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Accuracy Evaluation of Regional and Global Tidal Models (TPXO9 and Goddard Ocean Tide) at Kabil Tidal Station

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Abstract

Indonesia is an archipelagic country with a total marine area of 5.9 million km², consisting of 3.2 million km² of territorial waters and 2.7 km² of Exclusive Economic Zone waters, not including the continental shelf. With the vast waters in Indonesia, sufficient information about the tides is needed. Limitations of terrestrial tide data amidst the increasing need for marine information can be overcome by using global and regional tide models. This study uses the regional tidal data model released by BIG (Geospatial Information Agency) and the global tide model TPXO9 and GOT (Goddard Ocean Tides). From the two global tidal models, the tidal harmonic constant values are extracted at the tidal observation point in Kabil. Evaluation of global and regional tide models is carried out by comparing the amplitude values of the main harmonic constants of the tide models of global and regional tides with the amplitude values of the harmonic constituent of observation tidal data to obtain a comparison of accuracy. The results show that the smallest discrepancy value is shown by the GOT4.10 model compared to TPXO9 and regional model, which means that the GOT4.10 model is more suitable model to be used as a tidal prediction in the area.

Keywords: tide model, tide harmonic constituent, TPXO9, GOT

1. Introduction

Indonesia is a maritime country with a long coastline reaching 81,000 km. The consequence of the long coastline is the need for more tidal stations along the coastline to provide a true picture of tidal conditions. The lack of available tidal stations means that the need for tidal data on Indonesian waters cannot be accommodated.

Tide data is very important information for coastal area management activities. From these data, information on sea level and estimates of the highest and lowest sea water can be obtained as a reference for regional development and development. Tidal data is also important for use as a correction for SSH (Sea Surface Height) and SLA (Sea Level Anomaly) altimetry satellites, given the development of data acquisition technology using altimetry satellites which are increasingly prevalent. However, due to limited availability, tidal information in certain waters cannot be known.

The development of altimetry satellite technology such as TOPEK/Poseidon, ENVISAT, Jason-1, Jason-2, and Jason-3 for global tide modeling makes it possible to use it as a solution to overcome these limitations. Global tide models are classified into three categories, the first of which are models based on empirical tide models such as the DTU16, EOT20, and GOT (Goddard Ocean Tide) models. The second category is pure hydrodynamic models such as the HYCOM, HIM, and STORMTIDE model and the last category is hydrodynamic models which are assimilated with observational tide data such as the TPOX09, HAMTIDE, and and FES2014 models (Wang et al , 2021).

In addition to the global tide model, there is a regional tide model which is formed from the results of assimilation and validation with tide data in certain waters. In general, this tidal model has increased accuracy for these waters compared to the global tide model so that it is only suitable for use in these waters. However, the most suitable tidal model is not yet known, so it is necessary to identify the appropriate global and regional tidal models by comparing the tidal harmonic constants of a waters from the tidal model with the tidal harmonic constant values from field data (Lyard et al., 2006).

The European Space Agency (ESA) (2014) compared the GOT4.8 model with FES2004 using 7.5-year long-track residual data and Jason-2 and ENVISAT satellite data. The results show that the GOT4.8 model reduces residual variance to a greater extent than FES2004 in shallow waters. The reduced variance is greater than 25 cm^2.

Faridatunnisa (2015) conducted a study by evaluating the TPXO7 and FES2014 tide models. The results of the study show that the RMS value of each constant ranges from 7 cm to 28 cm for M2, 3 cm to 7 cm for S2, 2 cm to 3 cm for O1 and 1 cm to 4 cm for K1. The RSS values for the BIG model are 0.1411, 0.2948 for the TPXO7 model and 0.11035 for the FES2012 model, while the RSSIQ of harmonic constant value from tidal observations is 0.3846. The D value obtained for the FES2012 model shows the smallest result compared to the other two models. The D values of each model, namely the BIG, TPXO7-Atlas and FES2012 models were 36.6972%, 76.6712% and 28.6967% respectively.

In this study, an evaluation of the accuracy of the regional models issued by BIG and the global tide models TPX09 and GOT4.10 was carried out to determine the most suitable tidal model, in this case a case study was conducted in the Kabil region, Central Java. The smaller the difference between the tidal harmonic constants of the model and the tidal observation data, the better the tidal model is for use in certain waters (Fok et al., 2010).

The tidal model evaluation method used in this study is the analysis of control point data in the field. This method involves bilinear interpolation on the tidal constant grid model to determine the position of the tidal record available for later evaluation between the two. This method uses the calculation of the RMS deviation of the harmonic constants for each constituent j derived from the tide model compared to reference data in the field (Fok, et al, 2010). RSS (Root Sum of Squares) and RSSIQ (Root Sum of Squares of the In-Phase and Quadrature) values are used to determine the Discrepancy (D) value. The smaller the D value indicates the smaller the error or difference between the tide model and the terrestrial On the other hand, the larger the D value indicates the greater the difference between the tide model and the terrestrial data.

2. Method

2.1 Tidal Data

Kabil Tide Station (BATM) located at 1º 04' 23.29'' North Latitude and 104º 08' 11.72'' East Longitude. Figure 1 shows the tide station position relative to the water level reference.

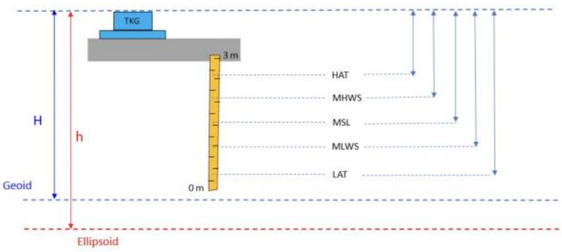


Fig 1. Tide Station Relative to Water Level at Kabil Tide Station

The observation tide data used is data for 15 years as presented in Figure 2. The tidal model data used are global TPXO9, GOT4.10, and Regional BIG data respectively obtained from the websites https://earth.gsfc.nasa.gov/geo dan https://www.tpxo.net/home in the same time period as observation tide data.

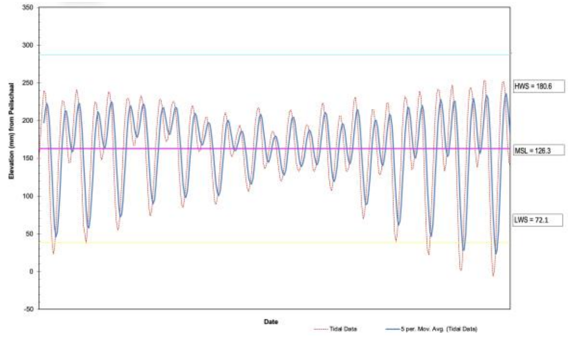


Fig 2. Tide observation data at Kabil Station

2.2 Data Quality Control

It is necessary to carry out quality control graphically and numerically on observational tidal data. Tidal data quality control is used to avoid spike data. Numerical quality control is carried out by calculating the standard deviation. The standard deviation for determining the value of the tidal error uses a confidence level of 99.7% or 3σ. In addition, graphic quality control also checks tidal data whether there are spikes or outliers.

Quality control is carried out on data for one month at a time. This data quality control will show the accepted and rejected data. The data received is data that meets the criteria for the left and right limits that have been determined. Rejected data is outlier data, namely data that is outside the left and right limits, including empty.

2.3 Tidal Harmonic Analysis

Tidal harmonic analysis was carried out to obtain the amplitude and phase constants of the tidal harmonics. Based on the repetition period, ocean tides can be classified into three the main components (Table 1) (Khusuma, 2008), namely:

1. The semi-diurnal component
2. The diurnal component
3. Long period components

Table 1. Tidal Constituent

Component	Symbol	Period (h)
Semidiurnal	M2	12.42
	S2	12.00
	N2	12.66
	K2	11.97
Diurnal	K1	23.93
	O1	25.82
	P1	24.07
Long Period	M4	327.86
	MS4	661.30

In this study, only two main diurnal harmonic constants, namely O1 and K1, and two main semidiurnal harmonic constants, namely M2 and N2, will be used. The harmonic analysis was carried with the least square method. The analytical equation with the least squares adjustment can be seen in equation 1 (Fok et al, 2010).

$$h(t) + v(t_n) = hm + \sum_{i=1}^{k} A_r \cos \omega_{i} t + \sum_{i=1}^{k} B_r \sin \omega_{i} t \quad (1)$$

where and is the i-th harmonic constant, k is the tidal component and is the hourly observation time. The magnitude of the mean water level calculated by equation 1 is close to the observed tidal elevation as a function of time if it meets the requirements of the law of least squares, namely the sum of the squares of the minimum residue. This condition is then derived against Ar and Br. Based on the least squares method, the completion of the harmonic analysis of the least squares method can be described as follows.

With the sea level quation L = AX, the correction equation V = AX-L shown in equation 2, with A is the coefficient matrix, L is sea level data, Ar is parameter A of the tidal-forming component, and Br is parameter B of the tidal-forming component.

$$v(t_n) = hm + \sum_{i=1}^{k} A_r \cos \omega_{i} t + \sum_{i=1}^{k} B_r \sin \omega_{i} t \quad (2)$$

The amplitude and phase of the tidal constituent are determined by equations 3 and 4.

$$A_i = \sqrt{Ar_i} + Br_i \quad (3)$$

$$g_i = \frac{Ar_i}{Br_i} \quad (4)$$

2.4 Extraction of Tidal Harmonic Constituent from Tide Model Data

The TPXO9 model is operated using TMD (Tide Model Driver) in Matlab which will display a GUI (Graphical User Interface). From the GUI it can be extracted the value of the harmonic constants at a certain time. In the GUI, you can choose the harmonic constants to be extracted based on coordinates that you can choose yourself in the GUI or based on a list of coordinates stored in a certain file format. Figure 3 presents a view of the TPXO9 model.

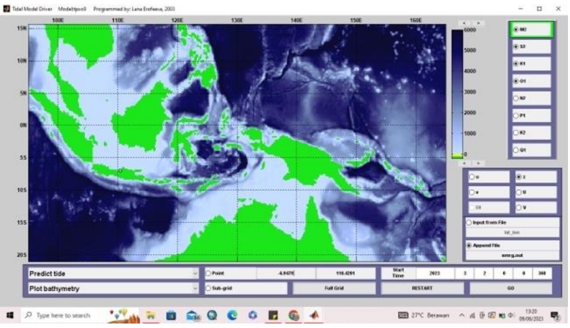


Fig 3. TPXO9 interface

In addition, GOT4.10 and BIG regional model has information in the form of tidal harmonic constituent values in *.nc data format (NetCDF File) which is then extracted using ODV (Ocean Data View).

2.4 Discrepancy Value Calculation

Discrepancy value (D) is a value that indicates the percentage difference between the tidal harmonic constant data from the ground station data and the tidal harmonic constant data from the model. The greater the value of D, the greater the error indicated in the tidal model compared to the tidal station (Fok et al., 2010). The D value is obtained by calculating the RMS, RSS, and RSSIQ values. The RMS describes the value of the harmonic constant for each constituent j which is derived from the tidal model compared to observation/reference data (Fok, et al, 2010).

$$\mathrm{RMS}_j = \sqrt{\frac{1}{2N}\sum_{i=1}^{N}\{[h_1^{sol}(i,j) - h_1^{ref}(i,j)]^2 + [h_2^{sol}(i,j) - h_2^{ref}(i,j)]^2\}} \quad (1)$$

where h_1^{sol}, h_1^{ref}, h_2^{sol} and h_2^{ref} are in-phase and quadrature tidal amplitudes with control points for each station i and constituent j and N are the number of locations where in-phase and quadrature amplitudes are calculated.

Furthermore, RSS (Root Sum of Squares) is the sum of the effects of n tidal constituents for each model. Root Sum of Squares of the In-Phase and Quadrature (RSSIQ) is a formula for estimating all tide model errors with field control data from RSS:

$$\mathrm{RSSIQ} = \sqrt{\frac{1}{2N}\sum_{j=1}^{n}\sum_{i=1}^{N}\{(h_1^{ref}(i,j))^2 + (h_2^{ref}(i,j))^2\}} \quad (2)$$

The discrepancy D that describes the error value or the difference between the tidal observation data and the tide model is described according to the following equation:

$$D = \frac{RSS}{RSSIQ} \times 100\% \quad (3)$$

3. Result and Discussion

3.1 Tidal Constituent

The diurnal harmonic constants used are K1 and O1 while the semidiurnal harmonic constants are M2 and N2. All constants were extracted from each model and then compared with tidal observation data. The tidal harmonic constituent values at the coordinates of the tidal station are shown in Table 2. Each model gives different harmonic constant values even at the same point location.

Table 2. Tidal Harmonic Constituent Value

Constituent	Amplitude			
	Observation Data	**Model BIG**	**Model TPXO9**	**Model GOT4.10**
O1	0,3063	0,4277	0,2005	0.3241
K1	0,2948	0,613	0.1531	0.3254
M2	0,6248	0,607	0.4283	0.4744
N2	0,2273	0,0961	0.0528	0.0996

The M2 constant is the moon's semidiurnal tides due to the average movement of the moon. Furthermore, the M2 constituent is called the main moon semidiurnal tide while N2 is the main sun semidiurnal constituent. O1 and K1 are the main diurnal constituent (Pugh, 1996). The tidal stations of Kabil has amplitude values of the main semidiurnal harmonic constituent that are more dominant than the values of the main diurnal harmonic constituent, as can be seen in Table 2 for all the model data and observation data.

3.2 Model Evaluation

The tidal model evaluation method is carried out by calculating the value of the difference (D) between the harmonic constituent from the tidal observation data and the model's harmonic constituents. The percentage of discrepancy is calculated from the RMS value of each harmonic constant. The RMS value is then used to calculate the RSS value. Harmonic constants from tidal observations are used as a reference for calculating the difference values by calculating the RSSIQ value from the harmonic constants of the tidal observation data.

The results presented in Table 3 show that the highest RMS value for regional model evaluation is the K1 constant, while the smallest RMS value is indicated by the M2 constant. The value of D in the evaluation of this model has a value of 46.303.

Table 3. Regional model evaluation

Constituent	Model Evaluation			
	RMS	RSS	RSSIQ	D
O1	0,085843	0,258379	0,558017	46,303
K1	0,225001			
M2	0,012587			
N2	0,092772			

Meanwhile, Table 4 shows that the largest and smallest RMS values in the global TPXO9 model are shown by the constants M2 and O1 respectively. The value of D in the TPXO9 global model evaluation has a value of 40.139, a difference of 6.164 with the regional model.

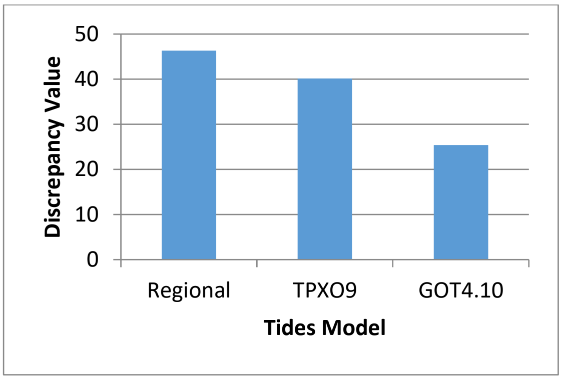
Table 4. TPXO9 model evaluation

Constituent	Model Evaluation			
	RMS	RSS	RSSIQ	D
O1	0,074812	0,223981	0,558017	40,139
K1	0,100197			
M2	0,138946			
N2	0,12339			

Table 5 which describes the evaluation of the GOT4.10 model has similar results to Table 4, where the largest and smallest RMS values in the GOT4.10 global model are shown by the constants M2 and O1. The D value in the GOT4.10 global model evaluation has the smallest value of all existing models, namely 25.401.

Table 5. GOT4.10 model evaluation

Constituent	Model Evaluation			
	RMS	RSS	RSSIQ	D
O1	0,012587	0,14174	0,558017	25,401
K1	0,021637			
M2	0,106349			
N2	0,090298			



Discrepancy value obtained from the model evaluation shows a different values between models. The smaller D value, the better tides model presented. This means that the difference between the model's harmonic constant and the tidal observation data owned by the model is smaller (Chayati and Nuraeni, 2021). From the model evaluation results, it is shown that the D values of the GOT4.10 model has the minimum value compared to all the models with 25,401. Meanwhile TPXO9 and reginal model shows similar D value with 40,139 and 46,303 respectively, with difference between the two models is only 6,164.

5. Conclusions

The smallest discrepancy value is shown by the GOT4.10 model compared to TPXO9 and regional model, which means that the GOT4.10 model is more suitable model to be used as a tidal prediction in the area.

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