Validation of Badan Informasi Geospasial Tide Model in the Sunda Strait Waters using Sebesi Island Tide Gauge Data

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Abstract. Badan Informasi Geospasial (BIG) has developed tide model using 128 tide gauges (TG) data in 2015. During the period of 2016-2020 BIG has established new 31 TG and these stations have not yet been included into the model, one of them was Sebesi TG located in Sunda Strait. The aim of this research was to validate the BIG tide model using latest data of Sebesi TG by comparing Harmonic Constituents (HC) and tide prediction. HC to be compared were M2,S2,N2,K2,K1,O1,P1,Q1 from BIG tide model and Sebesi TG data. Each HC were used to generate tide predictions for August 10-20, 2020 compared with Sebesi TG raw data. HC comparison results showed the maximum amplitude difference was S2(0.011 m) and minimum was Q1(0.001 m). The maximum phase difference was Q1(14.2170) and minimum was N2(1.4510). The RMS generated for tide prediction using BIG tide model HC compared to TG raw data was 17.788cm, while RMS generated for tide prediction using HC from Sebesi TG data compared to TG raw data was 17.707cm. The correlation between raw data and tide prediction using BIG tide model HC was 0.977 while the correlation between raw data and tide prediction using Sebesi TG HC was 0.980.

1. Introduction
Indonesia is an archipelagic state that has oceans with diverse characteristics. One of the factors that causes the diversity of marine characteristics is ocean tide. Tides are events of rising and falling sea levels caused by the attractive forces of celestial bodies, especially the moon and sun [1], [2], [3]. This phenomenon of rising and falling sea levels can be recorded into tidal data using tide gauge. Tidal data can be analyzed to obtain harmonic constants i.e. tidal wave forming constituents consisting of amplitude and phase [3]. One of the functions of harmonic constituents is to create a model to predict tidal events at a specific time and location [2], [4], [8], [9]. BIG has a tide model developed with one of them using data from 128 tide gauges built up to 2015. In the period 2015-2020 BIG have built 31 new tide gauges to strengthen the distribution of the existing tide stations. A study on the validation of the BIG tide model using tide gauges data that was built in 2015-2020 were needed to determine the ability of the BIG tide model in terms of accuracy of harmonic constituents and accuracy of tide predictions.

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2. Data and Methodology

2.1. Badan Informasi Geospasial Tide Model

The BIG tide model is a representation of the rise and fall of sea level to provide information including prediction of sea level in all Indonesian waters [5]. In 2015, Badan Informasi Geospasial (BIG) created tide model using observation data from 128 permanent tide gauges that can be accessed on [http://tides.big.go.id](http://tides.big.go.id). The calculation of the BIG tidal model was carried out using sea level data from the BIG tide gauge (tide gauge staff) and the Sea Surface Height (SSH) altimetry satellite data to complete tide information in the high seas. Figure 1 shows the distribution of 128 BIG tide stations overlaid with altimetry satellite data passing through Indonesian waters.

![Figure 1. BIG tide station location superimposed with altimetry satellite path. This data was used to construct the BIG tidal model.](image)

The BIG tide model was created by the method of analyzing the response to the value of tidal components consisting of amplitude and phase values. The amplitude and phase values are then assimilated into the hydrodynamic equation to obtain tidal component values at each point of Indonesia's water location [5]. After that, the model was validated by comparing the sea level data from the tide gauge observations then the model result is calculated to generate Root Mean Square (RMS). The results of BIG tide model harmonic constituents were stored in 16 grid files. The 16 files consist of 8 grids of amplitude files (K1, K2, M2, N2, O1, P1, Q1, S2) and 8 grid phase files (K1, K2, M2, N2, O1, P1, Q1, S2). These harmonic constituents will then be analyze by comparing with the harmonic constituents as a result of data processing from the Sebesi Island tide gauge records.

2.2. Sebesi Island Tide Gauge

The Sebesi Island tide gauge was installed on January 10, 2019 with a modular design that was fabricated on-site using stainless steel. The Sebesi Island tide gauge has 3 sensors: OTT CBS (bubbler sensor), Tokyo Keiki KRG-10 (radar sensor), and VEGAPULS WL 61 (radar sensor). Bubble chamber probe of OTT CBS sensor installed on the dock pillar, while Tokyo Keiki KRG-10 and VEGAPULS WL 61 mounted on an extension of a pole that juts into the water surface. The placement of sensor is described on figure 2. Inside the control box there were CBS sensors, battery pack, data logger, and modem. Solar panels as a power source were placed on top of the tide gauge pole on the right and left side. The top center of the tide gauge is a mount for attaching a GNSS antenna. The Sebesi Island tide gauge has 3 sensors installed but only 2 sensors, the CBS OTT and VEGAPULS WL 61 were operated, while the Tokyo Keiki KRG-10 was installed as a backup.
Figure 2. (a) Drawing design of Sebesi Island tide gauge. Sebesi Island tide gauge was designed in modular form for easy transport and installation purposes. (b) Sebesi Island tide gauge picture after installation has finished. 1= Solar Panel; 2= GNSS Receiver; 3= radar gauge (VEGAPULS WL 61); 4= radar gauge (Tokyo Keiki KRG-10); 5=bubbler gauge (OTT CBS, installed underwater); 6=control box (data logger, battery, solar charger controller, and modem). (c) The installation process of tide gauge.

The Sebesi Island tide gauge was located at the Port of Sebesi Island, Lampung Province, in the Sunda Strait water. The initial purpose of installing this station was to increase the number of tide gauges to support mapping references in Indonesia. The Sebesi Island tide gauge also has a function in supporting Indonesia Tsunami Warning System (Ina-TEWS) data. The nearest existing tide gauge of the Sunda Strait built before the Sebesi Island tide gauge are: Bengkunat (Lampung Province), Krui (Lampung Province), Pelabuhan Panjang (Lampung Province), Banten (Banten Province), and Serang (Banten Province). Data from these existing stations was used as input data for the processing of BIG tide model. Since the location of the Sebesi Island tide gauge is far from the existing stations and built after existing stations, Sebesi Island tide gauge can be used as a validator for BIG tide model made in 2015.
2.3. Sebesi Island Tide Gauge Data

The Sebesi Island tide gauge was record data at 1-minute interval. The data recorded are timestamp, water level obtained from bubbler sensors and radar sensors, battery voltage, and solar panel voltage. The data is then saved to an ASCII file and sent to the server via modem.

This research was used data from radar sensor VEGAPULS WL 61. The data used are data on February 1, 2019 to March 23, 2020 or as many as 416 tidal periods as described on figure 4. The data will be validated with MGPSdb software to eliminate blunders and systematic errors. After blunders and systematic errors were eliminated, the data was ready for harmonic analysis.

Figure 3. (a) Sebesi tide gauge located on the Sebesi Island in the middle of Sunda Strait waters. The existing station used by BIG tide model shown by yellow rectangle. A= Bengkunat tide gauge; B= Kotaagung tide gauge; C= Panjang tide gauge; D= Banten tide gauge; E: Serang (Marina Jambu) tide gauge. The Sebesi Island tide gauge shown by blue dot. (b) Location of Sebesi Island tide gauge indicated by yellow arrow. All image above was taken from Google maps.

Figure 4. (a) 416 days of Sebesi tide gauge data. Outlier indicated with red marker (b) Sebesi tide gauge data after outlier removal. (c) 5-Days data zoom in. Moving average filter needed to reduce the influence of high wave frequency. (d) Data condition after filtered with moving average 15 minutes and ready to process.
2.4 Tidal Harmonic Analysis

Tidal harmonic analysis is a calculation of the tidal harmonic constant value which includes the calculation of the amplitude and phase difference of each constituent. [4], [6], [7]. Tidal harmonic analysis can be performed using the admiralty method, the least square method, or the Fast Fourier Transform (FFT) method. This research will use the least square method with tidal harmonic equations [1], [2], [3]:

\[ h(t) = h_m + \sum_{i=1}^{k} A_i \cos(\omega_i t - g_i) \]  

Keterangan:
- \( h(t) \): function of water level with respect to time
- \( A_i \): the amplitude of the \( i \)-constituent
- \( \omega_i \): the angular speed of the \( i \)-constituent
- \( g_i \): the phase of the \( i \)-constituent
- \( h_m \): mean water level (Z₀)
- \( t \): time
- \( k \): number of tidal constituents

2.5. Tidal Harmonic Analysis using Geotide

Geotide is a software to perform tidal harmonic analysis using the least square method. The software was developed by Geomatix Hydrographic Solutions [8]. Clean data that is free from blunder and systematic errors was carried out with harmonic analysis using this software. In this research, 8 harmonic constituents of Sebesi Island tide gauge were taken using Geotide. The harmonic constituents will then be analyzed for comparison with the harmonic constituents obtained from the BIG tide model.

Figure 5. (a) Geotide User interface. (b) Geotide Data processing flow diagram. The output of data processing using geotide is harmonic constituents and rms error.
2.6. Tide Prediction using TASK

The harmonic constituents that have been obtained from harmonic analysis were used to predict tides [9]. Tide prediction is a process to determine the estimated sea level elevation at a certain time and time span [2], [10]. TASK (Tidal Analysis Software Kit) is a software developed by the Marine Data Products Team, National Oceanography Center, UK. This software has the capability to perform tidal harmonic analysis and tide prediction [11]. The software user interface and the tidal data processing flow chart with TASK were described in Figure 6.

![TASK software interface](image)

![TASK prediction flow diagram](image)

**Figure 6.** (a) TASK user interface. (b) TASK prediction flow diagram. The input used by TASK is a set of harmonic constituents and the output is a tidal prediction.

In this research, the TASK software was chosen to predict tides because it has the ability to customize harmonic constituents that will be used as tide prediction input. The harmonic constants that will be used to make predictions are 8 harmonic constants from the Geotide (Sebesi Island tide gauge) and 8 harmonic constants from the BIG tide model. The two sets of harmonic constituents will be used as input for tide predictions from 10 to 20 August 2020. The results of the tide predictions were then compared with the raw data from the Sebesi Island tide gauge with the same time window and then a comparison analysis was carried out.

The extraction of BIG tidal model harmonic constants was started by downloading the grid files from [http://tides.big.go.id/pasut/konstanta/](http://tides.big.go.id/pasut/konstanta/). On this web page there were 16 grid files with *.nc extension consisting of co-tidal and co-phase charts that contain amplitude and phase values of 8 harmonic constituents throughout Indonesia. The global mapper software was used to plot the coordinates of the Sebesi tide gauge then proceeded by importing 16 grid files from the website. The extraction of amplitude and phase values was carried out by looking at the pixel information value at the coordinates of the Sebesi Island tide gauge. The process of the extraction are described in figure 7.
3. Results and Discussions

3.1. Comparison of the harmonic constituents of the BIG Tidal Model with the Harmonic constituents of Geotide Processing.

The comparison result of harmonic constituent extracted from BIG Tide Model and Sebesi Island Tide Gauge showed at Table 1.

Table 1. The result of harmonic constituents extracted from BIG tide model and from Sebesi Island tide gauge processed with Geotide.

| Component | Amplitude (m)       | deviation | Phase (degree)     | deviation |
|-----------|---------------------|-----------|--------------------|-----------|
|           | BIG model | Sebesi data (Geotide) |           | BIG model | Sebesi data (Geotide) |           |
| K1        | 0.123    | 0.118     | 0.005              | 154.437   | 148.749               | 5.688     |
| K2        | 0.042    | 0.039     | 0.003              | 53.589    | 58.609                | -5.020    |
| M2        | 0.312    | 0.316     | -0.004             | 356.248   | 358.074               | -1.826    |
| N2        | 0.069    | 0.065     | 0.004              | 331.032   | 332.483               | -1.451    |
| Q1        | 0.075    | 0.071     | 0.002              | 151.018   | 145.274               | 5.744     |
| P1        | 0.035    | 0.033     | 0.002              | 154.643   | 148.079               | 6.564     |
| Q1        | 0.015    | 0.016     | -0.001             | 140.023   | 125.806               | 14.217    |
| S2        | 0.136    | 0.147     | -0.011             | 51.746    | 55.904                | -4.158    |

The Sebesi Island tide gauge data that has been validated were then processed by Geotide. The result of harmonic analysis using Geotide shows the RMS of processing was 55.1 millimeters. The results of the comparison analysis described on Table 1 and figure 8 that the maximum amplitude difference was S2 component of 0.011 meter, while the minimum difference in amplitude was Q1 component of 0.001 meters. The maximum phase difference was found in Q1 component of 14.217°, while the minimum phase difference as in N2 component of 1.451°.
3.2. Comparison of Tide Predictions using the Harmonic Constituents of the BIG Tide Model with Tide Predictions using the Harmonic Constants of Sebesi Island Tide Gauge

Harmonic constituents obtained from the BIG tide model and from the Sebesi Island tide station data calculations were used to make tide predictions on 10-20 August 2020. The two sets of tide prediction results were then compared with the raw tide observation data to determine which tide prediction is the most accurate with the raw data. The RMS value was calculated to determine the accuracy of the tide prediction while the correlation analysis was carried out to see the strength of the relationship between the two sets of tide predictions to the tide raw data.

The tide prediction results using the harmonic constituents from the BIG tide model was produce an RMS of 17,788 centimeters, while tide prediction using harmonic constituents from the tide data processing of the Sebesi Island tide gauge produces an RMS of 17.707 cm. From the results of the RMS analysis, it can be seen that the RMS prediction with the Sebesi Island tide gauge data was generated smaller RMS, therefore it can be concluded that this prediction was more accurate. However, the
difference between the RMS of the BIG tidal model and these results was only 0.081 cm. This value was small when compared to the smallest reading of the radar sensor, which is 1 centimeter.

The correlation coefficient between tidal predictions using HC from TASK and raw data is 0.977. Meanwhile, the correlation coefficient between tidal predictions using the Sebesi Island tide gauge data and the raw data is 0.980. Table 2 was described that the correlation between tidal prediction results using harmonic constituents from Sebesi tide gauge with raw data has a positive value and greater than the correlation of tidal prediction results using harmonic constituents from BIG tide model with raw data. This shows that tidal predictions using harmonic constituents from the Sebesi data have a stronger relationship than tide predictions using harmonic constituents from BIG tide model. However, the coefficient correlation value of the two data sets to raw data is positive and very strong.

**Table 2.** The correlation between raw data, tidal prediction using BIG harmonic constituents extracted from tide model, and tidal prediction using harmonic constituents from Sebesi tide gauge data.

| Correlation                              | RAW data | 8HC BIG Tide model Prediction | 8HC TASK Prediction |
|------------------------------------------|----------|------------------------------|---------------------|
| RAW data                                 | 1        | 0.97663095                   | 1                   |
| 8HC BIG Tide model Prediction            | 0.97663095 | 1                           |                      |
| 8HC TASK Prediction                      | 0.980303199 | 0.997053508                 | 1                   |

Figure 9. The Comparison of timeseries tide data from raw data, tidal prediction using BIG HC tide model, and tidal prediction using Sebesi HC data August 10-20, 2020

4. **Conclusion**

Comparative analysis of tidal harmonic constituents can be used to validate a tide model. Comparison of the harmonic constituents between the BIG tide model and harmonic constituents from Sebesi Island...
tide data shows that the maximum amplitude difference was found in the S2 component of 0.011 m and at minimum was Q1 component of 0.001 m. The maximum phase difference was in the Q1 component of 14.217° and a minimum of 1.4510° in the N2 component. The tide prediction generated by the BIG tide model was proven to have high accuracy when compared to tide prediction using the Sebesi Island tide gauge data with a data length of 416 days, the RMS difference between the two was 0.081 cm. The results of the correlation analysis show that the correlation value between tide predictions using Sebesi data and raw data was 0.980, while the correlation value between tidal predictions using the BIG tide model and raw data was 0.977. From the correlation analysis between tide prediction and raw data, it can be concluded that the tide prediction using Sebesi station harmonic constituents data has a stronger correlation than the BIG tide model harmonic constituents, however the comparison shows that the two tide predictions have a positive value and very strong relationship to the raw data of Sebesi Island Tide gauge.

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