Analysis of Sea level Rise by Using Satellite Altimetry Data of West Sumatra Waters in 2009 – 2019

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Abstract. The West Sumatra Waters is one of the vulnerable area exposed to impact of Sea Level Rise where the West Sumatra Waters located adjacent to the Indian Ocean Waters and Andaman Sea. Some of the negative impact caused by SLR are coastal abrasion, erosion, and sinking of small islands also increases risk of flooding. Therefore, research about SLR must be continued as an information in management of coastal areas. The technology that is widely used in observing SLR is the satellite altimetry. The data used in this research are Jason 2 and Jason 3 satellite altimetry data from NOAA since 2009 until 2019 and the tidal data of the IOC as a comparator. The research uses linear regression method to get the sea level rise value. From the research results obtained SLR value in the West Sumatera Waters is -2.5 mm/years. The decline of the sea level in the region is caused by many factors such as the Indian Ocean Dipole and ENSO phenomenon.

1. Introduction

Sea Level Rise is one of the deformations that can threaten life, especially in coastal areas. Indonesia has a coastline of approximately 99,123 km which causes the majority of residents in Indonesia to live in coastal areas [1]. This Sea Level Rise can cause some adverse impacts on life in coastal areas. The impact that will be incurred such as coastal abrasion, erosion, and the sinking of small islands due to the suspension of land, as well as increased risk of flooding [2].

Sea Level Rise is caused by factors such as global warming, soil decrease and removal due to the movement of the tectonic plates, gravity changes, compaction and the unification of sediment, and changes in water circulation patterns and wind patterns, as well as decreased surfaces resulting from the occurrence of soil mass change caused by human activities and changes in a fluid under the ground surface [3]. Besides, another factor is the change in sea level temperature. Since the end of the 19th century until 2100, the Earth’s temperature is predicted to rise about 1.4 ° – 5.8 ° C. So it is estimated that the sea level in the year 1999 – 2100 will rise around 1.4-5.8 m [4].

Satellite altimetry is one of the remote sensing technologies that can be used to observe the dynamics of the sea. Data from satellite altimetry results in sea level altitude information, geostrophic velocity, wind speed, and wave height. Satellite altimetry was instrumental in estimating the Sea Surface Height [5].

Analysis of SLR using satellite altimetry had previously been conducted by Khasanah and Umar (2018) with the research location in the West Sumatra Waters. The study explained that altimetry satellite data has the best quality in the Jason-2 altimetry satellite data, then Jason-1 and the latter being TOPEX/Poseidon. This is because the Jason-2 satellite at the time was newly launched so that it could improve errors – errors in the previous satellites. Results obtained in the year 1993-2015 average SLR in the West Sumatra Waters is 1.35 mm/year [6]. Other research about SLR in the West of Sumatra...
Waters in period 2011 – 2014 was also conducted by Sidabutar (2016) with a trend of 15.22 mm/year [7]. Based on this, it is necessary to research with the longer observation time of the SLR and use the latest satellites that are Jason-2 and Jason-3.

2. Methods
The location of the research is in the area of West Sumatra Waters that can be seen in Figure 1.

The satellite altimetry trajectory used in this study were passed 090, 014, 166, 103, 027, 179, 001, 077, 153. The geographic position of research locations can be seen in table 3.1.

| Research location | Coordinates          | Pass       |
|-------------------|----------------------|------------|
| R01               | 5°56’7.88” U dan 93°32’18.55” T | 014 dan 027|
| R02               | 2°0’24.92” U dan 95°0’18.01” T | 014 dan 103|
| R03               | 2°1’37.38” U dan 97°48’39.98” T | 090 dan 179|
| R04               | 2°1’47.25” S dan 96°21’55.80” T | 014 dan 179|
| R05               | 2°2’54.67” S dan 99°13’57.18” T | 090 dan 001|
| R06               | 5°55’8.66” S dan 100°36’14.31” T | 090 dan 077|
| R07               | 5°57’31.32” S dan 103°27’10.07” T | 166 dan 153|

The satellite altimetry data used in this study was Jason 2’s satellite data with cycle 18-303 and Jason 3’s satellite data with a cycle of 24-143 in the West Sumatra Waters [8-9]. The satellite altimetry data used in this research is obtained online through the website data.nodc.noaa.gov/. Satellite altimetry data obtained online is still in NC format so that it can be legible then should be converted with the software BRAT 4.2.1 [10] to get the SLA value of each cycle. The tidal data used in this research was obtained online from the website http://www.ioc-sealevelmonitoring.org/list.php. Tidal data is used to validate Sea Level Anomaly data from satellite altimetry. The tidal data used is tidal data at Sabang, Padang, and Sibolga stations.

The Converted satellite altimetry Data generates SLA values per cycle. The SLA value is then created a regression chart using Microsoft Excel software with the following equation:

\[ y = mx + c \]  \hspace{1cm} (1)

Linear regression is used to perform to estimate of the sea level rise for a certain period of time. This is because the SLR relies the changed of SLA value over time. Where y is the SLA data from satellite altimetry in meters, m is a gradient that shows the value of SLR in meters/cycles, and x is the period in...
which this is a cycle. From the chart the SLR value obtained is the meter/cycle converted to mm/year with the equation:

\[
SLR \left( \text{mm/year} \right) = \text{gradient} \left( \text{m/cycle} \right) \times \frac{365}{10} \times 1000
\]  

(2)

3. Result and Discussion

The tidal graph results from the IOC data compared to the SLA graphs of the satellite altimetry data to prove that the result of SLA from the satellite altimetry data show the phenomenon of sea level correctly. In this research, the tidal graph used are tidal data at Sabang, Padang, and Sibolga stations shown by figure 2.

![Figure 2. The SLA graphic comparison of the satellite altimetry data with graphic tidal of the IOC](image)

Based on the Figure 2, there is a similarity of tidal pattern from altimetry satellite data with tide gauge data. This indicates that the value of SLA obtained from altimetry satellites in the waters of West Sumatra is correct.

From the result of the processing of the SLA graph generated the trendline value in each location in the West Sumatra Waters from satellite altimetry data.
Figure 3. The SLA graph of West Sumatran Water period 2009-2019 with the x-axis represents the period (years) and the y-axis is the SLA value.

From Figure 3, it can be seen that the graphs in each location have similarities of tidal patterns. The similarity of the pattern indicates that one location with the other location is still in the same waters area. This is because each the water area has a different pattern and tidal type [11]. The trendline value in
Figure 3 shows the Sea Level Rise (SLR) value for 11 years in each location. The value of SLR in the West Sumatra Waters can be seen in table 2.

Table 2. The value SLR of each location

| Location | Trendline (m/cycle) | SLR (mm/tahun) |
|----------|---------------------|----------------|
| R01      | -2.5 x 10^{-7}      | -9.1 x 10^{-3} |
| R02      | -1.4 x 10^{-5}      | -5.1 x 10^{-1} |
| R03      | -5.5 x 10^{-7}      | -2.0 x 10^{-2} |
| R04      | -8.1 x 10^{-5}      | -3.0           |
| R05      | -9.2 x 10^{-5}      | -3.4           |
| R06      | -1.2 x 10^{-4}      | -4.5           |
| R07      | -1.7 x 10^{-4}      | -6.2           |
| Average  | -6.9 x 10^{-5}      | -2.5           |

From table 2 can be seen that the value of SLR year 2009-2019 in 7 locations has a negative. Based on the results of table 2 indicates that the SLR in the West Sumatra Waters decline by -2.5 mm/year. This result is very much different from previous research conducted by Khasanah and Umar (2018) indicating that in 1993-2015 the SLR in West Sumatera Water is 1.35 mm/year and conducted by Sidabutar (2016) indicating that in 2011-2014 the SLR is 15.22 mm/year that also use linear regression. This can happen due to several factors, one of which is the time difference used so that there are natural phenomena that occur at different times.

The decline of sea level in the waters of West Sumatra is due to the effect of Indian Ocean Dipole (IOD), where the West Sumatra Waters adjacent with the Indian Ocean. Badan Meteorologi dan Geofisika (BMKG) Indonesia released that in 2019 regions in Indonesia suffered a fairly severe drought due to the more cold temperatures in the sea surface in Indonesia, which is lower from normal condition. It is triggered by the sea-front temperature anomaly phenomenon in the Indian Ocean where the sea-front temperature is lower in Western Sumatra (IOD +) from April to December 2019 [12]. The condition causes low rainfall resulting in a high decline in sea level. According to the value of Dipole Mode Index of NOAA 2009-2019, the IOD Positive has been several times and the strongest in the 2019 [13]. Based on the research of Doi et al., (2019), the positive IOD was very strong in the years 1994 and 1997, as well as the more extreme positive IOD events that occurred in the year 2019 which resembled the previous events [14].

In addition to the effect of IOD, the decline and rise of sea level in the West Sumatra Waters are also affected by the phenomenon ENSO (El Nino Southern Oscillation). ENSO consists of two phases namely El Nino and La Nina. The El-Nino incident occurs when sea level temperatures in the eastern Pacific Ocean rise and in Indonesian waters decline. While La Nina occurs when the sea level temperatures in the eastern Pacific Ocean decline and in Indonesian waters rise [15]. Released from the Science & Information for a climate-smart nation in the period 2009 to 2019 it was recorded that the El-Nino event in a longer period occurred in the years 2009, 2015, and 2019 while La Nina at 2010 and 2011 [16]. The sea level decline that occurred in the West Sumatra Waters 2009 to 2019 based on the results of the research can also be effect by the El Nino events that occurred during this period where the sea surface temperature in Indonesia is low that resulted in drought. The positive IOD and El-Nino that occurred in 2009 - 2019 is causing a decline of the SLR, especially in 2019 that occur simultaneously.

The results show, there are differences value the SLR in each location. This can be due to several factors, such as phenomena IOD, El-Nino, and La Nina have different influences in each location, the difference of data retrieval time in each pass of location, the presence of empty data and error data, and other natural phenomena occurring in the West Sumatra Waters from 2009 to 2019. SLR is a trend of sea level overtime during a certain period, so in this research sea level rise obtained is trend result during period 2009-2019.
4. Conclusion
From the results of the study can be concluded that the value of SLR obtained from satellite altimetry data of Jason 2 and Jason 3 in the West Sumatra Waters declined by -2.5 mm/year. The SLR that was obtained from this research is a trend of sea level from year to year during the period 2009-2019. The SLR is negatively valued indicating that in the period the sea level trends to decline due to is influenced by natural phenomena occurring during the period such as the IOD and ENSO phenomenon.

Acknowledgment
The authors would like to sincerely thank National Oceanic and Atmospheric Administration (NOAA) which has provided altimetry satellite data and IOC Sea Level Monitoring which provides tidal data.

References
[1] Maulana, M., Awaluddin, M., & Janu, F. (2017). Analisis Pengaruh Perubahan Garis Pantai terhadap Batas Pengelolaan Wilayah Laut Provinsi Jawa Timur dan Provinsi Bali di Selat Bali. Jurnal Geodesi Undip, 6(4), 342 - 350.
[2] Wuriatmo, H., Koessuma, S., & Yunianto, M. (2012). Analisa Sea Level Rise dari Data Satelit Altimetri Topex/Poseidon, Jason-1 dan Jason-2 di Perairan Laut Pulau Jawa Periode 2000 - 2010. Journal of Applied Physics, 2(7), 65 - 74.
[3] Williams, S. J. (2013). Sea Level Rise Implications for Coastal Regions. Journal of Coastal Research, 184 - 196.
[4] Wirasatriya, A., Hartoko, A., & Suripin. (2006). Kajian Kenaikan Muka Laut sebagai Landasan Penanggulangan ROB di Pesisir Kota Semarang. Jurnal Pasir Laut, 1(2), 31 - 42.
[5] Mansawan, A. A., Gaol, J. L., & Panjaitan, J. P. (2016). Variation and Trend of Sea Level Derived from Altimetry satellite and Tide Gauge in Cilacap and Benoa Coastal Areas. International Journal of Remote Sensing and Earth Sciences, 13(1), 59 - 65.
[6] Khasanah, I. U., & Umar, M. (2018). Sea Level Rise of West Sumatra Waters based on Multi-satellite Altimetry Data. Journal of Geography, 50(2), 162 - 167.
[7] Sidabutar, Y. L., Sasmito, B., & Ammarohman, F. J. (2016). Analisis Sea Level Rise dan Komponen Pasang Surut dengan Menggunakan Data Satelit Altimetri Jason-2. Jurnal Geodesi Undip, 5(1), 243 - 252.
[8] NOAA. (2017). OSTM/Jason-2 Product Handbook. Retrieved on November 8, 2019 from https://www.ospo.noaa.gov/Products/documents/hdbk_j2.pdf.
[9] NOAA. (2018). Jason-3 Product Handbook. Retrieved on November 8, 2019 from https://www.ospo.noaa.gov/Products/documents/hdbk_j3.pdf.
[10] Broadview Radar Altimetry Toolbox (BRAT). (2018). Software User Manual (Brat version 4.2.1). Diakses 25 November 2019 dari http://www.altimetry.info/filestorage/brat_user_manual.pdf
[11] Wyrtki, K. (1961). Physical Oceanography of the Southeast Asian Waters. California: UC San Diego.
[12] Thirafi, Hatif (2019, 30 Desember). Refleksi 2019 : Kejadian Bencana Terkait Cuaca, Iklim, dan Gempa Bumi yang Signifikan. Cited on July 20, 2020 from https://www.bmkg.go.id/press-release/?p=refleksi-2019-kejadian-bencana-terkait-cuaca-iklim-dan-gempabumi-yang-signifikan&tag=press-release&lang=ID.
[13] Smith, C. (2020, May 1). Download Climate Timseries. Cited on August 9, 2020 from NOAA ESRL Physical Sciences Laboratory: https://psl.noaa.gov/geos_wgsp/Timeseries/DMI/
[14] Doi, T., Behera, S.K., & Yamagata, T. (2019). Predictability of the Super IOD Event in 2019 and Its Link With El Nino Modoki. Geophysical Research Letters.
[15] Cane, M. (1986). El Nio. Annual Review of Earth and Planetary Sciences, 14(1), 43–70. https://doi.org/10.1146/annurev.earth.14.1.43
[16] Dahlman, LuAnn. Climate Variability : Oceanic Nino Index. Cited on July 20, 2020 from https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o-index.