Comparison of Global and Regional Tidal Models at Sekupang Tidal Station

1st Siti Noor Chayati
Geomatics Engineering, Dept of Informatic Engineering
Politeknik Negeri Batam
Batam, Indonesia
sitinoorchayati@polibatam.ac.id

2nd Sefi Nuraeni
Geomatics Engineering, Dept of Informatic Engineering
Politeknik Negeri Batam
Batam, Indonesia
sefinur.ani@gmail.com

***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. However, in reality the number of tidal stations targeted by the Geospatial Information Agency (BIG), which is as many as 400 stations, has not been fulfilled. The data used in this study include tidal data at Sekupang station, global model data TPXO9 and regional model data from BIG. The components studied are the main components M2, K2, O1, and S1 using the Least Squares Adjustment method. The minimum discrepancy value is shown by the TPXO9 model, which means that the TPXO9 global model is a more suitable model to be used as a tidal prediction model in the waters of Batam Island.**

Keywords—tides, TPXO9, regional model, harmonic constant

I. Introduction

Indonesia is the largest archipelagic country in the world. The total area of Indonesia's sea area is 5.9 million km², consisting of 3.2 million km² of territorial waters and 2.7 km² of waters of the Exclusive Economic Zone, not including the continental shelf. Judging from the total area of the area, most of the development will be carried out in coastal areas [1]. Tidal data contains information regarding the highest and lowest seawater estimates that can be used as a reference for the development of coastal areas and the construction of piers and ports. Therefore, sufficient tide stations are needed to provide tidal information throughout Indonesian waters. Indonesia until 2018 only had 139 tidal stations from a target of 400 stations under the coordination of the Geospatial Information Agency [2]. Due to the inadequacy of tidal data from tidal stations, it is necessary to use another alternative, namely by using a tidal prediction model to meet the need for tidal information. Some of the tide prediction models that are often used are the global TPXO prediction model and the regional model by BIG.

Tides are rhythmic fluctuations (movements up and down) of sea level due to the attraction of objects in the sky, especially the moon and sun, to the mass of sea water on earth [3]. In the earth-moon system, the tidal generating forces are caused by the resultant forces that cause the tides, namely, the centrifugal force of the earth-moon system (Fs) and the moon's gravitational force (Fb) [4] . The characteristics of the tides in some areas may vary. This is not only influenced by the attraction of the moon, but also by the morphology of the seabed, the shape of the coastline, and the characteristics of the waters themselves. In an area of water there can be two or one tides. [5] The types of tides in a water area can be categorized into four types, including:

- Semi-diurnal tide
- Diurnal tide
- Mixed prevailing diurnal tide
- Mixed tide prevailing semi diurnal

Variations in sea level at a particular location are expressed as a result of the superposition of various waves of tidal harmonic constants. Determination of the value of the change in amplitude and phase delay due to the attractive force of celestial bodies against the earth's equilibrium condition will later be expressed in a constant. These constants are referred to as harmonic components. [6] The dominant tidal constituents are the semidiurnal constituents M2, S2, N2, and S2, with periods of 12.42, 12.00, 12.66, and 11.97 h, respectively, and the diurnal constituents, K1, O1, P1, Q1, and S1, with periods of 23.93, 25.82, 24.07, 26.87, and 24.00 h, respectively.

Least Square Method is a formula used to get the best approximation value with minimal error. The goal is to use the least squares method so that the approximate value obtained is as close as possible to the actual situation in the field. In the Least Square method, suitability with field data is defined by the situation, where the square integral of the value of the difference in water level elevation results from calculations and measurements and minimal measurements (Least of square of error) [7]. The principle of this method is to minimize the difference between the composite signal and the size signal. [8] If *ht* is the water level observation data at time *t* and *h(t)* is the predicted water level, in the Least Squares method, the square of the difference between the observations and the model must be minimal. Therefore,

$$\sum_{k=1}^{n}[h_t - h(t)]^2 = minimal \quad (1)$$

The global tide model provides tidal modeling in all seas on he earth's surface, both in wide oceans and in coastal oceans which is built using altimetry satellite data for a certain period and several tide stations in the field. The TPXO-Atlas incorporates all local models except the Mediterranean Sea plus the Baltic Sea model. The Atlas model will fit coastal tidal stations significantly than the base model however still worse than the local model due to the smaller resolution [9].

In addition to the global tidal model, there is a regional tidal model in the territory of Indonesia, namely the tidal model made by BIG. The harmonic constants provided include K1, K2, M2, N2, O1, P1, Q1, and S2. The regional tidal model was created for a particular water area. The accuracy is increased in these water areas when compared to the global tidal model. The regional tidal model was obtained from several altimetry data and other datasets such as assimilated observational data at tidal stations.

II. METHODOLOGY

A. Tidal Data

In this study, 3 tidal data were used, namely tidal data for the Sekupang tidal station, regional model data by BIG, and TPXO9.1 global model data. Tidal data at the Sekupang station used is hourly observation data. The BIG regional model data is downloaded from the http://tides.big.go.id/pasut/konstanta/ page. The harmonic constants provided include the constants K1, K2, M2, N2, O1, P1, and S1. This data file has *.nc format (NetCDF.File) which contains Amplitude and Phase data. The TPXO9 model data is downloaded from the official website of OSU (Oregan State University) Tidal Data Inversion at http://volkov.oce.orst.edu/tides/. There are 4 data obtained in the extracted file, namely grid_tpxo9, h_tpxo9, u_tpxo9, and data model_tpxo9.

B. Research Method

The design activities are presented in Fig 1. In general, the research stages include tidal data collection, tidal data processing by handling blank data, data quality control, tidal harmonic analysis, and calculating RMS, RSS, RSSIQ, and D values.

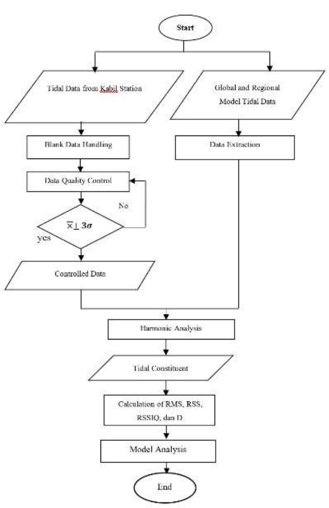

Fig. 1. Research design

C. Data Quality Control

After checking and handling tidal data, then the data will be quality controlled to see the quality of tidal data, by knowing the outlier or spike data, i.e. tidal data that is strange or out of most data, and offset data, i.e. tidal data that has a different height reference in the observation range. the same one. The tidal data quality control can be done graphically and numerically.

Numerical quality control is carried out by calculating the standard deviation/standard deviation to determine the value of the tidal error. The global test using a confidence level of 99.7% or 3σ is used to check tidal data.

Meanwhile, graphical quality control is also carried out to check the tidal data whether there are spikes or outliers. Fig 2 shows the results of data quality control graphically.

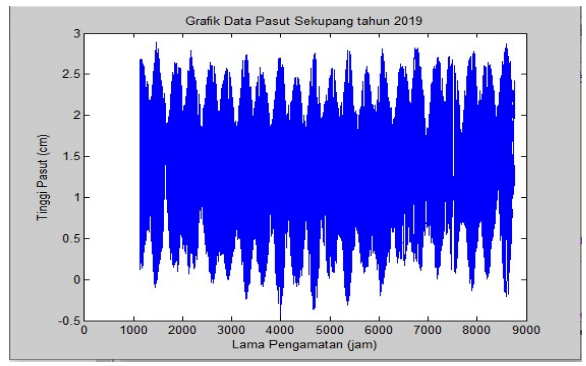

Fig. 2. Tidal data after quality control

D. Harmonic Analysis

Harmonic analysis was carried out to obtain the harmonic components present in the water level signal, in the form of amplitude and phase. In this research, we calculated the constituent of M2, S2, K1, and O1.

The analytical equation with the least squares count can be seen in equation 2[8].

$$h(t) + v(t_n) = hm + \sum_{i=1}^{k} A_i \cos(\omega_i t - g_i) \quad (2)$$

From equation 2, where:

$$A_i \cos g_i = A_r \ dan \ A_i \sin g_i = B_r \quad (3)$$

Therefore,

$$h(t) + v(t_n) = hm + \sum_{i=1}^{k} A_r \cos \omega_i t + \sum_{i=1}^{k} B_r \sin \omega_i t \quad (4)$$

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 A_r and B_r. Based on the least squares method, the completion of the harmonic analysis of the least squares method can be described as follows [8]:

- Equation of sea level observation L=AX

- The correction equation V=AX-L, shown in equation 5.

$$v(t_n) = hm + \sum_{i=1}^{k} A_r \cos \omega_{i^t} + \sum_{i=1}^{k} B_r \sin \omega_{i^t} \quad (5)$$

The amplitude and phase of the tidal components are determined by equations 6 and 7.

$$A_i = \sqrt{Ar_i} + Br_i \quad (6)$$

$$g_i = \frac{Ar_i}{Br_i} \quad (7)$$

The design of the tidal observation matrix is determined in equations 8, 9, 10 and 11.

$$_nA_k = \begin{bmatrix} 1 \cos \omega_1 t_1 \sin \omega_2 t_1 \ldots\ldots & \cos \omega_k t_1 \sin \omega_1 t_1 \ldots . \sin \omega_k t_1 \\ 1 \cos \omega_1 t_1 \sin \omega_2 t_1 \ldots\ldots & \cos \omega_k t_1 \sin \omega_1 t_1 \ldots . \sin \omega_k t_1 \\ \vdots & \vdots \\ 1 \cos \omega_1 t_n \sin \omega_2 t_n \ldots\ldots & \cos \omega_k t_n \sin \omega_1 t_n \ldots . \sin \omega_k t \end{bmatrix} \quad (8)$$

$$\mathrm{L} = \begin{matrix} h_1 \\ \vdots \\ h_n \end{matrix} \quad (9)$$

$$\mathrm{X} = (A^T PA)^{-1}(A^T PL) \quad (10)$$

$$_kX_i = \begin{bmatrix} h_0 \\ A_i \\ \vdots \\ A_k \\ B_1 \\ \vdots \\ B_k \end{bmatrix} \quad (11)$$

Where,

L : sea level data

A : coefficient matrix

V : correction value

A_r : parameter A of the tidal-forming component

Br : parameter B of the tidal-forming component

Ω : angular velocity of harmonic wave

t : observation time

E. Tidal Model Evaluation

The evaluation of the tidal model was carried out to determine the value of D in each tidal model. The smallest D value is the best value, which means that the model is the most suitable for use in these waters. To calculate the RMS (Root Mean Squares) value between each tidal harmonic constant from the station data and the model data, equation (12)[10]:

$$\sqrt{\frac{1}{2N}\sum_{i=1}^{N}\{[h_1^{sol}(i,j) - h_1^{ref}(i,j)]^2 + [h_2^{sol}(i,j) - h_2^{ref}(i,j)]^2\}} \quad (12)$$

The RSS (Root Sum of Squares) value is the value of all effects of the tidal harmonic constant for the model with tidal stations. Using equation (13)[10].

$$\mathrm{RSS} = \sqrt{\sum_{j=1}^{n} RMS_j^2} \quad (13)$$

The RSSIQ value is an estimate of all errors (errors) between the model and the tidal station obtained previously from the RSS value. Using equation (14) and equation (15) for D value [10]:

$$\mathrm{RSSIQ} = \sqrt{\frac{i}{2N}\sum_{j=1}^{N}\sum_{i=1}^{N}\{(h_1^{ref}(i,j)^2 + h_2^{ref}(i,j)^2)\}} \quad (14)$$

$$\mathrm{D} = \frac{RSS}{RSSIQ} \times 100\% \quad (15)$$

III. Result and Discussion

A. Data Quality Control

Based on the results of checking the tidal station data in Table I, it is known that the amount of data rejected by the Sekupang tidal station is 14.46% while the percentage of data accepted is 85.56%.

TABLE I. TIDAL DATA AT SEKUPANG STATION

STDEV	0,11291923
Total Data	8761
Accepted Data	7495 (85,55%)
Rejected Data	1266 (14,46%)

B. Tidal Constituent

From the data in Table II, it is known that the amplitude value for each tidal component has a significant status. The highest amplitude value is found in the tidal constant M2, it indicates that the area is dominated by the main semidiurnal tide which is more dominant than the main diurnal harmonic constant value.

TABLE II. MAIN TIDAL CONSTITUENT FROM SEKUPANG TIDAL STATION

Constituent	**Amplitude (cm)**	**Status**
O1	0,2269	Significant
K1	0,2775	Significant
M2	0,7929	Significant
S2	0,3261	Significant

In Table III, each model provides a different value for the harmonic constant even at the same point location. This difference is because the data used in the formation of the model is different. As in the BIG model, this model is made from the TPXO model which is assimilated and validated using tidal observation data. The difference in constant values between models is only in the millimetre to centimetre fraction so that it does not provide a large difference in the range of amplitude values or when used for correction.

TABLE III. MAIN TIDAL CONSTUTUENT FROM TIDAL MODEL DATA

Constituent	**Amplitude of Tidal Model Data (cm)**	
	Global Model TPXO9	***Regional Model BIG***
O1	0,1852	0,2578
K1	0,1643	0,2649

Constituent	Amplitude of Tidal Model Data (cm)	
	Global Model TPXO9	*Regional Model BIG*
M2	0,4942	0,5131
S2	0,2158	0,1855

C. Model Evaluation

TABLE IV. TIDAL DATA AT SEKUPANG STATION

Regional Model				
Constituent	*RMS*	*RSS*	*RSSIQ*	*D*
M2	0,378	0,420	0,665	63,137
S2	0,043			
K1	0,167			
O1	0,059			
Global Model TPX09				
M2	0,299	0,348	0,665	52,364
S2	0,110			
K1	0,113			
O1	0,084			

In Table IV and Fig 3, it is known that the highest constant value in the two tidal models, namely the M2 constant in the regional model is at a value of 0,378 while for the global model TPXO9 is 0,299. The same thing happened to KI value, with 0,167 and 0,113 for regional model dan global model respectively. On the other hand, RMS value for S2 and O1 of regional model has lower value than the global model TPX09.

The TPXO9 global prediction model has a resolution accuracy of 1/30°×1/6° which is assimilated data. This also affects the resulting elevation results. The minimum error value shows the tidal prediction model has a small error rate and a high level of accuracy.

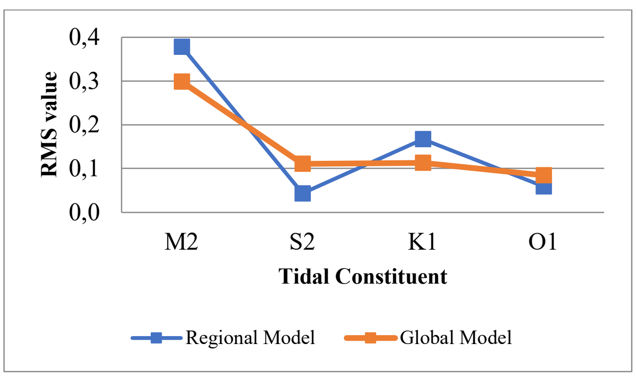

Fig. 3. Comparison of RMS value for both data models

Table IV shows that the RSS value for regional model is bigger than the value of global model TPX09. The RSSIQ value in both data models has a value of 0.665 which indicates that the estimates of all errors between the tidal model and the Sekupang tidal station obtained previously from the RSS value are not significantly different.

The discrepancy value obtained shows different values between models. The best model is the model that has the smaller D value. This means that the difference between the model's harmonic constant and the tidal observation data owned by the model is smaller. From the calculation results, it is known that the D values of the regional model and global models are 63,137 and 52,364, respectively, which means that the smaller D value is the TPXO9 model. This is possible because the TPXO9 model has a denser grid so that it can perform better data interpolation.

IV. CONCLUSION

From the research result, it is known that the dominant tidal component is the M2 tidal constituent, this indicates that the area is dominated by the semidiurnal tide which is more dominant than the value of the diurnal harmonic constituent. The minimum discrepancy value is shown by the TPXO9 model, which means that the TPXO9 global model is a more suitable model to be used as a tidal prediction model in the waters of Batam Island.

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