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Sea Level Variability Around Belitung Using Satellite Altimetry

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***Abstract*—The Sea around Belitung Island is an oceanic pathway for the South China Sea and the Java Sea which has some characteristics. This paper addresses to determine sea level variation around Belitung Island using satellite altimetry observation. Several parameters applied to determine sea level anomaly. Based on the altimeter measurements for a period of 24 years (1993 – 2016), the rates of sea level rise are 4.3 mm year^{-1} of B1, 4.6 mm year^{-1} for B2 and 4.5 mm year^{-1} for B3. The southern sea of Belitung island has a higher sea level rate than northern area, due to its influenced by El Niño Southern Oscillation. The correlation indices between Multivariate El Niño Southern Oscillation and detrended Sea Level Anomaly are -0.41, -0.56 and -0.54 for points of B1, B2 and B3, respectively.**

Keywords—sea level variability, Belitung, satellite altimetry, El Niño Southern Oscillation

I. Introduction

The long-term sea level change is the one crucial indicator of climate change and variability due to its close relation with the ocean, cryosphere, hydrosphere, and atmosphere systems. Sea level rise can be a big problem in the future, related to the climate change. Sea level rise may cause inundation of low-lying areas, flooding, salt seawater intrusion into surface water and aquifers [1], [2].

Since the end of 19th century, tide gauges have been installed to measure sea level variability along coastlines and islands. However, they are in limited amount and distribution in some regions of the world [3]. At present, the satellite altimetry is used to monitor sea level routinely. There are several satellite altimeters that providing precise and continuous datasets for sea level studies with global coverage and moderate spatiotemporal resolution.

Global mean sea level observed by satellite altimetry has been estimated to be about 3.0 – 3.4 mm/year [4]. However, some places have higher rates of sea level variation, such as the Southern Indian Ocean and the Western Pacific Ocean. The El Niño – Southern Oscillation (ENSO) events are correlated with the inter-annual global mean sea level (GMSL) [5], notably in the tropical Pacific Ocean [6]. The Indonesian seas, located between the Pacific and Indian oceans are strongly impacted by ENSO [7].

Some authors pointed that the rates of sea level rise around the Indonesian seas are between 2 and 10 mm/year depend on location and period [7],[8]. The eastern Indonesian seas have a higher rate of sea level rise than the western of Indonesian seas [8].

Belitung Island is located in an oceanic hub between the South China Sea (SCS) and the Indian Ocean. The sea around of Belitung Island is passed by fresh waters and low salinity from SCS through the Karimata Strait and Java Sea to the Indian Ocean [9]. Moreover, the Belitung Island is a central of the monsoon between Eurasian and Australia continents which affects sea surface temperature [SST] around the sea [10].

Those characteristics are very interesting to be investigated. This study focuses to determine sea level variability, included sea level rate and its relationship with ENSO around Belitung Island using satellite altimetry.

II. Data and Method

A. Data

In this study, altimeter data have been extracted from Radar Altimeter Database System (RADS), developed by the Delft Institute for Earth-Oriented Space Research and the NOAA's Laboratory for Satellite Altimetry, except the GPD+ data were provided by FCUP, Portugal [11]. The altimeter data used are TOPEX/Poseidon (1993 – 2001), Jason-1 (2001 – 2008) and Jason-2 (2008 – 2016). Multivariate ENSO Index (MEI) for the similar period is provided by NOAA. MEI is an index which is determined from the varying principle component of six atmospheric-oceans of the Comprehensive Ocean-Atmosphere Data Set (COADS) parameters measured over the tropical pacific and can reflect multiple characteristics of the ENSO phenomena [12].

B. Method

A satellite altimetry measures the vertical range between the satellite and the sea surface. A short pulse of microwave radiation is emitted from the on-board radar antenna toward the sea surface, part of the signal being reflected back to the satellite. The range can be determined by measuring the two-way travel time of the signal. Thus, the sea-surface height (SSH) is obtained by the difference between the satellite height above the reference ellipsoid and the range of the satellite to the sea surface [12].

The observed altimeter range must be corrected before it can be used to determine SSH. For studies of sea level variability, it is often more convenient to refer the sea surface height to the mean sea surface height rather than to the geoid, thus creating the sea level anomalies (SLA) [13].

$$SLA = H - R - \Delta h_{dry} - \Delta h_{wet} - \Delta h_{iono} - \Delta h_{ssb} - h_{DAC} - h_{tides} - h_{MSS} \quad (1)$$

where H is satellite height above a reference ellipsoid determined by precise satellite orbit determination, R is corrected altimeter range (including instrumental effect), Δh_{dry} (dry tropospheric correction), Δh_{wet} (wet tropospheric correction), Δh_{iono} (ionospheric correction) and Δh_{SSB} (sea state bias), h_{DAC} (dynamic atmospheric correction) and h_{tides} (tides: ocean, load, solid earth, and pole) are range and geophysical corrections, and h_{mss} is a mean sea surface model.

SLA around Belitung Island was determined based on equation 1 using parameter in Table I.

In order to estimate the annual trend and linear trend of sea level variability, the "Seasonal and Trend based on LOESS" (STL) [15] and Original Least Square (OLS), respectively, were performed. For investigating the correlation between SLA and the ENSO event, the Multivariate ENSO Index (MEI) from NOAA was used.

TABLE I. THE RANGE AND GEOPHYSICAL CORRECTIONS USED IN THIS STUDY

Parameter	Mission		
	TOPEX/Poseidon	***Jason-1***	***Jason-2***
Year	1993-2002	2002-2008	2008-2016
Cycles	11-353	11-248	10-312
Dry Tropo	ERA	ERA	ERA
Wet Tropo	GPD+	GPD+	GPD+
Ionosphere	SDF	SDF	SDF
Sea state bias	CLS	Tran2012	Tran2012
Tides	GOT4.10	GOT4.10	GOT4.10
MSS	CNESCLS 2011	CNESCLS 2011	CNESCLS 2011

GPD+ = GNSS-derived Path Delay
SDF = Smoothed Dual Frequency

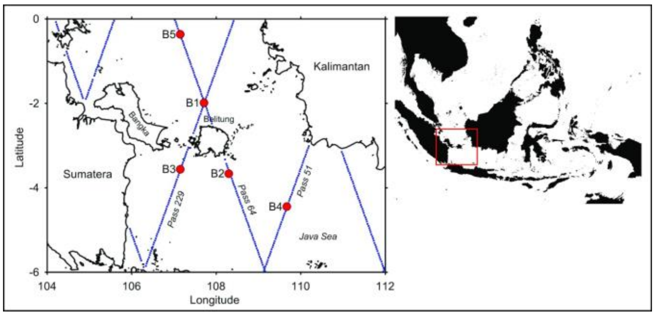

Fig. 1. The sea around Belitung. Red dots are the point observations and blue lines are along-track of TOPEX/Poseidon, Jason-1 and Jason-2 Satellite altimeters

III. RESULTS AND DISCUSSION

The estimation of sea level variability using parameters described in [7] was performed for the following altimetry missions: T/P, Jason-1, and Jason-2. The Sea Level Anomaly time series at the observation points from these missions over the 25-year period is also presented (see fig.1). Several points, B1 (north), B2 and B3 (south), B4 (Java Sea), and B5 (near the South China Sea), were estimated for SLA (see Fig.1 and Fig.2).

To make a stable and continuous time series across these satellites during the nominal reference orbit phase, the inter-satellite sea level anomalies are calibrated during the tandem phases when the pair of satellites sampled the same ground track within one minute of each other. The relative difference between each mission (example, T/P - J1, and J1-J2) was determined by averaging the differences between all corresponding tandem mission cycles.

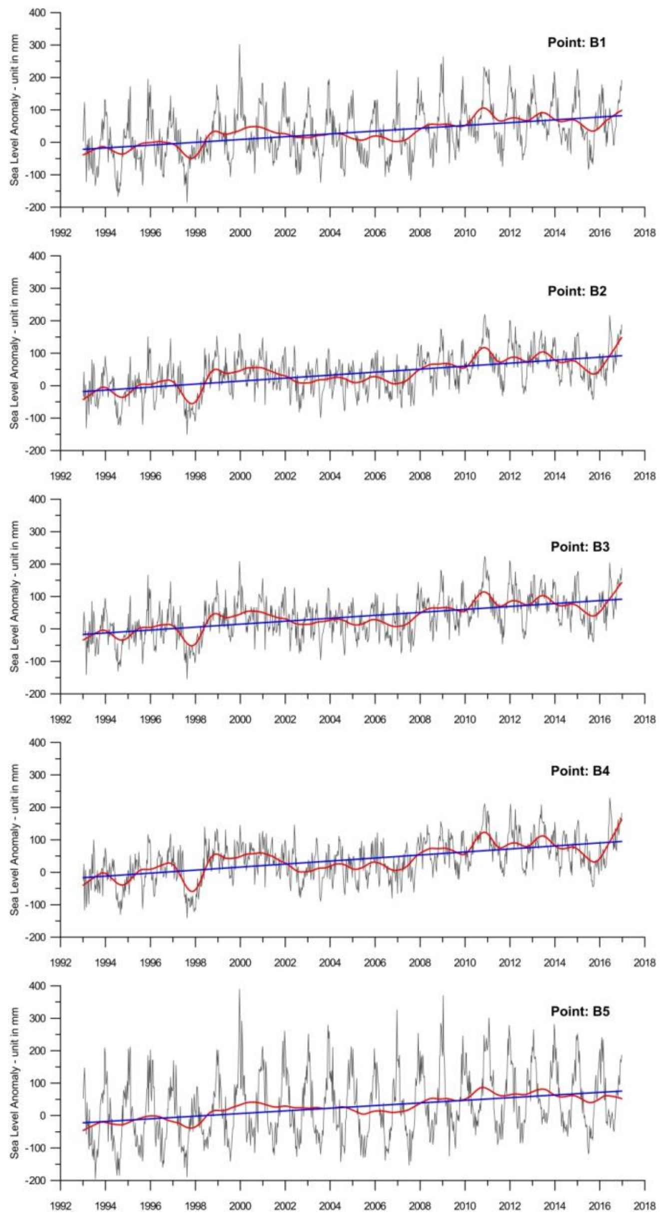

Fig. 2. SLA (mm) time series around the Belitung Island sea from three different satellite altimeters (grey curve), annual trend (red curve) and SLA linear trend (blue line)

TABLE II. CORRELATION OF SLA AT THE OBSERVATION POINTS

	B1	B2	B3	B4	B4
B1	-	0.82	0.88	0.65	0.95
B2	0.82	-	0.98	0.95	0.59
B3	0.88	0.98	-	0.90	0.68
B4	0.66	0.95	0.90	-	0.41
B5	0.95	0.59	0.68	0.41	-

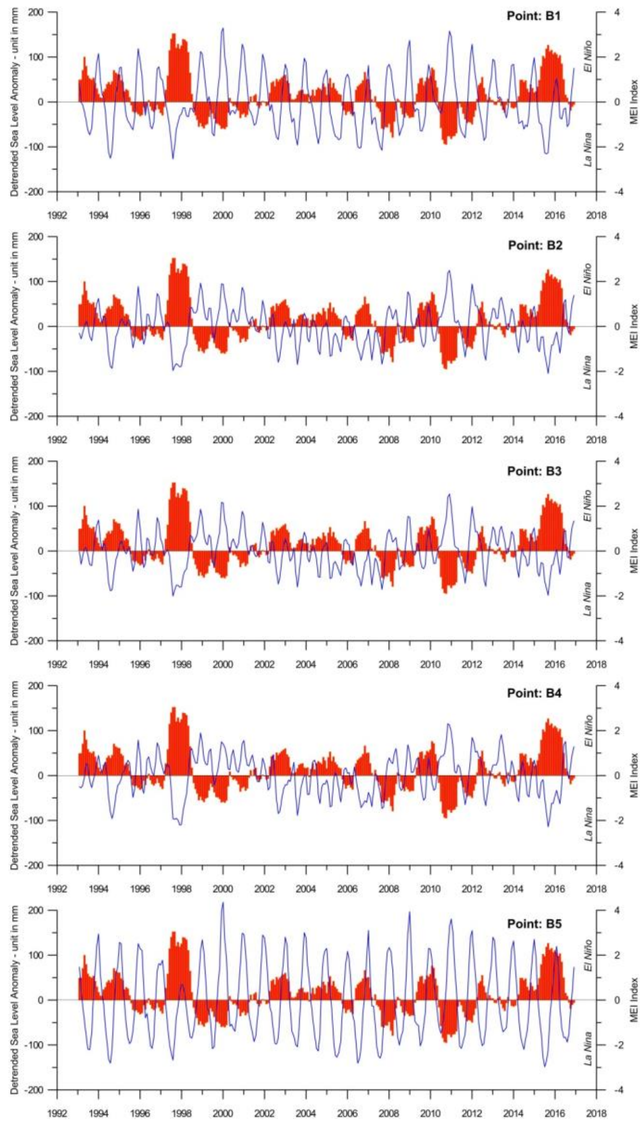

Fig. 3. Detrend SLA (mm) time series around the Belitung Island from three different satellite altimeters (blue curve) and MEI (red vertical box). The positive value refers to the El Niño condition and negative value refers to the La Nina

Table II shows the correlation of SLA at observation points. According this table, Point B1 has a strong correlation (0.95) respect to B5 (near the South China Sea). It means that Point B1 is influenced by the South China Sea. Meanwhile, Points B2 and B3 are strongly influenced by Java sea, these shown the high correlation (0.95 and 0.90, respectively) with B4 (Java Sea).

The Sea level time series is a combination from TOPEX/Poseidon, Jason-1 and Jason-2 altimetric data. Figure 2 presents the inter-calibrated, relative difference-corrected sea level anomalies SLA time series around the Indonesian seas from T/P, J1 and J2 missions between 1993 and 2016.

SLA time series have been decomposed into seasonal, inter-annual and residual signal using Seasonal Trend decomposition based on LOESS (STL). The rate of sea level trend was calculated by the Original Least Square for annual trend. The result is shown in fig. 2, the inter-calibrated data are shown in grey curve, the annual trend is in red curve, and blue straight line is linear trend.

Table 3 shows the trend of each measurement point. The lowest trend is 4.1 mm/year near the South China Sea and the highest is 4.7 mm/year around the Java Sea. The Point B2 is influenced by Point B4 associated with the Java Sea. Opposite of B2 and B3, Point B5 (near the South China Sea) impacts sea level trend at B1.

Indonesian seas are influenced by ENSO event. According [7] the correlation index between MEI and detrended SLA for the Indonesian Seas in the same period is -0.8. However, the detrended SLA and with ENSO is not correlating uniformly across the Indonesian Seas. The eastern Indonesian seas are stronger correlation than western part. Fig.3 presents the correlation between detrended SLA and MEI during a study period.

Table 4 shows that B4 has high correlation (-0.58) between MEI and detrended SLA. The negative sign means that they are opposite each other when SLA decreases (negative) with the MEI increases (positive) and vice versa.

IV. Conclusion

In this study, the sea level variability around the Belitung Island using TOPEX/Poseidon, Jason-1 and Jason-2 data for a period of 24 years.

The sea level trends at several points are about 4.1 to 4.7 mm/year. The northern sea of Belitung Island is influenced by the South china Seas, opposite, the southern sea is influenced by Java Sea. ENSO does not impact in the northern sea but adequate impact in southern sea of Belitung Island.

Sea level trend has been deduced only from satellite altimetry data. Complementary and relevant information on sea level variation can be derived from tide gauge data.

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TABLE III. SEA LEVEL TREND AT OBSERVATION POINTS FOR A PERIOD 24 YEARS (1993 – 2016). UNIT IN MILLIMETER YEAR^{-1}

	B1	B2	B3	B4	B4
Trend	-	0.82	0.88	0.65	0.95

TABLE IV. CORRELATION BETWEEN MEI AND DE-TRENDED SLA AT OBSERVATION POINTS

	B1	B2	B3	B4	B4
MEI	-0.41	-0.56	-0.54	-0.58	-0.28

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