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Strong Negative Indian Ocean Dipole Phenomenon in 2016 Reduce the Upwelling Intensity along the Seas of Southern Java

Marthin Wahyu Bethara Wahyono Undap[1],
Agus Anugroho Dwi Suryoputro[1], Anindya Wirasatriya[1*]

[1] Department of Oceanography, Faculty of Fisheries and Marine Sciences, Diponegoro University Prof. Sudarto Road, Tembalang, Semarang, Middle Java, 50275, Indonesia

* Corresponding author's e-mail: anindyawirasatriya@lecturer.undip.ac.id

ABSTRACT

The seas of Southern Java are located at the eastern equatorial Indian Ocean and therefore, they are strongly influenced by the Indian Ocean Dipole (IOD). Strong negative IOD occurred in 2016. However, none of the previous studies investigated its effect on the seas of Southern Java. This study aims to reveal the influence of the strong negative IOD in 2016 on the upwelling intensity along the seas of Southern Java as represented by surface temperature and chlorophyll-a. This research was conducted using satellite-based data and the analysis was based on climatology, and anomaly for 15 years (2007–2021). The data used includes sea surface temperature (OISST), wind (ASCAT), IOD index (DMI), chlorophyll-a (OC-CCI), and sea level anomaly (altimetry). The findings show that the strong negative IOD in 2016 had a significant impact on sea surface temperatures which made these waters warmer. The most visible impact is through the sea surface temperature anomaly map where in 2016 throughout the year it experienced a positive anomaly with a value of 2°C higher than the climatological average. The value of chlorophyll-a in these waters has also dropped drastically which, when viewed from the anomaly map, has a value of 0.2 mg/m^3 lower than the climatological average, especially during the upwelling month. This means that, strong negative IOD in 2016 reduced the upwelling intensity along the seas of Southern Java. We also found the propagation of downwelling Kelvin waves from the Indian Ocean to the Southern Java waters which bring warm temperatures and cause downwelling events during the strong negative IOD in 2016 that hampers coastal upwelling along the seas of Southern Java.

Keywords: sea surface temperature, Chlorophyll-a, IOD, South Java waters, Kelvin waves.

INTRODUCTION

Upwelling, as a complex oceanic phenomenon, entails the intricate interplay of various physical and biological processes. At its core, upwelling is the result of vertical water movement from the ocean's depths to the surface, and this ascent carries with it a rich assemblage of phytoplankton, the cornerstone of marine ecosystems. This transport of nutrients and microscopic organisms from the abyssal realms to the sunlit surface creates a veritable banquet for marine life. In light of these ecological intricacies, regions characterized by upwelling emerge as veritable hotspots for marine biodiversity and, subsequently, as highly productive fishing areas. The elevated concentration of phytoplankton near the surface serves as a beacon for smaller pelagic fish species, which in turn become a magnet for larger predatory fish—the desired targets of the fishing industry. As such, the understanding and study of upwelling dynamics, encompassing its spatial and temporal variations, have taken center stage in the scientific community. The mapping and monitoring of upwelling events are instrumental not only in identifying potential fishing grounds but also in predicting fluctuations in fish populations. In this intricate web of ecological interactions, the exploration of upwelling's far-reaching impacts extends beyond the realm of fisheries and encompasses broader implications for marine conservation and ecosystem management (Banjarnahor et al. 2020; Kunarso et al. 2012).

In the realm of marine science, the variability of SST and Chlorophyll-a become the indication of upwelling occurrence since the lifting water mass from the deeper layer brings cold and nutrient rich water mass that can cool sea surface and increase phytoplankton biomass (Wirasatriya et al. 2020). Along the seas of Java, the variability of upwelling shows robust seasonal cycle which peaks in August (Susanto et al. 2001; Susanto and Marra 2005; Iskandar et al. 2009, Wirasatriya et al. 2018). For the interannual variability, Indian Ocean Dipole (IOD) plays stronger influence than El Niňo Southern Oscillation (Chen et al. 2016; Wirasatriya et al. 2020). IOD is characterized by sea surface temperature and atmospheric pressure changes in the eastern and western parts of the Indian Ocean. The IOD can significantly impact the climatic conditions in its surrounding regions, including the seas of Southern Java, which are located at the eastern equatorial of the Indian Ocean. Positive and negative IOD can be determined by Dipole Mode Index (DMI) as shown in Fig. 1.

Fiveteen years of DMI index in Fig. 1 shows that the strongest positive (negative) IOD occurred in 2019 (2016). The influence of strong positive IOD in 2019 on the upwelling intensity along the seas of Southern Java has been investigated by Safinatunnajah et al 2021). They showed that strong positive IOD in 2019 increase upwelling intensity along the seas of Southern Java as denoted by lower SST and higher chlorophyll-a than their climatological mean due to the reduction of downwelling Kelvin wave. On the other hand, the effect of strong negative IOD in 2016 has never been investigated by the previous studies. In the present study, we investigate the influence of strong negative IOD in 2016 to the upwelling intensity in the seas of the Southern Java. This study utilized Dipole Mode Index data from 2007 to 2021 to investigate its influence on upwelling, along with data on wind patterns, sea surface height, chlorophyll-a levels, and SST.

MATERIAL AND METHOD

Study area

The research location is situated along the waters of Southern Java, ranging from -5° to -15° latitude south and 104° to 115° longitude east. As presented in Figure 2.

Research materials

This study utilizes two types of data: primary data and secondary data. The primary data employed includes the Dipole Mode Index (DMI), which serves as an indicator to ascertain the Indian Ocean Dipole (IOD) phenomenon, sea surface temperature from NOAA AVHRR (Moderate Resolution Imaging Spectroradiometer) imagery, and Chlorophyll-a from OC-CCI (Ocean Color – Climate Change Initiative) imagery. DMI index is provided by https://stateoftheocean.osmc.noaa.gov/sur/ind/dmi.php.The secondary data consists of wind data from the ASCAT satellite and sea level anomaly (SLA) data from altimetry satellites. Moreover, the data in this study is based on monthly observations, as global climate variability such as the Indian Ocean Dipole (IOD) are typically assessed using monthly data. The data period encompassed in this research spans 13 years, from January 2007 to December 2021, to ensure more accurate results.

Sea surface temperature data acquisition method

Sea surface temperature data is collected using daily OISST (Optimum Interpolation Sea Surface Temperature) data from the years 2007 to 2021, obtained from NOAA satellites. The sea surface temperature data is downloaded from the open-source website http://www.remss.com with a resolution of 9 km, in the Network Common Data Form (NetCDF) format. The OISST analysis was developed by Richard Reynolds of the National Climatic Data Center (NCDC) and is the result of satellite observations and direct in-situ observations. The in-situ data comes from observations using buoys and ships. NOAA satellites are equipped with the Advanced Very-High-Resolution Radiometer (AVHRR) instrument, and the data is combined with the Advanced Microwave Scanning Radiometer (AMSR) data. For the validation of sea surface temperature data, in 2019, Rachman conducted validation by comparing NOAA OISST data with Buoy RAMA data. The results obtained from satellite imagery and field data showed a fairly strong relationship with a determination coefficient (R^2) of 0.74. The Root Mean Square Error (RMSE) between satellite data

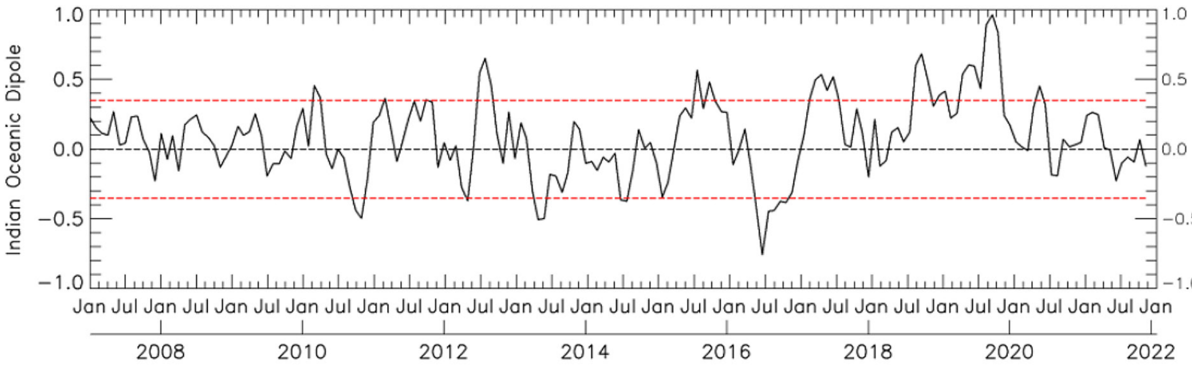

Fig. 1. Dipole mode index in 15 years

Fig. 2. Study area

and field data is relatively low, at only 0.38°C. These results are categorized as being within the acceptable tolerance of 0.4°C (Emery et al. 2001).

Chlorophyll-a data acquisition method

Chlorophyll-a data is derived from the OC-CCI (Ocean Color-Climate Change Initiative) project spanning from 2007 to 2021 (Sathyendranath et al., 2019). OC-CCI aims to provide high-quality long-term ocean color data to support climate research. This initiative is a collaboration between the European Space Agency (ESA) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). The data results from various satellite missions including

Sea-Viewing Wide Field-of-View (SeaWiFS), Moderate Resolution Imaging Spectroradiometer (MODIS), and Medium Resolution Imaging Spectrometer (MERIS). Ocean Color-Climate Change Initiative version 5.0 provides remote sensing chlorophyll-a data and is provided by the European Space Agency (ESA, http://www.esa-oceancolour-cci.org). Daily chlorophyll-a data is extracted within the range of 2007–2021 with a horizontal spatial resolution of 4 km x 4 km. Validation of chlorophyll data from various satellites was conducted by Sá et al. (2015), revealing that OC-CCI satellite imagery showed a fairly strong relationship with field data, with a determination coefficient (R^2) of 0.74 (Li et al. 2023).

Sea level anomaly acquisition method

The research covers the waters of Southern Java and the Indian Ocean. The sea level anomaly (SLA) parameter is a level 4 product derived from Copernicus Marine Environment Monitoring Service (https://resources.marine.copernicus.eu/?option=com_csw&task=results). It is processed from various altimeter satellite missions, including Sentinel-3A, HY-2A, Saral/AltiKa, Cryosat-2, Jason-2, Jason-1, TOPEX/Poseidon, ENVISAT, GFO, and ERSI1/2. Altimetry satellites are specifically designed to monitor ocean dynamics. They employ microwave signals with frequencies ranging from 0.3 to 300 Hz, falling between the infrared and radio waves. The fundamental principle of altimetry satellites involves measuring the time taken for microwave radiation emitted by the satellite to be reflected back after touching the water's surface. This time delay is used to calculate the distance (range) from the satellite to the water's surface. The correlation coefficient (R) between altimetry satellite data and in-situ data was 0.95, with a determination coefficient of 0.9025. This indicates that 90.25% of remote sensing data effectively represents the variations present in the field-based in-situ data (Lumban-Gaol et al. 2020)

Data processing method

In the processing of sea surface temperature, chlorophyll-a, wind, and sea level anomaly data, programming languages are employed to handle NetCDF-format data. Image cropping, aligned with the research area, is the initial step in data processing, as this can affect the spatial data distribution. Image cropping must be carried out using consistent coordinates for each variable. After cropping, the displayed data will be extracted along with its variables and attributes to enable identification and visualization in the final stage. Once the daily data is extracted, it will be compiled monthly to calculate the monthly averages. The compiled monthly data will then undergo climatology compilation, revealing the monthly averages from January to December. The monthly climatology calculation followed Wirasatriya et al. (2017). After climatological calculations in hand, maps will be generated based on the results. These climatological computations are useful in discerning the average values of each variable from 2007 to 2021. Following a comprehension of the monthly and climatological outcomes, calculations will be performed to depict the anomaly map for the year 2016. This aids in identifying deviations in each variable, particularly during the negative IOD event of 2016, and the monthly anomalies are derived by subtracting the monthly averages and climatological data for the corresponding month. This enables an understanding of changes from January 2007 to December 2021. The monthly and climatological results for each variable also contribute to creating Hovmöller diagrams of the Indian Ocean.

RESULT AND DISCUSSION

Seasonal variation of upwelling along the seas of Southern Java

To obtain the seasonal variability of upwelling along the seas of Southern Java, we plot the monthly climatology data of SST and chlorophyll-a. The variability SST over 15 years (2007–2021) in the seas of Southern Java is presented in Figure 3. The calculation results show that over the 15-year period, the sea surface temperature in this area fluctuates up and down from season to season. During the west monsoon (December, January, February), there is a spread of warm temperatures covering most of the seas of Southern Java, peaking in December at around 30°C or even higher. The increase in warm temperature spread continues as we enter the second month of the transitional period I (March, April, May). In March and April, the sea surface temperature in the seas of Southern Java is warmer than during the west monsoon, especially in the eastern part of the area, where temperatures

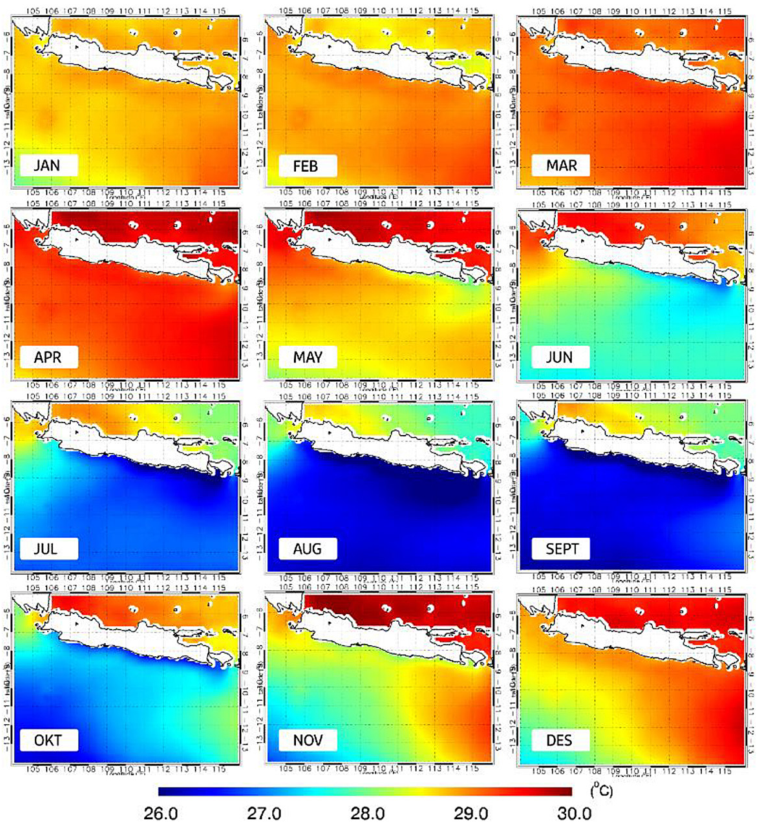

Fig. 3. Climatological Map of SST in the seas of Southern Java Over 15 Years (2007–2021)

reach approximately 29–30°C. By the end of the transitional period I, in May, the sea surface temperature experiences a drastic decrease, indicated by the color contours shifting from red to orange and yellow, representing temperatures ranging from 28–29°C. This decrease in sea surface temperature continues into the east monsoon (June, July, August) with significant changes.

The transition from the transitional period I to the east monsoon shows a decrease of about one degree, indicated by light blue contours on the May map. In July, the sea surface temperature further cools by about 0.5°C, with the peak temperature drop observed in August, represented by dark blue color, indicating temperatures around 26°C, possibly even lower. The contours in August also reveal cooler sea surface temperatures near Java Island, especially in the eastern part of East Java, and gradually warming as they move towards the open sea, with an increase of approximately 0.5°C. Moving into the transitional period II (September, October, November), the sea surface temperature overall shows an increase. In the first month of this season, the distribution of sea surface temperature remains similar to the previous month, but temperatures near Java Island, which previously appeared cooler, become more uniform, resembling the open sea. As October approaches, temperatures begin to rise by about 1.5°C, spreading from the eastern seas of Southern Java, a trend that continues into November and December.

The variability of chlorophyll over 15 years (2007–2021) in the South Java Waters is presented in Figure 4. The results of the average calculations over these 15 years show diverse chlorophyll-a variability on a monthly basis. During the western monsoon (December, January, February), chlorophyll variability is minimal, and the highest concentrations are found closest to Java Island. Chlorophyll-a concentrations during this season vary across locations. In the central part of Java Island, chlorophyll-a concentration can reach up to 1.5 mg/m^3, whereas along the coastline from central to eastern Java, concentrations decrease to around 0.5 mg/m^3. This condition remains relatively stable until entering the transitional period I (March, April, May). During this period, there is an increase in chlorophyll concentration along the coastline from central to eastern Java, indicated by yellow to reddish colors on the contour map. In May, there is also an increase in chlorophyll-a in the eastern waters, marked by light blue distribution beneath

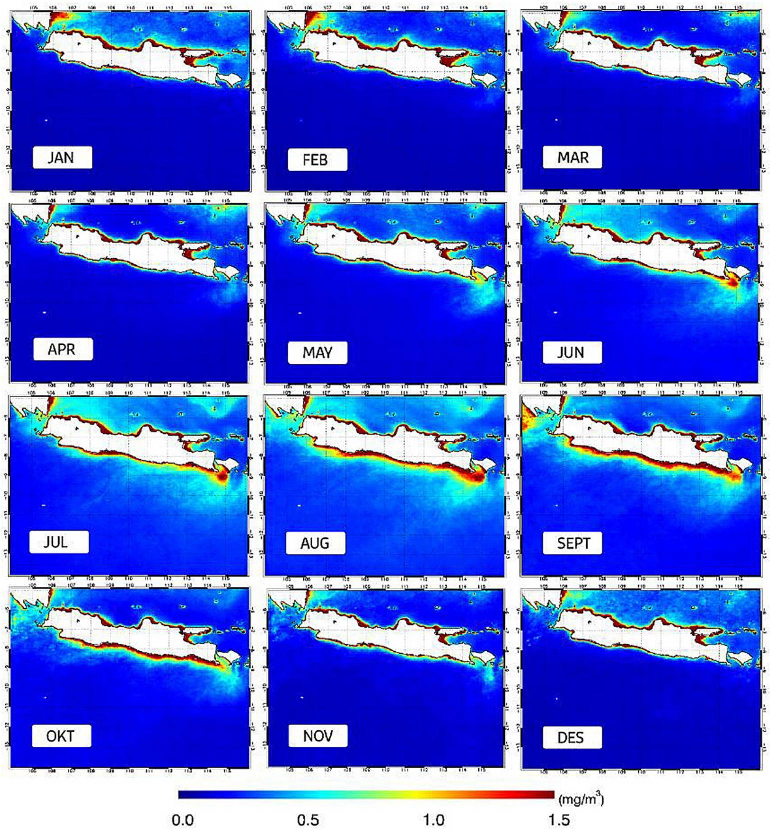

Fig. 4. Climatological map of Chlorophyll-a in the seas of Southern Java Over 15 Years (2007–2021)

Bali Island, indicating chlorophyll-a values of around 0.5 mg/m³. Moving into the eastern monsoon (June, July, August), the distribution of chlorophyll-a near Java Island expands. While in June, offshore waters are almost devoid of chlorophyll-a, in July and August, they contain roughly 0.5 – 0.75 mg/m³, peaking in August.

During this month, there is a notable rise in the distribution of chlorophyll-a in the lower regions of East Java and Bali. This is characterized by the appearance of red hues near the islands, indicating concentrations ranging from 1 to 1.5 mg/m³. As we move away from the islands, the chlorophyll-a levels gradually decrease to approximately 0.5 to 0.8 mg/m³. This increase in chlorophyll concentration isn't restricted to the southern part of East Java; there's also a surge in chlorophyll-a concentration along the South Java coastline. This is evident by the expanding red areas, which indicate concentrations of roughly 1.5 mg/m³. From the monthly climatology data of SST and chlorophyll-a, it can be concluded that the peak of upwelling intensity along the seas of Southern Java occurs in August as denoted by minimum (maximum) SST (chlorophyll-a). As we enter the second transitional period, there's a significant decrease in chlorophyll-a concentration both near the coast and further offshore. This decrease continues until November and remains relatively stable until December. Notably, the concentrations in the southern part of East Java and Bali noticeably decline, going from 1 mg/m³ in November to gradually diminishing to 0.5 mg/m³, eventually disappearing completely in December, as indicated by dark blue areas on the contour map.

Sea surface temperature anomaly

Based on the sea surface temperature anomaly map, it is evident that a strong positive anomaly occurred in 2016, with temperatures recorded as being 2°C warmer, as can be observed in Figure 5. Throughout the year 2016, temperature anomalies occurred across the entire waters of Southern Java. Based on the map representation, during this period, the dominant anomalies in the Southern Java Waters were positive anomalies, ranging from moderate to strong. This indicates that in 2016, during the strong IOD phenomenon, sea surface temperatures were warmer by 1–2°C compared to the climatological averages for various months. During the west monsoon

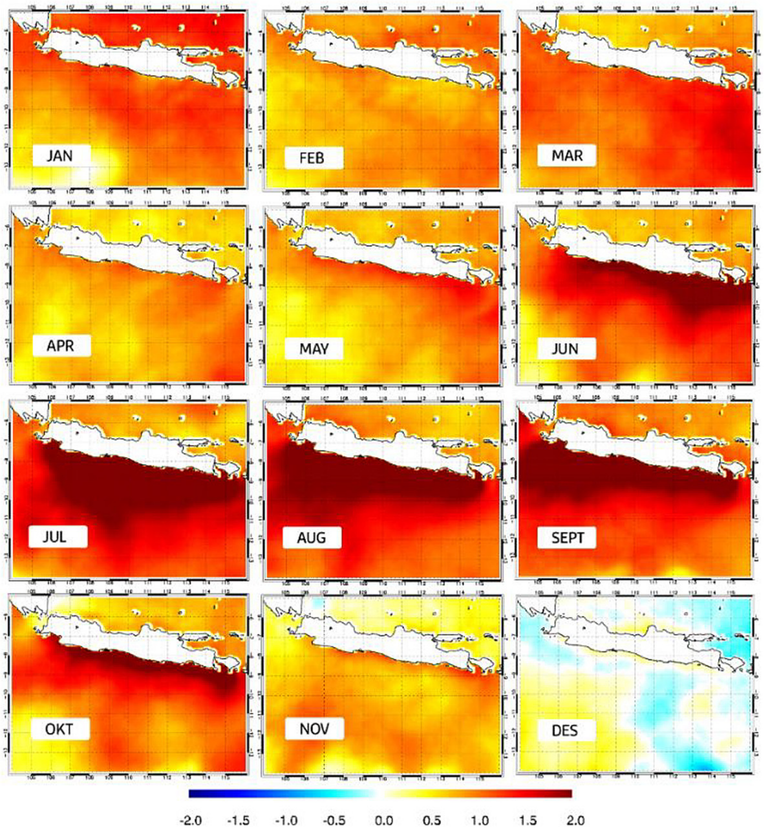

Fig. 5. Anomalies map of sea surface temperature in 2016 from their climatology

season, in December, the anomalies appear neutral, with light blue interspersed with white and yellow, indicating that the average temperature in December 2016 matched the climatological average. Moving into January and February, the dominating anomaly is positive, with a value of 0.5°C, signifying that during these months, the temperatures were around 0.5°C warmer than the respective climatological averages.

Transitioning into the first transition season (March, April, May), temperatures remained relatively stagnant, with a dominance of positive anomalies at 0.5°C. As the east monsoon season (June, July, August) progressed, sea surface temperature anomalies significantly increased. July and August reached their peaks with anomalies of up to 2°C in the Southern Java Waters. This condition began in June, where an increase in temperature was observed in the eastern regions of the waters adjacent to Java Island. This temperature increase continued into July and August, spreading along the entire South Java coastline and extending into offshore waters. This indicates that sea surface temperatures in July and August 2016 were 2°C higher than the climatological averages for those months over the 15-year period. Entering the second transition season, sea surface temperatures started cooling again, with anomalies of 0.5°C, almost evenly distributed across the waters of Southern Java in November.

Chlorophyll-a anomaly

Based on the chlorophyll-a anomaly map, it is evident that a strong negative anomaly occurred in 2016, with chlorophyll-a concentrations recorded as being lower by up to 0.2 mg/m³, as can be observed in Figure 6. In 2016, the chlorophyll-a anomaly map indicated strong and persistent negative anomalies throughout the year in the Southern Java waters. This negative anomaly pattern was attributed to the powerful negative IOD event. During the west monsoon season, negative anomalies dominated, signaling lower chlorophyll-a values by about 0.05 mg/m³ compared to previous years. In January, an intense negative anomaly was observed near Java Island, with values 0.2 mg/m³ lower than the previous year. The negative anomaly trend continued into the first transition season, with similar negative anomalies around 0.05 mg/m³. These anomalies spread in southern East Java and Bali, remaining negative

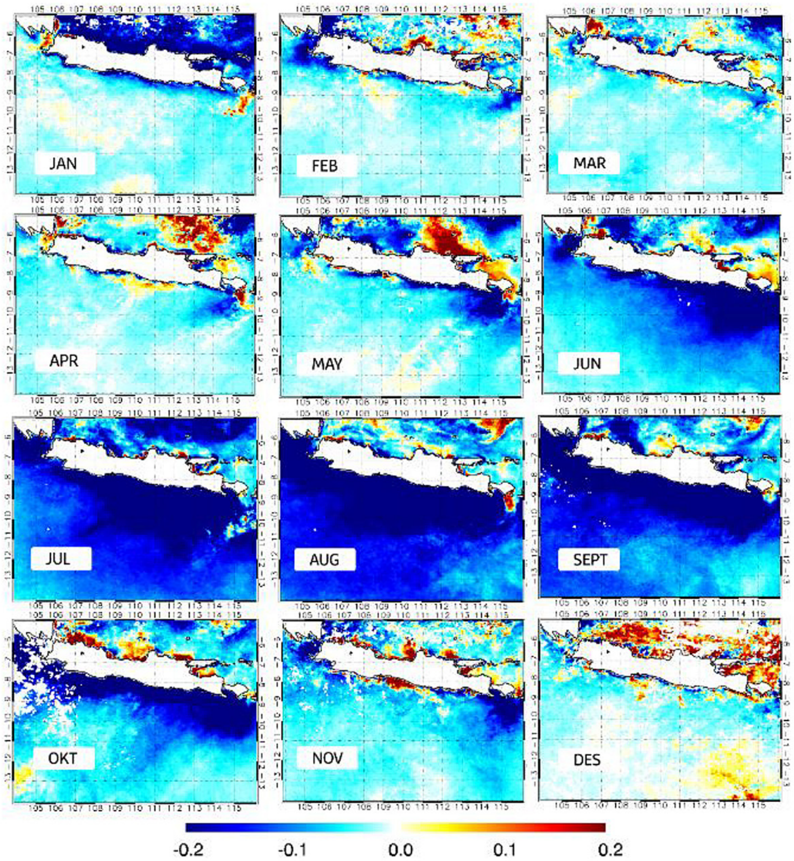

Fig. 6. Anomalies map of Chlorophyll-a in 2016 from their climatology

by 0.1 to 0.2 mg/m³ compared to climatological averages. Strong negative anomalies persisted into the east monsoon season, reaching their peak in August, covering wider areas. By November, anomalies started to normalize, except for a positive anomaly observed in southern Central Java. These anomalies reflected the impact of the strong negative IOD event on chlorophyll-a concentrations, particularly in the waters of Southern Java.

Sea level anomaly

The strong negative IOD phenomenon of 2016 also had a significant impact on sea level anomaly (SLA), as depicted in Figure 7. The SLA anomaly values shown are the result of calculating the difference between the climatological SLA values over a 15-year period (2007–2021) and the eastward wind values for the year 2016. The presented image uses colors ranging from blue to dark red, indicating strong negative to strong positive anomalies. Strong negative anomaly indications are represented by the blue color, signifying instances where the SLA anomaly values were lower than the climatological values for that month. On the other hand, positive anomaly indications, depicted in red, represent SLA values higher than the climatological averages for that month.

The SLA anomaly map for 2016 revealed anomalies throughout the year, divided into negative and positive phases. These anomalies were location-dependent and not evenly distributed. During the west monsoon season (Dec, Jan, Feb), fluctuating SLA anomalies were observed. Positive anomalies were evident in Dec near Java Island (around 0.1 meters). January saw a shift from negative to positive anomalies (0 to 0.1 meters). In Feb, a positive anomaly emerged in Southern Java waters (0.1 meters). In the first transition season (Mar, Apr, May), anomalies remained stable, with a positive anomaly appearing in May along Java's southern coast (around 0.1 meters). During the east monsoon (Jun, Jul, Aug), positive SLA anomalies intensified (up to 0.3 meters), notably along the Southern Java coastline and offshore. This trend continued into Aug. In the second transition (Sep, Oct, Nov), anomalies grew near Java Island (0.3 meters) and offshore (0.1 to 0.2 meters). By Nov, positive anomalies decreased, averaging around 0.2 meters across Southern Java waters.

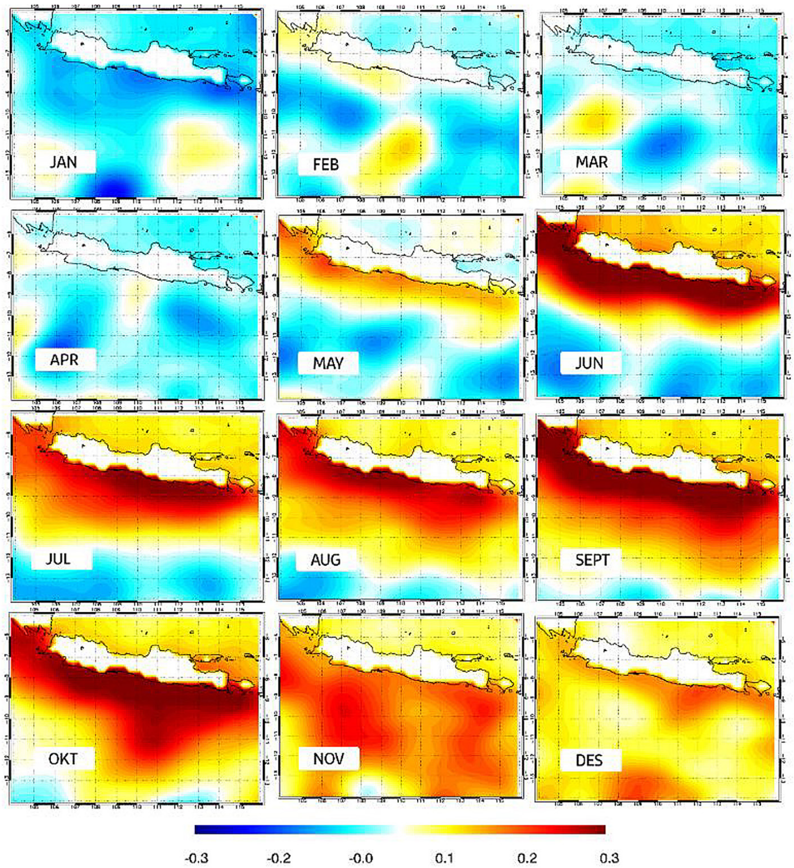

Fig. 7. Anomalies map of SLA in 2016 from their climatology

Hovmöller diagram

The Hovm**ö**ller diagram is used to identify factors influencing upwelling indicators along the Southern Java coast, especially during the strong negative IOD of 2016. The Hovm**ö**ller diagram is constructed from the mean value of 0.5°×0.5° bin size along the equator and following the coastal line of western Sumatra and Southern Java from 13°E to 113°E with 146 sampling bins. Hovm**ö**ller diagrams were generated using 15 years of monthly average sea surface temperature data and high sea level anomaly data (2007–2021). Figure 8 shows Hovm**ö**ller diagrams for sea surface temperature and SLA anomalies to understand the propagation of Kelvin waves during the negative IOD of 2016, with 2010 as a comparative data. The Hovm**ö**ller anomaly sea level data over 15 years demonstrates alternating positive and negative anomalies propagating from the Indian Ocean equator to the Southern Java coast. During the negative IOD of 2016, Kelvin waves propagated from the equator to the Southern Java coast, showing stronger positive anomalies compared to negative anomalies. This pattern was also seen in 2010 during another strong negative IOD, though the IOD index value was lower. Contrary to the positive IOD of 2019, weak downwelling Kelvin waves propagated from the equator. The propagation of Kelvin waves during the strong negative IOD of 2016 and 2010 is believed to contribute to the absence of coastal upwelling indicators in the seas of Southern Java. Additionally, the Hovm**ö**ller of sea surface temperature indicated that in August, a typical upwelling month, temperatures drastically increased in 2016 and 2010, unlike previous years with normal or positive IOD conditions.

DISCUSSION

In 2016, a very strong positive anomaly in sea surface temperature (SST) occurred, as shown in Figure 5. The majority of the seas of Southern Java experienced strong positive anomalies, with the strongest positive anomaly occurring during the upwelling month of August. During this month, the recorded SST anomaly was >2°C, which is contrary to the expected cooler SST values for August in each year. Other research indicates that the

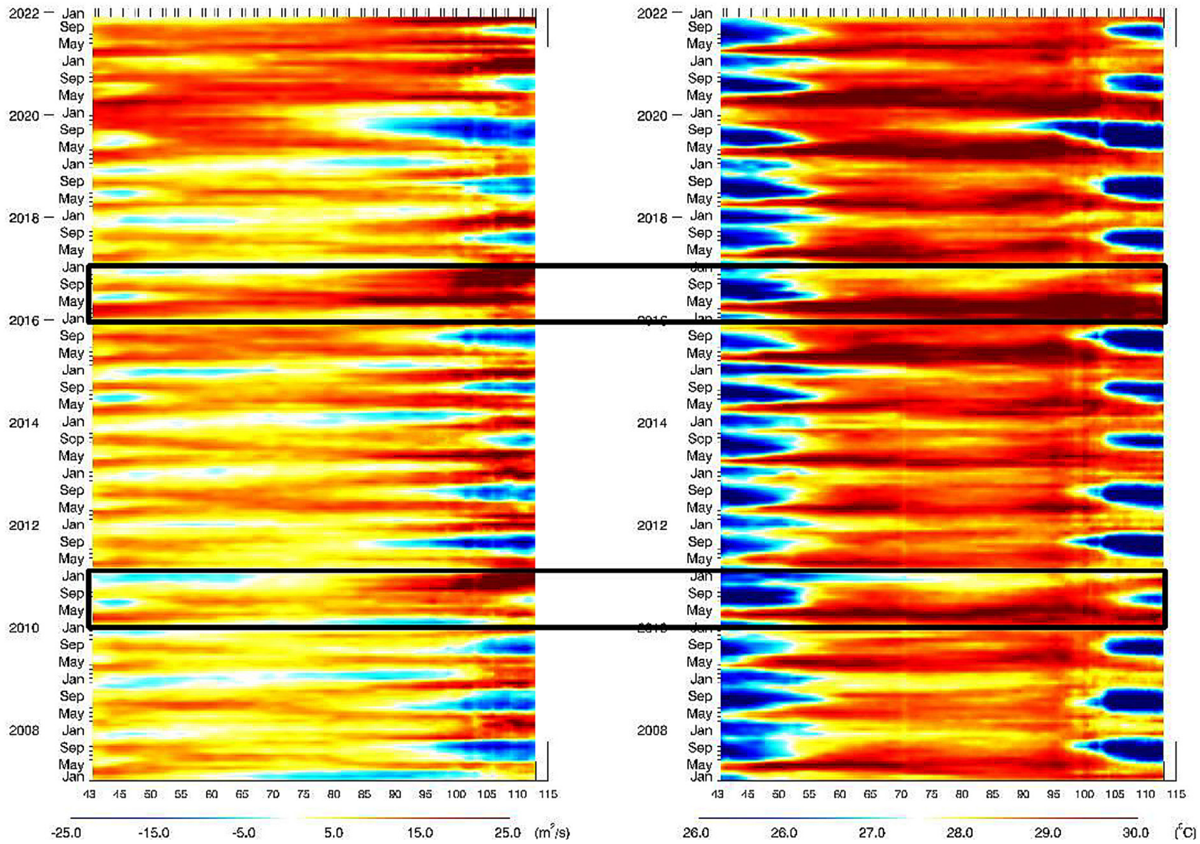

Fig. 8. Monthly Hovmöller Map of SLA (left) and sea surface temperature (right) from 2007–2021. Black boxes denoted the negative IOD events

average SST in the seas of Southern Java ranges from 26°C to 29°C, with the lowest recorded SST being 25°C in August and November This study concludes that the surface temperature variability in the seas of Southern Java varies significantly throughout the seasons, with the western monsoon having warmer temperatures and the eastern monsoon, particularly in August, exhibiting lower temperatures (Susanto et al 2001). However, this pattern was disrupted in August 2016. The strong positive SST anomaly is also accompanied by a strong negative anomaly in chlorophyll-a for the same month, August, during the upwelling period, as shown in Figure 6. The obtained chlorophyll-a anomaly values contradict the climatological results, suggesting a unique mechanism in 2016 that obscured the typical upwelling indication in August of that year. Thus, strong negative IOD in 2016 tends to reduce upwelling intensity along the seas of Southern Java.

Based on the findings of this research using quantitative spatial methods, the increase in sea surface temperature (SST) during the negative phase of the Indian Ocean Dipole (IOD) in 2016 can be attributed to the influence of downwelling Kelvin waves flowing from the Indian Ocean. The study indicates that the strong warming effect and lack of significant influence from the coastal winds along the Southern Java coast contributed to the absence of chlorophyll-a variability. The observed rise in SST is likely due to the downwelling Kelvin wave activity, as evident in the sea level anomaly (SLA) pattern shown in Figure 8. As the Eastern monsoon season progressed, there was a visible increase in SLA values, originating from the Indian Ocean. It has been established that SLA can directly affect sea surface temperature in the waters, leading to increased temperatures with positive SLA and decreased temperatures with negative SLA. This phenomenon also extends its influence to chlorophyll-a production, where changes in sea surface temperature directly impact chlorophyll-a variability (Kunarso et al., 2012). Therefore, the decrease in surface chlorophyll-a values during this period could be attributed to the Kelvin wave propagating from the Indian Ocean, inducing a downwelling Kelvin wave event during the Eastern monsoon in 2016. This event caused chlorophyll-a values to be driven below the surface, rendering them less visible at the surface. Downwelling Kelvin waves are a type of Kelvin wave that propagate along the equator and can affect sea surface temperatures (SST) in the eastern Indian Ocean. They can influence the environmental mixing in the waters and are triggered by the Madden-Julian Oscillation (MJO) in the eastern and central Indian Ocean. During the negative phase of the IOD, the observed anomaly of downwelling in the eastern Indian Ocean concludes with a strong and persistent downwelling Kelvin wave from the west, as depicted in Figure 7, indicating an increase in SLA, which signifies a rise in wave activity (Nienhaus et al. 2012).

The results of this study are also depicted in Figure 7, which illustrates the sea level anomaly (SLA) map, and Figure 5, which shows the sea surface temperature (SST) anomaly map. The rise in SLA values in these waters is attributed to the propagation of high SST from the Indian Ocean. In Figure 8, the propagation of SLA along the equator from the Indian Ocean to the Southern Java waters is evident. The increase in SLA in 2016 from the Indian Ocean, accompanied by high sea surface temperature values, is similar to the pattern observed in 2010. During both years, a consistent rise in SLA values is observed, coinciding with higher sea surface temperatures compared to other months. The anomalies in SLA and sea surface temperature from the Indian Ocean are also visible in Figure 8. In 2016, a strong positive anomaly propagates along the Southern Java coast, accompanied by higher sea surface temperature anomalies compared to other months. This trend is also observed in 2010, where positive anomalies are evident in both SLA and sea surface temperature variables. The condition of upwelling intensity during negative IOD is in reverse with positive IOD. During strong positive IOD in 2019, upwelling is intensified due to the reduction of downwelling Kelvin wave that makes the SST (chlorophyll-a) in August lower (higher) than its climatology (Safinatunnajah et al. 2021).

The seas of Southern Java is well known as the fishing ground of Tuna with the maximum catch occurs during the upwelling period at the east monsoon (Kunarso et. al. 2009, 2012; Lahlali et al., 2018). Thus, the finding of this study suggests that the weakening of upwelling intensity during negative IOD may reduce Tuna catches. Thus, responsive anticipation should be performed by stake holders of fisheries to mitigate the more loss due to the decline of Tuna catches during negative IOD event.

CONCLUSION

The upwelling along the seas of Southern Java occurs during east monsoon season which peaks in August as denoted by the minimum SST and maximum chlorophyll-a. Strong negative IOD in 2016, reduce upwelling intensity as shown by the positive anomaly of SST and negative anomaly of chlorophyll-a during east monsoon season. In August 2016, SST (chlorophyll-a) is higher (lower) of about 2°C (0.2 mg/m^3) than its climatology. The intensified downwelling Kelvin wave that propagates from equatorial Indian Ocean hampers the coastal upwelling along the seas of Southern Java.

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