Prediction of Tidal Elevations and Barotropic Currents in the Gulf of Bone

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Abstract. Tidal elevation and barotropic current predictions in the gulf of Bone have been carried out in this work based on a two-dimensional, depth-integrated Advanced Circulation (ADCIRC-2DDI) model for 2017. Eight tidal constituents which were obtained from FES2012 have been imposed along the open boundary conditions. However, even using these very high-resolution tidal constituents, the discrepancy between the model and the data from tide gauge is still very high. In order to overcome such issues, Green’s function approach has been applied which reduced the root-mean-square error (RMSE) significantly. Two different starting times are used for predictions, namely from 2015 and 2016. After improving the open boundary conditions, RMSE between observation and model decreased significantly. In fact, RMSEs for 2015 and 2016 decreased 75.30% and 88.65%, respectively. Furthermore, the prediction for tidal elevations as well as tidal current, which is barotropic current, is carried out. This prediction was compared with the prediction conducted by Geospatial Information Agency (GIA) of Indonesia and we found that our prediction is much better than one carried out by GIA. Finally, since there is no tidal current observation available in this area, we assume that, when tidal elevations have been fixed, then the tidal current will approach the actual current velocity.

1. Introduction

Tidal information is very important for those who work around coastal waters. In practical applications, the knowledge of the times, heights, and extent of the ebb and flood of tidal waters is of importance. This includes navigation for professional workers such as intra-coastal waterways; construction of bridges, docks, breakwaters, and deep water channels within bays and harbours and commercial fishing. This is also important leisure activities, for example recreational boating, surfing, and swimming [1]. Moreover, prediction of tide is also important for military in which they can use the information for operational planning and execution in marine environments. In addition, knowing the tidal elevation, at high tide, it can be used as beach landing, while at low tide at the same location may strand amphibious vehicles on muddy tidal flats. In addition, high tide can be used to generate electricity as well as wave height as renewable energy [2].

Similarly, prediction of tidal current is also important as it can affect the movement under the seafloor and the most important is for tidal current energy if they are very strong as shown in [3]. Therefore, in this present work, both tidal elevation and current will be predicted particularly for 2017. However, we will only consider barotropic current.
In order to achieve this goal, **ADvanced CIRCulation (ADCIRC) model** will be employed but it will be limited to two-dimensional depth integrated (ADCIRC – 2DDI) [4-6]. This model has been widely used and verified for ocean circulation and particularly to study tidal elevation and current, see for example in [1,7-10] and the references therein. As pointed out by some researchers, such as Zang et al. [11], open boundary conditions have significant impact for the regional tidal model. In fact, model output strongly depends on the tidal open boundary conditions. In order to overcome this problem, a Green’s function approach will be used. This method was developed by [12,13] and has been proven that the method is very powerful to optimize open boundary conditions for a regional tidal model [3,14,15].

This work will be presented in the following way. Short description of the location and model setup will be presented in section 2. Furthermore, model validation will be presented in section 3. In section 4, we will describe and show the method of optimizing open boundary conditions. Predictions of tidal elevation and barotropic current will be presented in section 5 and followed by summary and conclusion in section 6.

**2. Location and methods**

**2.1. Location of the Gulf of Bone**

Gulf of Bone is located between south Sulawesi and southeast Sulawesi provinces in Sulawesi Island which is one of the largest islands in Indonesia as shown in Figure 1. The area of this gulf is about 28,632 km² which are between longitudes 120.277° E and 121.688° E and latitudes 5.417° S and 2.610° S.

![Figure 1. Location of the study (https://fr.wikipedia.org/wiki/Golfe_de_Bone, https://upload.wikimedia.org/wikipedia/commons/9/93/Buton_Topography.png).](image)

**2.2. ADCIRC model**

A two-dimensional, depth-integrated version of Advanced Circulation model (ADCIRC – 2DDI) uses a depth-integrated equation of mass and momentum conservation which subject to Boussinesq, incompressible and the approximation of hydrostatic pressure. Even though this equation is based on shallow water equation, ADCIRC does not solve the primitive equation. Instead, it is based on the generalized wave continuity equation of the shallow water equation [5]. A complete set of equation can be found in [7,16,17] and the numerical implementations are documented in [4,5] and [18].
2.3. Model setup

The bathymetry data used in this research were obtained from the General Bathymetric Chart of the Oceans (GEBCO) in which its resolution is about 30 arc-seconds (~ one kilometre). Moreover, the bathymetry is freely available for entirely globe (https://www.bodc.ac.uk/data/hosted_data_systems/gebco_gridded_bathymetry_data/). For our study location, the bathymetry is presented in Figure 2b and the finite element mesh is shown in Figure 2a. The number of elements and nodes of the domain are 30,695 and 15,722, respectively. Moreover, the maximum grid is 8,495 m while the minimum grid is 397 m. Usually the minimum grid’s spacing is around the coastline and the maximum grid’s spacing is on the open boundary.

![Mesh and Bathymetry](image)

**Figure 2.** Features of Gulf of Bone (a) Mesh and (b) Bathymetry.

Eight major tidal constituents are imposed along open boundary conditions as it has been argued by some researchers that these eight constituents will be enough for tidal elevation and current simulation. From all eight major tidal constituents, four of them namely $K_1$, $O_1$, $P_1$ and $Q_1$ are diurnal tides while other four constituents which are $M_2$, $N_2$, $K_2$, $S_2$ are semi diurnal tides. Moreover, the phases and amplitudes of these tidal constituents will be obtained from FES2012 (*Finite Element Solutions* 2012) tidal database in which the resolution is $1/16^\circ$. This database was produced by Noveltis, Legos and CLS Space Oceanography Division and distributed by Aviso, with support from Cnes (http://www.aviso.altimetry.fr/).

3. Model validation

In order to verify the accuracy of the model, observation is needed to validate the model output. Fortunately, tide gauge is available in this location, even though the data are not free. In fact, the data have to be purchased from Geospatial Information Agency in Indonesia. This is the national surveying and mapping agency of Indonesia. The tide gauge is located near Palopo city which is the capital city of Luwu regency. The longitude and the latitude of the observation are 120.2098° E and 2.9834° S, respectively. Tidal component of the model and observation have been extracted using a harmonic analysis tool so-called *T_TIDE* [19]. The comparison between tidal elevations obtained from the
model and observation for 2015 and 2016 are presented in Figure 3 and Figure 4, respectively. The root mean square errors (RMSE) for each case are 11.58 cm and 11.46 cm, respectively. Moreover, correlation coefficient for case 2015 is 0.9765 while the correlation coefficient for 2016 is 0.9768. It should be noted that we have run two cases for prediction purposes. At the end, it is expected that two predictions with different starting time should not be different significantly. As a matter of fact, the model has been run for 200 days for each case but for simple presentation, only first 800 hours are presented.

![Figure 3. Tidal elevation comparisons between tide gauge data and ADCIRC model in 2015.](image)

![Figure 4. Tidal elevation comparisons between tide gauge data and ADCIRC model in 2016.](image)

### 4. Improving open boundary condition

Based on the previous results, we have been using high resolution tidal database but the discrepancy between model and observation is still large. In fact, as aforementioned, RMSEs for the cases 2015 and 2016 are 11.58 cm and 11.46 cm, respectively. Therefore, in this section, the amplitudes and phases of tidal constituents will be improved using Green’s functions approach. Full description of this method can be found in [12,13] and the implementation method can be found in [3,14,15]. Basically, in order to apply this method, one has to have an observation inside the domain of the simulation. This observation will be used to tune the tidal amplitude and phase of the tidal constituents imposed along open boundary conditions. Moreover, one needs to run perturbation for each parameter. Therefore, since we employ eight tidal constituents, 16 perturbations have to be run. Finally, the change of amplitude and phase of each constituent will be determined by Green’s function.

Furthermore, the corrected values of amplitude and phase for each constituent will be re-imposed along open boundary conditions. The comparison between tidal elevation and observation after applying Green’s function for the years 2015 and 2016 are presented in the Figure 5 and Figure 6, respectively. Root-mean square error (RMSE) for the case of 2015 decreased dramatically from 11.58 cm to 2.86 cm which is about 75.30%. Similarly, Root-mean square error (RMSE) for the case of 2016 decreased significantly from 11.46 cm to 1.30 cm which is about 88.65%. The correlation coefficients for these two cases are 0.9988 and 0.9997, respectively.
5. Prediction of tidal elevation and currents
Prediction of tidal elevation including validation and currents will be presented in this section. First of all, the validation of tidal elevation will be shown for two different cases. Then, the predictions of tidal elevation for 2017 will be presented. Finally, tidal current approximation will also be shown.

5.1. Prediction of tidal elevation and its validation
After applying Green’s function approach, the model, then, be run for 11 months which is from February to December 2015. In this case we suppose that the prediction was for three months. Furthermore, the model’s output is validated based on the observation data. This comparison is presented in Figure 7. As seen from the figure, it is difficult to differentiate between tidal elevation from model and observation. In fact, RMSE is quite small that is 2.47 cm.

Figure 7. Validation of the tidal elevation’s prediction in 2015.

Similar case has been carried out for the case of 2016 and the comparison with respect to observation is shown in Figure 8. The RMSE for this case is also very small, that is 1.84 cm which indicates that model’s output and observation are in an excellent agreement.
5.2. Predicted tidal elevation in 2017

As shown in the previous sub-section, the results for the cases in 2015 and 2016 are in a perfect agreement with respect to the observation. Using the improved tidal constituents that have been obtained from Green’s function approach for cases 2015 and 2016, in this part, the prediction for 2017 will be presented. Therefore, in order to use data from 2015, the model has to be run for 1065 days. The comparison between tidal prediction obtained from Geospatial Information Agency (GIA) of Indonesia and the model for 2017 which is based on 2015 data assimilation is shown in Figure 9. Although the figure shows a small different between GIA’s prediction and our prediction, we have shown that our prediction has much higher accuracy the GIA’s prediction. In fact, using the data in 2015 and 2016, we have shown that the RMSEs between observation and GIA’s prediction are 14.21 cm and 16.02 cm respectively (figures not shown).

Similarly, using the improved tidal constituents for 2016, the model has been run from February 2016 until December 2017. Tidal prediction based on Geospatial Information Agency (GIA) and model which is based on 2016 data assimilation is presented in Figure 10. Figure 11 reveals the comparison prediction for 2017 using two different starting time, namely based on 2015 and 2016 data assimilations. It is expected that both prediction should not have a very significant different. To this end, RMSE and correlation coefficient of these two predictions were calculated and we found that RMSE is very small, that is 3.52 cm. Similarly, correlation coefficient is very close to 1 as expected, which is 0.9979.

5.3. Barotropic currents

Since there is no observation for tidal current available in the study location, we could not compare our results with respect to observation. However, since tidal elevation has been validated which is in an excellent agreement with tide gauge data, it is a plausibility to assume that tidal current from the model is very close to the actual current. From our simulation, tidal current is quite weak around the
location which is less than 50 cm. One selected location has been chosen in which longitude and latitude are 120.7788° E and 2.9384° S, respectively. Predicted meridional and zonal velocities for 2017 are presented in Figure 12 and Figure 13, respectively. Moreover, the absolute tidal current at the location is less than 25 cm. The figure is not shown for simplicity.

Figure 10. Tidal prediction in 2017 based on GIA and the 2016 data assimilation.

Figure 11. Comparison prediction for 2017 based on 2015 and 2016 data assimilation.

Figure 12. Predicted meridional current velocity in the selected location in 2017.

Figure 13. Predicted zonal current velocity in the selected location in 2017.
6. Summary and conclusions

Tidal elevation and barotropic current for 2017 has been predicted in this work. Two different starting times namely 2015 and 2016 have been used and it is found that both prediction does not have a significant different. In fact, RMSE is only about 3.52 cm. We also found that our prediction is better compared to the prediction of Geospatial Information Agency.

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