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Tidal current modeling of the Caspian Sea using PMODynamics

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Abstract

Monitoring and Modeling studies of the southern Caspian Sea is one of the national projects, performed by the Ports and Maritime Organization (PMO). Simulating currents in the southern continental shelf regions of the Caspian Sea is one of the important parts of this project. To aim that, PMODynamics is applied. PMODynamics, Persian Model for Ocean Dynamics, is a 2D Iranian numerical model developed by Iranian modelers. PMO has invested on developing this software for coastal engineering studies. This study is focused on applying the hydrodynamic module of PMODynamics to simulate wind-driven currents in the southern continental shelf stations of the Caspian Sea. Considering of tidal body forces is one of the special capability of PMODynamics. In this paper effects of tidal currents in Caspian Sea in addition to wind driven currents simulated by PMODynamics. To validate the results, vertical current speed profiles have been measured for one year by ADCP at six stations called Anzali port and Amir Abad port (at 10 meters depth), Roudsar and Astara port (at 30 and 10 meters depth).

Keywords: PMODynamics, Current speed, tidal level changes, Caspian Sea

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1. INTRODUCTION

PMODynamics, Persian Model for Ocean Dynamics, is an Iranian numerical model developed for coastal engineering studies by the authors and some other hydrodynamic modelers in NAMROOD Consulting engineers. The Model is applicable in different fields of coastal engineering, including simulations of tidal currents, wind-driven currents and coriolis induced currents, currents in large scale environments (oceans), wave generated currents, large and small scale wave generation and wave propagation simulations, coastal morphology, sediment transportation and finally tidal analysis and tidal parameters extraction. Comprehensive information about PMODynamics software can be gained at http://pmodynamics.pmo.ir/en/home.

One of the important stages in a software development process, especially computational models, is utilizing the software for simulating different phenomena in the real situations in order to find probable computational problems and fix them. Although in the preliminary stages of the software development the verification of the developed software is performed by academic cooperation, un-predicted behaviors in the model may occur in other different situations by other different users. It is obvious that the more the model is tested, the more it makes it become valid. Hence, this paper aims to validate the computational engine of PMODynamics software in large scale water bodies. The current field of the Caspian Sea is simulated using the hydrodynamic module of PMODynamics. Time series of the depth-averaged current speed values in five stations located at the Iranian coasts are validated against the measured data.

2. MODEL SET-UP

In this paper, the 2D hydrodynamic module of PMODynamics is applied to simulate current field of the Caspian Sea. Bathymetry is constructed from the Caspian Environmental Program (CEP) data [1] combined more accurate bathymetry data for the southern part of the Caspian Sea. The CEP data are contour lines constructed from USSR hydrography data and the southern bathymetry is obtained from the Iranian National Cartographic Center maps with an accuracy of 1:25000. An unstructured triangular grid is applied as horizontal mesh for the 2D hydrodynamic model. The grid is finer in shallower areas with the highest resolution being 0.02 degree near the Iranian coasts and the coarsest resolution is 0.1 degree (Figure).

Figure 1. Unstructured triangular mesh applied in hydrodynamic model

In addition, a wind field with an accuracy of 0.1° modeled by the WRF model over the Caspian Sea [2] is applied. Wind velocity and pressure are set as inputs varying in time and domain. The Coriolis parameter and bed roughness are also set variable in domain. Although the tidal forcing is negligible in the Caspian Sea, tidal potential forcing is included to evaluate the effect of tides on sea level. The drag coefficient is set to be variable depending on the wind speed and based on the equation proposed by Wu (1980) [3].

In this study we focus on model results for the southern part of the Caspian Sea, especially near the Iranian coasts. Therefore, the model is calibrated and validated against measured current ADCP data in 5 stations (Figure) for two years from 2012 to 2013.

Figure 2. Location and water depth of available ADCP stations

3. MODEL VALIDATION

Reproducing correct peak values of current speed is essential in extreme value analysis. Therefore, in this study the capability of the 2D hydrodynamic model in predicting peak values of current speed is assessed. Figures 3 to 7 compare time series of observed and predicted depth-averaged current speed, after 24-hour filtering, at stations Amirabad 10m, Anzali 10m, Astara 10m and Astara 30m. The measured and predicted data are shown by scatter red points and blue lines, respectively. Quantile-quantile plots and statistical parameters are also illustrated for the results of the 2D model (Figure and **Error! Reference source not found.**). The comparisons are made for months which observational data is available. The statistical parameters include bias, root mean square error (RMSE), correlation coefficient (CC) and skill.

Overall, results demonstrate the very good performance of the 2D hydrodynamic model in simulating depth-average currents in storm conditions. The RMSE and bias values for all stations are low for both models. CC and Skill values are satisfactory for all stations except Amirabad 10m, where these values are low. It is speculated that the effects of Amirabad port coastal structures, which are not considered in simulations, account for the lower values. The main reason for the 2D model satisfactory performance is the effect of strong winds on the Caspian Sea currents. In storm conditions the water column is well mixed, resulting in a uniform vertical distribution of current field. This uniform distribution is also detected in observational data. Hence, application of 2D shallow water equation models for simulating currents in storm conditions in this region and also extreme value analysis is reasonable.

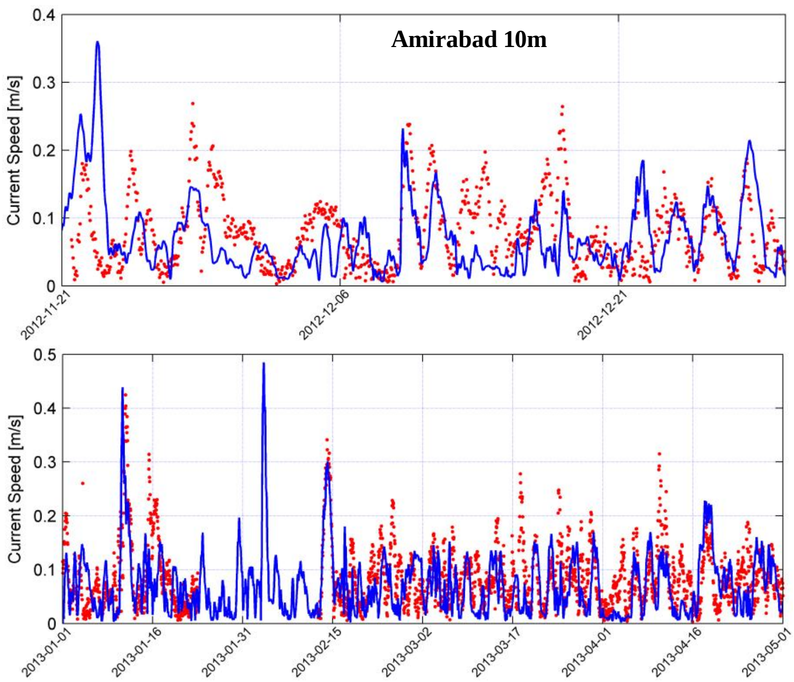

Figure 3. Time series of the simulated and observed current speed at Amirabad 10m

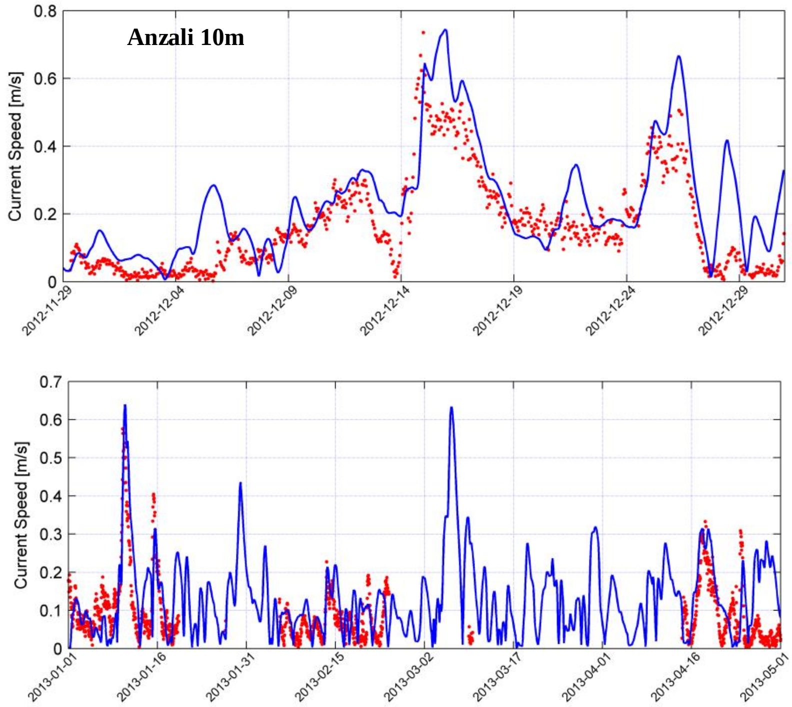

Figure 4. Time series of the simulated and observed current speed at Anzali 10m

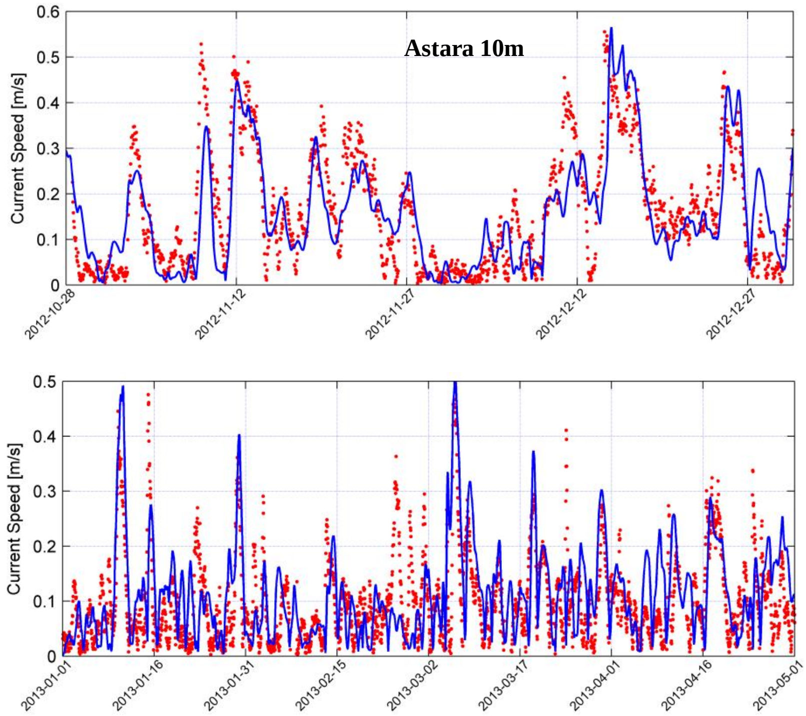

Figure 5. Time series of the simulated and observed current speed at Astara 10m

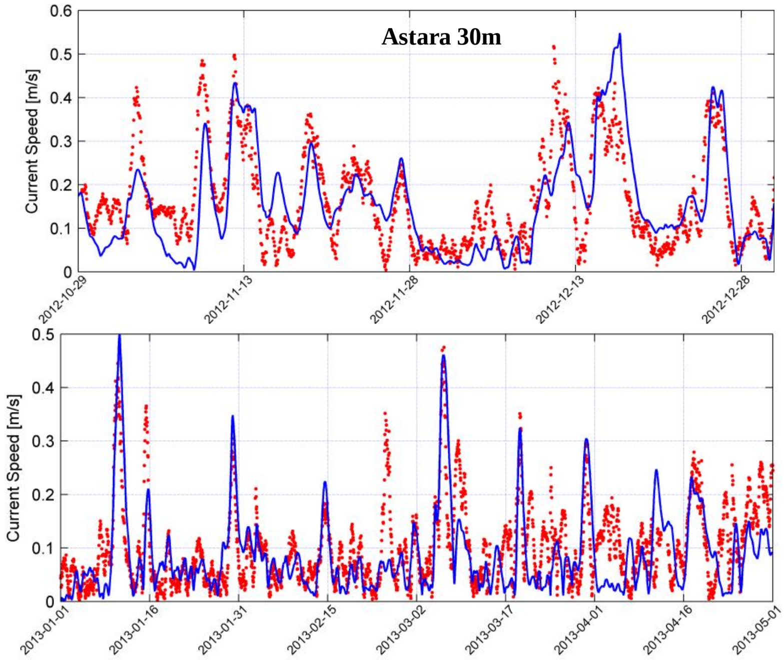

Figure 6. Time series of the simulated and observed current speed at Astara 30m

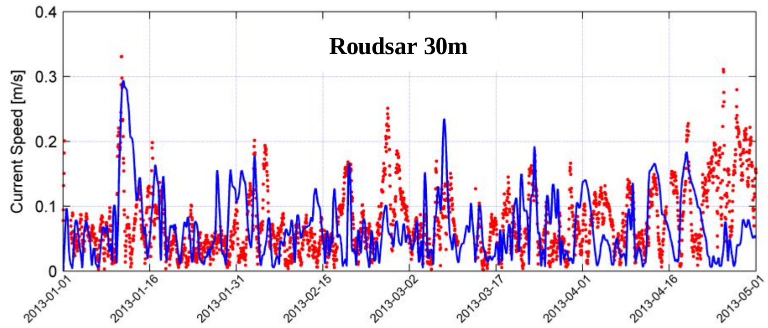

Figure 7. Time series of the simulated and observed current speed at Roudsar 30m

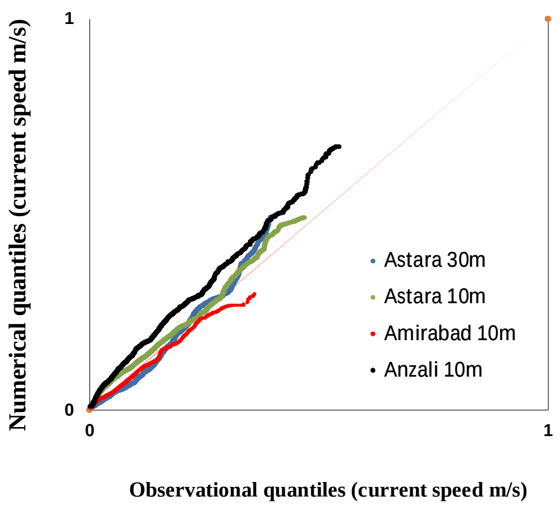

Figure 8. Q-Q diagram showing quantiles from measured and 2D model currents (after 24-h filtering)

Table 1- Comparison of calculated statistical parameters for simulated current speed at Iranian coasts

Stations	Bias	RMSE	CC	Skill
Amirabad 10m	0.01	0.05	0.53	0.73
Anzali 10m	-0.05	0.09	0.82	0.87
Astara 10m	-0.02	0.07	0.78	0.87
Astara 30m	0.01	0.07	0.73	0.85

4. TIDAL ANALYSIS AT ASTARA 30M

Observed water level data measured at higher frequencies (10-min periods) exhibit periodic and regular fluctuations with small amplitudes, as illustrated in Figure . Spectral analysis of water level also demonstrates two major peaks at the periods of 12 and 24 hours, indicating the presence of semi-diurnal and diurnal tidal constituents (M2 and K2). On this basis, for separating daily fluctuations that can be generated by the tidal effects, a 24-hour filtering is made on the water level data so that a markedly large part of tidal effects is masked out. Having subtracted the obtained time series from the first time series, one can gain the main part of tidal water level fluctuations (Figure). As clearly seen in Figure , the main periods of water level fluctuations are 12 h and 24 h, indicating the presence of tidal effects on water level changes at Astara 30m. The amplitudes of different tidal constituents at Astara 30m are tabulated (
) based on the tidal constituents' analysis using PMODynamics software developed in NAMROOD Company (http://pmodynamics.pmo.ir/en/home).

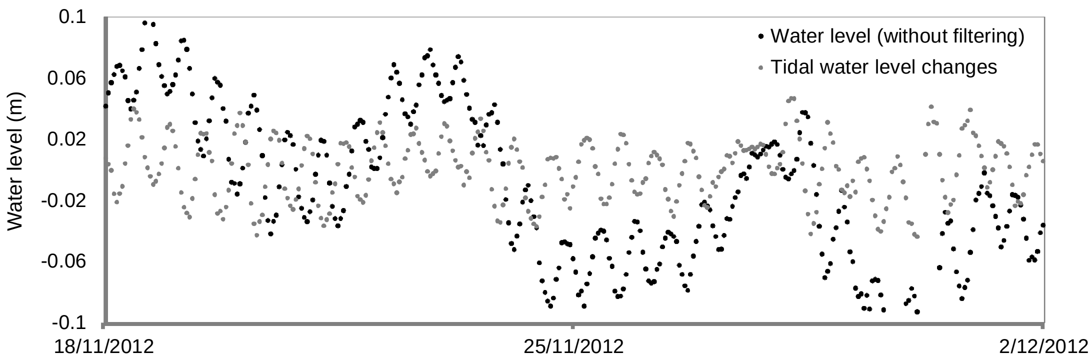

Figure 9. Time series of water level (without filtering) and tidal water level changes at Astara 30m

Table 2- Analysis of Tidal Constituents at Astara 30m

Constituents	Amp(m)-Obs
M2	0.0215
K1	0.0054
OO1	0.005
N2	0.0048
2Q1	0.0042
O1	0.0041
J1	0.0038
NO1	0.0028
SK3	0.0022
Q1	0.0018
UPS1	0.0017
S2	0.0015

5. CONCLUSIONS

An unstructured two dimensional shallow water equation model is used to simulate current field of the Caspian Sea. The grid resolution varies from 0.02° in Southern Caspian Sea to 0.1° in Middle and Northern Caspian Sea. Comparison of time series of observed and simulated current speed at the five stations indicates that the 2D hydrodynamic model can well simulate peak values of depth-averaged current speed occurring in storm conditions in continental shelf zone. The tidal analysis is made at Astara 30, this tidal analysis shows that tidal body forces in PMODynamics works properly in case study of Caspian Sea that do not have any open boundaries.

6. REFERENCES

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