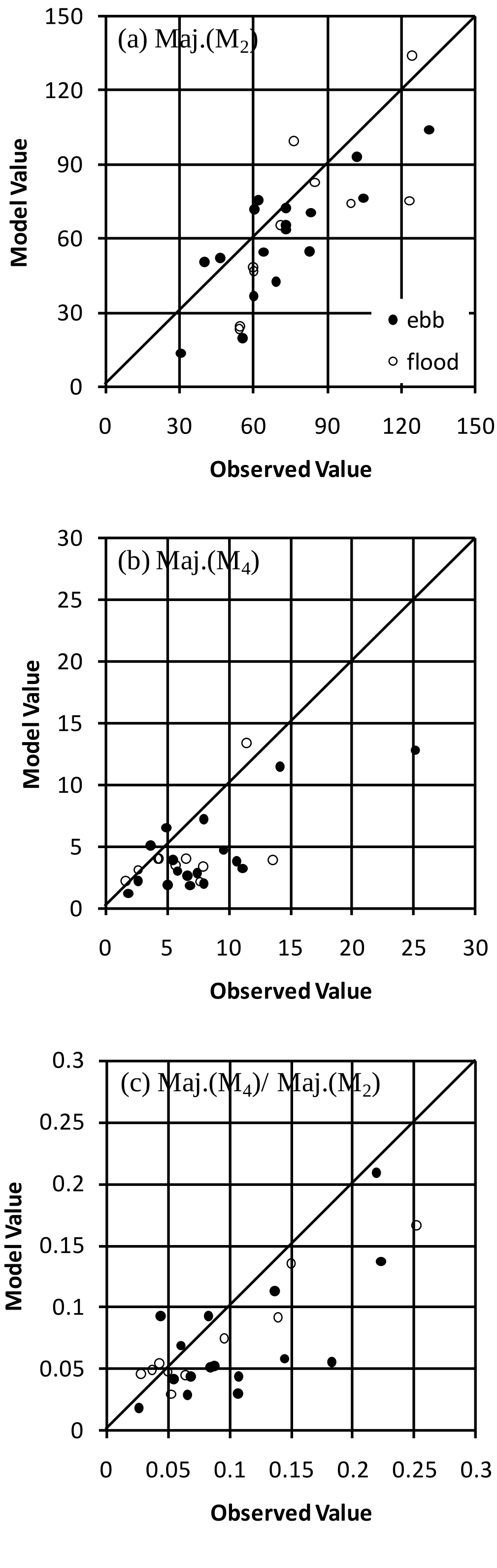

Fig. 5 Comparison between numerical model and observation for C_d = 0.002: (a) tidal current speed in major axis direction of M2 tide (cm/s), (b) and M4 tide (cm/s), (c) and the ratio between them .

For the identification of M4 generation in shallow coastal waters induced by M2 tide from offshore, the ratio of current velocity along major axis between M2 and M4 were plotted as in Figs. 4(c) and 5(c). Based on the observation results in Fig. 1, The current velocity on major axis on the ebb dominant point was denoted by solid circles (•), and values on the flood dominant point by void circle (°).

When the 0.002 was defined as C_d , modeled tidal current were underestimated both for M2 and M4 tide, compared to the model with C_d = 0.001. The ratio between the magnitude of major M2 and M4 current in Fig. 5(c) also shows the generation M4 from M2 outside was depressed by the increased bottom stress than the results in Fig. 4(c). The ratio between Maj.(M4) and Maj.(M2) from model results with C_d = 0.002 also underestimated the observation, especially in the higher M4 current velocity points.

Applicability of wet/dry treatment

Wet/dry treatment was found out to be not capable of reasonable reproduction of flooding and drying in MC with 100 - 400 m resolution. In some of observation points in Fig. 6(a), modeled M2 current are significantly underestimated the observations. These underestimated points are located near the entrance of Mokpo harbor, indicated in Fig. 3. Access to Mokpo harbor is through three narrow entrance called Mokpogu, Chunggu, and Pukgu (Kang, 1999). Because of narrow geometry of these channel entrances, the cross-section of them did not reproduced in detail with 100 m resolution. In the Mokpogu channel, only two elements were displaced across the channel which is not enough to describe the channel bathymetry. Channel depth interpolated from the elevation of adjacent land elevated the entire channel depth abnormally. As a result, channel functioned as barrier in the simulation with wet/dry treatment, which closed the water exchange through these channels. Therefore, the great flowrate through entrance of Mokpo harbor were disappeared and decreased the circulating velocity of water of neighboring seas.

DISCUSSION

Wet/dry treatment technique was applied for the tidal current modeling of South western coastal region with broad intertidal zone. With minimum 100 m resolution along the coastline, the flow pattern was not described accurately, especially in the current speed around inlet to Mokpo harbor. Because of poor representation of channel to sea of Mokpo Harbor, the water transport between the sea of Mokpo harbor and outside was blocked and the circulation pattern around this region was significantly distorted. Higher resolution should be used around the inlet channel to capture the accurate flow patter n in this area.

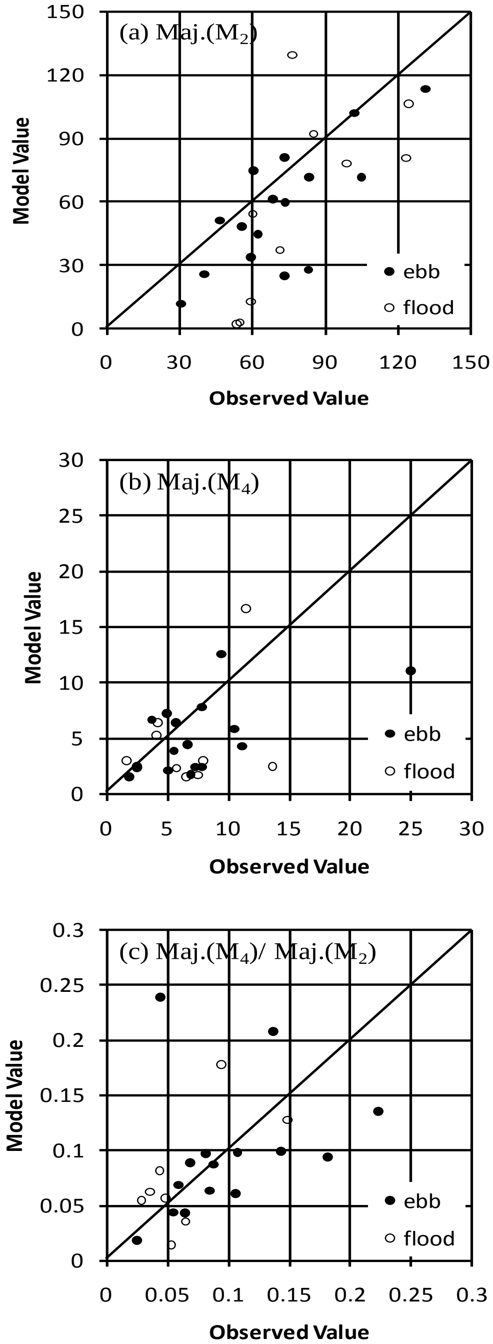

Fig. 6 Comparison between numerical model with wet/dry treatment and observation: (a) tidal current speed in major axis direction of M2 tide (cm/s), (b) and M4 tide (cm/s), (c) and the ratio between them .

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