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# Tidal Correlation using Altimetry Satellite

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**Abstract.** Tides data is strongly needed especially on Indonesian Coastal Environment mapping to achieve its accuracy. Usually, tides data derived from direct or indirect measurement. From palm observation, the tides data collected directly. Indirect measurement takes the advantages of altimetry satellite, where tides data collection carried in a shorter time and large area. In the supremacy of using altimetry satellite, we could obtain tides information not only in coastal but also in open waters. Study of altimetry data is required to prove whether tides components resulted represent real tides condition in coastal or vice versa. Finding out the linkage between tidal components resulted from Jason-1 altimetry satellite became the aim of this paper. Cross-over analysis method ran to examine the linkage between each tidal constituent. The tidal correlation value determined the accuracy of amplitude result from altimetry satellite. Gaussian Distribution played a role in determining the status of cross-over point data. The amplitude will point whether the cross-over point will continue to involve in tidal amplitude gridding process. The higher value of cross-over amplitude related to influence subsists between tides components in which the emerging values do not represent each tidal constituent itself.

## 1. Introduction

Under the Constitution No. 4 of 2011 concerning the Geospatial Information (GI), one of the credentials that hold by the Geospatial Information Agency (BIG) is to provide an Indonesian Coastal Environment Map and a National Marine Environment Map. In the implementation, those maps are assuredly required tidal data to achieve accuracy and precision. Article 13 paragraph 4 in the GI Constitution explained that coastline determination used the lowest water level which is obtained from tides measurement and tides component analysis. Customary methods for the tides of acquisition are using tides staff and altimeter data. However, the two methods will provide a gap in the differences of measurement area. Spatially, altimetry data will answer the provision of tidal data needs over wide oceans but less reliable for coastal regions. About 10 - 50 km shoreward from the coastline, altimeter data usually are flagged as unreliable and discarded, it will depend on the particular measurement instrument and the local coastal morphology [1]. However, for now, altimetry satellite remains a major source in providing wide-ranging data, especially for tides modelling. Improvement of (open) ocean tide model has been significantly rising since the day of satellite altimeter launched [2]. As the essential part of tidal and sea level determination, the amplitude of each tidal constituent produced from altimetry data processing needs to be correlated to determine the relationship between tidal components. The tidal constituents that do not affect each other gives better accuracy. Utilization of altimetry satellite data for tidal analysis has been developing for decades, especially for the purposes of determining sea level [2-6]



Tidal information regarding its properties and characteristics can be derived from the tidal harmonic analysis. According to [7], Tidal harmonic components divided into four parts namely diurnal tide, semidiurnal tide, long period tide, and harmonic constituents of shallow water tides. The tides constituents used in this study were SA, SSA, MSF, K1, Q1, O1, M2, S2, N2, K2, 2N2, MS4, and M4. The usefulness of each tidal constituent showed in table 1.

**Table 1.** Tidal constituents.

No.	Tidal Constituents	Stake Period (hours)	Phenomenon
1	SA	4381.088	SSA Derivatives
2	SSA	2191.43	Semi-Annual Variations
3	MSF	3,091	Interaction between MM and M <sub>f</sub>
4	K1	23.93	Declination of the Moon and Sun System
5	O1	28.52	Moon Declination
6	Q1		O1 Derivatives
7	M2	12.24	Lunar gravity with the circular orbit and parallel with earth equator
8	N2	12.66	Change distance of the moon to earth due to the ellipse-shaped trajectory
9	S2	12.00	Sun gravity with a circular orbit and parallel with earth equator
10	K2	11.97	Changes in the distance of the moon to Earth due to the ellipse-shaped trajectory
11	2N2	6,449	MU2 derivative
12	MS4	2.20	Interaction between M2 and S2
13	M4	6.21	2 Times of M2 angular speed

### 1.1. Harmonic Analysis

Sidabutar et al. [8] explained that the tides nature and characteristics of a place from tidal observations in a certain period can be known by conducting the tidal harmonic analysis. The calculation using tidal harmonic analysis has the purpose of calculating the amplitude and delay phase of tides. The calculated amplitude is the response from a local sea condition to balanced tides in a location. The phase delay itself defined as the delay of the wave to the equilibrium tides in that location. This amplitude values and phase delay admitted as the tidal harmonic constituents. One way for tides analysis is by using the Least Square analysis. Doodson identified 400 tidal constituents in a 19-years period [9]. Of the 400 constituents, only 146 commonly referred to as harmonic constituents. This study used approximately 6-12 main constituents used to determine the type of tides. By doing the harmonic analysis, the tidal constituents are set in frequency. Also, we can measure the relative amplitude to find out the main constituents of tides [10].

To focus on the applicability of altimetry satellites to obtain tidal harmonic constituents due to the satellites' advantages. Altimeter data can be used to observe ocean dynamics particularly to almost all regions of Indonesia quickly without depending on weather, safe and cheaper compared to observations using conventional tide stations. Pratama, Jaelani, & Sulaiman [11] explained the basic principle of altimetry satellites is the difference in the time interval of radar wave propagation emitted by satellites. Reflection of radar pulses into the ocean is used to analyze sea level, while the magnitude and shape of radar pulses contain additional information about sea surface characteristics. Altimetry satellites application run for various activities such as monitoring Sea Level Rise, determining Sea Surface Topography, determining ice surface topography, determining geoids in the ocean region, determining height and wavelength, studying the El Nino phenomenon, tidal studies, and others [12]. Several things were crucial in determining the tidal constituents by using Altimetry satellite data.

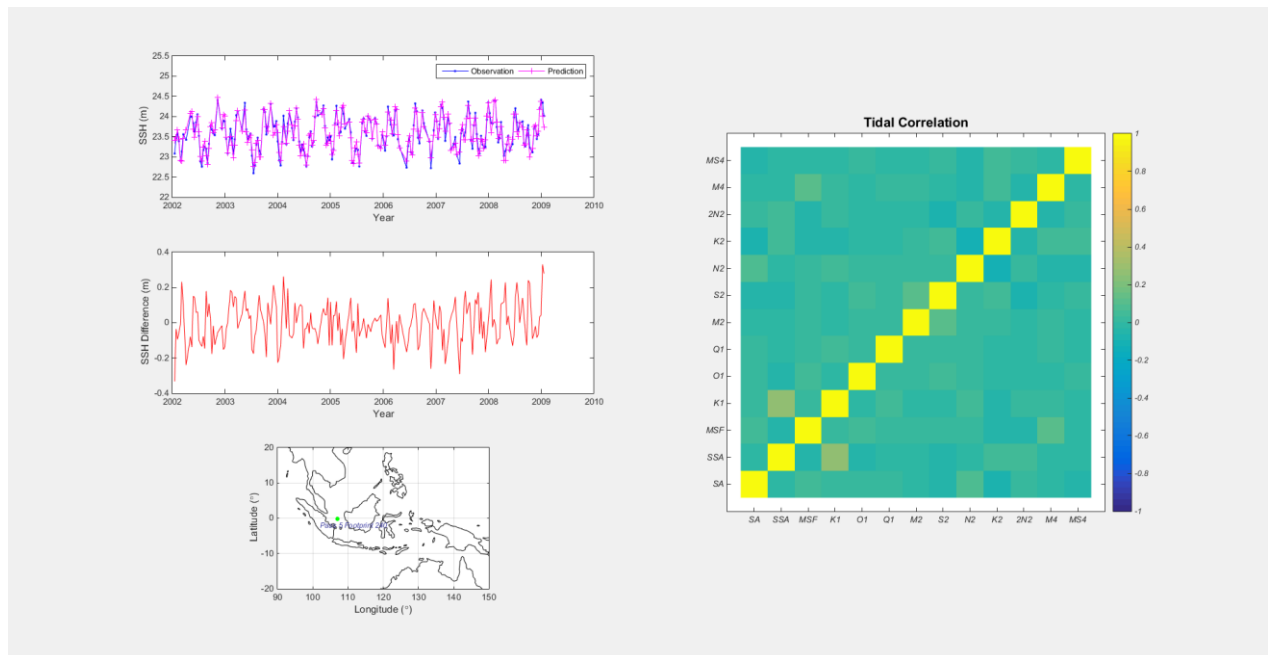
1. According to Gumelar [13] Jason-1 with 9,9156 days repetition in recording tides data is more excessive than other observation of tides in general. Aforementioned had caused aliasing of the diurnal and semi-diurnal tides. Tidal aliasing defined as the change in the original frequency of the original tidal component to a aliasing component. The frequencies that can be analyzed are those in the range of zero to Nyquist frequency. If the resulting constituents enter the Nyquist Frequency, it can reflect the periodic tidal phenomenon at that location [14].
2. Jason-1 had designed to sense the globe with an inclination of 66 degrees orbit. The distance between tracks is about 315 km at the equator, and the distance of each observation points are 7 km in trajectory. Towards the next cycle, the position of the satellite cannot always be precisely in its position but misses about 1 km. The observation time for Jason-1 stored in the RADS (Radar Altimeter Database System) database uses UTC on January 1, 1985. The time of observation in this second is needed to analyze harmonic analysis of sea tides. Parameters of ocean tidal harmonic analysis that are affected by the observation time system used are the sea phase. [15].
3. Crossover is the point in an intersection between ascending and descending passes. The selection of crossover points lay on the consistency of tidal harmonic constituent values which calculated from the two satellite paths themselves — this crossover point considered as a tide gauge station.

## 2. Method

Generally, two methods usually used for the empirical tides estimation. Those are the Least Squares harmonic analysis and the response method [16]. The tide analysis using altimeter data faces two general difficulties - the aliasing effect and the problem of de-correlating tidal signals. Aliasing effects emerge when the sample high-frequency signals with periods of some 12 and 24 hours only happened in a short period. In this case, the tides appear as signals with periods much longer than the sampling interval. These periods – called alias periods – are different for the tidal constituents and depend on the repeat period of the altimeter satellite. Thus, we need to implement the Rayleigh criterion to express the capability of separate neighboring periods from each other[5]. The minimal period needed for the accurate separation of two tides is called the Rayleigh period. Least Square method used in this study aimed to get the harmonic tidal constituent value using the weighting principle based on the residual value. The tidal harmonic analysis used to determine the nature and character of tides from tidal observations for a certain period. The purpose of harmonic analysis is to determine the amplitude and phase of each tidal constituents based on astronomical frequency from a time series data recording. We used data provided by RADS server: TU Delft [rads.tudelft.nl/rads/rads.shtml](http://rads.tudelft.nl/rads/rads.shtml).

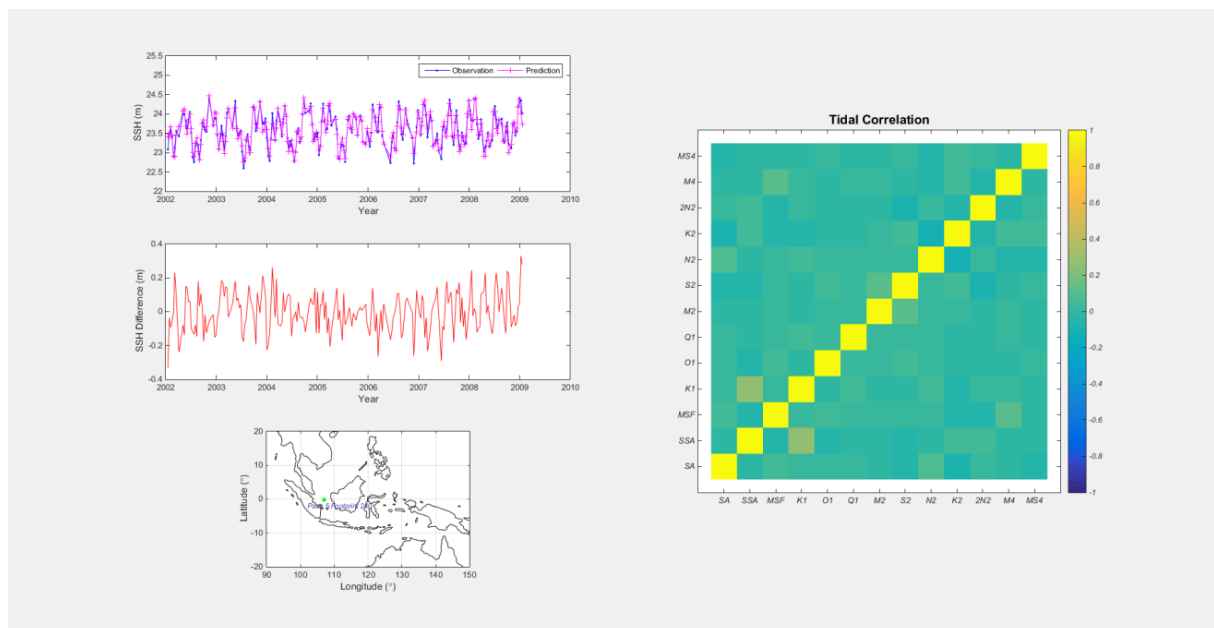
## 3. Results and Discussion

The result outlined the plot of SSH time series observations with SSH prediction values, the plot of observation-predictions SSH error, and tidal correlations of each constituent. Figure 1 and figure 2 illustrated the time series plot of SSH observation with SSH prediction, and plot SSH error observations and tidal correlations of each constituent at one of each ascending and descending p1s. The plot was performed to discover whether the initial input data entered into the program is appropriate or not. If interferences occur on Jason-1 data, it will affect the accuracy of the process of determining the amplitude value to determine the tidal constituents.



**Figure 1.** Plot tidal estimate Jason-1 ascending.

Figure 1 pointed that the ascending pass on the Jason-1 phase-a gave the plot of time series SSH from 2002 to 2009 ranged from 29-30 meters (sample taken from footprint- 185 and pass-185). The difference between SSH observation and SSH prediction values range from -0.18-0.18 meters. The tidal correlation which approaches -1 and 1 explained the relationship between the two constituents. Thus, in the next step of processing, those constituents will affect each other and result in less accurate amplitude. In the ascending pass according to figure 1, the constituents that still have a close correlation are K1 and SSA.

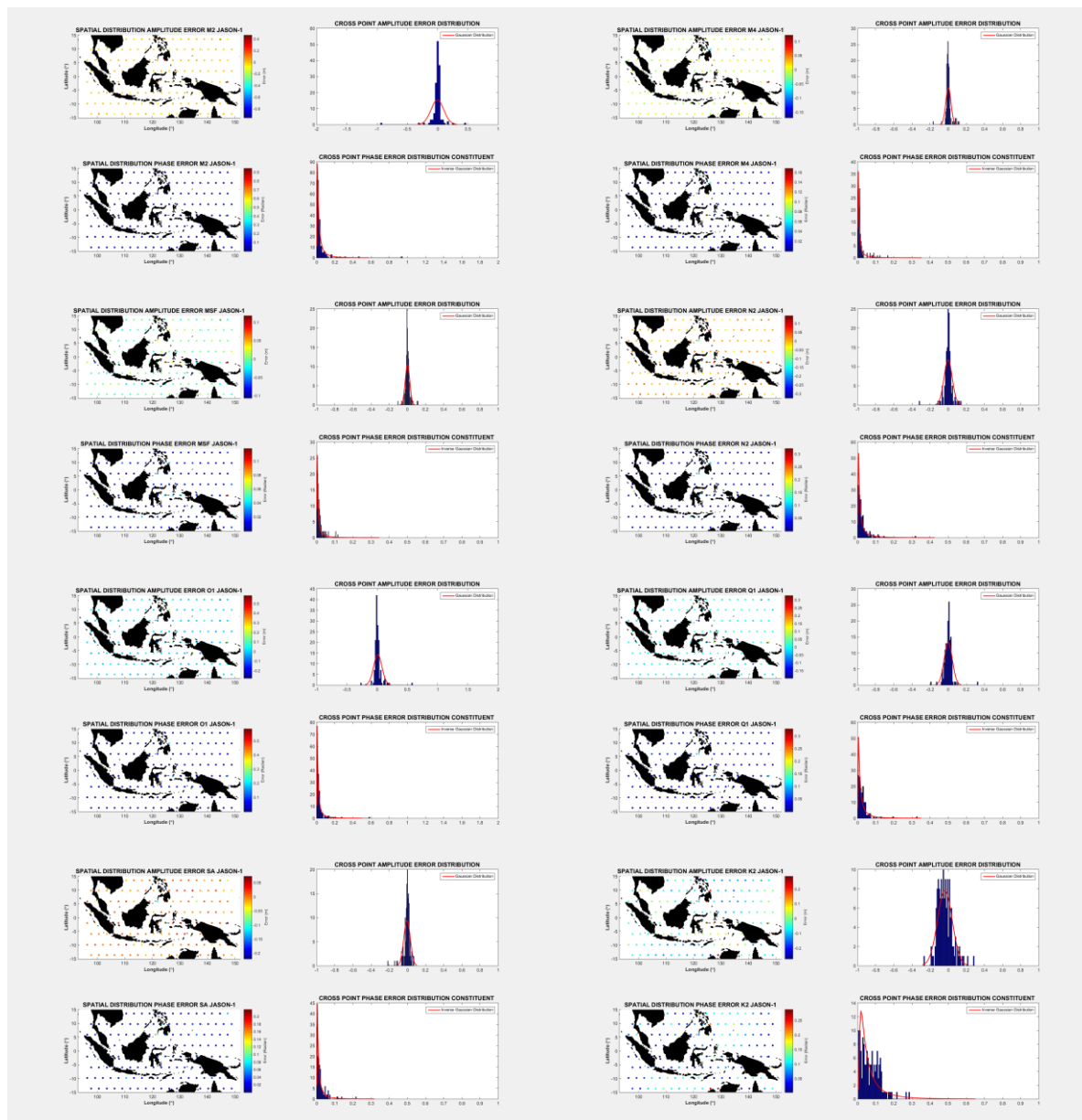


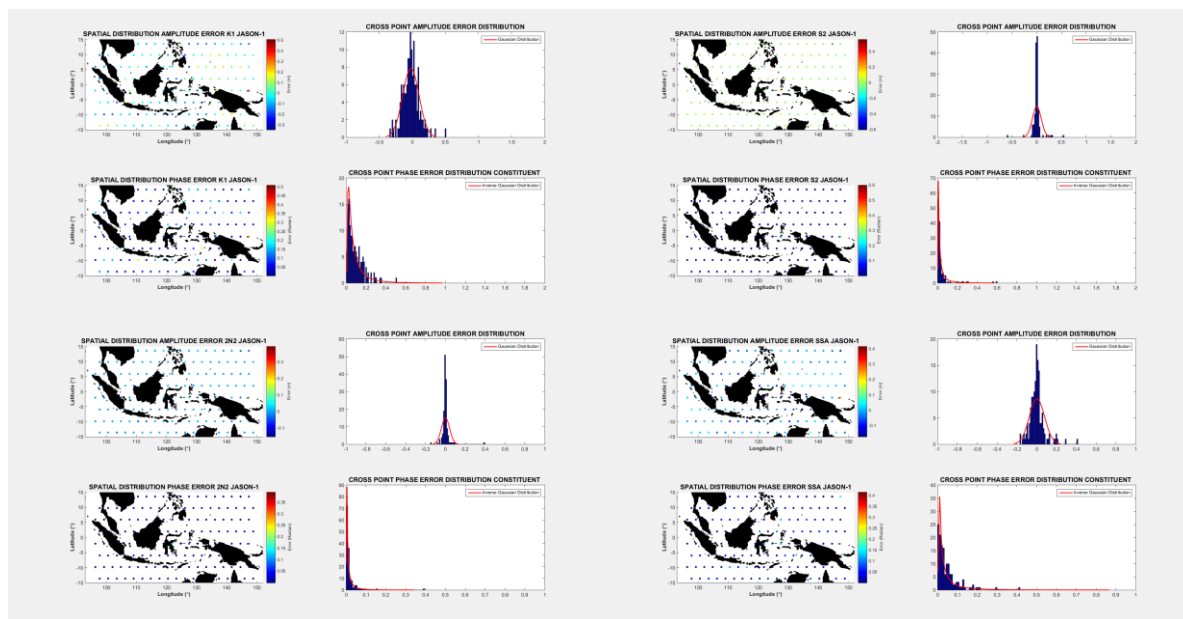
**Figure 2.** Plot tidal estimate Jason-1 descending.

While in **figure 2**, for descending pass on the Jason-1 phase a, the plot of time series SSH observation from 2002 to 2009 ranging from 22 – 35 meters in the sampling pass-5 at footprint-240. The difference from SSH observation value and SSH prediction value are around -0.4 – 0.4 meters.

Since the tidal correlation of each constituent is close to -1 and 1, the similar condition with ascending plot result (**figure 1**) applied for the relation of constituents, also the amplitude. In the ascending path according to Figure 2, the tidal constituents that still have a close relationship are the constituents of K1 and SSA.

The time-series altimetry satellite Tidal data in this study still contains orbital and noise errors that occur due to the error of the Altimetry satellite instrument itself. The premise of the data processing was the altimetry data still engaged with all errors, and inevitably, the noise will affect the value of the constituents formed. The figure below explained the relationship between the tidal components which formed to the normal distribution of statistics.





**Figure 3.** Residual amplitude plots and Jason-1 phases.

Figure 3 revealed the amplitude and phase error at all crossover points for all tidal constituents. Thus, could be expected which constituents that are good for further analysis will be known. More straightforward, the range of error and phase error values for all harmonic constituents forming showed in table 2.

**Table 2.** The Range of Amplitude and Phase Error in Each Tidal constituent.

No	Tidal Constituents	The Range of Amplitude Error (meter)	The Range of Amplitude and Phase Error (radians)
1	2N2	-0.10 - 0.10	-0.20 - 0.05
2	K1	-0.30 - 0.50	-0.08 - 0.05
3	K2	-0.20 - 0.20	-0.40 - 0.05
4	M2	-0.20 - 0.20	-0.40 - 0.10
5	M4	-0.10 - 0.10	-0.20 - 0.02
6	MSF	-0.10 - 0.10	-0.20 - 0.01
7	N2	-0.25 - 0.10	-0.35 - 0.05
8	O1	-0.20 - 0.20	-0.40 - 0.10
9	Q1	-0.15 - 0.25	-0.40 - 0.05
10	S2	-0.20 - 0.20	-0.04 - 0.10
11	SA	-0.15 - 0.05	-0.02 - 0.02
12	SSA	-0.10 - 0.40	-0.50 - 0.06

Figure 3 and table 2 showed the tidal constituents indeed for K1 (Declination of the Moon and Sun System), and the SSA constituents (Semi-Annual Variation) have the broadest range of error amplitude and phase values compared to other tidal constituents. The higher the error value of the amplitude and phase, the less tidal constituents produced. Furthermore, for the next data processing process, either it will be difficult to conduct the amplitude gridding process, or the gridded results will be less expected. The tidal constituents that produce the most error range of the smallest amplitude and phase are 2N2 (Derivatives of MU2), MSF (Interactions between MM and Mf) and SA (Derivatives of SSA). The results shown are the smallest value indicating that the forming tidal constituents are the most suitable on this Jason-1 Altimetry satellite.

#### 4. Conclusion

The smallest range of error values for amplitude and phase of the tidal constituents from the Jason-1 Phase A is 2N2, MSF, and SA constituents. Meanwhile, the highest range of error values for amplitude and phase of tidal constituents found in K1 and SSA.

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