Waveform identification and retracking analyses of Jason-2 altimeter satellite data for improving sea surface height estimation in Southern Java Island Waters and Java Sea, Indonesia

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Abstract. Indonesian waters containing many small islands and shallow waters leads to a less accurate of sea surface height (SSH) estimation from satellite altimetry. Little efforts are also given for the validation of SSH estimation from the satellite in Indonesian waters. The purpose of this research was to identify and retrack waveforms of Jason-2 altimeter satellite data in southern Java island waters and Java Sea using several retrackers and performed improvement percentage analyses for new SSH estimation. The study used data of the Sensor Geophysical Data Record type D (SGDR-D) of Jason-2 satellite altimeter of the year 2010 in the southern Java island waters and 2012-2014 in Java Sea. Waveform retracking analyses were conducted using several retrackers (Offset Center of Gravity, Ice, Threshold, and Improved Threshold) and examined using a world reference undulation geoid of EGM08 and Oceanic retracker. Result showed that shape and pattern of waveforms were varied in all passes, seasons, and locations specifically along the coastal regions. In general, non-Brownish and complex waveforms were identified along coastal region specifically within the distance of 0-10 km from the shoreline. In contrary, generally Brownish waveforms were found in offshore. However, Brownish waveform can also be found within coastal region and non-Brownish waveforms within offshore region. The results were also showed that the four retrackers produced a better SSH estimation in coastal region. However, there was no dominant retracker to improve the accuracy of the SSH estimate.

1. Introduction
Thousands of small islands in Indonesian waters are particularly vulnerable to sea level rise due to global warming such as melting ice sheets and glaciers in Antarctica and Greenland, and as a result of sea water expansion [1-4]. For example, the rate of sea-level rise in Indonesian waters was about 5.82 mm/yr or about twice of the world sea level rise rate [5, 6]. Therefore, the dynamics of Indonesian sea level rise should be monitored using synoptic and near-real time data that can be obtained from altimeter data.

Altimeter satellite data have been successfully used to accurately estimate sea surface height especially for offshore waters [7-15]. For offshore waters, modern microwave altimeter satellites can measure instant sea surface height with an accuracy of about 4.1 cm [16]. However, altimeter satellites still face problems for estimating sea surface height in coastal waters or shallow waters. Altimeter satellite data in coastal areas or shallow waters may be contaminated by complex topographic surfaces
and coastlines of radar echoes, strong marine dynamics including tides, and land locations close to the sea that make it impossible to make accurate geophysical corrections such as correction wet troposphere, tidal correction, and atmospheric correction [17-19]. The terrestrial effects can induce many additional peaks in the waveform of distorted Brown’s theoretical model (waveform) as a surface wave signal (radius ~ 7 km in 1Hz sampling) as it approaches or leaves the coastline [16].

Previous study using altimetry Jason-2 satellite data of 2013 in southern Java island waters and based on waveform identification, about 69% (the highest number) of non-Brown-waveform was found within 0-10 km of the coastline. Meanwhile, within the distance of 10-50 km and 50-100 km from the shoreline, the numbers of non-Brown waveforms were 5% and 3%, respectively [20]. Using similar data of 2012-2014 along central-eastern part of Java Sea, [21] also found that majority non-Brown waveform was found near to the coast and sometime also found in offshore.

Based on waveform retracking analyses conducted along central-eastern part of Java Sea of 2012-2014, the waveform retracking analyses were able to improve the accuracy of SSH estimation about 29.7% in the north coast and 56.4% in the south coast of total non-Brown-waveform in each region. However, there was no specific retracker producing dominant improvement percentage (IMP) of sea surface height (SSH) estimation [21].

The results of previous studies showed that the shape and pattern of waveform altimetry Jason-2 satellite data in the waters of southern Java island and central-eastern part of Java Sea varied based on location and season and did not have a definite pattern, especially in coastal waters. In general, the non-brownish waveform was found in coastal waters particularly near the coast and brownish waveform in offshore waters. However, non-brownish waveforms were sometimes found in offshore waters. Therefore, the waveform identification of the altimetry Jason-2 satellite data is very important to be conducted for all passes and the waters of southern Java island and the Java Sea. The previous results of retracking analysis were also showed that there were no single (dominant) retracker to produce the best improvement percentage (IMP) of sea surface height (SSH) estimates in areas with non-brownish waveform. However, some retrackers may provide improvements to SSH estimates in areas that were previously invalid (non-brownish waveform) by the standard (oceanic) retracker. Therefore, further retracker analyses are very essential to be conducted for all Indonesian waters to obtain optimal results in improving the accuracy of SSH estimates from altimetry satellite data. Increasing the accuracy of SSH estimation results from satellite data through the effort of waveform identification and retracking analyses are very important considering that Indonesian waters containing lots of shallow/coastal waters and are susceptible to less accurate estimates of SSH. The objectives of this study were to identify waveform and perform retracking analyses for altimetry satellite Jason-2 data to improve accuracy of SSH estimation especially along the coastal region.

2. Methods

2.1. Study Areas and Data
The study areas were the waters of southern Java island and Java Sea with limit of about 2.5°-7.5°S and 106°-116°E (yellow rectangle in figure 1).

We used altimetry Jason-2 satellite data of D-type sensor geophysical data record (SGDR) of 2010 for the region of southern Java island waters (Indian Ocean off Java island) and 2012-2014 for the region of Java Sea (figure 1). The data were obtained from the "NOAA's comprehensive large array-data stewardship system" (www.class.ncdc.noaa.gov) data website, AVISO (http://www.aviso.oceanobs.com), and the global geoid undulation model of EGM2008 version WGS 84 obtained from "NGA: National Geospatial-Intelligence Agency" data network (http://earth-info.nga.mil/GandG/wgs84/gravimod/egm2008/egm08_wgs84.html).

The ascending pass (a pass of the satellite crossover moving from the southern part of the earth to the northern part of the earth (latitude -66.15° to +66.15°) and given an odd number) of 229, 051, 121, and 203 were used in this study. The descending pass (a pass of the satellite crossover moving from the northern part of the earth to the southern part of the earth (latitude +66.15° to -66.15°) and given...
an even number) of 242, 604, 140, and 216 were also used in this study (figure 1). One cycle is the time required by the satellite to cross the same pass which takes about 9.9156 days (~10 days) with orbital accuracy ± 1 km [22]. In this study, the retracking waveform analyses was performed on the above eight Jason-2 satellite passes.

Figure 1. Altimetry Jason-2 satellite passes in Indonesian waters. The yellow colored box was the location of the identification and retracking waveform analyses of altimetry Jason-2 satellite data in this study.

2.2. Waveform Identification
The altimeter Jason-2 satellite measures the altitude of the sea level by transmitting microwaves to the sea surface and then measuring the time difference during the wave reception and reflection. The following was SSH calculations according to [23]:

\[
\text{SSH} = \text{Altitude} - \text{Range} \nonumber
\]

(1)

where: SSH = sea surface height (m), Altitude = satellite elevation of the ellipsoid reference (m), Range = satellite altitude of sea level (m). The equations used to obtain the Range value are shown in the following equation [24]:

\[
\text{Range} = \frac{c (\text{tr} - \text{te})}{2} \nonumber
\]

(2)

where: Range = satellite height from sea surface (m), \(c = \) speed of light (299792458 m/s), \(\text{te} = \) time when satellite transmits microwaves to sea surface (s), \(\text{tr} = \) time when satellite receives wave reflected from sea surface (s).

The raw data of altimetry Jason-2 satellite is in the form of wave (power in y-axis and gate number in x-axis) and it is called a waveform. The center point at the leading edge of a waveform corresponds to the range at the nadir point of the sea surface [25-28]. On the offshore region where generally found the Brownish-waveform, the midpoint of the leading edge waveform lies on the 32\textsuperscript{nd} gate so that the midpoint of the on-board leading edge on the Jason-2 Satellite is set at the 32\textsuperscript{nd} gate [25]. However, in shallow coastal waters due to its waveform shape which normally does not follow Brownish-waveform model, it causes the midpoint position of the leading edge to vary the extent of the sea surface physical condition so that it does not correspond to the value of the leading edge position assigned to the satellite. This causes the range calculation of SSH to produce a less accurate value [25-
Gate is the time of observation when the reflection wave occurs. The Jason-2 satellite has 104 gates where the gate spacing is 3.125 ns (nano second) so that the time span required to record a single data waveform is 325 ns [29].

In this study, we used in-house built Matlab program to perform waveform identification processes. The main idea of this process was to identify each waveform either belong to the form of Brownish or Non-Brownish waveform.

2.3. Waveform Retracking Analyses
Retracking waveform is a method for finding the right tracking gate cutting the midpoint of the leading edge to get the actual range value [27]. There are several methods of retracking waveform (retracker) used in this research i.e., ocean, ice, OCOG, threshold (10%, 20%, and 50%), and improved threshold (10%, 20%, and 50%). The ocean retracker method (standard/default retracker) is an on-board retracker in the SGDR-D Jason-2 data so that the range value of the retracker does not need to be counted again [25]. The ocean retracker was developed using a Brown-waveform model [30]. The ice retracker was originally developed to observe the polar ice heights which developed based on the 30% threshold retracker using the average power quantity of the waveform previously calculated by the OCOG method [31]. OCOG retracker was developed by [32] where the purpose of this method is to obtain the center point of the wave-form. The formula and explanations in the calculation of the retracker threshold method (10%, 20%, and 50%), as well as the improved threshold (10%, 20%, and 50%) are presented in [13] and [28].

2.4. Estimating Sea Surface Height (SSH)
According to [16] and [24] the result of the retracking waveform analysis is the value of the range correction calculated by putting aside the gate value from the midpoint position of the leading edge of the retracking waveform result with the midpoint position of the on-board leading edge (equation 3). The retracking range is obtained from the addition of Jason-2 Satellite on-board range with correction range (equation 4):

\[ dr = c \times \Delta G_a \times (G_r - G_0) / 2 \] ........................................................ (3)

\[ R_r = R + dr \] ........................................................ (4)

where: \( dr \) = satellite altitude correction with retacked sea level (m), \( c \) = speed of light (299792458 m/s), \( \Delta G_a \) = time interval for one gate Jason-2 satellite (3.125 ns), \( G_r \) = gate observation at midpoint leading edge of retracking, \( G_0 \) = gate on-board observation of Jason-2 Satellite (32), \( R \) = range of satellite measurement (m), \( R_r \) = range of retracking (m).

The next calculation is to add a correction of geophysical and atmospheric disturbance to the retracking range (\( R_r \)) to get the corrected range (\( R_{corr} \)), as shown in equation 5 [33]:

\[ R_{corr} = R_r - \Delta h_{dry} - \Delta h_{wet} - \Delta h_{iono} - \Delta h_{sph} - h_{tides} - h_{atm} \] .................................................. (5)

where: \( R_{corr} \) = corrected range (m), \( R_r \) = range of retracking (m), \( \Delta h_{dry} \) = dry troposphere correction (m), \( \Delta h_{wet} \) = wet tropospheric correction (m), \( \Delta h_{iono} \) = ionospheric correction (m), \( \Delta h_{sph} \) = surface shape correction sea (m), \( h_{tides} \) = tidal correction (m), \( h_{atm} \) = dynamic atmospheric correction (m).

The last step to get the SSH value of retracking waveform was by using equation from Yang et al. (2008) as shown in Equation 6. The Jason-2 satellite had an altitude value or satellite elevation of an ellipsoid reference of 1336 km in the equatorial region [22].

\[ SSH_{retracking} = \text{Altitude} - R_{corr} \] ........................................................ (6)
where: $\text{SSH}_{\text{retracking}} =$ retracted sea surface height (m), Altitude = satellite heights of the ellipsoid reference (m), $R_{\text{corr}} =$ corrected range (m).

In this study, we used in-house built Matlab program to perform retracking analyses for altimetry Jason-2 satellite data and produce SSH estimation specifically for coastal waters region.

2.5. Improvement Percentage Determination and SSH Retracking Validation

The performance of the retrackers can be calculated using the Improvement Percentage (IMP) formula based on [28] and developed by [25] so that the ability of each retracker can be calculated by making the ocean retracker (standard/on-board retracker) as a benchmark for improving the ability. Improvement Percentage (IMP) formula of retracted SSH versus standard (on-board) estimated SSH is shown in equation 7.

$$\text{IMP} = \frac{\sigma_{\text{ocean}} - \sigma_{\text{retracker}}}{\sigma_{\text{ocean}}} \times 100\%$$  \hspace{1cm} (7)

where: IMP = percentage improvement (%), $\sigma_{\text{ocean}} =$ standard deviation of on-board SSH divide by geoid undulation (m), $\sigma_{\text{retracker}} =$ standard deviation of SSH retracking with geoid undulation (m).

The percentage value of the IMP of each retracker shows how much improvement of the retracker produce against the on-board retracker so the greater the value of the IMP the better the ability of the retracker and vice versa. Validation of retracted SSH was compared to its profile against the geoid undulation profile (EGM08). If the profile of retracted SSH did not resemble the geoid undulation profile then the retracted SSH was considered to be not valid values even if it had been able to correct the errors of SSH on-board [25-27, 34-35].

3. Result and Discussion

3.1. Waveform Identification

Using in-house built Matlab program, we performed identification on shape and pattern of waveform of Jason-2 altimeter satellite data of the year of 2010 in the southern Java island waters and during 2012-2014 in Java Sea region. In previous study, Nababan et. al. reported that the brownish waveform was very rare in coastal areas at a distance of 0-10 km from the coastline [20]. Generally, the brownish waveform was found in offshore waters at a distance of 50-100 km from the coastline. Given the non-uniformity pattern and shape of the waveforms based on the track and distance from the coastline or based on the seasons, therefore, identification of the shape and pattern of the Jason-2 altimeter satellite data for the year of 2010 in the southern Java island waters was continued to be performed in this study. All ascending (229, 051, 121, and 203) and descending (242, 604, 140, and 216) passes were analysed in this study.

The results showed that generally non-brownish waveform was found in coastal waters, especially near the coast. However, the shape, pattern, and frequency of occurrence in each pass did not show the same pattern (figure 2). In pass 051, the non-brownish waveform was found only in coastal waters about 0-5 km from the coastline and the rest was seen as brownish waveform. In pass 64, a non-brownish waveform was encountered in coastal waters at a distance of 0-10 km from coastline, whereas in pass 127 some non-brownish waveform were encountered at a distance of 0-5 km and 15-23 km from coastline. Likewise on pass 140, the non-brownish waveform group was encountered in two locations, namely at a distance of 0-8 km and 17-19 km. In pass 203 and 242, non-brownish waveforms were formed at a distance of 0-15 km from the coastline. In pass 229, the non-brownish waveforms were also found near to coast at about 0-3 km from the coastline (figure 2). In general, the non-brownish waveforms commonly encountered in coastal waters near the shoreline because radar waves from altimeter satellites were affected by shoreline or land. The footprint of radar waves from altimeter satellites reaching the sea surface was also strongly influenced by the condition of the surrounding waters to a distance of about 2-5 km while the distance between these two satellite data points was about 300 m [36-37].
Figure 2. Shape and patterns waveform of the Jason-2 altimeter satellite data in southern Java island waters of the year 2010 along the coastal waters. The waveforms circled in black were non-brownish waveform. Note: D = distance from shore.

The identification of the shape and pattern waveform of the altimetry Jason-2 satellite data for offshore water region was also conducted in this study with the distance from the coastline limited to about 100 km from the coastline in the southern Java island waters. We limited to this distance because in general the waveform of altimetry Jason-2 satellite data along the offshore region (at the depths >1000 m) was generally in the form of Brownish waveform [7-15].

In general, the waveform patterns in offshore waters were found as brownish waveform, however, sometimes non-brownish waveforms were also found in offshore waters (eq. pass 64, 140, and 203) (figure 3). The black-circled waveforms were non-brownish waveforms because the middle edge of the leading edge waveform was not around the 32nd pre-given gate. The Jason-2 satellite had a pre-given gate on the 32nd gate [25]. By using the ocean retracker, the waveform circled in black would result in a less accurate SSH estimation or invalid value (NaN).
Figure 3. The waveform shape and pattern of the Jason-2 altimeter satellite data for the southern Java island waters of the year 2010 along the offshore waters. The waveforms circled in black were non-brownish waveforms. D=distance from shore.

For Java Sea, waveform identification showed that generally non-brownish waveforms were found along coastal areas and brownish waveforms along the offshore region with average of 94.4%. The percentage of non-brownish waveform for all passes during the period of 2012-2014 was found about 5.6% (table 1). The highest percentage of non-brownish waveforms was encountered in the pass number 203 with a value of 6.9%, while the lowest percentage of non-brownish waveform was found in pass number 140 of 4.9% (table 1). The waveform pattern in the Java Sea generally had a similar pattern with the southern waters of Java island specifically along the coastal areas which predominantly non-brownish waveforms. Non-brownish waveforms in coastal areas were caused by reflected signals from the mainland, the bias of the sea state, and the complex shoreline [20, 27].
Table 1. Average percentage of non-brownish waveforms of all Jason-2 altimeter satellite waveform data of 2012 - 2014 on each pass in the Java Sea.

| Pass number | Pass length (km) | Total waveform | Number brownish waveform | Number non-brownish waveform | Non-brownish waveform (%) |
|-------------|------------------|----------------|--------------------------|------------------------------|---------------------------|
| 051         | 426.3            | 1,537          | 1,449                    | 88                           | 5.7                       |
| 064         | 405.7            | 1,463          | 1,391                    | 72                           | 4.9                       |
| 127         | 386.0            | 1,392          | 1,315                    | 77                           | 5.5                       |
| 140         | 423.7            | 1,528          | 1,452                    | 76                           | 5.0                       |
| 203         | 352.4            | 1,271          | 1,183                    | 88                           | 6.9                       |
| 216         | 391.0            | 1,410          | 1,334                    | 76                           | 5.4                       |
| 229         | 356.1            | 1,286          | 1,214                    | 72                           | 5.6                       |
| 242         | 133.5            | 482            | 454                      | 28                           | 5.8                       |
| Average     | 133.5            | 1,296.13       | 1,224                    | 72.13                        | 5.6                       |

3.2. Waveform Retracking Analyses for Improving SSH Estimation Accuracy

Waveform retracking analyses for Jason-2 altimeter satellite data of 2010 for the southern Java island waters and for the period of 2012-2014 for the Java Sea were conducted using retracker method like OCOG, Threshold 10%, Threshold 20%, Threshold 50%, Improved Threshold 10%, Improved Threshold 20%, Improved Threshold 50%, and Ice. After performing retracking waveform analyses, the sea surface height (SSH) estimate was also calculated based on each retracker.

For non-brownish waveform conditions, the standard ocean retracker generally produce inaccurate or invalid (NaN) SSH estimate values. To improve this inaccurate or invalid SSH estimate values, therefore, retracking was done using another retracker such as OCOG, Threshold 10%, Threshold 20%, Threshold 50%, Improved Threshold 10%, Improved Threshold 20%, Improved Threshold 50%, and Ice. The success of each retracker to produce a better SSH estimate value was determined by calculating the value of improvement percentage (IMP). The IMP was calculated from the percentage between the difference of standard deviation of the on-board SSH (standard ocean retracker) with the geoid and standard deviation of the other SSH retracker with the geoid divided by the standard deviation of the standard on-board retracker. Figure 4 showed an example of retracker analyses for SSH estimation in the southern coastal waters of Java island for pass number 242. In the figure 4, it showed that at a distance of 0-7 km from the coastline, the standard oceanic retracker did not succeed in providing SSH estimation value (invalid SSH estimation or produce NaN value). This meant that the waveforms in this area were identified as non-brownish waveforms so that the standard ocean retracker produced an invalid value (NaN) for SSH estimation. However, the 20% threshold retracker was successfully provide valid SSH estimation values up to a distance of about 1.8-7 km from the coastline where the standard ocean retracker gave the invalid (NaN) SSH values. OCOG retracker was also able to generate SSH estimation value at a distance of 1.8-7 km from the coastline but the value was considered less accurate because it was too much different from the comparator value of SSH based on the EGM08 model.

The results of the waveform retracking analyses in the Java Sea using Jason-2 altimeter satellite data in the period 2012-2014, it showed an improvement of SSH estimate values in the range 31.9-62.8% (table 2). Unlike in the southern Java island waters which the improvement can reach of 95.24%, in the Java Sea the maximum percentage of improvement was only of 62.8%. This was because the Java Sea was relatively shallower (<200 m) and flanked by two coastlines with some small islands within the Java Sea. These conditions were more likely to have more complex waveform shapes and patterns compared to the shape and pattern of waveforms in the deeper water. The roughness of the sea surface may also give noise to the waveform and causes the waveform to be more
difficult to analyze [27]. Each retracker had specific advantages and disadvantages with its area of study so that each retracker performs differently depending on the characteristics of its waters [16, 26]. It seems that Threshold 10% retracker provide better percentage improvement for SSH estimate in Java Sea (table 2).

![Figure 4](image-url)

**Figure 4.** An example of retracking analyses of Jason-2 satellite altimeter data pass number 242 in the southern Java island waters. In the black box, SSH estimates by 20% Threshold retracker produced IMP of 20.20%.

| Pass number | Pass length (km) | Best retracker      | Improvement Percentage (IMP) |
|-------------|------------------|---------------------|------------------------------|
| 051         | 426.3            | Threshold 10%       | 61.0                         |
| 064         | 405.7            | Threshold 10%       | 61.5                         |
| 127         | 386.0            | Ice                 | 56.7                         |
| 140         | 423.7            | Threshold 10%       | 57.5                         |
| 203         | 352.4            | Threshold 50%       | 31.9                         |
| 216         | 391.0            | Ice                 | 62.8                         |
| 229         | 356.1            | Improved Threshold 20% | 58.4                   |
| 242         | 133.5            | Threshold 10%       | 55.6                         |

**Table 2.** Best retracker and percentage improvement of SSH estimate for Jason-2 altimeter satellite data in Java Sea waters.

The results of the retracker analyses for 2010 Jason-2 altimeter satellite data in the southern Java island waters showed various improvements to the SSH estimation particularly in coastal/shallow
waters compared to the standard ocean retracker. The best results were generated by the 50% Threshold retracker which provided a 95.24% improvement in coastal waters (0-10 km distance) on pass 242 in the southern Java island waters. While a small percentage of the improvements was generated by retracker of 50% Improved Threshold which results in an improvement of 8.51% at a distance of 0-10 km from the coastline (pass number 127, table 3). However, the results of this analyses showed that no dominant retracker producing the best SSH estimate. For that, we need to perform retracking analyses for all Jason-2 altimeter satellite data specifically in shallow waters.

**Table 3.** Best retrackers and percentage improvement of SSH estimate for Jason-2 altimeter satellite data in southern Java island waters.

| Pass number | Distance from coastline (km) | Best retracker          | % Improvement (IMP) |
|-------------|------------------------------|-------------------------|---------------------|
| 051         | 0-10                         | Improved Threshold 20%  | 67.04               |
|             | 10-50                        | Threshold 10%           | 41.26               |
|             | 50-100                       | Ice                     | 14.96               |
| 064         | 0-10                         | Ice                     | 11.33               |
|             | 10-50                        | Improved Threshold 10%  | 49.16               |
|             | 50-100                       | Threshold 20%           | 36.60               |
| 127         | 0-10                         | Improved Threshold 50%  | 8.51                |
|             | 10-50                        | Threshold               | 19.0                |
|             | 50-100                       | Improved Threshold 20%  | 60.85               |
| 140         | 0-10                         | Improved Threshold 10%  | 86.34               |
|             | 10-50                        | Improved Threshold 10%  | 83.32               |
|             | 50-100                       | Threshold 20%           | 38.73               |
| 203         | 0-10                         | Threshold 20%           | 76.16               |
|             | 10-50                        | Improved Threshold 20%  | 54.99               |
|             | 50-100                       | Threshold 20%           | 85.04               |
| 229         | 0-10                         | Threshold 50%           | 59.95               |
|             | 10-50                        | Ice                     | 44.11               |
|             | 50-100                       | Threshold               | 24.88               |
| 242         | 0-10                         | Threshold 50%           | 95.24               |
|             | 10-50                        | Ice                     | 12.92               |
|             | 50-100                       | Improved Threshold 20%  | 49.21               |

4. Conclusion
In general, non-Brownish and complex waveforms were identified along coastal region specifically within the distance of 0-10 km from the shoreline. In contrary, generally Brownish waveforms were found in offshore. However, Brownish waveform can also be found within coastal region and non-Brownish waveforms within offshore region. Therefore, the identification of the waveform for all passes of Jason-2 altimeter satellite data in Indonesian waters remains necessary. The number of non-brownish waveforms in the Java Sea was found more in the northern part of the Java Sea (coast around southern Borneo island) than in the southern part of Java Sea (north coast of Java island). This relates
to the more complex topography of the coastline in the northern part of the Java Sea (the southern coastline of the Borneo island) compared to the southern part of the Java Sea (the northern coastline of Java Island).

The waveform retracking analyses of Jason-2 altimeter satellite data were successfully improve the accuracy of sea level estimation (SSH) in the southern Java island waters and Java Sea particularly in coastal region. However, there was no dominant retracking method to improve the accuracy of the SSH estimate. These results indicated that it is necessary to perform retracking waveform analyses for all Indonesian waters specifically along the coastal or shallow waters.

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