Sea Level Rise in The Java Sea Based on Altimetry Satellites Data Over 1993-2015

Ratu Almira Kismawardhani1*, Anindya Wirastriya1,2, Dessy Berlianty3

1Department of Oceanography, Faculty of Fisheries and Marine Science, Diponegoro University, Semarang, Indonesia
2Center for Coastal Disaster Mitigation and Rehabilitation Studies, Diponegoro University, Semarang Indonesia
3Institute for Marine Research and Observation (BROK), Ministry for Marine Affairs and Fisheries, Bali, Indonesia

ratualmirakismawardhani@gmail.com

Abstract. At any location, sea level changes over time due to many well understood factors (ocean mass-induced, thermal expansion, etc.). By varied time series data, this research is purposing to get the rising sea level in the Java Sea related to thermal expansion and tide. Sea Level Anomaly (SLA) Altimetry data is supported by SST (Sea Surface Temperature) and SSH (Sea Surface Height) of tide measurement. SST is indicated relating to thermal expansion by surface distribution observed of SLA and SST. Both data trends are calculated by linear regression per grid of Java Sea area. Tidal components are determined by using FFT method to support long period data. The result showed the rising sea level increased up to 0.0039 m/year and followed by the increasing of SST for about 0.027°C/year over 23 years. Sea level rises and related positively to the rises SST produced by 0.56 paired statistic correlation. Temporally both tend to has the similarity in a yearly pattern on long-term period while short period shows the spatial relation. The lowest sea level falling trend occurred in 1997 and the highest rising trend in 2010. It is supported by El Nino and La Nina events. Based on the results, rising and falling rate of sea level in the Java Sea are highly related to the events through ONI (Oceanic Niño Index) value.

Keyword: SLA, SST, Java Sea.

1. Introduction

Sea level rise is the basis, of all regional or global factors, determination of climate change due to global warming. This is because all global climate change factors may have a direct effect on sea level change. The influence of atmospheric pressure due to rising global temperatures triggers a change in sea level position. In a stable state (stationary condition) the sea level can drop or rise up to 1 cm for every 1 mbar atmospheric pressure increased [1]. Changes in sea level rise can also be due to thermal expansion of inputs or heat loss in water bodies due to mass transfer of freshwater between the oceans and continents [2]. The distribution of water masses to the oceans is not always constant but constantly changing constantly and is strongly influenced by seasonal variations. The value of sea-surface
changes on the coast of Australia having a change due to climate and regional climate reduction processes. The value is changed from $1.4 \pm 0.3$ mm per year (1966 to 2009) and $4.5 \pm 1.3$ mm per year (1993 to 2009) to $1.6 \pm 0.2$ mm / year (1966 to 2009) and $2.7 \pm 0.6$ mm / year (1966 to 2009). Changes are generated by reducing the ENSO-related signal factor. After the correction of GIA and atmospheric pressure is done, the re-change occurs to be of $2.1 \pm 0.2$ mm / year and $3.1 \pm 0.6$ mm / year [3]. This value is close to the global sea level rise in the last 45 years.

Observations of sea level rise can change in time scale (temporal) and space (spatial). Temporarily sea level rise has the difference due to time series data used varies and even less than 18.6 years [4]. Sea level observation of sea level position requires a long observation time of 18.6 years. Many studies proved that changes occur due to the variation of latitude on earth. Spatially, the range of global sea level rise or decrease ranges from - 10 mm to 10 mm per year. Based on observations from 1992 to present on a global scale, global sea level rise has increased by $+3.28$ mm annually [5].

Indonesia which located on $6^\circ$S - $11^\circ$S and $94^\circ$E-145$^\circ$E have a high potential for the impact of global sea level rise. Indonesia's territory is in the range of 2.5 mm to 6 mm per year. Sea level rise in Indonesia until 2012 to reach the value of 5.84 mm per year [6]. This value is almost twice times higher than the average global sea level rise. This certainly has a big effect on the small islands in Indonesia. There are five physical effects of sea-level changes in coastal areas (ie. coastal erosion and headlands) increased flooding and hurricane damage, lowland pools, salt intrusions through groundwater aquifer systems, and an increased water position.

Thus in this paper, we focus on describing the increasing value of sea-level rise and variability around Java Sea supported by its connection to the variability of SST and tidal records.

2. Data and Method

2.1. Satellite Altimetry Data
The altimetry data set used for this study is re-processing daily sea level anomalies (SLA) Level 4 maps composed yearly with the spatial resolution of $0.25^\circ \times 0.25^\circ$ grids provided by Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/). This data contained multi-mission data result of altimetry satellites since January 1993 to December 2015. It is standardized and validated by all standard geophysical and environmental corrections, including the ionospheric correction, dry and wet tropospheric corrections, solid Earth, and ocean tides, ocean tide loading, pole tide, electromagnetic bias, inverted barometer corrections, and instrumental corrections [7].

Generally, SLA data will be compared with SST and tide gauge data records. SLA and SST have analyzed spatial and temporal analysis and data for such long and short period time series. Trend value is obtained from linear trend calculation. In accordance with tide records, SLA data is computed using the daily data at the closest grid points to the tide gauge location.

2.2. Sea Surface Temperature Data
Specifically, SLA altimetry combined with sea surface temperature (SST) with the spatial resolution of $0.25^\circ \times 0.25^\circ$ grids and accessed from National Oceanic & Atmospheric Administration (https://www.esrl.noaa.gov/). Both SLA and SST of Java Sea compiled into yearly calculation with. Those data were also composited towards El Nino and La Nina events, determined by using Oceanic Niño Index (ONI) provided by http://www.cpc.ncep.noaa.gov/. ONI index is the anomalies of SST in the Niño 3.4 region ($5^\circ$N-$5^\circ$S, $120^\circ$-170$^\circ$W), based on the basis period of 1993-2015. The threshold for determining El Niño and La Niña period is $+0.5^\circ$C.

2.3. Tide Gauge Data
To compare to satellites altimetry data, long-term tide gauge records of six stations are chosen to investigating the present study of sea level rise. There are station Sunda Kelapa, Cirebon, Jepara, Surabaya, Tuban, and Semarang with hourly tide data from 2011 to 2015. Most data are contained some time series with several missing observations. This observation data which distributed by BIG (Geospatial Information Agencies) is separated by its validity to preserve a good data. This study
implied FFT calculation to gain the tide components. Thus, this data will be used to determine the tidal type of area observation which is led to amplitude value on each station.

3. Result and Discussion

3.1. Long Period Analysis SLA in The Java Sea

The long period spatial analysis of SLA in the Java Sea is presented in fig. 1. The trend map of SLA in the Java Sea was calculated from 1993 to 2015. The trend map shows significant spatial variability (fig.1). In some region, such as region A of the Java Sea, sea level rise up to twice faster than the global mean, while the sea level near the region (112°E, 3°S) exhibited drop. The trend map displays the Java Sea as the region with the fast anomaly. It is indicated that SLA rising trend dominating most of region-observed.

![Figure 1](image-url)  

**Figure 1.** Spatial Variability of SST in the Java Sea. Region-observed is focused on (a) highest rising rate, (b) middle rising rate, and (c) lowest rising rate.

The trend of SLA in the Java Sea (fig.2) shows that there is increasing value since the year 1993 approximately 0.0032 m per year. In 2010, sea level rise in the Java Sea reached the fastest trend of Java Sea for about 0.0985 m while the slowest is occurred in 1994 for about -0.039 m. This interval extends for 16 years spanned the time from the lowest until the highest trend. It is showed the interval in between is about 0.14 m in 22 years. Inter-annual data for sea level trend in the Java Sea reaches its highest rising point in 1997 to 1998 and get the most falling year in 1997 to 1998. Trend value in 1997 rose from -0.035 m to 0.035 m. It means that there is increasing trend value for about 0.07 m or 7 mm on period 1997 to 1998 and decreasing value for about 0.069 m or 6.9 mm on period 1996 to 1997. Both show an extreme change of sea level trend occurred in period 1996 until 1998.
In the comparison with SST during the time of observation, the value trend of SST shows a positive trend. The increasing value for about 0.027°C/year. Temporally, the variation between period reaches the highest on 1998 with value of 29.48°C and 2010 for about 29.69°C. The lowest is valued on 1994 by 28.52°C. Those values closely showing the relation between SST toward SLA which SLA also fell to the lowest value in 1994 (-0.038 m/year) and reached the highest in 2010 (0.09895).

The anomaly is caused by the increase of sea level in the Pacific Ocean and giving more stress on the surface, there is occurred mass-induced through the Pacific Ocean to keep the balance in the ocean [8]. This phenomenon supports the Java Sea to surpassing the ocean mass to fill the empty chamber of Pacific Ocean. There are two factors of sea level anomaly such as steric variation caused by thermal expansion in the ocean and mass-induced between the land and ocean [9]. The location of Java Sea which is located between island probably causing mass-induced of land and ocean or vice versa.

In accordance with SST distribution in the Java Sea, ONI value (Table 1) showed the relation of El Nino and La Nina events towards the anomaly of sea level. During 2009 to 2011, the La Nina and El Nino event support the increasing of SLA up to the highest value as it showed below.
Table 1. Oceanic Nino Index (ONI) on Region Latitude 50° N-50° S and longitude 120° -170° W from 2009 to 2011. (*) displayed the event of El Nino and (**) displayed the event of La Nina.

| Year | DJF | JFM | FMA | MAM | AMJ | MJJ | JJA | JAS | ASO | SON | OND | NDJ |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2009 | -0.7 | -0.6 | -0.4 | -0.1 | 0.2 | 0.4 | 0.5* | 0.5  | 0.6  | 0.9  | 1.1  | 1.3  |
| 2010 | 1.3  | 1.2  | 0.9  | 0.5  | 0.0  | 0.4 | -0.9** | -1.2  | -1.4  | -1.5  | -1.4  | -1.4  |
| 2011 | -1.3  | -1.0  | -0.7  | -0.5  | -0.4  | -0.3  | -0.6  | -0.8  | -0.9  | -1.0  | -0.9  |

3.2. Short Period Analysis of SLA in The Java Sea

To investigate the short period analysis of SLA to the variability of SST in the Java Sea, we composed the SLA in spanned time up to five years and compared with also five years data of SST as shown in Fig. 4. Generally, SST has a strong correlation with the SLA. But SST displays contrary influence toward the rising of SLA spatially in the first period of observation. It is showed from spatial visualization that given in figure 4. The image of the high rising area of SLA displayed red while SST on the same area showed blue. SLA image has the rising level that gradually decreasing from land to open ocean. The correlation is also shown the value of correlation between region a, b, and c as displayed in figure 1. Region a has the lowest correlation value for about 0.488 meanwhile region b has the value of 0.547 and the highest correlation is region c with the value of 0.572. It is showed that the faster rates of SLA caused the lower correlation with the distribution of SST. Thus, it showed complex factors causing the variability of highest SLA in a region.
Figure 4. The comparison of the spatial trend between SLA towards SST in the Java Sea on short time series. The variability consists of several short period such as (a) 1993- 1997, (b) 1998 – 2002, (c) 2003 – 2007, and (d) 2008 – 2015.

For investigating thermal expansion, SST parameter is chosen yet displayed the main movement of thermal expansion in the Java Sea. Due to lack in-situ data, spatial observation of thermal expansion is not quite displayed. Both data showed the higher rate of the anomaly since the first time span and increasing over time. The first time span observation rates highly due to the occurring El Nino and the fourth time span by La Nina. Spatial observation showed that the second decade (2004-2015) the Java Sea has a higher rising rate in both of parameter and falling trend happened for the first decade (1993-2003). As it is displayed in figure 3, the first decade reaches the value of 0.01025 m/year. In another case, the value of the second decade (during 2004 to 2015) reaches up to 0.051091 m/year.

Table 2. The comparison between satellite altimetry and tide gauge data at the same observation time span

| Tide Gauge Station | Location | Time Span | Distance (km) | Trends (m/yr) |
|--------------------|----------|-----------|---------------|---------------|
|                    | Longitude | Latitude  |               | Tide Gauge    | Altimetry     |
| Sunda Kelapa       | 106°48'34.21" E | 6° 7'30.77" S | June 2012 - December 2015 | -0.000052 ± 0.00065 | -0.00025 ± 0.00014 |
| Semarang           | 110°25'25.49" E | 6°56'30.77" S | September 2011 – October 2015 | -0.00093 ± 0.0011 | -0.0013 ± 0.00066 |
| Jepara             | 110°38'55.04" E | 6°35'30.46" S | April 2011 – June 2015 | -0.00064 ± 0.47 | -0.0005 ± 0.0017 |
Comparing with tide gauge data, SLA showed less related to tide gauge trend spanned in five years observation. Each station has different time span based on the records. That is shown in Table 1 which every station stated different time observation. It is due to lack of the data records and also we only separated the valid value of tide gauge data. Table 1 showed a quite significant different value of observation between the two parameters. It is left for future study to have longer time span and more accurate tide data. In another case, rising and falling pattern between tide gauge and altimetry data showed more correlation by its time span. The longer data used the better correlation will be made.

4. Conclusion

Sea level rise in the Java Sea has been investigated by using long-term observation of altimetry data (1993-2015). The conclusions are as follows:

1. The Java Sea shows increasing the value of sea level trend for about 0.032 m/year during 23 years observation. It is nearly 0.09895 m/year with the highest rising anomaly on 2010. Meanwhile, the lowest falling trend reaches on 1994 for about -0.039 m/year.

2. The first decade of observation (during 1993 to 2003) results in the lower trend of sea level anomaly by the value of 0.01025 m/year. In another case, the value of the second decade (during 2004 to 2015) reaches up to 0.051091 m/year which is indicated that rising trend happen mostly in the second decade.

3. Sea level anomaly trend increases over time and in line with the increasing of SST. Particularly, during extreme El Nino (1997-1998) and La Nina (2009-2010) events. In another case, SLA is correlated with tide gauge data yet particularly with the longest data such as station of Surabaya and Sunda Kelapa.

4. The lowest and highest SST anomaly throughout the year of observation occurs exactly the same as SLA by the value of 28.34°C in 1994 and 29.66°C in 2010 with the average value of 28.93°C. SLA and SST is closely correlated by the correlation value of 0.56. Yet, shows the mass-induced from thermal expansion as the main factor of SLA anomaly trend in the Java Sea.

References

[1] Lisitzin E 1974 Sea Level Changes Elsevier Scientific Publishing Company Netherlands 295
[2] Willis Josh K 2010 Global Sea Level Rise Recent Progress and Challenges for The Decade to Come Oceanography 23 (4) 26-35
[3] White Neil J 2014 Australian Sea Levels—Trends Regional Variability and Influencing Factors Earth-Science Review 136 155-174
[4] Ali M, D K Miharja and S Hadi 1994 Pasang Surut Laut (Bandung: Institut Teknologi Bandung)
[5] AVISO 2015 Through Indonesia https://www.aviso.altimetry.fr/en/news/idm/2015/apr-2015-through-indonesia.html
[6] Nababan B 2015 Dinamika Anomali Paras Laut Perairan Indonesia. Journal Ilmu Kelautan and Teknologi Kelautan Tropis 7 (1) 259-272
[7] Geruo A, Wahr J and Zhong S 2013 Computations of the viscoelastic response of a 3-D compressible Earth to surface loading: an application to glacial isostatic adjustment in Antarctica and Canada. Geophys J. Int. 192(2) 557

[8] Trujillo Alan P and Harold V Thurman 2011 Essentials of Oceanography Ed 10 Prentice Hall United Stated 577

[9] Wei Feng and Zhong Min 2015 Global Sea Level Variations from Altimetris GRACE and Argo Data over 2005-2014 Geodesy and Geodynamics 6 (4) 274-279