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Sea Level Rise of West Sumatra Waters based on Multi-Satellite Altimetry Data

Isna Uswatun Khasanah and Masrinedi Umar

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Abstract TThe information of sea level rise was needed in the Indonesia as archipelago country to management risk and development coastal area. This research study took in West Sumatra waters, because the majority people have lived in coastal area and some areas is located below 100 m above Mean Sea Level (MSL). The sea level data was taken from multi-satellite altimetry, they are Topex/Poseidon, Jason-1, and Jason-2. The period of data started from 1993 until 2015. Preliminary data processing of satellite altimetry was done by global test and post-processing of satellite altimetry data. The sea level rise analysis done by linear regression methods. Linear regression formula of sea level rise in West Sumatra Waters during the period was $y = 1.586 + 0.0000113x$. The change of sea level during period 1993 until 2015 was 3.394 cm with mean sea level rise value was 1.35 mm/year.

Keywords: Satellite Altimetry, Sea Level Rise, West Sumatra Waters.

Abstrak *Informasi kenaikan muka air laut sangat diperlukan oleh Negara kepulauan seperti Indonesia untuk manajemen bencana dan pengelolaan wilayah pesisir. Pada penelitian ini, dilakukan analisis terkait kenaikan muka air laut di perairan Sumatera Barat karena beberapa areanya terletak dibawah 100m dari muka air laut rata-rata (msl). Data permukaan laut yang digunakan adalah data dari multi satelit altimetri yang meliputi satelit Topex/Poseidon, Jason-1 dan Jason-2. Periode data dimulai dari tahun 1993 s.d 2015. Pengolahan data satelit altimetri dimulai dengan uji global dan post processing. Nilai kenaikan muka air laut dihitung menggunakan metode regresi linier. Persamaan regresi linier dari kenaikan muka air laut di perairan Sumatera Barat adalah* $y = 1.586 + 0.0000113x$. *Perubahan kenaikan muka air laut dari tahun 1993 s.d 2015 adalah 3.394 cm dengan rata-rata kenaikan muka air laut pertahun adalah 1.35 mm/tahun.*

Kata kunci: *Satelit Altimetri, Kenaikan Muka Air Laut, Perairan Sumatera Barat.*

1. Introduction

The phenomenon of Sea level rise (SLR) is one of the important problems faced by the coastal countries or island states in the world. That phenomenon are caused by many factor. According to the IPCC report (IPCC, 2001) the surface temperature of the earth will raise steadily during the post industry era of the 19th century. Some of the impact of the global climate change is a change of rainfall (Aldrian, 2006)and sea level change phenomenon. This natural phenomenon need to be accounted in all the activities of coastal zone management. One of them in the waters of West Sumatra where some areas is located below 100 m above Mean Sea Level. Many people that live at coastal area really need of sea level rise information.

Many research that investigated about sea level change in Indonesia. The mean sea level rise in Indonesia waters since 1993 s.d 2011 was increased about 4 mm / year. The value of sea level rise were calculated based on satellite altimetry data and four tidal station data (Fenoglio-Marc et al 2012). Additionally, sea level rise in the waters of Padang was also assessed using the station data Permanent Service for Mean Sea Level (PSMSL). This research was conducted by Fatimah (2013). In research carried out analysis of changes in the value of the MSL for five years and external factors that influence it. Research results indicate that the sea level rise for 5 years is +5.8 mm or +1.8 mm / year. In fact, sea level rise varies with time and position. Coverage area and the length of data period will greatly affect to outcome of sea level change in some places. Therefore, this study examines the rise of sea level with local coverage in the West Sumatra waters using long-period data.

The development of technology has increased data acquisition and advanced. At present, the sea surface data can be obtained in the long period. One technology that can present data sea level is a long period of satellite altimetry. Satellite altimetry is designed with three main missions: to observe the global ocean circulation, observing the polar ice volume and observed changes in global sea level (Abidin, 2007). Considering the usefulness and the very significant contribution of satellite data in the study of marine altimetry, the satellite altimetry mission designed to have sustained. One altimetry satellite whose mission is sustainable satellites Topex/Poseidon, launched in 1992 then continued with the Jason-1 satellite, which was launched in 2002 and Jason-2 satellite, which was launched in 2008 until now. The third satellite altimetry has the same mission that is monitoring

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the dynamics of sea water. Therefore, in this study using three satellites. Problems arise when dealing with long-period data, including satellite data altimetry. Errors in the data include multi-satellite altimetry data entering the mainland, empty data, the outlier data, multi reference of each satellites data, and errors due to geophysical factors. Therefore, it needs special handling to satellite altimetry such as post-processing.

Given the importance of information of sea level rise on coastal zone management and sea level data are available over the longer term, this research aims to identify the sea level rise in the waters of West Sumatra.

2. The Methods

Research Location

This research was conducted in the waters of West Sumatra with the coverage area of south latitude 4o South Latitude to 1o North Latitude and 98o to 102o East Longitude. Location of the study can be seen in Figure 1. According to Figure 1, the track number of satellites altimetry that pass through the waters of West Sumatra is track numbers 001, 179, 014 and 090.

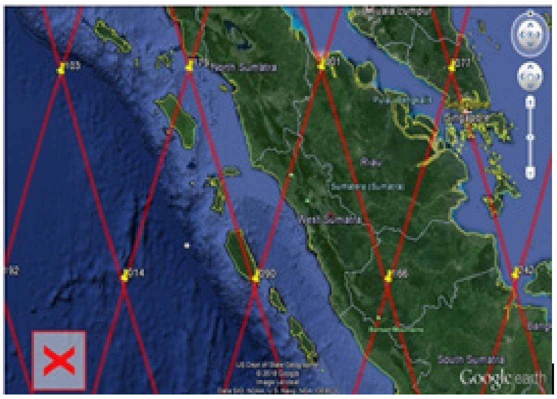

Figure 1. Research Location (Google earth)

Multi Satellite Altimetry Data

Data Type of altimetry satellite that used in the study named by Sea Surface Height (SSH) is the sea level altitude above ellipsoid. In this study, the SSH data is referenced to the geoid. Sea surface data is referenced to the geoid called by Sea Level Anomaly (SLA). SLA data is used for identification of sea level rise. SLA value is considered closer to the value of actual sea surface because it has been referenced to the geoid. Geoid is one model of the earth that is considered closest to the actual shape.

Satellite altimetry used include satellite Topex / Poseidon, Jason-1, Jason-2. Data obtained from the data Geophysical Data Record (GDR) each cycle of each satellite altimetry passing through the waters of West Sumatra with the track number are 001, 014, 090, and 179. Data of each satellite altimetry can be seen in Table 1 . The data of each satellite can be downloaded for free via the official website as follows:

1. Topex/Poseidon : ftp://podaac-ftp.jpl.nasa.gov/allData/topex/L2/mgdrb
2. Jason-1 : ftp://podaac-ftp.jpl.nasa.gov/allData/jason1/L2/gdr_netcdf_c/
3. Jason-2 : ftp://data.nodc.noaa.gov/pub/data.nodc/jason2/gdr/gdr/

Table 1. List of satellite altimetry data

Satellite	Cycle	Number of Pass/ Track	date (d.m.y)
Topex/Poseidon	C001 to C481	001, 014, 090 and 179	3/10/1992 to 1/10/2005
Jason-1	C001 to C254		4/2/2002 to 2/6/2012
Jason-2	C001 to C276		12/7/2008 to 30/12/2015

Geopotential Global Model EGM96

EGM96 data used to calculate the value of geoid undulation,which that value used as reference of SSH value. SSH value as referenced toward geoid named by Sea Level Anomaly (SLA). GGM EGM96 Data can be downloaded via the site http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/binary/binarygeoid.html.

Value undulations in the waters of West Sumatra by MGG EGM96 shown in Figure 2.

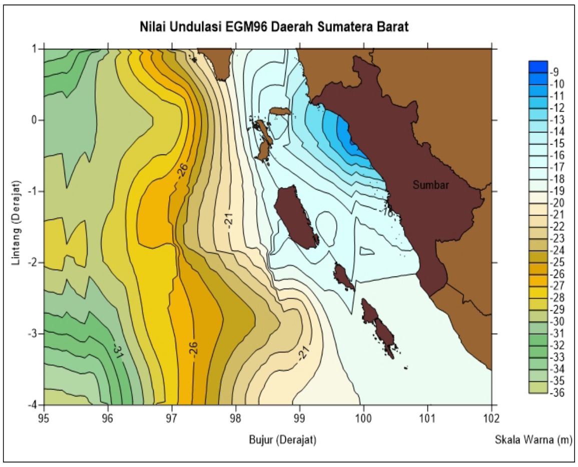

Figure 2. The value of undulation of Global Geopotential Model EGM96 of West Sumatra

Multi Satellite Altimetry Processing

Downloaded Multi-satellite altimetry data is in Binary data format. Therefore, need to be extracted and converted into ASCII format. Extracted data is data Sea Surface Height (SSH) or sea surface height data from ellipsoid. Software that used for extract the data is BRAT SSH v3.1.

SSH Extraction proceed by post processing to eliminated geophysic errors. This action of post processing satellite altimetry data is increased study accuracy data satellite observe by given many correction of geophysic/ geometric model like troposphere correction, ionosphere correction, refraction sea-state correction and tidal correction (Andersen and Scharroo 2011 in Putra 2013). Here its the explanation for each correction.

1. Troposphere correction. Satellite signal has refraction that cause the change in velocity and satellite signal if trough the troposphere. Troposphere refraction different by two are dry tropospher dan wet troposphere.
2. Ionosphere correction. On Ionosphere layer be found electron that influence velocity direction, polarization, and power of satellite signal. Magnitude of refraction from ionosphere effect is depends on variation of electron concentration along the signal path is affected by sun activity.
3. Refraction Sea state Correction, is error from reflective media toward satellite that number between Electromagnetic refraction and skewnes refraction.
4. Tidal Correction. Tical correction can be elastic ocean tides, load tides, solid earth tides, and pole tides

Equation (1) is used to extract the corrected SSH geophysical (Seeber, 2003).

$$SSH = h - \rho_{cor} \tag{1}$$

Where,

$$\rho_{cor} = \rho - \Delta h_{dry} - \Delta h_{wet} - \Delta h_{iono} - \Delta h_{ssb} - \Delta h_{inv\_bar} - \Delta h_{earth\_tide} - \Delta h_{ocean\_tide} - \Delta h_{pole\_tide}$$

ρcor : range of satellite to the sea level correction
Δhdry : dry tropospheric corrections
Δhwet : wet tropospheric corrections
Δhiono : ionospheric corrections
Δhssb : sea-state- biascorrections
Δhinv_bar : inverse barometer corrections
Δhocean_tide : ocean tide corrections
Δhearth_tide : earth tide corrections
Δhpole_tide : pole tide corrections

To obtain the SLA (sea surface data referenced to the geoid) value then takes the value of undulation. Undulation value obtained by extracting the data EGM96 (Binary format data) using software intptdac.exe. Software intptdac.exe requires input in the form of latitude and longitude coordinates of the location of research. The input file is derived from satellite altimetry SSH data is corrected. The output of this program is data undulation corresponding coordinate input file. Equation (2) is used to calculate the value of the SLA.

$$SLA = SSH - N \tag{2}$$

Where SLA is sea level anomaly, SSH is sea surface height and N is undulation value

Identify of Sea Level Rise

Rising sea levels are identified by using linear regression method. Linear regression equation shown in equation (3) (Nawari 2010 and 1985 in Putra Ebdon Bapennas 2013 and 2010).

$$y = a + bx \tag{3}$$

where,
y : sea level height
x : time
a : offset value
b : slope and trend value

Values of a and b is a constant linear regression. Constants a usually referred to intercept. Intercept the distance of the point of origin or point of reference with the point of intersection of the regression line with the Y-axis is also called slope constant b, which shows the inclination or the inclination of the regression line on the X-axis regression constants Values can be calculated using Equation (4) and (5) (Nawari Ebdon 2010 and 1985 in Son 2013).

$$b = \frac{\sum xy - nXY}{\sum X^2 - nX^2} \tag{4}$$

$$a = Y - bX \tag{5}$$

X : average of x variable
Y : average of y variable

3. Result and Discussion

Sea Surface of West Sumatra Waters

The average existence of data sea surface waters of the West Sumatra from Topex/Poseidon satellites approximately 82.492% of the Jason-1 satellite approximately 93.642% data and Jason-2 satellite is 94.25%. The percentage above is the percentage of multi-satellite altimetry data has been corrected from geophysical error, empty data, the data on the mainland and outliers. Based on these results, the best quality satellite altimetry data are on the Jason-2 satellite and then Jason-1 satellite and the last is Topex / Poseidon satellite. This can be happen because the Topex / Poseidon satellite was the first satellite that launched, so the quality of the recorded data has errors. While the next two satellites (Jason-1 and Jason-2) satellite was launched in the next period. Where errors are contained in the satellite Topex / Poseidon has been fixed on the satellite Jason-1 and Jason-2, because the third satellite has a sustainability mission that is monitoring the dynamics of sea level.

Visualization value of Sea Level Anomaly (SLA) waters of West Sumatra is shown in Figure 3.a, Figure 3.b and Figure 3.c consecutive shows SLA West Sumatra waters from the satellites Topex / Poseidon, Jason-1 and Jason- 2. Value SLA West Sumatra waters from the satellites Topex / Poseidon in range between -5.5 to 6 m. Based on the Jason-1 satellite, West Sumatra waters SLA values ranging from -1 to 3.6 m and from the satellite Jason-2 ranged between -0.8 to 3.6 m.

SLA value of satellites Topex / Poseidon has the greatest range. Based on Figure 3.a can be seen that in general, the value of the SLA in the waters of West Sumatra ranging from -1 to 4.5 m. SLA value of -5.5 to 6 m is not visible and it is possible that value is close to the mainland, which has a contour that is so tight. It can be caused due to an area adjacent to the mainland has a value less rigorous, which can cause a range of satellite Topex SLA / Poseidon is quite large.

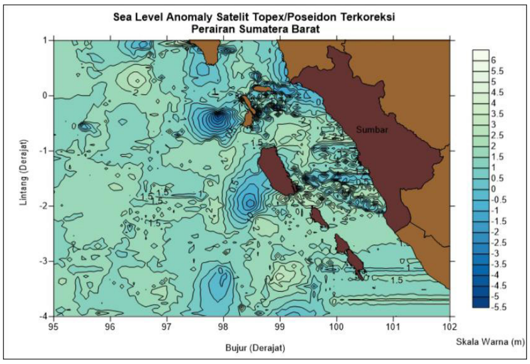

Figure 3.a. Visualization Sea Level Anomaly value from Topex/Poseidon satellite

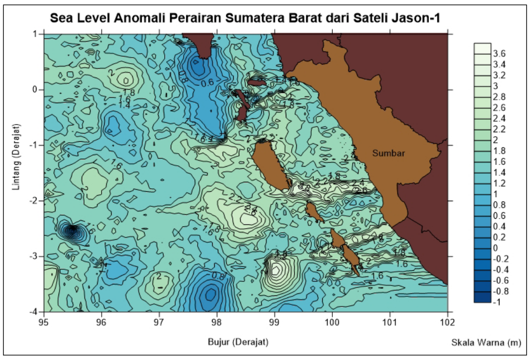

Figure 3.b. Visualization Sea Level Anomaly value from Jason-1 satellite

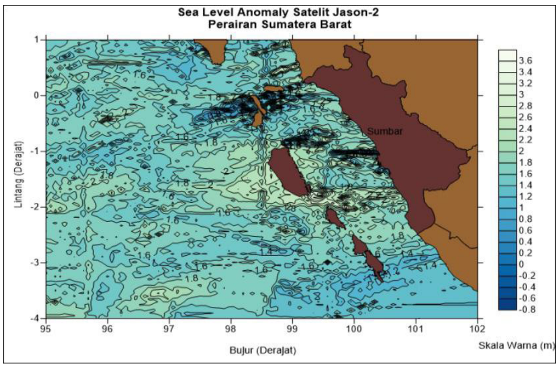

Figure 3.c. Visualization Sea Level Anomaly value from Jason-2 satellite

Sea Level Rise of West Sumatra Waters

In this study, the value of sea level rise calculated from the waters of West Sumatra each satellite altimetry. Value of sea level rise calculated by linear regression method (Equation 3). SLA data is used to calculate the value of SLR is the average value of each date multi-satellite altimetry data recording. Value of sea level rise of each satellite is shown in Table 2.

Tabel 2. The value of sea level rise of West Sumatra Waters

Regression Linear				
Satellite	Period	Constanta		SLR value (mm/th)
		a	b	
Topex/Poseidon	1993 to 2004	1.461	1.322E-05	1.44
Jason-1	2004 to 2009	1.673	1.327E-05	1.65
Jason-2	2009 to 2015	1.624	7.535E-06	0.96

Based on data from Topex / Poseidon recording period from 1993 to 2004 shows that the linear equations that form is y = 1.461 + 0.0000132x. Based on these equations can be calculated changes in sea level during the 12 years that happened in waters of West Sumatra is about 1.727 cm so that the average value of sea level rise per year was 1.44 mm / year. Figure 4 shows a graph of data Topex / Poseidon.

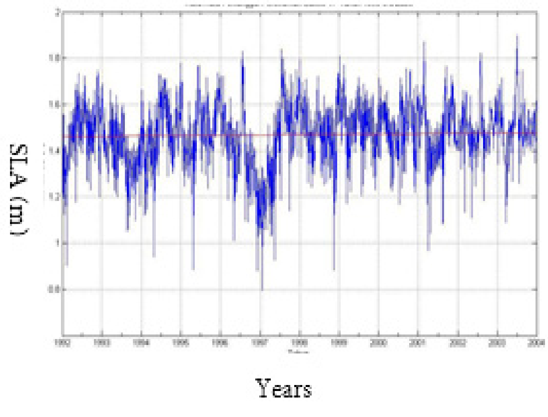

Figure 4. Graphic of sea level anomaly from Topex/ Poseidon satellite

SLA Data from satellites Jason-1 can be seen in Figure 5. Based on data from Jason-1 recording period from 2004 s.d 2009 shows that the linear equations that form is y = 1.673 + 0.0000137x. Since 2004 s.d 2009, the value of changes in sea level in the waters of West Sumatra is 0.993 cm so that the average value of sea level rise per year of data is Jason-1 is 1.65 mm / year.

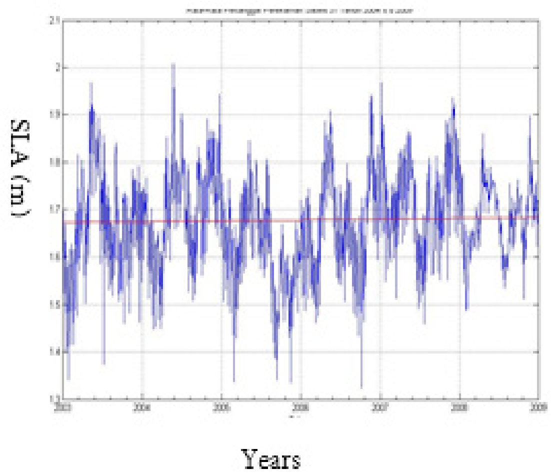

Figure 5. Graphic of sea level anomaly from Jason-1 satellite

Changes in sea surface of West Sumatra waters in 2009 to 2015 calculated from the Jason-2. The SLA value from Jason-2 satellite can be seen in Figure 6. The linear regression equation is established from the data Jason-2 is y = 1.624 + 0.00000753x. Based on data from Jason-2, during the last 7 years the sea level change in the waters of West Sumatra is 0.67 cm, and mean sea level rise value was 0.96 mm / year.

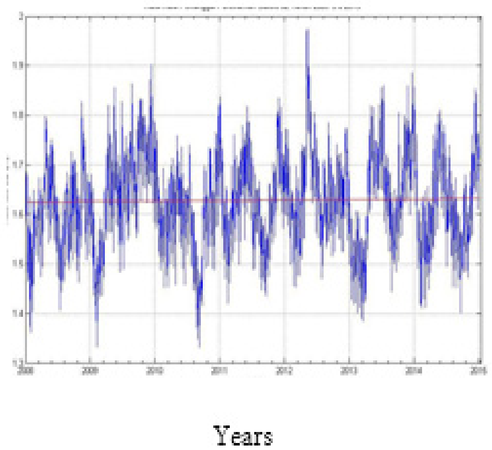

Figure 6. Graphic of sea level anomaly from Jason-2 satellite

Average value of sea level rise of West Sumatra waters during research period (1993 till 2015) obtained from sea level rise that calculated from Topex/Poseidon satellite, Jason-1 and Jason-2. Based on this case, so we have mathematical equation y = 1.586 + 0.0000113x. Where the intercept value is 1.586 and slope value is 0.0000113. Sea level changes value during 23 years of West Sumatra Waters is increase approximately 3.394 cm with average value is 1.35 mm/year.

The average value of sea level rise per year in waters of West Sumatra smaller than average sea level rise globally is 3.39 mm / year (http://www.aviso.altimetry.fr/) and also smaller that compared to the sea level rise value of Indonesia waters is about 4 mm / year (Fenodlio-March, et al, 2011). The sea level rise value of West Sumatra waters based on research is compatible with the results of his research Fenoglio-March, et al (2011), which is based on Figure 7 the value of SLR in the waters of Sumatra was less than 2 mm / year till 4 mm / year.

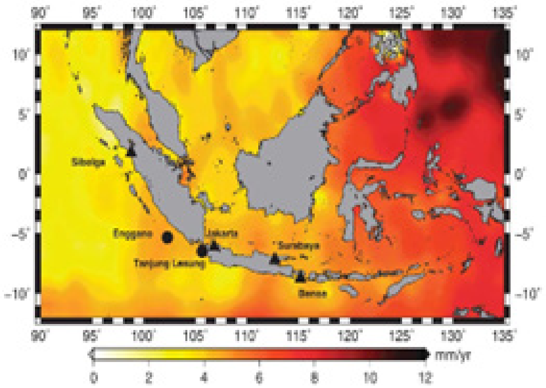

Figure 7. Visualization of sea level rise in Indonesian waters from 1993 to 2011 years (Fenoglio-March, et al, 2011)

4. Conclusion

The existence of sea surface data from West Sumatra Waters of multi satellite altimetry has a good enough quality, from the satellites Topex / Poseidon approximately 82.492% of the Jason-1 satellite approximately 93.642% data and Jason-2 is 94.25%. Based on multi-satellite altimetry data, sea level change of West Sumatra Waters since 1993 to 2015 (23 years) approximately 3.394 cm. It's mean the mean sea level rise value is about 1.35 mm / year.

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