

EDDY CURRENTS VARIABILITY FROM SATELLITE ALTIMETRY AND ITS RELATION TO PHYSICAL CONDITIONS OF JAVA SEA

VARIABILITAS ARUS EDDY MELALUI SATELIT ALTIMETRI DAN HUBUNGANNYA TERHADAP KONDISI FISIS LAUT JAWA

Kautsar Fadlih Akbar^{1,*}, Ahmad Bayhaqi², Khikmah Muliati¹, dan Denny Darmawan¹

¹Faculty of Natural Science, Yogyakarta State University, Indonesia

²Physical Oceanography and Climate Laboratory, Research Center for Oceanography, Indonesia Institute of Science (LIPI), Indonesia

^{1,*}Pos-el: kautsar.fadlih2015@student.uny.ac.id

ARTICLE INFO

Article history

Received date

23 April 2019

Received in revised form date

28 August 2019

Accepted date

13 November 2019

Available online date

May 2020

Abstrak

Pola arus Laut Jawa sangat dipengaruhi oleh siklus monsun, yang menciptakan kondisi bolak-balik berdasarkan musim sepanjang tahunnya dan berpotensi memengaruhi variabilitas arus eddy. Dengan menggunakan data arus geostropik permukaan dari satelit altimetri periode 2013-2017, penelitian ini bertujuan untuk mengetahui variabilitas arus eddy dan hubungannya terhadap kondisi fisis Laut Jawa seperti suhu permukaan laut, tinggi paras laut, dan konsentrasi klorofil-a. Hasil menunjukkan 60 kejadian arus eddy di lokasi penelitian yang terdiri dari 40 siklonik dan 20 antisiklonik. Eddy siklonik terbesar terjadi pada bulan April 2013 (112,05 BT; 5,37 LS) dengan diameter 134,07 km, sedangkan eddy antisiklonik terbesar terjadi pada Oktober 2017 (114,54 BT; 6,24 LS) dengan diameter 159,69 km. Eddy siklonik memiliki tinggi paras laut yang lebih rendah dan inti dingin, sedangkan eddy antisiklonik memiliki tinggi paras laut yang lebih tinggi dan inti yang hangat. Fenomena arus eddy berpotensi meningkatkan/menurunkan konsentrasi klorofil-a.

Kata Kunci: Arus eddy, Laut Jawa, SST, SSH, CHL

Kata kunci:

Arus Eddy

Laut Jawa

SST

SSH

CHL

Abstract

© 2020 Widyariset. All rights reserved

INTRODUCTION

The Java Sea is a part of Sunda Shelf that connects three large Indonesian islands, namely Sumatra, Borneo and Java. The sea has an area of around 310,000 km². The depth of Java Sea varies from 20 m off the coast of South Sumatra to more than 60 m in its eastern part (Wyrcki 1961). Due to the characteristics of warm tropical waters and shallow depth, the Java Sea has high productivities, supports coral reef ecosystems and has abundant of demersal and pelagic fish resources (Genia et al. 2007). Based on that condition, the Java Sea contributes 31% of fisheries production in Indonesia (Purwanto 2003).

The ocean currents in the Java Sea particularly depend on the monsoonal cycle, which creates alternating conditions according to the seasons throughout the year. Northwest monsoon reaches its peak in December to February accompanied by high rainfall or better known by the people of Indonesia as the rainy season. Whereas the southeast monsoon reaches its peak in June to August accompanied by low rainfall or dry season (Wyrcki 1961). Java Sea physical condition, such as sea surface temperature, sea surface height and chlorophyll-a concentration are directly affected by monsoon (Wyrcki 1961; Gaol and Sadotomo 2007; Napitu, Gordon, and Pujiana 2015; Sheppard 2018). The strong influence of the monsoon also raises the potential of eddy currents during the transition period when the currents begin to reverse direction (Wyrcki 1961; Ismoyo, Oki, and Putri 2014). In addition to monsoon, physical conditions in the Java Sea are also influenced by global atmospheric phenomena, namely Indian Ocean Dipole (IOD) and El Nino Southern Oscillation (ENSO) (Gaol and Sadotomo, 2007; Kunarso et al. 2011).

Eddy currents are rotating sea currents which have a considerable impact on the

waters such as transport, trap and disseminate chemical elements, solutes, nutrients, microorganisms, and heat (Robinson 1983). Every scale of eddy current gives ecologically significant effects on the water (Owen 1981). On the southern part of the Earth, a clockwise or cyclonic eddy can trigger upwelling, while counterclockwise or anticyclonic eddy triggers downwelling (Stewart 2008). The previous study shows that eddy current in Java Sea has the size of sub-mesoscale, formed in the monsoonal transition period and heavily affected by surface height and wind velocity (Ismoyo Oki, and Putri 2014). Another study of eddy currents in southern waters of Java-Bali also stated that, although the relations between eddy and phenomenon of upwelling and downwelling was not seen by its surface temperature, the area where eddy formed always have a higher chlorophyll-a concentration (Aulia et al. 2015). However, the effect of eddy current to the physical condition has not been studied in the Java Sea. Based on how important Java Sea to national fisheries industries, the relation between eddy current occurrence and its effect on the physical condition of Java Sea is needed to be examined.

This study aims to determine the spatial and temporal distribution of eddy currents in the Java Sea and their relations with sea surface height, surface temperature and the effect to chlorophyll-a concentration in the Java Sea. Chlorophyll-a can be used as an indication of aquatic fertility because chlorophyll-a describes the phytoplankton biomass which is the primary producer in the marine food chain.

METHODS

Data Sources

The study area of this research is Java Sea located at 1,9°-8,13°S and 105,44°-115,65°E (Fig. 1). This study has been con-

ducted using Copernicus Marine Service Products. The data used in this study are L4 processed satellite altimetry data from 2013–2017. These data contain a geostrophic current component, Sea Surface Height (SSH), Sea Surface Temperature (SST), and chlorophyll-a concentration. In addition, Nino 3.4 and Dipole Mode Index (DMI) were used to determine the climate events over the periode.

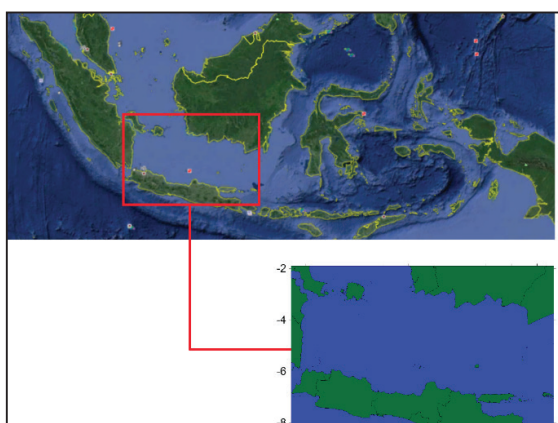


Figure 1. Research Area

Data Processing

The existence of eddy currents can be identified visually from the geostrophic current pattern vector each month during the period of 2013–2017 which can be seen as separate currents from the main flow (Aulia et al. 2015; Nuzula et al. 2017; Umaroh, Anggoro, and Muslim 2017). Eddy currents were analyzed in the direction of the rotation and diameter, then divided by northwest monsoon (DJF), transition I (MAM), southeast monsoon (JJA), and transition II (SON). The diameter calculation ignored the length difference between latitude and longitude (1° latitude = 111 km and 1° longitude = $111 \cos \phi$ km, where ϕ is latitude) since the study area is at low latitude (Stewart, 2008).

To determine the effect of eddy currents on physical parameters in the Java Sea, a map of the geostrophic current pattern was overlaid with the contours of SSH, SST, and the concentration of Chlorophyll-a. Upwelling and downwelling were identified by analyzing SSH, SST, and Chlorophyll-a concentration in the location where eddies occur.

RESULTS AND DISCUSSION

Eddy Currents Distribution

In the 2013–2017 period, a total of 60 eddy flows were observed, 40 cyclonic and 20 anticyclonic. Eddy currents occurred in the transition I and transition II with the exception of 2017, where eddy phenomena also occurred in the southeast monsoon. Diameter of eddy currents varies from 44.84 km to 159.69 km. The longest duration of eddy current was observed in 2017 (115.29°S , 7.77°E) that began in May and ended in September. The largest cyclonic eddy was observed in April 2013 (112.05°S , 5.37°E) with a diameter of 134.07 km, while largest anticyclonic eddy was observed in October 2017 (114.54°S , 6.24°E) with a diameter of 159.69 km. The size of eddy currents in Java Sea is smaller although appear more frequently compared to eddy currents in southern waters of Java that can reach a diameter of 555 km but at most only occur three times a month (Aulia et al., 2015). This happened because of the characteristic differences of the waters in southern Java and the Java Sea, as stated by Setyawan and Pamungkas (2017) that the Java Sea currents move according to the monsoon while the Southern Waters of Java are influenced by Indian Ocean and its coastline configuration.

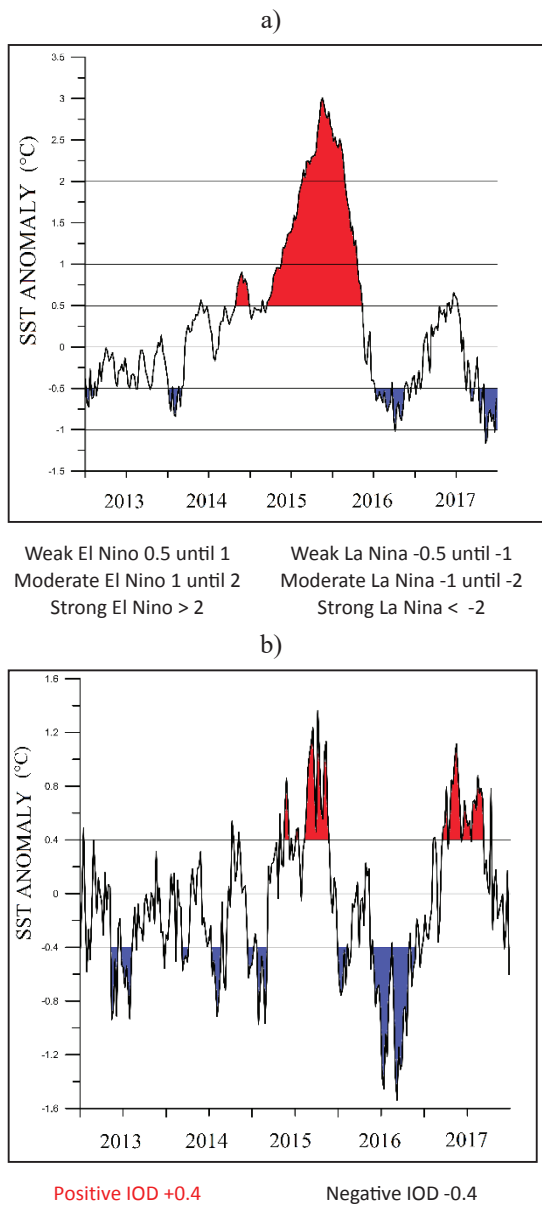


Figure 2. (a) Nino 3.4 and (b) Dipole Mode Index

The majority of eddy currents in the study site occur in the transitional season, especially in the second transition season, namely in September, October and November. ENSO and IOD do not directly affect the number of eddy currents occurring in the Java Sea, but ENSO and IOD affect wind speed depending on the monsoon system that is occurring. El Nino tends to weaken the west wind during northwest monsoon and strengthens the east wind during southeast monsoon and transition II, while La Nina strengthens the west wind

during northwest monsoon and weakens the east wind during southeast monsoon and transition II (Juneng and Tangang 2005; Wirasatriya et al. 2018).

In transition II (SON) 2015, occurred strong El Nino and pIOD which produce stronger geostrophic currents whereas in the same month in 2016 occurred weak La Nina and nIOD which produce weaker geostrophic currents.

Eddy Currents Relation to Sea Surface Height

Based on a map of geostrophic flow patterns and monthly sea surface height, eddy currents occurred in both low and high SSH. The height of sea level in the core of eddy will depend on its direction of rotation (Stewart 2008). Cyclonic eddy will cause divergence of water mass and anticyclonic eddy will cause convergence of water mass due to Ekman transport. This was clearly seen in November 2013 (111.89°S, 5.63°E) and September 2017 (115.28°S, 7.75°E) (Fig. 3), where the surface height in the cyclonic eddy core (black circle) is 0.06 m lower than the surrounding area, while in the anticyclonic eddy core (red circle) is 0.06 m higher SSH difference in the core of eddy only visible if the surrounding area has relatively same height.

Eddy Current Relation with SST

SST difference in the eddy current core can be used to identify upwelling and downwelling. Cyclonic eddy has a cold core, while anticyclonic eddy has a warm core. This is because in the southern hemisphere cyclonic eddy has shallow lower density water mass, while anticyclonic eddy has deeper lower density water mass (Stewart, 2008). In October 2016 (110.53°S, 5.14°E) there is cyclonic eddy (black circle) with a cold core (-0.2 ° C) which indicates upwelling and June 2017 (114.92°S,

7.65°E) anticyclonic eddy (red circle) with warm core (+0.2 °C) which indicates downwelling (Fig. 4). Same as SSH, SST difference in the core of eddy only visible if the surrounding area of eddy currents has relatively same temperature.

Eddy Current Effect to Chlorophyll-a Concentration

Chlorophyll-a distribution in the Java Sea has a high concentration in coastal areas and is relatively lower in the open seas. The chlorophyll-a concentration reaches its peak in the northwest monsoon and decreases in the southeast monsoon and reaches its lowest point in the Transition I and II seasons (Table 1).

Table 1. Monthly Average of Chlorophyll-a Concentration and Sea Surface Temperature

Month	CHL	SST
January	1.087	29.114
February	0.794	28.958
March	0.363	29.520
April	0.203	30.186
May	0.293	30.059
June	0.436	29.619
July	0.669	28.934
August	0.725	28.442
September	0.612	28.534
October	0.500	29.309
November	0.457	30.003
December	0.953	29.616

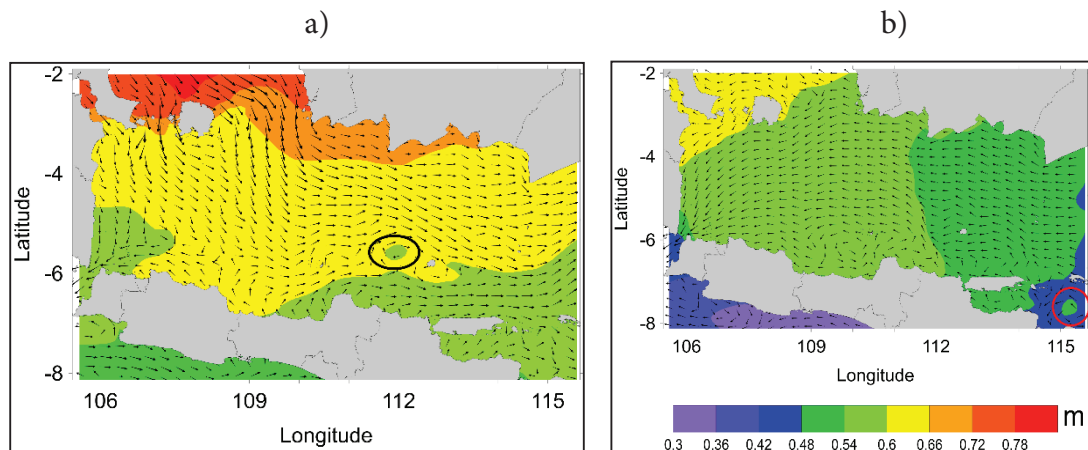


Figure 3. SSH Difference at the Core of Eddy Current, (a) November 2013, and (b) September 2017

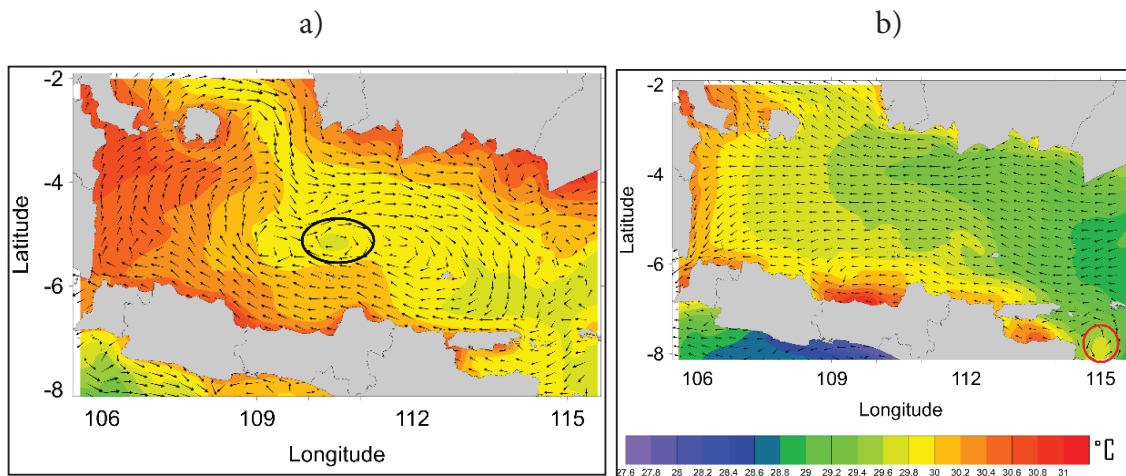


Figure 4. (a) Cold-Core Eddy October 2016, and (b) Warm-Core Eddy June 2017

The effect of eddy currents on the levels of chlorophyll-a in the eddy core is not significant even though it was seen that temperature difference indicated upwelling or downwelling. High concentration in the coastal area is due to another factor such as rivers that can give a significant amount of chlorophyll-a to the sea (Wirasatriya et al. 2018). In addition, eddy currents that occur a lot in the monsoon transition are the opposite of the levels of chlorophyll-a which actually decreases during the transition season. Contrary to the previous study (Aulia et al. 2015) chlorophyll-a concentration in an area where eddy current formed is not always higher. Cyclonic eddy (black circle) in October 2016 (110.53°S, 5.14°E) did not show any increase of chlorophyll-a concentration in the surrounding area. However, an anticyclonic eddy that occurred in May–September 2017 (114.92°S, 7.65°E) showed very low chlorophyll-a concentration in the area (Fig. 5). This happened because there is a 1.5 to 2 months lag time between upwelling or downwelling and the increase or decrease of chlorophyll-a concentration as it requires a certain time to stimulate the growth of phytoplankton (Pranowo, Philips, and Wijffels 2005).

CONCLUSION

Eddy currents in Java Sea occur in the transition Season I and Transition II, although long duration eddy can occur throughout the Northwest and Southeast monsoon. Cyclonic eddy has a cold core with lower surface height while anticyclonic eddy has a warm core with higher surface height than the surrounding area due to divergence and convergence of water mass. The eddy core that indicates upwelling or downwelling only shows an effect to chlorophyll-a concentration after a certain time. Further studies on the eddy currents vertical structure and the effect on other parameters are still needed.

REFERENCES

- Aulia, A., N. P. Purba, Rosidah, and Martono. 2015. Eddy Currents Variability in the Southern Waters of Java-Bali. Bandung: Faculty of Fisheries and Marine Science Padjadjaran University.
- Gaol, J. L., and B. Sadhotomo. 2007. “Karakteristik dan variabilitas parameter-parameter oseanografi Laut Jawa hubungannya dengan distribusi hasil tangkapan ikan.” *Jurnal Penelitian Perikanan Indonesia*, 13 (3): 201–211.

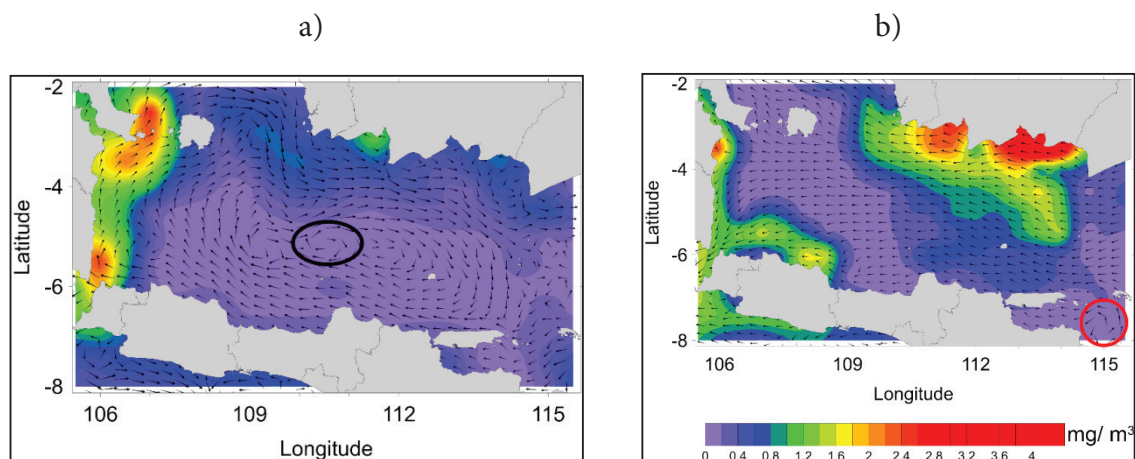


Figure 5. Chlorophyll-a Concentration (a) October 2016, and (b) June 2017

- Genia, A. N., N. A. Sasongko, and J.O. Olakunle. 2007. *Introduction of Java Sea Oceanography*. University of Stavanger.
- Ismoyo, D. O., and M. R. Putri. 2014. "Identifikasi Awal Eddies di Perairan Laut Jawa." *Jurnal Oseanologi Indonesia*, 1 (1): 12.
- Juneng, L., and F. T. Tangang. 2005. "Evolution of ENSO-related Rainfall Anomalies in Southeast Asia Region and Its Relationship with Atmosphere–Ocean Variations in Indo-Pacific sector." *Int. J. Climatol.*, 25: 337–350.
- Kunarso, S., N. S. Hadi, M. S. Ningsih, and Baskoro. 2011. "Variabilitas Suhu dan Klorofil-a di Daerah Upwelling pada Variasi Kejadian ENSO dan IOD di Perairan Selatan Jawa sampai Timor." *Jurnal Ilmu Kelautan*, 16: 171–180.
- Nagara, G. A., N. A. Sasongko, and O. J. Olakunle. 2007. *Introduction to Java Sea. Oceanography*. Stavanger: University of Stavanger.
- Napitu, A. M., A. L. Gordon, and K. Pujiana. 2005. "Intraseasonal Sea Surface Temperature Variability Across the Indonesian Sea." *Journal of Climate*, 28: 8710–8727.
- Nuzula, F., M. L. Syamsudin, L. P. S. Yuliadi, N. P. Purba, and Martono. 2017. "Eddies Spatial Variability at Makassar Strait – Flores Sea." *IOP Conf. Series: Earth Environmental Science*, 54 (1).
- Owen, R. W. 1981. *Fronts and Eddies in the Sea: Mechanisms, Interactions and Biological Effects*. California: NOAA Southwest Fisheries Science Center
- Pranowo, W. S., H. Phillips, and S. Wijffels. 2005. "Upwelling Event 2003 Along South Java Sea and Lesser Sunda Islands." *Jurnal Segara*, 3: 93–135.
- Purwanto. 2003. "Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries." *World Fish Center Conference Proceedings*, 67: 793–832.
- Robinson, A. R. 1983. *Eddies in Marine Science* Chap. 22. Berlin: Springer.
- Setyawan, B. W., and A. Pamungkas. 2017. "Perbandingan Karakteristik Oseanografi Pesisir Utara dan Selatan Pulau Jawa: Pasang-surut, Arus, dan Gelombang." In *Prosiding Seminar Nasional Kelautan dan Perikanan III*, edited by W. A. Nugraha, A. Romadhon, and Insafitri, 191–202. Madura: Universitas Trunojoyo Madura.
- Sheppard, C (Ed.). 2018. *World Seas: An Environmental Evaluation*. 2nd Edition, Volume II: The Indian Ocean to the Pacific. Massachusetts: Academic Press.
- Stewart, R. H. 2008. *Introduction to Physical Oceanography*. Texas: Department of Oceanography, Texas A&M University.
- Umaroh., S. Anggoro, and Muslim. 2017. "The Dynamics of Sea Surface Height and Geostrophic Current in the Arafura Sea." *IOP Conf. Series: Earth Environmental Science*, 55.
- Wirasatriya, A., I. B. Prasetyawan, C. D. Triyono, Muslim, and L. Maslukah. 2018. "Effect of ENSO on the variability of SST and Chlorophyll-a in Java Sea." *IOP Conf. Series: Earth Environmental Science*, 116.
- Wyrtki, K. 1961. *Physical Oceanography of the South East Asian Waters*. San Diego: The Scripps Institution of Oceanography University of California.