VARIATION AND TREND OF SEA LEVEL DERIVED FROM ALTIMETRY SATELLITE AND TIDE GAUGE IN CILACAP AND BENOA COASTAL AREAS

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Abstract. Observation of sea levels continuously is very important in order to adapt the disasters in the coastal areas. Conventionally observations of sea level using tide gauge, but the number of tide gauge installed along the coast of Indonesia is still limited. Altimetry satellite data is one solution; therefore it is necessary to assess the potential and accuracy of altimetry satellite data to complement the sea level data from tide gauges. The study was conducted in the coastal waters of Cilacap and Bali by analysis data Envisat satellite altimetry for period 2003 to 2010 and data compiled from a variety of satellite altimetry from 2006 to 2014. Data tidal was used as a comparison of altimetry satellite data. The altimetry satellite data in Cilacap and Benoa waters more than 90% could be used to assess the variation and the sea level rise during the period 2003-2010. The rate of sea level rise both the data of tidal and satellite altimetry data indicates the same rate was 3.5 mm/year in Cilacap. in Benoa are 4.7 mm/year and 5.60 mm/year respectively.

Keywords*: altimetry, sea level rise tide, satellite*

1 INTRODUCTION

Altimetry satellite technology is one of the remote sensing techniques that had potency to observe the spatial and temporal dynamic of the ocean. Data from this satellite used to produce the information of the sea level height, geostrophic speed, wave height and the wind velocity (Digby *et al.* 1999). Up to today, there were 8 types of altimetry satellite radar that was high precision, i.e. Geosat that had been Launched from 1985 to 1989, *European Remote Sensing Satellite* (ERS-1) from year 1991 to 1998, Topex/Poseidon from year 1992 to 2006, ERS-2 from year 1995 up to now, GFO from year 1998 up to now, Jason-1 from year 2001 up to now, ENVISAT from year 2002 to 2010, and Jason 2 from year 2008 up to now (Fu and Cazenave, 2001).

Altimetry satellite has important role for oceanography division, especially for forecasting the rate of sea level. This satellite has the ability to show the image of global synoptic from the ocean circulation and shows the measurement result of sea level topography as an integral of the ocean interior (Traon *et al.* 1998). Today, the global warming issue become world-wide public attention and has impact to the sea level rise, which become the economic activities around the beach.

Based on the result of the research that has been done before for both regional and global, it looks the existence of the rate of sea level rise. Therefore, the observation of the rate of sea level rise locally is important observation to do the adaptation steps remained this sea level rise could cause the disadvantages to public live in the coastal areas.

Conventionally, the observation of sea level used *tide gauge*. But the total number of *tide gauge* that were applied along the beach in Indonesia were inadequate. One of the ways to solve this limitation was the usege of altimetry satellite data.

According to altimetry satellite data during the period of 1993 to 2015 the mean of rate of the sea level rise in the world's water was about 3.4±0.2 mm/year (Nerem *et al.*, 2010). In Southeast Asia water, the rate of sea level rise varied from 1 to 10 mm/year (Strassburg *et al.* 2015). For the area of Java Sea and waters of South Java, the rate of sea level was about 0.71 – 2.72 mm/ year (Wuriatmo *et al.* 2012).

The waters of Cilacap Beach and Benoa Bali are ones of the economical centers. Various activities, such as fish farming and fishing and also the tourism activities has been long standing and become people's livelihoods. Meanwhile, the global climate change that causes the rise sea level became a threat for people around the beach. The monitoring of the rate of sea level rise as on going basis needs to be done from both the tidal gauges and altimetry satellite.

This research aimed to analyze the potency of altimetry satellite data on the for measurement of rate of the sea level rise rate and to analyze its variability and the rate of sea level rise rate and to analyze its variabillity and the rate of sea level rise around Cilacap and Benoa waters, Central Java.

2 MATERIALS AND METHODOLOGY

This research was done in Remote Sensing Laboratory and Geographic Marine Information System, Departement of Marine Science and Technology, Faculty of Fisheries and Marine Science, Institut Pertanian Bogor Agricultural University. The research area was selected in Cilacap and Benoa coastal waters. With the position of Tidal Data Recording Station fromUniversity of Hawaii Sea Level Centre (UHSLC) on 7,75° South Latitude and 109,00° East Longitude (Cilacap) and 8,776600° East Longitude (Benoa). While for Envisat satellitedata with of the track number 107 and 006 that was gotwere obtained from Aviso. On along that those satellite track, then it was chosen some we selected several recording points as data collection station, i.e. 206, 213, 220, 227, 234 and 241for track 107. On track 006, it was chosen the station number 196, 202, 209, 216, 223 and 229 as focus the sites of SLA data collection. The distance of each station was 50 km (Figure 2-1).

The used data on this research was altimetry satellite data from Aviso and Colorado University. The satellite data was downloaded from http://colorado. sealevel/ and the tidal data was from UHSLC with the time of data collection per day or hour was downloaded on http://uhslc.soest. hawaii.edu/data/download/rq.

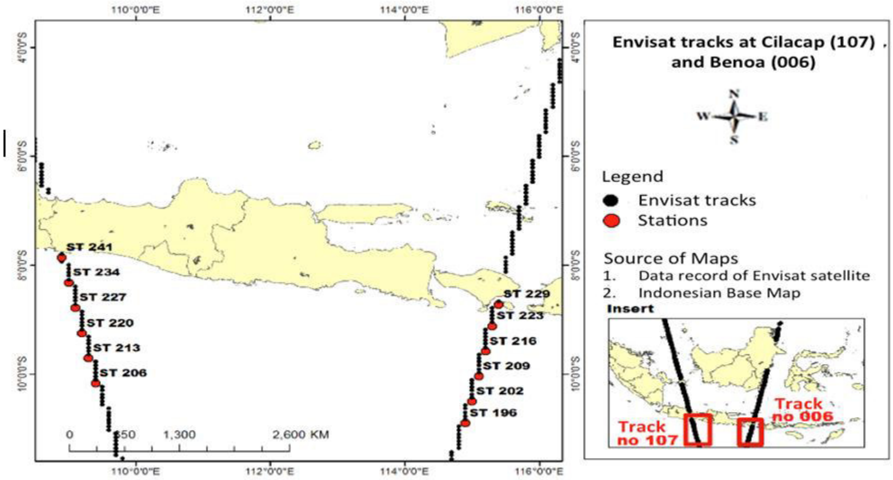

Figure 2-1: Research location map

The altimetry satellite data is processed with the aid of Matlab software that was written by Vignudelli (2014). The Sea Surface Height (SSH) is counted by the equation:

$$SSH = MSSH + SLA \quad (2\text{-}1)$$

Where, SSH is the sea surface height and MSSH is mean sea surface height and SLA is sea level anomaly. The distance of sea surface above ellipsoid (*h*) was counted by the equation (Fu and Cazenave, 2001):

$$h = H - R \quad (2\text{-}2)$$

Altitude (*H*) refers to the distance from the center of satellite mass above reference point/ellipsoid. *Range* (*R*) is the distance from satellite mass to the earth's surface. *Height (h)* refers to the distance from the sea level above ellipsoid.

The sea surface height is calculated from altimetry *range* and the satellite height above the ellipsoid. The range from satellite to the surface is estimated from the travel time of round trip by (Fu and Cazernave, 2001):

$$R = \hat{R} - \sum_j \Delta Rj \quad (2\text{-}3)$$

Where $R = ct/2$, c is the light speed and t is time.

ΔRj, j = 1 … is correction from various atmosphere components and bias of atmospheric scattering. The range measurement is usually stated as height (*h*) from the relative sea level to the ellipsoid as follow:

$$\begin{aligned} h &= H - R \\ &= H - R + \textstyle\sum_j \Delta R \end{aligned} \quad (2\text{-}4)$$

The approximation of precision this *h* is still influenced by geoid, the dynamic geostatic tidal so the height is estimated as follow (Lu and Cazevave, 2001).

$$\begin{aligned} h_d &= h - h_{geoid} - h_{tides} - h_{IB} \\ &= H - R + \textstyle\sum_j \Delta Rj - h_{geoid} - h_{tides} - h_{atm} \end{aligned} \quad (2\text{-}5)$$

The distance between satellite and sea level is calculated based on the travelling time from the pulse of microwaves that has been emitted. From time (t=0), when the first tip from the pulse arrives in the surface, for time (t= ĩ) when the last tip from one pulse with width from ĩ arrives in the surface.

3 RESULTS AND DISCUSSION

3.1 Altimetry Satellite Data Potency in Cilacap and Benoa Waters

On Figure 3-1, it shows the data condition of sea surface height from Envisat satellite that was recorded throughout the track number 107 and

006 at the time of 2003 until 2010. The data shows that along the satellite track, the data percentage that is available and could be used to measure the sea surface height around the coast was 90%.

Basically, the altimeter satellite is aimed to observe the ocean dynamic in the high seas and not for the coastal areas. It is caused that the altimeter satellite signal around the coasts experiences the disruption because of the ground effect in coastal area (Gommenginger *et al.*, 2011). But the experts especially from Europe tried to utilize this altimeter satellite data to measure the sea surface height around the coastal area (Vignudelli et al., 2011). The valid presentation of Envisat satellite data along the water park in Cilacap and Benoa coasts for about 10 years was high enough, which was about 90%. It shows that altimetry satellite data is potential to be utilized for studying the water dynamic and variability of sea surface height, especially in the Cilacap and Benoa coasts.

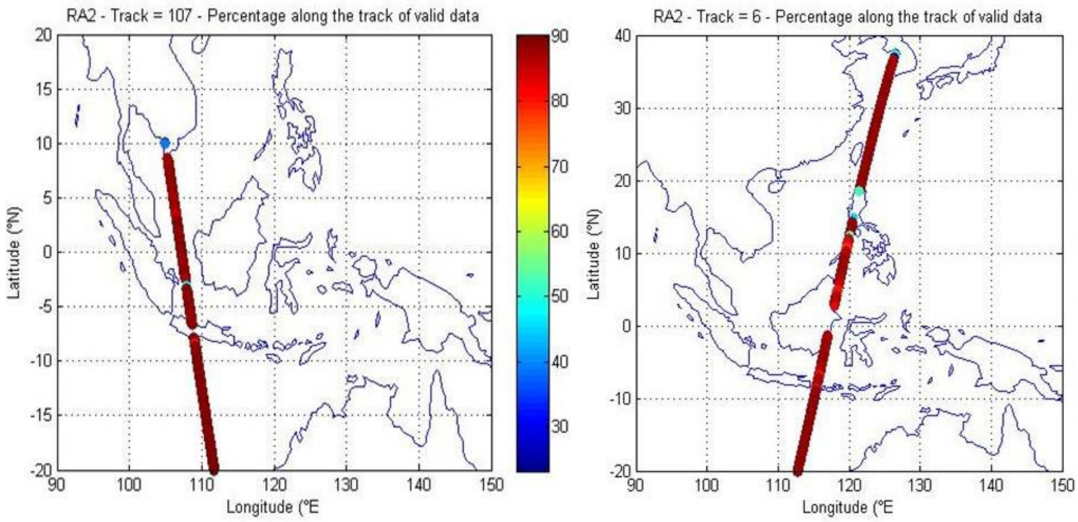

Figure 3-1: Distribution of valid data percentage on track 107 and 006 of Envisat Satellite

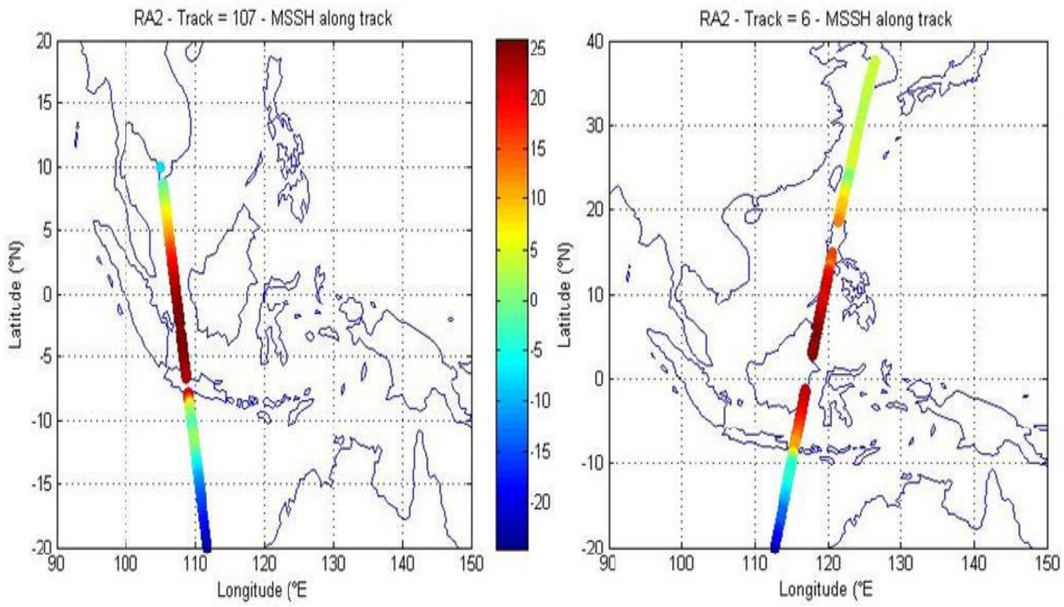

Figure 3-2: Distribution of MSSH value on track 107 and 006 of Envisat satellite

The tracking result shows that MSSH value is about -25 up to 25 cm (Figure 3-2). The highest MSSH value is seen in the shallow water areas and the lowest is in the south side of the deep sea island.

Figure 3-3 is RMS value from SLA in Cilacap coastal areas for about 0.1 up to 0.45. RMS SLA value was high if it was near from the coast. The lowest value is on open sea. The high and low values of RMS in coastal area show the existence of signal effect that is received by satellite sensor from the ground around the coast (Gommenginger *et al.,* 2011). But the RMS data value around Cilacap and Benoa coasts are low enough (0.10-0.15). It is caused by the Cilacap coastal areas are connected directly to the high seas.

3.2 Variability and the Rate of Sea Surface Cilacap and Benoa Waters

The result of anomaly data analysis of sea surface height for period 2002 until 2010 (Figure 3-4) shows the existence of annual and inter-annual variability. On the East Season, the sea surface height anomaly generally is in South of Java Waters is negative, on the contrary at the time of West Season (Potemra *et al.,* 1997). Similar condition was found around Cilacap and Benoa waters (Figure 3-5).

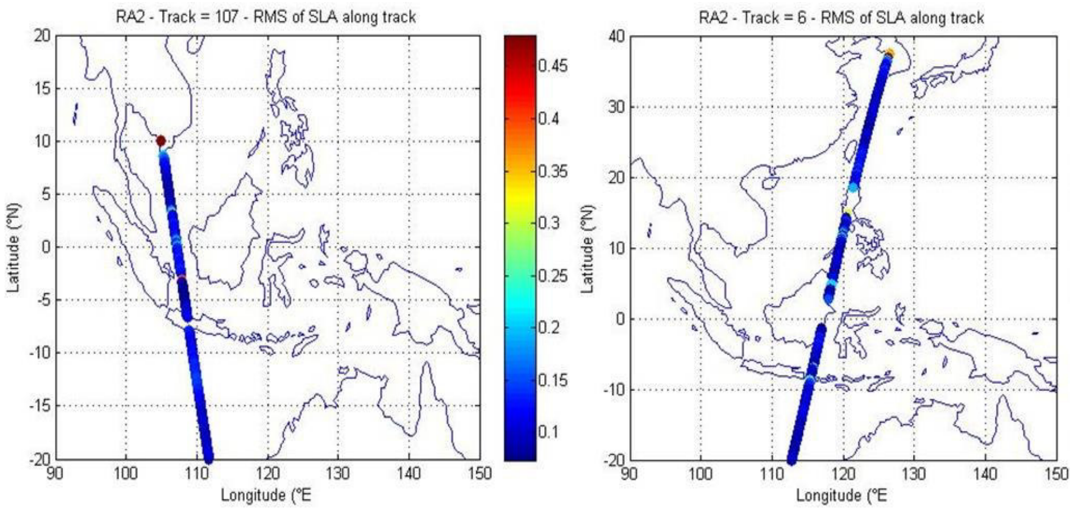

Figure 3-3: Distribution of RMS SLA value, track 107 and 006 Envisat satellite

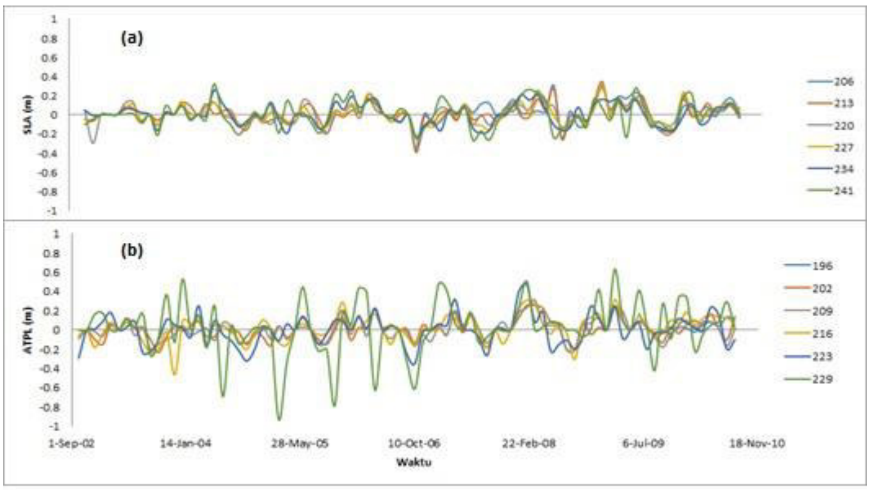

Figure 3-4: Variation of sea surface height anomaly in some points of (a) track 107 and (b) track 006 (2002 – 2010)

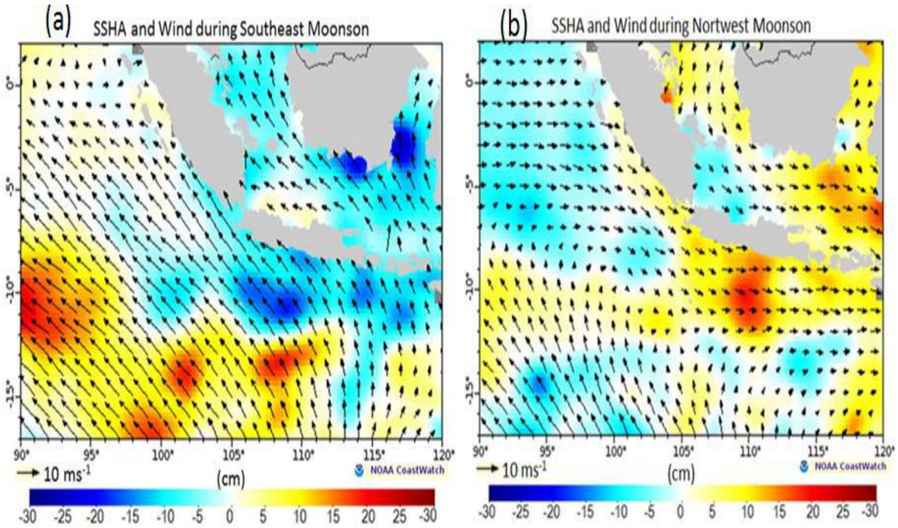

Figure 3-5: The direction and speed of the wind and sea surface height anomaly in eastern part of Indian Ocean (Lumban Gaol *et al.* 2015)

Waters in Indonesia is influenced by Moonson winds (Susanto *et al.,* 2001). At the time of East Season, the wind blows fully from the southeast and pushes out the water mass along the coasts on South Java (Wrytki, 1961; Purba *et al.,* 1997; Lumban Gaol *et al.,* 2015). Because of the coriolis force, the water mass would be deflected away from the coast so it caused the upwelling where the sea surface came down (Figure 3-5).

3.3 The Rising Rate of Sea Surface Height from Altimeter Satellite Data and *Tide Gauge*

On Figure 3-6, it was figured out the variations and the rate of sea surface from the tidal gauge tools and from altimeter satellite. The data show that the rate of sea surface rose in Cilacap coastal waters for both from satellite data and tide gauge tools were 3.5 mm/year. This increasing rate is relatively lower than the global increasing rate and some waters in Indonesia. The increasing rate of sea surface around Benoa Waters from tide gauge data is 4.7 mm/year while from the satellite data is 5.6 mm/year. The calculation of determination coefficient value for Cilacap Waters from satellite data is 0.078 and for tide gauge is 0.024. While for Benoa Waters, the determination coefficient value from satellite data is 0.067 and for tide gauge is 0.058.

This result shows that the increasing rate of sea surface between regions is different. It is accordance with the results of previous research (Sriartha and Putra, 2015; Sihombing, *et al.,* 2012; Strassburg *et al.*, 2015).

4 CONCLUSION

The valid Altimeter Envisat satellite data from year 2012 – 2010 for Cilacap and Benoa Waters were about 80 - 90%. It shows that the altimetry satellite data has potency to be utilized for measuring the sea surface height in coastal area of Cilacap and Benoa.

The high variability of sea surface in Cilacap and Benoa Waters is dominant influenced by moonson wind system. The sea surface height at the East Season and Transitional Season II is higher compared to the West Season and Transitional Season I for both in Cilacap Coastal Waters and Benoa Coastal Waters.

The increasing rate of sea surface in Cilacap and Benoa Waters is positive from both satellite data and tidal measurement data.

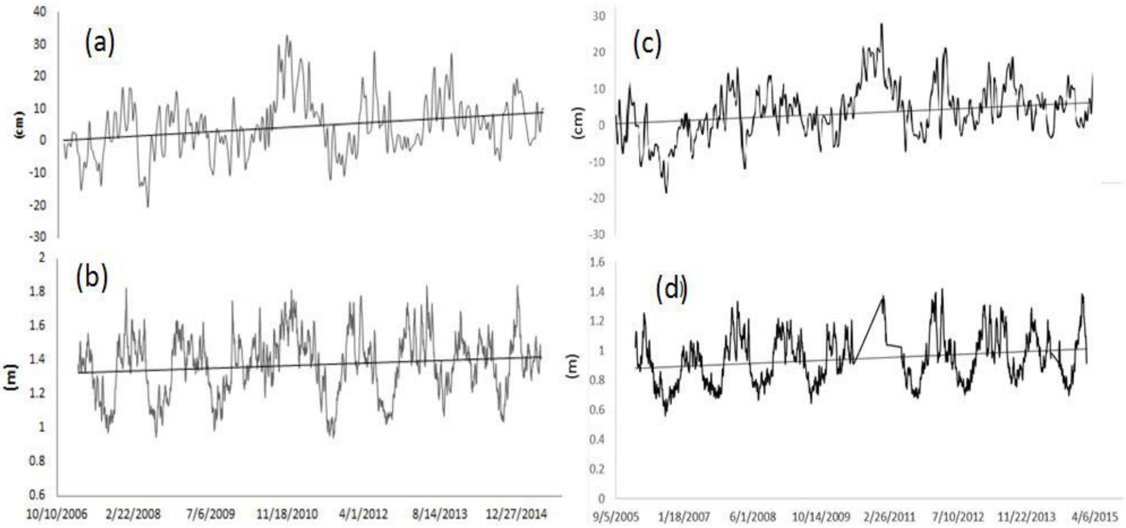

Figure 3-6: (a) The increasing variation and rate of sea surface from satellite data in Cilacap, (b) from the tidal (c) The increasing variation and rate of sea surface from satellite data in Benoa, (d) from the tidal

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