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Impact of tropical Cyclones Cempaka and Dahlia to the variability of chlorophyll-a and sea surface temperature in the Seas Southern Coast of Java Island

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ABSTRACT

Tropical Cyclone (TC) Cempaka and Dahlia are the consecutive cyclones that happen in Southern coast of Java waters, in November to December 2017. The purpose of this research is to investigate daily characteristic from TC Cempaka and Dahlia based on wind velocity, curl, and Ekman Pumping as surface wind component in accordance with the distribution of chlorophyll-a and Sea Surface Temperature (SST) by remote sensing. Wind Pattern Component Data will be used to indentify pattern, velocity, and direction of the movement of the tropical cyclone. Curl component data will be used to support tropical cyclone rotation pattern identification, while Ekman Pumping will be used to identify the existence of upwelling. Chlorophyll-a and SST will be overlayed with the surface wind parameter to be analyzed for its relation with the other parameters. Result show that during the occurrences of TC Cempaka and Dahlia, wind velocity increase up to 10-19 m/s. TC Cempaka and Dahlia movement shift from Northwest to Southeast direction. There is a connection between TC Cempaka and Dahlia with the chlorophyll-a and SST. When the wind velocity increased along with the strengthening of positive curl and negative Ekman Pumping, upwelling is generated leading to the increase of clorophyll-a and the decrease of SST.

Key words *: Tropical cylone, Cempaka and Dahlia, Upwelling, Ekman pumping, Sea surface temperature, Chlorophyll-a.*

Introduction

The seas southern coast of Java Island is part of Indian Ocean which is majorly influenced by the monsoon wind that blows easterly during southeast monsoon (June, July, August) and westerly during northwest monsoon (December, January, February). Wind is one of the most important climate element that has vital role in the interaction between sea and atmosphere, as it is not only pivotal topic in meteorology researchs, but also in marine-based researches. Especially for surface water dynamic; wind is one of the primary factor. Energy transfer from surface wind to the ocean will generate waves and ocean current (Wyrtki, 1961). Furthermore, this area is also influenced by several oceanographic and atmospheric forcings such as Indian Ocean Dipole, upwelling, Southern Equatorial Current, Java Coastal Current, Indonesian Troughflow, and Tropical Cyclone.

Tropical cyclone (TC) -or typhoon or hurricane is cyclonal vortex in low-pressure system developed in tropical warm water region with Sea Surface Temperature (SST) above 27 °C (Keener *et al.,* 2002). TC occurs in tropical region that accompanied by strong cyclonic wind and heavy rain. The condensed heat exerted by the convective cloud in the cyclone is the main energy of tropical cyclone (Schenkel, 2006). Specifically, six environmental conditions should be fulfilled for TC genesis including sea surface temperatures (SSTs) greater than 26°C, sufficiently high midtropospheric relative humidity, conditional instability, enhanced lower-tropospheric relative vorticity, weak vertical wind shear, and sufficiently large planetary vorticity (Emanuel and Nolan, 2004; Gray, 1968; McBride and Zehr, 1981).

The position of Indonesia which is located close to equator is theoretically difficult for tropical cyclone formation. However in fact, several TCs generated and entered Indonesian region. Tropical Cyclone Warning Centre (TCWC) Jakarta reported 5 TCs occurred within Indonesian Seas from 2008 to 2017. They are :

1. Durga tropical cyclone(22 April 2008)
2. Anggrek tropical cyclone (31 October – 4 November 2010)
3. Bakung tropical cyclone (10 - 13 December 2014)
4. Cempaka tropical cyclone (25 - 27 November 2017)
5. Dahlia tropical cyclone (27 November – 2 December 2017)

In the end of November until beginning of Desember 2017, Meteorology, Climatology and Geophysics Agency (BMKG) observed and released information regarding two active tropical cyclone in the Southern part of Indonesia. They were Cempaka and Dahlia TCs. Cempaka and Dahlia TCs formed in the south of Java Island, and in the south of Sumatera Island, respectively. Their consecutive occurrences caused extreme rain, strong wind, and high waves in numerous area in the south of Java Island and Sumatera Island. The post effect of those TCs lead the potential generation of strong wind as 20 knots (36 km/h) in the southern area of Java and induced high waves to 2.5-4 meter in the southern coast of Java (BMKG, 2019).

In the present study, we explore the different perspective of Cempaka and Dahlia TCs, not in the scope of disaster but we focus on their advantages for marine productivity. We investigated the impact of Cemapak and Dahlia TCs to the variability of SST and Chl-a in the southern coast of Java. The previous studies have already shown that the variability of SST and Chl-a within Indonesian Seas are mainly driven by surface wind (Setiawan and Kawamura, 2011; Setiawan and Habibi, 2011; Wirasatriya *et al.,* 2017; Wirasatriya *et al.,* 2018a; Wirasatriya *et al.,* 2018b; Wirasatriya *et al.,* 2019a; Wirasatriya *et al.,* 2019b). Thus, the occurrence of extreme strong surface wind during Cempaka and Dahlia TCs becomes the important event to be investigated in relation with the the SST and Chl-a distribution at the southern coast of Java.

Materials and Methods

We used surface wind data from the Cross-Calibrated Multi-Platform (CCMP) gridded surface vector winds version 2.0 which can be retrieved from www.remss.com. CCMP are produced using various satellites, moored buoy, and model wind data with the accuracy is higher than the other wind reanalysis data (Atlas *et al.,* 2011). Spatial and temporal resolutions of the surface wind data are 0.25 × 0.25 and 6 hourly, respectively. For SST data, we used the product of Remote Sensing System Advanced Microwave Scanning Radiometer (RSS AMSR). This is daily product with 0.25° × 0.25° spatial resolution (Wents *et al.,* 2005). Microwave SST product can penetrate through the cloud which makes this product is suitable to investigate SSTs under TC condition. The chlorophyll-a data used in this study is a daily Himawari-8 Level 3 satellite image from the MTSAT satellite equipped with a sensor called Advanced Himawari Imager (AHI) with a spatial resolution of 5 km x 5 km deep during the daily temporal (Murakami, 2016), Observation data was taken from November to December 2017.

We calculate Ekman Pumping Velocity (EPV) from surface wind data. First we converted surface wind data into wind stress (*ô*):

$$t = r_a C_d U^2_{10} \quad .. (1)$$

where $\tilde{n}_a$ is the density of air (1.25 kg m^{-3}), and U_{10} is the wind speed 10 m above sea level. The value of drag coefficient (C_d) follows (WAMDI, 1988) i.e.,

$$1000C_d = 1.29 \quad \text{for } 0 \text{ m s}^{-1} < U_{10} < 7.5 \text{ m s}^{-1} \quad .. (2a)$$

$$1000C_d = 0.8 + 0.0065U_{10} \text{ for } 7.5 \text{ ms}^{-1} < U_{10} < 50 \text{ ms}^{-1} \quad .. (2b)$$

Next, EPV (m s^{-1}) was calculated following (Wang and Tang, 2014) :

$$EPV = -\frac{curl}{\rho_w f} \quad .. (3)$$

$$curl = \frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \quad .. (4)$$

where $\tilde{n}_w$ is the density of seawater (1,025 kg m^{-3}) and f is the Coriolis parameter (Stewart, 2008). The units of EMT and EPV are $m^2 s^{-1}$ and $m\ s^{-1}$, respectively.

According to Tomczak and Godfrey (1994), in the Southern Hemisphere, the amount of wind curl and Ekman Pumping values indicate the divergence or convergence of water masses, the value of Ekman Pumping is positive (EPV> 0) indicates the existence of convergence on the surface that moves the water mass towards the bottom the sea is called downwelling. The negative value of the Ekman Pumping (EPV <0) indicates the surface divergence that moves the mass of water toward the sea surface is called upwelling. The results of the processing of wind curl and Ekman Pumping values are then compared with the distribution of SST and Chlorophyll-a to identify the characteristics and growth of Cempaka and Dahlia TCs.

Results and Discussion

Characteristic of TC Cempaka and Dahlia

According to Saragih *et al.* (2018), in general, the average time needed for a tropical cyclone from growing to extinction is around seven days, but can vary to reach 1 to 30 days. Wind patterns show the growth of Cempaka TC grows westerly for 3 days (25-27 November 2017). The cyclone vortex is shown by the existence the eye of cyclone denoted by the low wind area at the center of the vortex. The peak of the TC Cempaka occurs on November 27 at 06.00 when wind speeds reaches 9 to 12 m/s on the eye wall of the cyclone (Fig 1). Fig. 2 shows the genesis of TC Dahlia. Wind patterns show the mocvement of TC Dahlia grows northwesterly for 6 days (27 November - 2 December 2017). Peak of the Dahlia tropical cyclone is November 28th at 12.00 with the wind speed on the cyclone's eye wall reaches 15 m/s.

The results of the visualization of the direction of movement pattern of Cempaka tropical cyclone (Fig 1) starts from the northwest to the southeast, then tends to turn to the East. Whereas in the TC Dahlia (Fig 2.) the direction of movement pattern starts from the northwest to the southeast. The pattern of movement direction of Cempaka and Dahlia tropical cyclones is thought to be related to the west monsoon wind. This is because the Tropical Cyclone Cempaka and Dahlia occur in the period from November to December when the West monsoon occurs, this is supported by the research of Yananto and Sibarani (2016), that the northwest monsoon season occurs in October to February, in this period the sun located in the southern hemisphere, resulting in the Southern hemisphere especially Australia getting more solar heating than the Asian continent. As a result, Australia has a high temperature and low (minimum) air pressure. Furthermore, it is explained, on the contrary in Asia where the sun begin to leave, the temperature is low and the air pressure is high (maximum). That is why there is a movement of wind from the Asian continent to the Australian continent. The wind from this Asian continent will be deflected by the Coriolis force as it crosses the Equator and forms a northwesterly wind.

Early growth of tropical cyclone Cempaka (Fig 1) and Dahlia (Fig. 2) showed that the wind speed

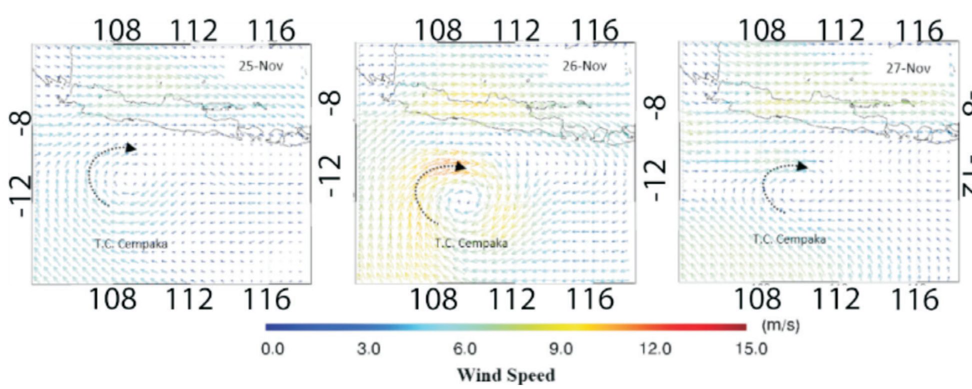

Fig. 1. Surface Wind Patterns during TC Cempaka (25-27 November 2017).

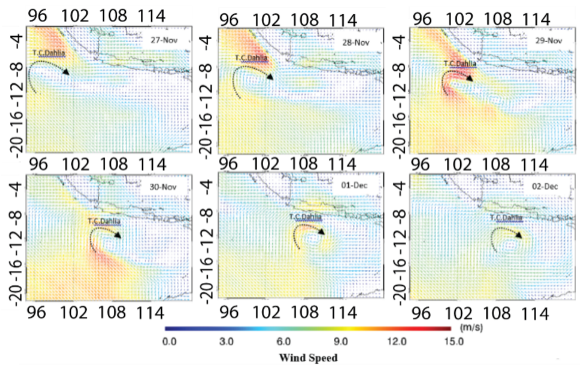

Fig. 2. Surface Wind Patterns during TC Dahlia (27 November - 2 December 2017)

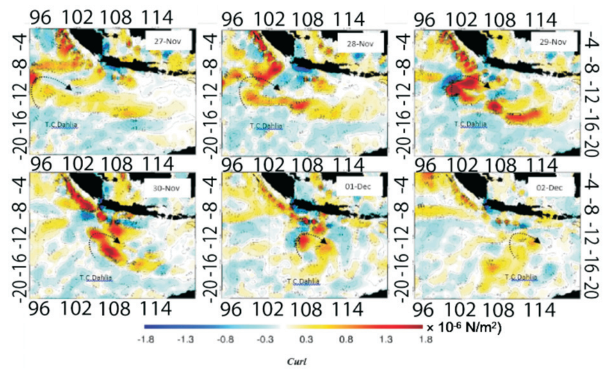

Fig. 4. Wind stress curl distribution during TC Dahlia (27 November - 2 December 2017)

starts to increase at the beginning stage. Furthermore, surface wind begin to form circular patterns due to the presence of low pressure and high temperatures. At the peak of TC Cempaka and Dahlia, the wind speed is maximum and the circular pattern gets stronger. This is because of the high sea surface temperature gradient. The growth of Cempaka and Dahlia tropical cyclones begin to weaken marked by decreasing wind speed and weakening of cyclone circular patterns. The weakening of wind speed occurs because the distance of the cyclone is already far enough from the southern Java waters and also the absence of a significant pressure gradient due to and low SST. This is consistent with the research of Haryanto *et al.* (2015), which shows that the wind speed at the genesis of a tropical cyclone is quite strong, this is because the higher the scale of the tropical cyclone, the pressure gradient that appears around the cyclone region is also greater which makes the moving wind also faster. Weakening tropical cyclones can be caused by pressure gradients starting to decrease after tropical cyclones become extinct.

The vortex of cyclone is also denoted by the positive curl as shown in Fig. 3 and 4 for Cempaka and Dahlia TCs, respectively. A positive value of curl means a clockwise wind rotation at the southern

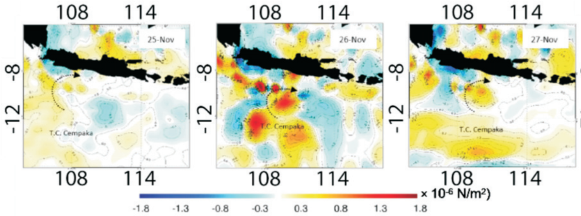

Fig. 3. Wind stress curl distribution during TC Cempaka (25-27 November 2017)

hemisphere. At the peak of the Cempaka TC on 26 November (Dahlia TC on November 29), the curl experiences a strong positive reaching +1 × 10-6 N/m2 (+1.8 × 10-6 N/m^2) which indicates that a strong rotation towards the center of the cyclone at the peak value. EPV shows strong negative value during the occurrence of TC Cempaka (Fig. 5) and TC Dahlia (Fig. 6). The negative EPV denotes that when the tropical cyclone occurs, it indicates upwelling. At the peak of the TC Cempaka on 26 November 2017 and TC Dahlia on 29 November 2019, EPVs experience a strong negative value reaching -40 × 10-6 m/s and -50 × 10-6 m/s, for TC Cempaka and Dahlia, respectively. This negative EPV is much larger than found along the southern coast of Java that generates upwelling as reported by Wirasatriya *et al.* (2020). This indicates that, the vortex of TC Cempaka and Dahlia can produce stronger upwelling than upwelling generated in the coastal area.

Chlorophyll-a and SST variabilities during TC Cempaka and Dahlia

TC Cempaka and Dahlia play important role in enriching the chlorophyll-a content in the study site through the upwelling mechanism driven by EPV at the location where tropical cyclones occurs. Based on the results of the vector plot of the wind pattern and countour map of chlorophyll-a and SST, before the tropical cyclone Cempaka occurred (Fig. 7), the wind speed is in normal conditions ranging from 4-6 m/s, SST is warm at the southern coast of Java ranging from 28 - 30 °C and chlorophyll concentration is low ranging from 0 to 0.12 mg/m^3. When TC Cempaka occurs (Fig. 8), SST decreases in the range of 27-28°C and the concentration of chlorophyll-a

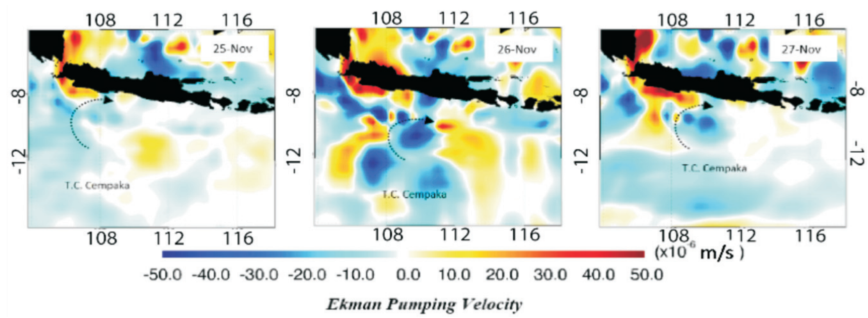

Fig. 5. EPV distribution during TC Cempaka (25-27 November 2017

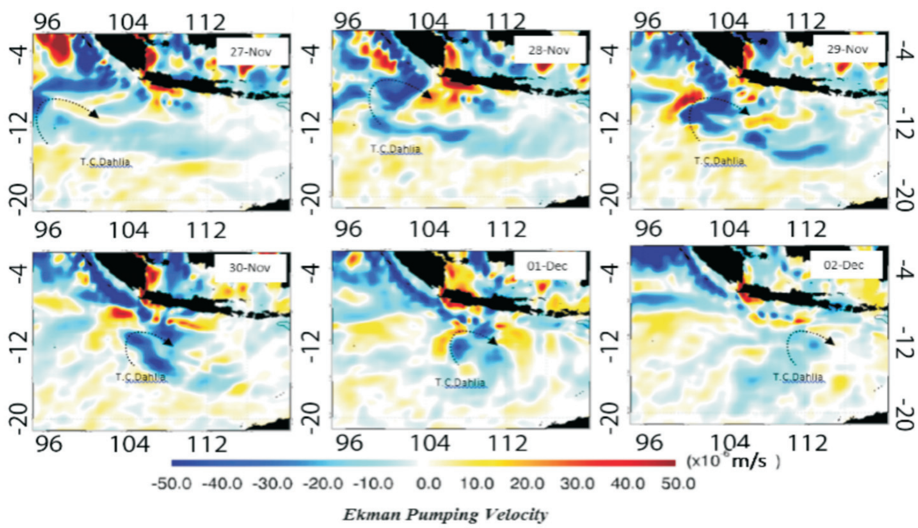

Fig. 6. EPV distribution during TC Dahlia (27 November - 2 December 2017)

increases reaching 0.15 - 0.2 mg/m^3. However, after the diminish of TC Cempaka (Fig. 9), the concentration of chlorophyll-a increased until the value reached 0.2 - 0.35 mg/m^3. SST appears to be lower in the range of 26-27 °C. After the TC Cempaka ended, the emergence of paths of TC Dahlia appears at the southern part of TC Cempaka track.

This is also supported by time series graph of TC Cempaka at the study site as shown in Fig. 10. It appears that before the Cempaka tropical cyclone occurred, sea surface temperature was 29.3°C, when the tropical cyclone occurred the wind speed increased to 15 m/s, while SST decreased to 28.2°C and chlorophyll-a concentration increased by 0.14 mg/m3 due to the strong upwelling of the Ekman pumping value of -12.86 m/s. While after Cempaka tropical cyclone, the wind speed decreased again to 4.9 m/s, but the sea surface temperature increased to 28.9°C which had an impact on the concentration of chlorophyll-a to reach 0.31 mg/m^3.

The same tendencies also occur during TC Dahlia. Normal wind speed conditions ranging from 3-6 m/s, warm SST at the southern waters of Java ranged from 28 - 31°C and chlorophyll concentrations ranged from 0.1 to 0.2 mg/m^3 occur before the TC Dahlia occurred (Fig. 11). When the Dahlia tropical cyclone occurs (Fig. 12), SST decreases in the range of 26.5 - 27.5 °C and the concentration of chlorophyll-a appears to increase until the value reaches 0.15 - 0.25 mg/m^3 due to the EPV value around -20 × 10-6 m/s which causes strong upwelling. However, after the TC Dahlia occurred (Fig. 13), the concentration of chlorophyll-a increased until the value reached 0.2 - 0.3 mg/m^3. The emergence of tropical cyclones Cempaka (Fig 7) and Dahlia (Fig 11) due to the low pressure marked by SST > 27 °C. This is in accordance with the requirements for the occurrence of tropical cyclones in the research of Prasetya *et al.,* (2016), regarding the impact of tropical cyclones that is, tropical cyclones can occur due to the existence of large waters with high SST, which is more than 27 °C so that air can be

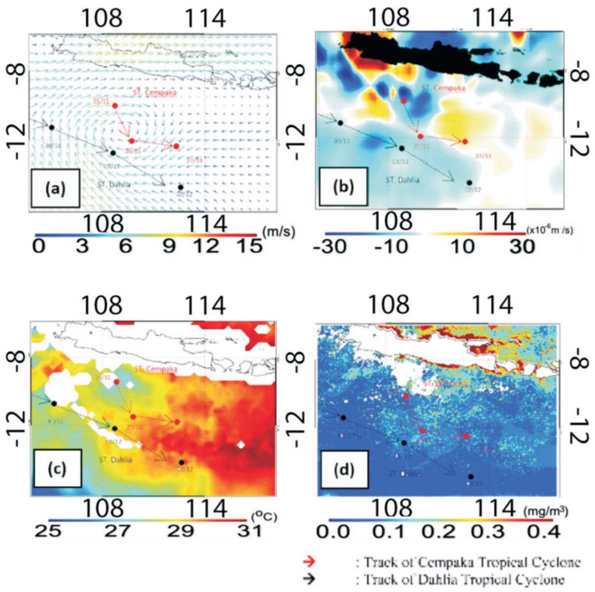

Fig. 7. Distribution of (a) Wind vector, (b) EPV, (c), SST, (d) and Chlorophyll-a before Cempaka Tropical Cyclone (18-24 November 2017)

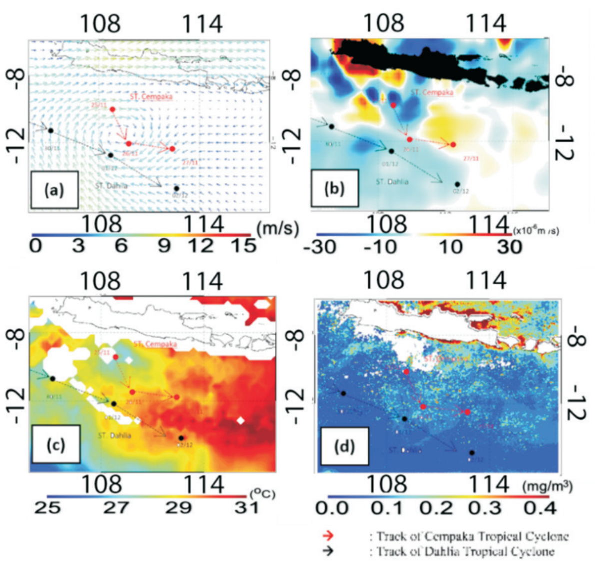

Fig. 8. Distribution of (a) Wind vector, (b) EPV, (c), SST, (d) and Chlorophyll-a during Cempaka Tropical Cyclone (25-27 November 2017)

lifted from the lowest atmospheric layer.

The time series analysis of the TC Dahlia at the study site is shown in Fig. 14 It shows that before the Dahlia tropical cyclone occurred, winds in normal conditions ranged from 2-5 m/s, sea surface temperature ranged from 27.8 to 28 °C, when tropical cyclones occurred wind speeds increased to 19,94 m/s meanwhile the sea surface temperature

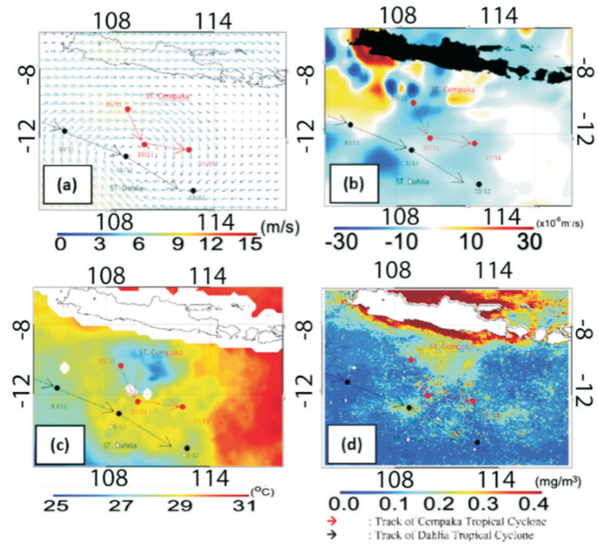

Fig. 9. Distribution of (a) Wind vector, (b) EPV, (c), SST, (d) and Chlorophyll-a after Cempaka Tropical Cyclone (28 November-1 December 2017)

decreased to be at 27.1 °C and the concentration of chlorophyll-a increased by 0.16 mg/m^3 due to the influence of EPV reaching -27.16 × 10-6 m/s. After the TC Dahlia, the wind speed decreased again to 6.2 m/s, SST increased reaching 27.6 - 28.3 °C. However, chlorophyll-a still keeps its concentration above 0.1 mg/m^3 until 2 December 2017. After that, Chlorophyll-a concentration decreased below 0.1 mg/m^3 on 3 December 2017.

The relationship of Ekman pumping is presented in graphic form on the Cempaka tropical cyclone (Fig. 10) and the Dahlia tropical cyclone (Fig. 14). Both tropical cyclones show almost the same chlorophyll-a value, with the maximum concentration value occurring when the peak of a tropical cyclone occurs and 2 to 4 days after the cyclone event. SST values also show almost the same in both tropical

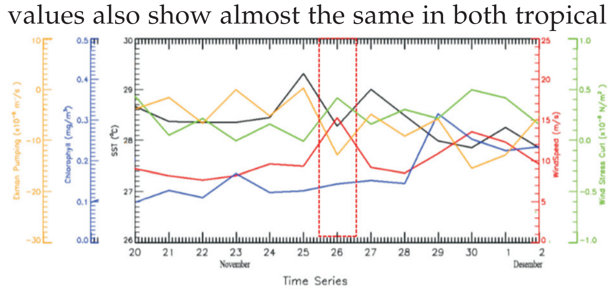

Fig. 10. Time series of wind speed, wind stress curl, EPV, Chlorophyll-a concentration, and SST during the occurrence of TC Cempaka at the area of 108-109°E and 11-12°S. The peak of TC Cempaka is denoted by red rectangle.

cyclones, the SST decreases to a minimum when the peak of a tropical cyclone occurs. Whereas the EPV values show the same on both the peaks of tropical cyclones, with low valuethat are thought to cause upwelling. TCs Cempaka and Dahlia are indicated by the occurrence of upwelling characterized by high increased chlorophyll-a concentrations and low SST. The high concentration of chlorophyll-a also lasted for 2 to 4 days after the incident, because the increase in water mass from upwelling still influences within a few days after the tropical cyclone event. This is supported by Krêzel *et al.*(2005), which shows that during autumn, upwelling were characterized by higher chlorophyll-a concentrations. Furthermore, it is explained that the chlorophyll-a concentration in the upwelling area is relatively stable and only occurs in the short term (1-3 days).

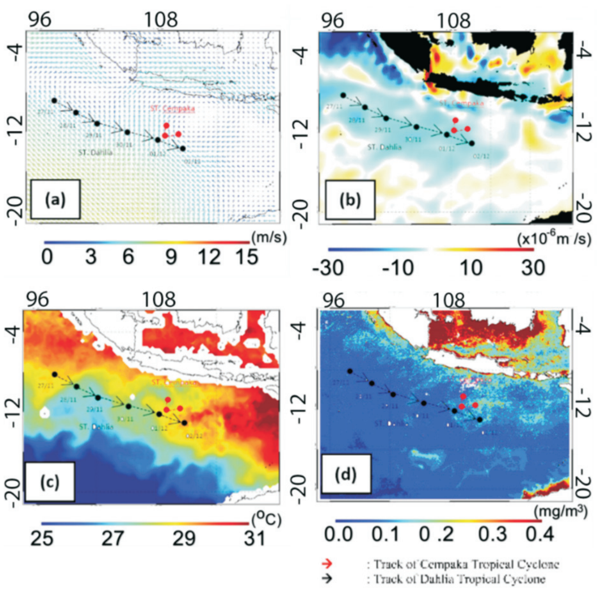

Fig. 11. Distribution of (a) Wind vector, (b) EPV, (c), SST, (d) and Chlorophyll-a before Dahlia Tropical Cyclone (20-26 November 2017).

When Cempaka and Dahlia tropical cyclones occur, SSTs experience significant cooling in areas where tropical cyclones occur and wind speeds experience rapid increases or storms. The decrease in temperature was allegedly due to very intensive upwelling, so that the mass of water that moves upward carries the mass of water with lower temperatures. Cempaka and Dahlia tropical cyclones play a role in enriching the chlorophyll-a content in the study site through the upwelling mechanism of EPV where tropical cyclones occur. This is consistent with what has been explained by Avila-Alonso *et al.* (2020) which investigated the oceanic response of TC Irma at the seas of Cuba and gulf of Mexico. They also found the evidence of SST cooling and increasing Chlorophyll-a during TC Irma. Furthermore, Zhang *et al.* (2014), stated that even relatively weak tropical storms could also cause increased levels of phytoplankton in the continental shelf. Further explained, the concentration of chlorophyll-a is usually low before a tropical storm, then chloro-

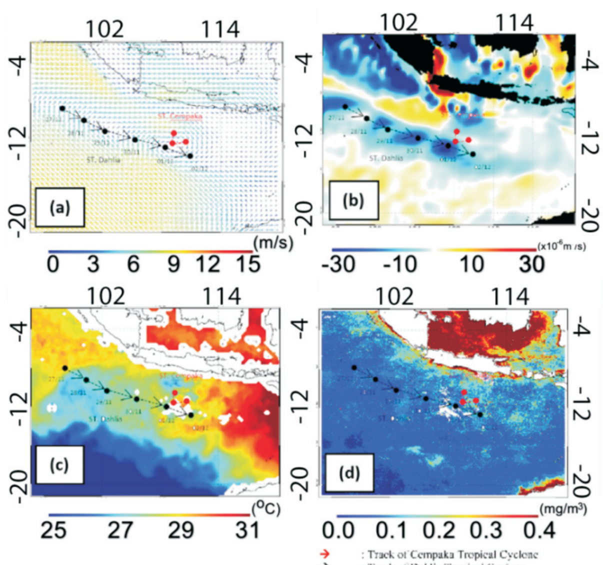

Fig. 12. Distribution of (a) Wind vector, (b) EPV, (c), SST, (d) and Chlorophyll-a during Dahlia Tropical Cyclone (27 November - 2 December 2017).

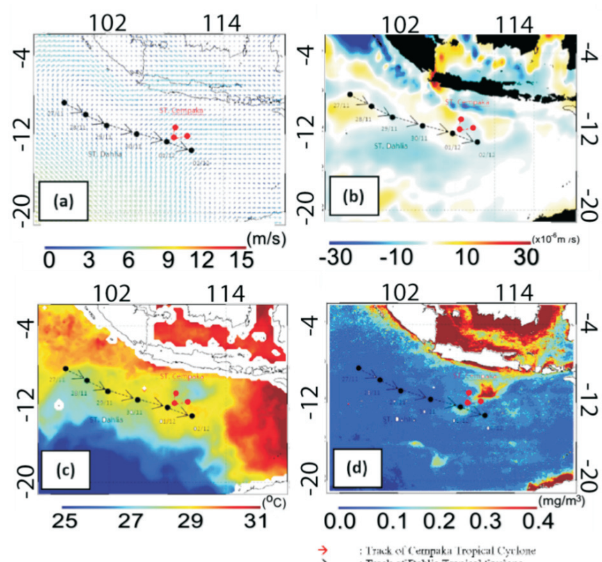

Fig. 13. Distribution of (a) Wind vector, (b) EPV, (c), SST, (d) and Chlorophyll-a after Dahlia Tropical Cyclone (3-9 December 2017).

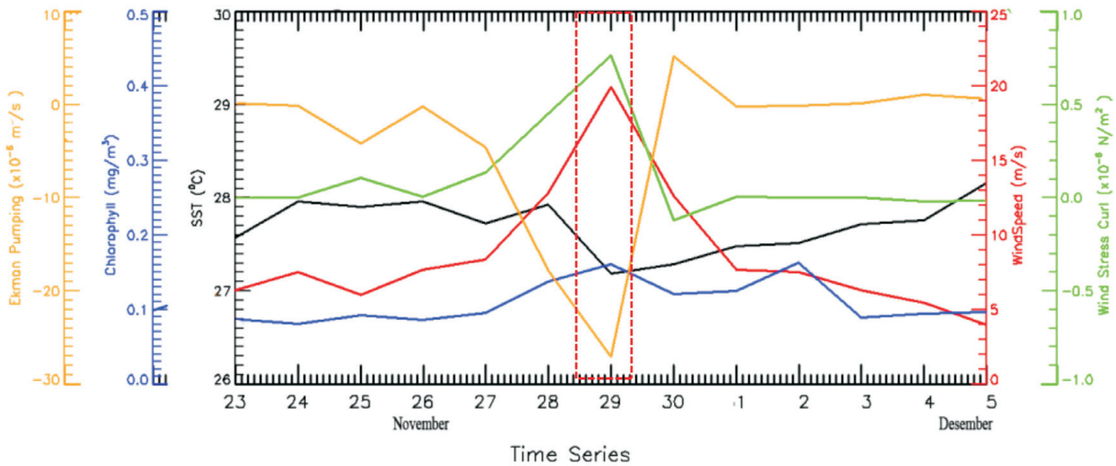

Fig. 14. Time series of wind speed, wind stress curl, EPV, Chlorophyll-a concentration, and SST during the occurrence of TC Dahlia at the area of 101-102°E and 10-11°S. The peak of TC Dahlia is denoted by red rectangle

phyll-a increases above 38% when a tropical storm occurs and 22% after a tropical storm occurs and the impact reaches 130 km from the center of the storm. The enrichment of chlorophyll-a concentrations when tropical cyclones are horizontal is also explained in a study conducted by Merrit and Chiao (2013), namely that biomass accumulation is specifically associated with cyclone storm path response as shown by SST flux and chlorophyll-a. Trends in SST that experience cooling in the beginning of the storm and an increase in chlorophyll-a during the storm and an increase in chlorophyll-a after the storm. The most striking difference is the variation in chlorophyll-a between the locations of the storm which is thought to be due to an increase in nutrient response due to the upwelling process that is apparent from the warm SST gradient returning after the tropical storm.

Conclusion

TC Cempaka occur from 25 to 27 November 2017 and then consecutively followed by the occurrence of TC Dahlia from 27 November to 2 December 2017 at the Seas southern coast of Java Island. Their occurrences are denoted by the increase of surface wind speed with strong positive curl and negative EPV which generate upwelling leading to the increase (decrease) of Chlorophyll-a concentration (SST).

Acknowledgment

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