Influence of ENSO and IOD to Variability of Sea Surface Height in the North and South of Java Island

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Abstract. Indonesia is one of the largest archipelagic countries in the world. Besides being in the tropics, these waters are also located between two continents and two oceans that making this area are heavily influenced by the global atmospheric phenomena such as El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). Sea level rise is one of the main threats faced by Indonesia and other island countries in the world. Not only global warming, sea level rise in the tropics also caused by inter annual variability such as ENSO and IOD. This research has been aimed to determine the influence of ENSO and IOD to variability of sea surface height in the north and south of Java. This research used Satellite altimetry data were constructed by multi-mission satellite. These results showed that the sea level anomaly generally inversely related to ENSO and Dipole Mode Index. The phenomenon that most influence a decrease sea level anomaly in the study area is a phenomenon IOD + and the phenomenon that most influenced the increase sea level anomaly is La Niña. South of Java is area that has the large effect of changes in sea levels than north of Java. During La Niña, sea level anomaly can be increase up to 0.3 m and sea level anomaly can be decrease up to -0.28 m during IOD+.

Keyword: Sea Level Anomaly, El Niño, La Niña, IOD

1. Introduction

Indonesia is one of the largest archipelagic countries in the world. Besides being in the tropics, it's also located between two ocean and two continents that making it as a center of atmospheric and global ocean circulation [1]. One of the effects of the circulation is change in sea level of Indonesian sea especially in the waters area of north and south of Java. Sea level conditions are currently linking to the phenomenon of global warming [2] which causes melting of the volume of ice in the Polar so increasing sea level in some area of the world [3]. Not only global warming, sea level rise in the tropics also caused by inter annual variability [4] such as ENSO [5][6] and IOD [7] especially in bordering region of the Pacific Ocean and the Indian Ocean. The waters area of north and south of Java has dynamics of the atmosphere and oceans which affected by ENSO and IOD [8]. Sea level rise is one of the main threats faced by Indonesia and other island countries in the world [9]. To observe of sea level changes, required the availability of adequate spatially and temporally data. The presence of satellite altimetry is a solution to comply of oceanographic data especially sea levels data, such as global and regional data [10]. The validation result of the altimetry data and tide observations were produced sea level measurement with very good accuracy and concluded that the altimetry data can represent the field observations data [11]. This research has been aimed to determine the influence of ENSO and IOD to variability of sea surface height in the north and south of Java. This research is important because changes in sea level can be effect for susceptibility of coast condition and coastal development especially in major cities in Java which has a quite high coastal development.

2. Methodology

2.1. Area of Study

The study was conducted in the waters of north and south of Java island with coordinate ± 3° – 11° S and 105° – 115° E (Figure 1) which includes six station points such as Jakarta (6.17° S, 106.67° E), Semarang (6.94° S, 110.42° E), Surabaya (7.21° S, 112.73° E), Prigi (8.28° S, 111.73° E), Cilacap (7.75° S, 109.02° E) and Pelabuhan Ratu (7.00° S, 106.50° E). Selection of a point by the big cities in Java and can represent the north and south coast of Java Island. The waters south of Java generally influenced by several factors phenomenon of ocean and atmospheric systems such as Monsoon, Indian Ocean Dipole (IOD), the El Niño Southern Oscillation (ENSO), a Kelvin wave and the Madden Julian Oscillation (MJO), Indonesian Trough Flow (ITF), South Equatorial Flow (SEF) and the flow of the west coast of Sumatra Island [12][13][14]. In the waters of Java Sea, the dominant factor affecting oceanography parameter is the activity of monsoon [15].

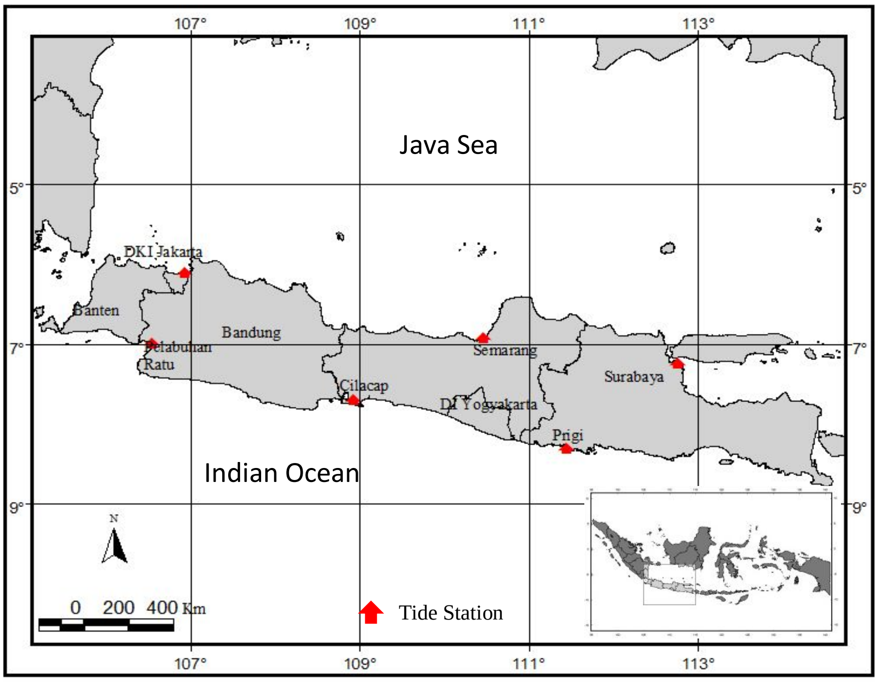

Figure 1. Area of Study

2.2. Satellite Altimetry Data

Satellite altimetry data used in this research were constructed by multi-mission satellite. The data downloaded from the AVISO web site (*ftp://ftp.aviso.altimetry.fr/global/delayed-time/grids/climatology/monthly mean/)* the reference version of gridded sea level anomaly (SLA) data. The data

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are mapped on a 1/4° Mercator grid and extracted for the area of study from the global SLA field for the period 1993-2015 (23 years). Sea level anomaly data are obtained from the following calculation:

$$SLA = SSH - MSSH \quad (1)$$

SLA is sea level anomaly, SSH is sea surface height and MSSH is mean of sea surface height.

2.3. ENSO Index

ENSO indices used in the determination of the value equation sea surface temperature (SST) anomalies in the Niño 3.4 region (120 ° W-170 ° W, 5 ° N-5 ° S) as follows:

$$\Delta SST_{3.4} = SSTa - SSTm \quad (5)$$

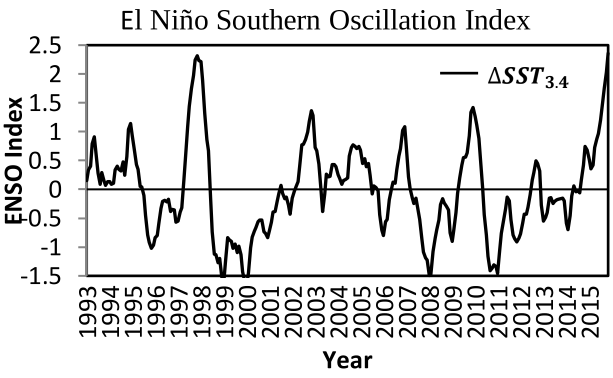
$\Delta SST_{3.4}$ is sea surface temperature anomalies in Niño 3.4 region, $SSTa$ is actual sea surface temperature in Niño 3.4 and $SSTm$ is mean of sea surface temperature from long time series in Niño 3.4 region. The result annual cycle for the Niña 3.4 region is shown in figure 2a. When SST anomalies are positive, then the phenomenon that occurs is El Niño and conversely if SST anomalies are negative then the La Niña phenomenon that will occur. Sea surface temperature anomaly data in 3.4 regions sourced from (*cpc.ncep.noaa.gov/data/indices/*).

2.4. Dipole Mode Index (DMI)

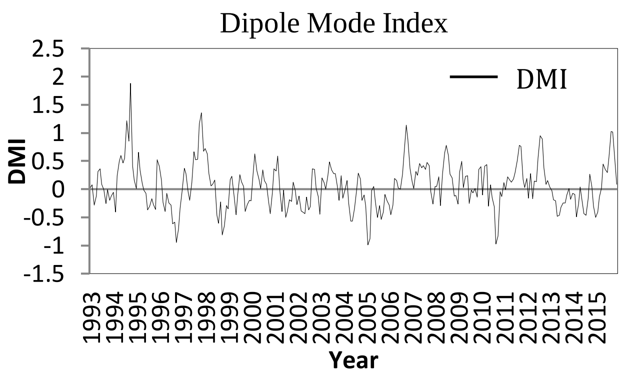
In determining the DM index, calculated the SST IOD [16] based on the following equation:

$$DMI = SSTmW - SSTmE \quad (2)$$

DMI is Dipole Mode Index, $SSTmW$ is mean of SST anomaly in west box area (10°N – 10°S, 50°E – 70°E) and $SSTmE$ is mean of SST anomaly in east box area (0° – 10°S, 90°E – 110°E). SST data sourced from *extreme.kishou.go.jp/itacs5/* (ITACS 5) in 1993-2015. The result of difference between anomaly west box and east box area is shown in figure 2b.



(a)



(b)

Figure 2. ENSO Index from SST anomaly in 3.4 region (a) and Dipole Mode Index (DMI) from difference of SST in Indian Ocean (b).

Based on the calculation above anomaly, furthermore do analysis the data to determine the relationship between sea surface height variability and the atmosphere phenomenon. Stages of analysis to be performed is describing the criteria for El Niño/La Niña in the Pacific Ocean and phenomenon of positive IOD (DM+) and negative IOD (DM-) in the Indian Ocean region. Analysis of the relationship between sea surface height variability and atmospheric phenomena by comparing the sea surface height anomaly with normal condition.

2.5. Surface Wind

Wind data show the vector represented by the direction and wind speed. To calculate the average wind at each point, the wind data must be parsed into an east-west wind component or commonly called zonal wind component (U) and the north-south wind component or commonly called the meridional wind component (V). Wind direction data indicated by the angle formed by the wind vectors with North [17]. The surface component wind data downloaded from the European Centre for Medium-Range Weather Forecasts (ECMWF) web site (*http://apps.ecmwf.int/datasets/data/*). The data are mapped on a 0.75º Mercator grid and extracted for the area of study from 1993-2015 (23 years).

3. Result and Discussion

Based on the index chart of ENSO and DMI (Figure 2) and then have been selected four cases of occurrence of ENSO and IOD such as ENSO + in 2002, ENSO- in 2007, IOD + in 2011, IOD- in 2005.

3.1. The Influence of ENSO on Sea Surface Height Anomaly in the Water of North and South of Java.

ENSO phenomenon includes the El Niño and La Niña is phenomenon that not only affects climate variability and weathers in Indonesia but also its affect the variability of marine phenomena and ocean parameters in Indonesian waters. In 2002, El Niño (ENSO+) that occurs indicated a moderate level in September to December (Figure 3).

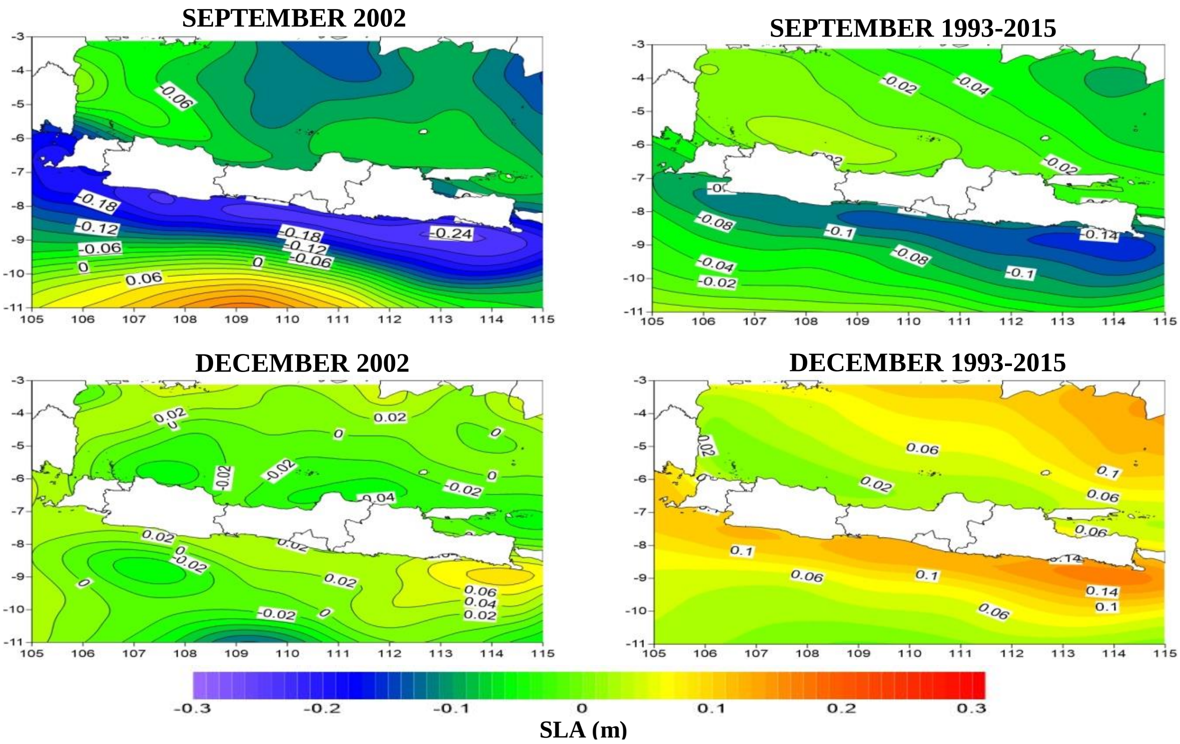


Figure 3. SLA in the water of north and south of Java at El Niño and average from 23 years

In 2002, it has shown quite obvious influence of El Niño on sea level anomalies in the north and south of Java. If compared with average conditions, when the El Niño phenomenon in 2002, the value of SLA tends to be lower than the average for 23 years. Based on these conditions, sea level anomaly in south of java decreased up to -0.24 m in September. In December that should anomalous sea surface height is positive in the southern region of Java however due to El Niño is active so it's causing SLA in southern of Java tends to be negative. Besides, almost all spatial regions decreased anomalously sea surface height.

When El Niño occurs, the entire system of trade winds weaken especially in west Tropical Pacific Ocean boundary. Consequently, the water that has accumulated in the west (warm pool) will flow turned to the east. Along with the warm pool shifting to the east and the weakening of the trade winds cause more shallow thermocline in Indonesia which accompanied by the increased upwelling. During El Niño, upwelling along the southern East Nusa Tenggara waters to the west of Sumatra has longer time and a wider distribution of spatial [18]. Based on mechanisms of upwelling, sea surface in upwelling region will be lower than other regions [19].

In September, October, November (SON) generally there is a change of wind easterlies become westerlies. When El Niño in 2002, wind condition showed an increase of easterlies wind in Java areas than normal conditions in September to December (Figure 5). Increased easterly wind to reach 1 to 1.5 m/s is followed by the weakening of the westerlies wind that moves from the equator [20]. Based on the Ekman transport theory where Ekman transport moves water to the left of the wind direction in the Southern Hemisphere. Combination of wind and the Coriollis Effect on Ekman transport creates areas of upwelling and downwelling in coastal locations of the Southern hemisphere. Therefore, when the easterlies wind dominant in the southern of Java, Ekman transport will creates area of upwelling in southern coastal.

In contrast to El Niño conditions, when La Niña (ENSO-) that occurred in late 2007 and early 2008, sea surface anomaly generally increased compared to the average conditions (Figure 4). In 2007/2008 La Niña has known occurred in November 2007 to March 2008.

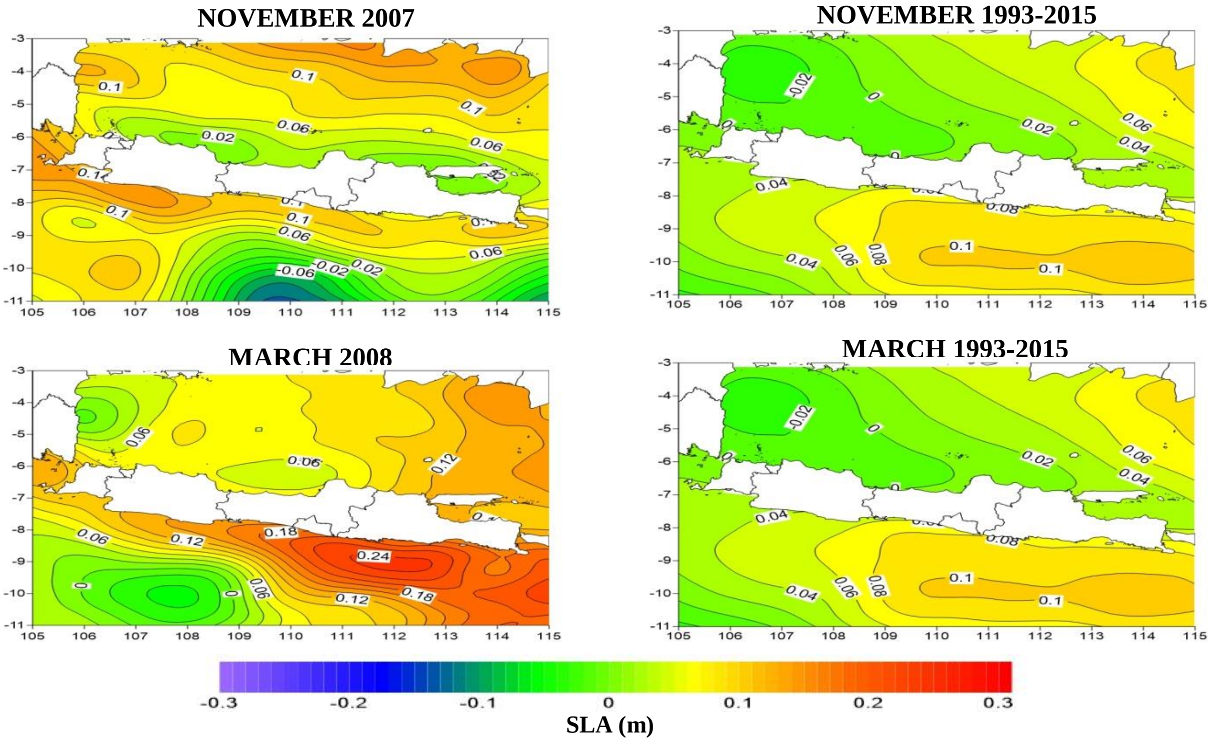


Figure 4. SLA in the water of north and south of Java at La Niña and average from 23 years

During La Niña phenomenon in 2007/2008, sea level anomaly in the waters north and south of the island of Java in general has increased. A significant increase occurred in January to March where along the southern coast of Java sea level anomalous increase reach 0.3m. This condition is higher than the average condition for 23 years is only 0.17 m. When normal conditions, in the northern waters of Java

generally tend anomaly has particularly negative in the westerly months, whereas during La Niña (2007/2008), nearly all waters including in the northern waters of Java has positive anomaly.
Changes in sea level will be increased during the period of transition from El Niño to La Niña, as well as during La Niña [6]. This is because the trade winds in the Pacific Ocean strengthen and bring the masses of water of the eastern Pacific around Peru to the Indonesian Waters. This condition is characterized by the movement of warm pool of the Central Pacific to Indonesia. As a result of heaping sea water mass in Indonesian waters which resulting in the majority of the Indonesian waters regions experienced downwelling and followed by an increase sea level anomaly. Based on, mechanisms of downwelling, sea surface in downwelling region will be higher than sea surface in other regions [19]. The impact of these conditions make the sea level anomaly in Indonesian waters generally increased from the average conditions. Besides that, different from El Niño conditions, there was a strengthening of the westerly wind in Java area during La Niña 2007/2008 (Figure 5). This condition makes downwelling area in southern coastal of Java and causes sea level anomaly increase.

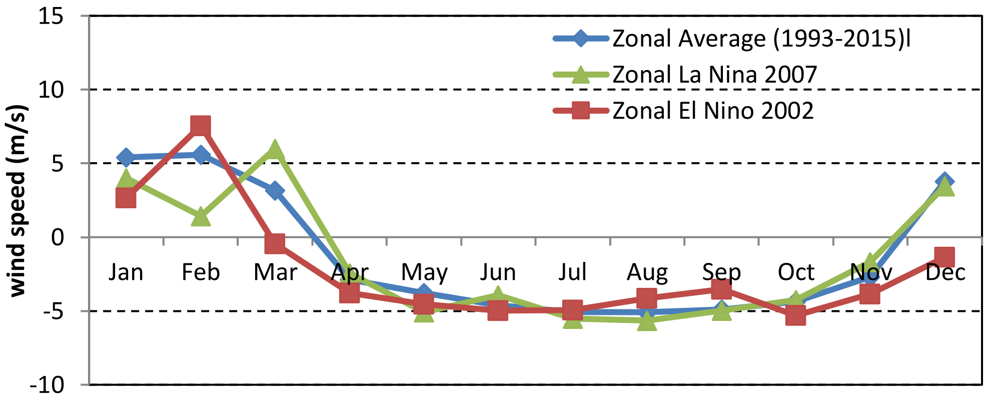


Figure 5. Zonal wind average in study of area during ENSO

Based on the observation station point (Table 1), in study area generally increase of the average conditions especially in January and March during La Niña. The highest increase occurred at stations in the southern of Java. At Prigi station in East Java observed increase in sea level can reach 0.23 m. As for the Cilacap and Pelabuhan Ratu station, sea level anomaly can reach 0.21 m. While on station in the northern of Java, the increase of sea surface height anomaly ranges from 0.07m until 0.12 m.

Table 1. Sea Level Anomaly in Station Point during ENSO

Station	ENSO + (2002)				ENSO - (2007/2008)				
	Sep	Oct	Nov	Des	Nov	Dec	Jan	Feb	Mar
Jakarta	-0.09	-0.03	-0.01	-0.02	0.04	0.01	0.04	0.05	0.07
Semarang	-0.09	-0.05	-0.07	-0.04	0.04	0.04	0.08	0.05	0.07
Surabaya	-0.10	-0.08	-0.05	-0.02	0.00	0.02	0.11	0.08	0.12
P. Ratu	-0.20	-0.11	-0.06	0.03	0.14	0.14	0.13	0.20	0.12
Cilacap	-0.22	-0.11	-0.08	0.03	0.11	0.11	0.14	0.21	0.16
Prigi	-0.21	-0.16	-0.07	0.02	0.08	0.10	0.19	0.23	0.20

3.2. The Influence of IOD on Sea Surface Height Anomaly in the Water of North and South of Java

IOD (Indian Ocean Dipole) phenomenon which covers the DMI+ and DMI- basically has the same principle with ENSO related relationship with the condition of the atmosphere and ocean in Indonesia. The difference between both of them is location of this phenomenon formed. IOD is formed in the Indian

Ocean while ENSO is formed in the Pacific Ocean. Based on SST anomaly difference charts between east box and west box of Indian Ocean (Figure 2) DM+ known have occurred in 2011 and DM- occurred in 2005. In 2011, DM+ indicated occurs in August to October and DM- indicated from February to March and July to September in 2005.

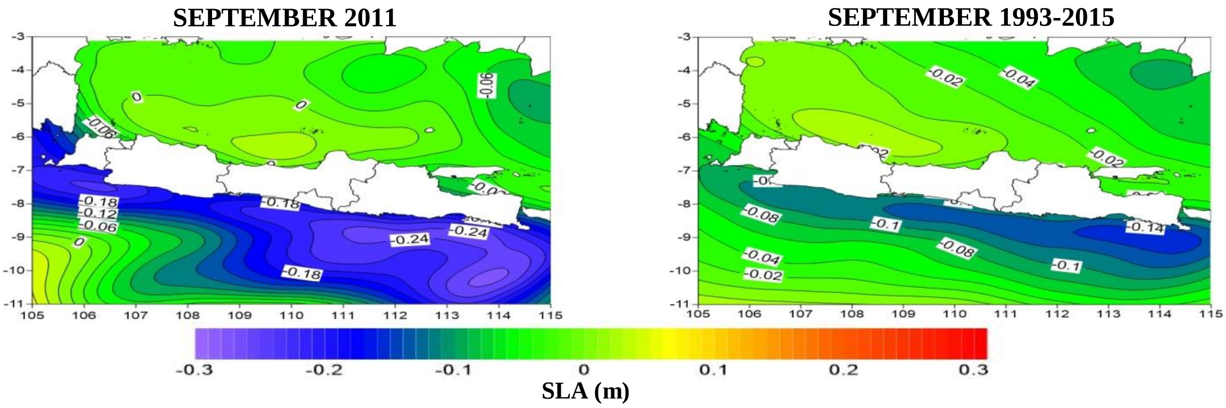


Figure 6. SLA in the water of north and south of Java at IOD+ in September 2011 and average from 22 years

IOD+ makes sea level anomaly in southern Java to be lower than the average conditions (Figure 6). In September 2011, IOD+ influence on sea level anomaly in the southern of Java can be seen. Under normal condition, sea level anomaly in September is concentrated in the southern area of East Java. While at IOD+ almost any area of the study had negative anomalies, especially in Southern of Java where the sea surface height anomaly is lower than the monthly average condition for 23 years. Sea level anomaly has detected down to -0.28 m in September, -0.22 m in August and -0.18 m in October 2011. If compared with El Niño in 2002, IOD+ 2011 more impact on the declining sea level in the southern of Java because the location of IOD + is in the Indian Ocean and this phenomenon is greatly affecting the dynamics of the waters in southern area of Indonesia.

Based on sea surface temperatures and chlorophylls data from another research showed the temporal and spatial variation of upwelling associated with variations in ENSO and IOD. However, based on variations in the case of ENSO and IOD to the variability that occurs in the area of upwelling waters south of Java to Timor indicated that IOD+ phenomenon more influence than ENSO to variability upwelling area occurred [21]. Significant decline in sea surface height that occurred in September caused by IOD+ was higher activity in this month. The activity caused wind speed anomaly peaked and upwelling along southern of Java and West Sumatra more intensified [16]. IOD+ caused upwelling intensity in easterly periods more increased and continued until transition period [22]. This condition make the sea level anomaly will decrease until October and November.

Different from IOD+, sea level anomaly generally increased than the average condition around Java area in July 2005 (Figure 7). This increase occurred because of Indonesia in general has downwelling due to the mass of water flowed to East Indian Ocean. Viewed from the increase in anomalies, IOD- phenomenon not sees significant changes over the average condition in 2005. Sea level anomaly only increased 0.09 m in February and March. This condition is even smaller than average sea level anomalies which reached 0.15 m. However in July and September sea level anomaly has increased about 0.13 m while the normal condition that only 0.08 m.

Although there is accumulation of water masses in the waters area of East Indian Ocean on IOD + but because of the weakening of the zonal winds in February and March (Figure8) made in the downwelling formation not quite strong. This condition caused the increased of sea level anomaly is below average condition. Meanwhile in July and September, due to the zonal wind are generally the same as the average conditions and couple with the mechanism of downwelling in the East Indian Ocean that result an increase in sea surface height anomaly becomes higher than the average condition.

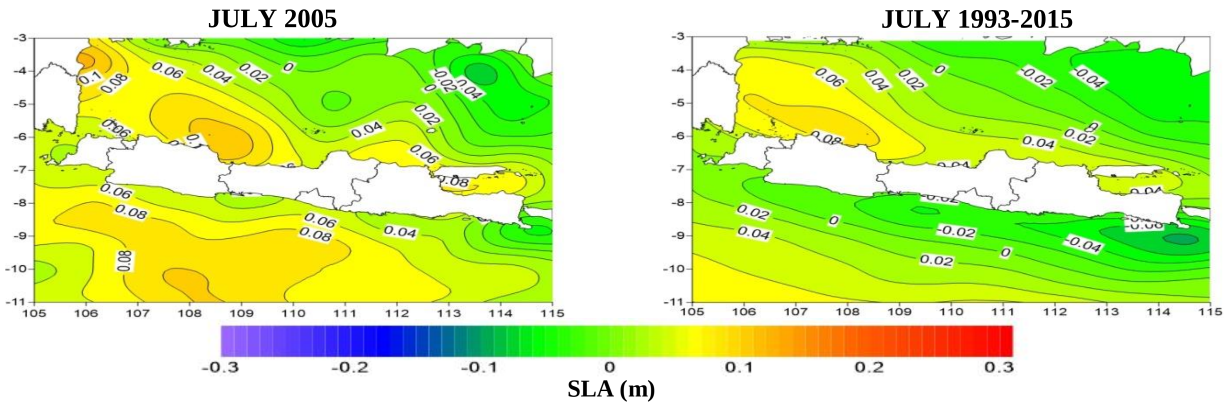


Figure 7. SLA in the water of north and south of Java at IOD- in July 2005 and average from 22 years

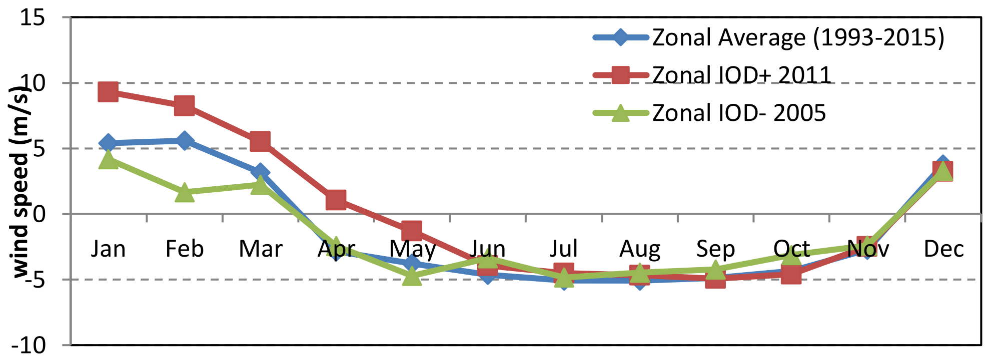


Figure 8. Zonal wind average in study of area during IOD

Based on the observation station point (Table 2), in study area generally decrease of the average conditions especially in the last year in IOD+ or IOD- period. The highest decrease occurred at stations in the southern of Java. At Pelabuhan Ratu station in Westt Java observed decrease in sea level can reach -0.19 m in October during IOD+. As for the Cilacap and Prigi station, sea level anomaly can reach -0.17 m and -0.19. While on station in the northern of Java, sea surface height anomaly has decrease ranges from -0.04m until -0.06 m.

Table 2. Sea Level Anomaly in Station Points during IOD

Station	IOD + (2011)			IOD- (2005)			
	Sep	Oct	Nov	Feb	Mar	Jul	Sept
Jakarta	0.0349	-0.0403	0.0496	-0.02007	-0.00922	0.068526	0.001248
Semarang	0.0172	-0.0075	0.0245	0.005635	0.010226	0.040417	-0.01002
Surabaya	0.0239	-0.0631	0.0046	0.025309	0.026965	0.054978	-0.02169
P. Ratu	-0.1872	-0.2148	-0.0659	0.04013	0.033713	-0.00623	-0.10523
Cilacap	-0.1705	-0.1787	-0.0534	0.072065	0.066265	-0.0291	-0.11301
Prigi	-0.1527	-0.1944	-0.0839	0.088296	0.075952	-0.02767	-0.11308

4. Conclusion

Based on the discussion that has been described, it can be concluded that the sea level anomaly generally inversely related to ENSO and Dipole Mode Index. The phenomenon that most influence a decrease sea level anomaly in the study area is a phenomenon IOD + and the phenomenon that most influenced the increase sea level anomaly is La Niña. South of Java is area that has the large effect of changes in sea levels than north of Java. During La Niña, sea level anomaly can be increase up to 0.3 m and sea level anomaly can be decrease up to -0.28 m during IOD+. The parameters that directly impact is the zonal wind conditions that moves above water areas north and south of Java. Southern of Java is area that has the effect of changes in sea levels very large. By knowing the influence of La Niña that caused sea level anomaly rise in the north and south of Java, we are expected to be alert of the impact that would be caused. La Niña not only causes sea level rise, but also cause high waves and rainfall increase significantly.

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References

[1] Aldrian, E. 2008. *Meteorologi Laut Indonesia.* BMKG: Jakarta
[2] Gregory, J. 2013. *Projection of Sea Level Rise*. IPCC AR5.
[3] Unnikrishnan, A.S. and Shankar D. (2007) Are sea level rise trends along the coasts of north Indian Ocean coasts consistent with global estimates? *Global and Planetary Change*, 57:301-307
[4] Church, J. A., White, N. J., Hunter, J. R. 2006. Sea-level Rise at Tropical Pacific and Indian Ocean Islands. *Global and Planetary Change*. 53:155-168
[5] Sofian, I., dan Antonius, B. W. 2008. Proyeksi Kenaikn Tinggi Muka Laut di Jakarta Berdasarkan Skenario IPCC AR4. *Jurnal Ilmiah Geomatika*. 14(2): 71-80
[6] Sofian, I. 2007. Simulation of The java Sea using an Oceanic Feneral Circulation Model. *Jurnal Ilmiah Geomatika*. 13(2): 1- 14.
[7] Antomy, P., Jumarang, M. I., Ihwan, A. 2014. Kajian Elevasi Muka Air Laut di Selat Karimata Pada Tahun Kejadian El Niño dan Dipole Mode Positif. *Prima Fisika*. 2(1): 01-05
[8] Kunarso, Hadi, S., Ningsih, N. S., Baskoro, M. S. 2012. Perubahan Kedalaman dan Ketebalan Termoklin Pada Variasi Kejadian ENSO, IOD dan Monsun di Perairan Selatan Jawa Hingga Pulau Timor. *Ilmu Kelautan*. 17(2): 87-98
[9] Syah, A. F. 2010. Indikasi Kenaikan Muka Air Laut di Pesisir Kabupaten Bangkalan Madura. [Thesis] Marine Enginering, Trunojoyo University, Madura.
[10] Handoko, E.Y. 2004. Satelit Altimetri dan Aplikasinya Dalam Bidang Kelautan. Scientific. *Journal Pertemuan Ilmiah Tahunan I*. Teknik Geodesi – ITS: Surabaya, 137-144.
[11] Fu, L.L., Stammer, D., Leben, R.R., Chelton, D.B. 2003. Improved Spatial Resolution of Ocean Surface Topography From The T/P Jason-1 Altimter Mission. *EOS, Transaction American Geophysical Union*. 84(26): 241-248
[12] Purba, M. 2007. Dinamika Perairan Selatan P. Jawa – P. Sumbawa Saat Muson Tenggara. *Torani*, 17(2):140-150
[13] Tubalawony, S. 2008. Dinamika Massa Air Lapisan Ekman Perairan Selatan Jawa – Sumbawa Selama Muson Tenggara. *Torani*. 17(2):140-150.
[14] Yoga, R. B., Setyono, H., Harsono, G. 2014. Dinamika Upwelling dan Downwelling Berdasarkan Variabilitas Suhu Permukaan Laut dan Klorofil-A di Perairan Selatan Jawa. *Jurnal Oseanografi*. 3(1):57-66
[15] Oki, D. dan Putri, M. R. 2014. Identifikasi Awal Eddies di Perairan Laut Jawa. *Jurnal Oseanografi*. 1(1): 12-20
[16] Saji, N. H., B. N. Goswani, P. N. Vinayachandran, and T. Yamagata. 1999. A Dipole in The Tropical Indian Ocean. *Nature*. 401:360-363.
[17] Hartoko, A., Sulistya, W. 2010. Meteorologi & Sifat Lautan Indonesia. Pusat Penelitian dan Pengembangan Badan Meteorologi Klimatologi dan Geofisika. Jakarta.

[18] Kunarso, Ningsih, N. S., Supangat, A. 2005. Karakteristik Upwelling di Sepanjang Perairan Selatan NTT Hingga Barat Sumatera. *Ilmu Kelautan*. 10(1): 17-23

[19] Lentz J.A. 2010. *Ekman Transpor and Coastal Sea Level*. Oceanography & Coastal Sciences.LSU.

[20] Mulyana, E. 2002. Analisa Angin Zonal di Indonesia Selama Periode ENSO. *Jurnal Sains dan Teknologi Modifikasi Cuaca*. 3(2): 115-120

[21] Kunarso, Hadi, S., Ningsih, N. S., Baskoro, M. S. 2011. Variabilitas Luasan Upwelling Intensitas Kuat pada Variasi Kejadian ENSO dan IOD di Perairan Selatan Jawa Hingga Timor. *Prosiding Seminar Nasional Kelautan POSEIDON.* 2012. ITB, 102-113

[22] Gaol, J. L., Nurjana, I. W., Amri, K. 2014. Dampak Perubahan Iklim Terhadap Kondisi Oseanografi dan Laju Tangkap Tuna Mata Besar (*Thunnus obesus*) di Samudera Hindia Bagian Timur. Simposium Nasional Pengelolaan Perikanan Tuna Berkelanjutan. Bali, 10-11 Desember 2014. *WWF Prosding*. 2015. Kementrian Kelautan dan Perikanan. Bali, VI-109.