The Identification of Upwelling in the Occurrence of Tropical Cyclone Charlotte in the Waters of Southern Java (Case Study: March 17-28, 2022)

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Abstract

Tropical cyclones are one of the meteorological phenomena that can have negative impacts on humans. These impacts can include heavy rainfall leading to floods and even storm surges. However, tropical cyclones can also have positive effects as they can trigger upwelling. Upwelling affects the fisheries aspect because in areas where upwelling occurs, sea surface temperatures are lower, and nutrients (such as phosphate and nitrate) are lifted from deeper layers of the ocean, which can affect the growth of phytoplankton. The objective of this research is to identify and analyze the upwelling phenomenon in the waters south of Java Island during the occurrence of Tropical Cyclone Charlotte. The data used in this research includes the intensity and movement direction of Tropical Cyclone Charlotte from the zoom.earth website and sea surface temperature, chlorophyll-a, mixed layer depth (MLD), and sea level anomaly data from the E.U. Copernicus Marine Service Information (CMEMS)-Global Monitoring and Forecasting Center during March 17-28, 2022. The results of this research indicate that upwelling was not identified during the period before or after the cyclone, as evidenced by sea surface temperatures between 28.5-29.5°C, chlorophyll-α concentration of <0.15 mg/m^3, and a sea level rise of 0.1 m.

1. Introduction

Upwelling is defined as the process of the upward movement of water masses from below towards the sea surface, accompanied by the rise of nutrients and fertilizers, thus leading to increased fertility on the sea surface (Nontji, 2002). The nutrients can be phosphates, nitrates, chlorophyll-α, and others (Nontji, 2002) which form the basis of the ocean food chain (Kampf & Chapman, 2016). The higher the nutrient content, the stronger the intensity of the upwelling. The decrease in sea surface temperature during upwelling occurs because the ascending water mass has a lower temperature than the sea surface. In contrast to sea surface temperature, the higher the chlorophyll-α concentration, the stronger the intensity of upwelling.

Identification of upwelling based on sea surface temperature and chlorophyll-a distribution has been carried out by Avrionesti et al. (2021); Lima et al. (2022). Upwelling in the waters south of Nusa Tenggara during the Tropical Cyclone Seroja event was identified by the decrease in sea surface temperature and the increase in chlorophyll-α distribution (Avrionesti et al., 2021). This was also supported by the research of Lima et al. (2022) which mentioned that upwelling caused by tropical cyclones in the Azores region, Portugal, from 1998 to 2020, could be identified based on negative anomalies in sea surface temperature and positive anomalies in chlorophyll-a distribution.

In addition to using sea surface temperature and chlorophyll-α as parameters for identifying upwelling, other supporting parameters can be used for analysis. These supporting parameters include mixed layer depth (MLD) and sea level anomaly. MLD can provide information about upwelling events (Guinehut et al., 2012). During upwelling events, MLD generally becomes shallower (Chen et al., 2009). Variability in MLD is strongly correlated with the occurrence of upwelling and can be used as a good indicator (Castelao et al., 2017).

Upwelling can also be analyzed based on sea level anomaly. Sea level in areas where upwelling occurs during tropical cyclone events will be lower than in the surrounding areas, and vice versa (Lentz, 2010). The decrease in sea level during upwelling occurs because there is a movement of water masses in opposite directions, creating a void on the sea surface. The void created by the movement of water masses in opposite directions causes sea level to be higher in the upwelling area compared to its surroundings (Colling et al., 2004).

The variability of upwelling in the waters south of Java is generally influenced by monsoon winds (Kunarso et al., 2020). However, upwelling can also be caused by tropical cyclone events (Surinati & Kusuma, 2018). The cyclonic circulation pattern during a tropical cyclone causes surface water to diverge (Colling et al., 2004). This divergence results in a void on the sea surface. Deep-sea water masses then move up to the surface to fill the void, leading to upwelling.

In addition to monsoon winds, upwelling can also be caused by tropical cyclones (Surinati & Kusuma., 2018). A tropical cyclone is defined as an intense storm originating in tropical regions with wind speeds exceeding 64 knots, forming over the warm waters of the northern Atlantic Ocean and the eastern North Pacific Ocean (Ahrens, 2011). In 2022, the Tropical Cyclone Warning Center (TCWC) Jakarta monitored 18 tropical cyclones in their area of responsibility (TCWC, 2022). One of the cyclones that occurred closest to Indonesia was Tropical Cyclone Charlotte.

Tropical Cyclone Charlotte formed in the Indian Ocean, specifically in the waters south of Java (BMKG, 2015). The Meteorology, Climatology, and Geophysics Agency (BMKG) reported that Tropical Cyclone Charlotte began forming on March 21, 2022, and dissipated on March 24, 2022. It developed from a tropical depression into a Category 1 tropical cyclone in the waters south of Java, approximately 500 km from the south coast of East Java, and continued to move southwestward and westward, away from Indonesia.

The intensity of Tropical Cyclone Charlotte continued to increase, reaching Category 3 on March 22, 2022, at a distance of approximately 900 km from the south coast of Central Java. During its lifetime, Tropical Cyclone Charlotte had maximum wind speeds of up to 110 knots.

2. Methodology

The data used in this study includes sea surface temperature, chlorophyll-α, Mixed Layer Depth (MLD), and sea level height obtained from the E.U. Copernicus Marine Service Information (CMEMS) Global Monitoring and Forecasting Center. Additionally, other parameters used are the direction and intensity of Tropical Cyclone Charlotte, obtained from the zoom.earth website. The data processing procedure commenced with the creation of maps depicting the direction and intensity of Tropical Cyclone Charlotte using QGIS software.

Subsequently, the data for sea surface temperature, chlorophyll-a, MLD, and sea level height from March 17 to 28, 2022, were divided into three periods to represent the conditions in the research area before (March 17-20, 2022), during (March 21-24, 2022), and after (March 25-28, 2022) the occurrence of Tropical Cyclone Charlotte. The data for sea surface temperature, chlorophyll-α, MLD, and sea level height were then processed using GrADS software to calculate their average values, which were then displayed spatially to observe the conditions in the research area before, during, and after the occurrence of Tropical Cyclone Charlotte.

Regarding the processing of the sea level height parameter, the average values of sea level height data for the periods before, during, and after the occurrence of Tropical Cyclone Charlotte were compared with the average data for the past 10 years in the research area. This was done using GrADS software and presented spatially. The purpose of this was to obtain the Sea Surface Height Anomaly parameter for the periods before, during, and after the occurrence of Tropical Cyclone Charlotte, as compared to the 10-year average conditions in the research area.

3. Result and Discussion

3.1. The Direction of Movement and Intensity of Tropical Cyclone Charlotte

The growth phase of Tropical Cyclone Charlotte began with the formation of a tropical depression to the east of Timor Island on March 17, 2022. The tropical depression continued to move southwestward and westward, eventually becoming a tropical storm on March 20, 2022, at 12:00 UTC. This tropical storm formed at a distance of approximately 500 km from the south coast of Java and continued to move in a southwestward to westward direction. An illustration of the direction of movement and intensity of Tropical Cyclone Charlotte can be seen in Figure 1.

Figure 1. Direction of Movement and Intensity of Tropical Cyclone Charlotte from Formation to Dissipation

In Figure 1, it can be observed that Tropical Cyclone Charlotte officially formed at a distance of approximately 550 km from the south coast of Java on March 20, 2022. The intensity of Tropical Cyclone Charlotte then increased to a Category 2 tropical cyclone on March 21, 2022, at 03:00 UTC, moving southwestward away from Indonesia. Tropical Cyclone Charlotte reached its highest intensity, which is Category 3, on March 21, 2022, at 18:00 UTC. This intensity was sustained for 36 hours, and then it began to decrease, indicating that Tropical Cyclone Charlotte was entering the dissipation phase on March 23, 2022, at 06:00 UTC. The cyclone moved southward and experienced a decrease in intensity, becoming a Category 1 tropical cyclone on March 23, 2022, at 18:00 UTC, and eventually downgrading to a tropical storm on March 24, 2022, at 00:00 UTC until it completely dissipated on March 24, 2022, at 12:00 UTC.

3.2. Before Tropical Cyclone

After The conditions of the SST and chlorophyll-α parameters during the period before Tropical Cyclone Charlotte occurred can be seen in Figure 2, it is evident that the sea surface temperature in the research area tends to be high, with a range of 27.5-30°C. This condition remained relatively constant from March 17 to March 20, 2022. In addition to SST, the figure also shows that the concentration of chlorophyll-a gradually decreases as it moves further away from the coastline. Near the south coast of Java, the concentration of chlorophyll-a can reaches >0.2 mg/m^3, while offshore, the concentration of chlorophyll-a is approximately <0.15 mg/m^3.

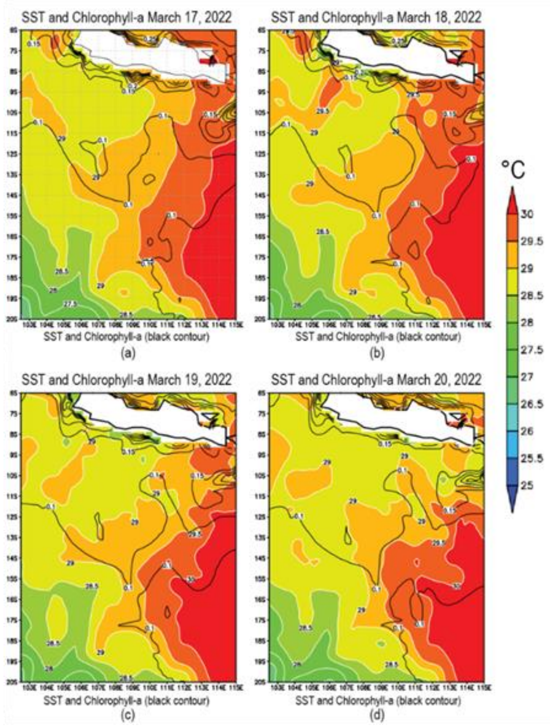

Figure 2. Conditions of SST and Chlorophyll-α Parameters Before the Tropical Cyclone (March 17-20, 2022)

Figure 3 depicts the conditions of the Mixed Layer Depth (MLD) and Sea Surface Height Anomaly parameters at the research location before the occurrence of Tropical Cyclone Charlotte. From the figure, it can be observed that the MLD is relatively uniform, with a thickness ranging from 10-30 meters. There was no significant change in the MLD parameter on March 17-19, 2022. However, on

March 20, 2022, the MLD experienced thickening, as indicated by the expanded green areas in the research location representing MLD with a thickness of 20-30 meters. This thickening occurred due to the mixing process driven by the intensifying tropical storm, which was soon to become Tropical Cyclone Charlotte.

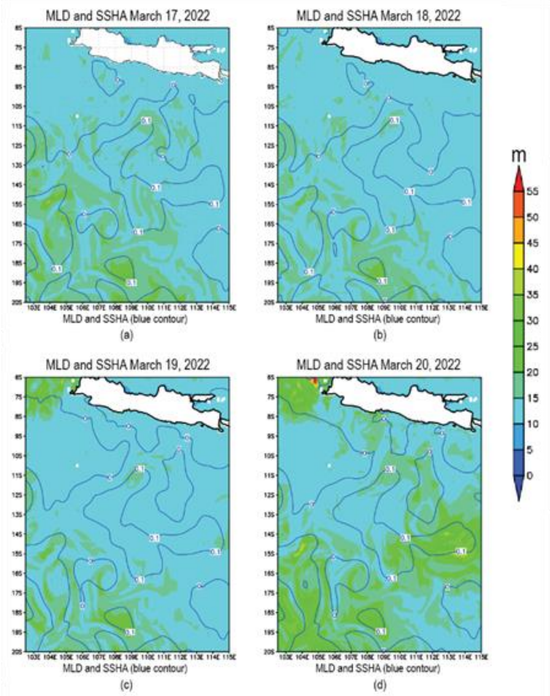

Figure 3. Conditions of MLD and Sea Surface Height Anomaly (blue contours) Before the Tropical Cyclone (March 17-20, 2022)

The Sea Surface Height Anomaly parameter during the period before the occurrence of Tropical Cyclone Charlotte ranged from 0-0.1 me. Positive sea level height anomalies indicate an increase in sea level height of up to 0.1 m or 10 cm compared to the normal conditions. Conversely, if there are areas with negative anomaly values, it means a decrease in sea level height in that area compared to normal conditions.

3.3. During Tropical Cyclone

The conditions of sea surface temperature (SST) and chlorophyll-a parameters during the period when Tropical Cyclone Charlotte occurred can be observed in Figure 4. Sea surface temperature is represented by a color gradient from bright red to dark blue, while chlorophyll-a is indicated by black contour lines. The position of the cyclone on March 21-24, 2022, is marked with weather symbols in the shape of a cyclone in black.

From Figure 4, it can be seen that the sea surface temperature at the research location ranges from 27.5 to 30°C. This condition is not significantly different from the period before the occurrence of Tropical Cyclone Charlotte. However, in Figure 4 a-c, a slight decrease in sea surface temperature can be observed in the areas affected by the cyclone. The sea surface temperature dropped from 29°C to 28.5-28°C. This decrease was temporary. In Figure 3.4d, it can be seen that as the cyclone moved farther away, the sea surface temperature increased back to 29°C.

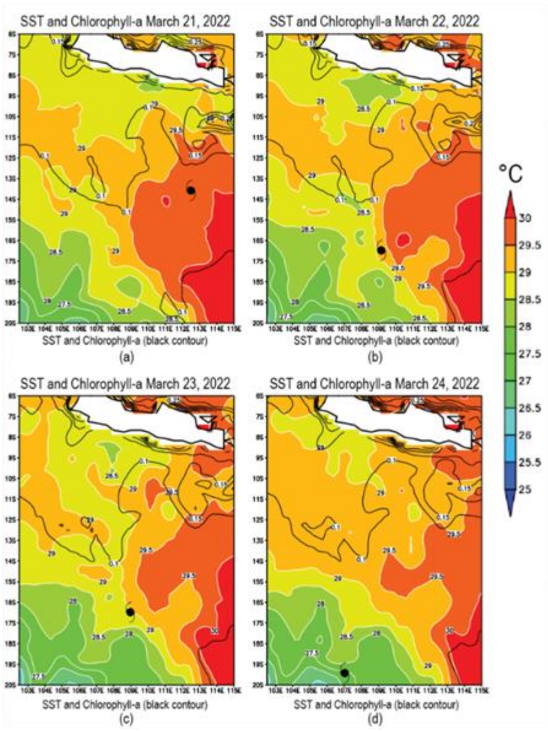

Figure 4. Conditions of SST and Chlorophyll-α Parameters during the Tropical Cyclone (March 21-24, 2022)

Regarding the chlorophyll-α parameter, there was no significant change on March 21-24, 2022. The concentration of chlorophyll-α remained relatively consistent, both offshore and along the south coast of Java. Offshore, the concentration of chlorophyll-α ranged from 0.1-0.15 mg/m^3, while it was >0.2 mg/m^3 near the coastline.

Figure 5 displays the conditions of the MLD and Sea Surface Height Anomaly parameters at the research location during the period when Tropical Cyclone Charlotte. Based on Figure 5, the MLD parameter appears to have a more variable thickness with a range of 10-55 meters compared to the period before the cyclone occurred (Figure 3). The mixing effect by the wind from Tropical Cyclone Charlotte led to the thickening of the MLD. Despite the mixing caused by Tropical Cyclone Charlotte, it did not bring significant changes to the sea level height. Along the path of Tropical Cyclone Charlotte, the sea level height increased to a maximum of 0.1 m or 10 cm. This increase in sea level height indicates the accumulation of water mass at the sea surface.

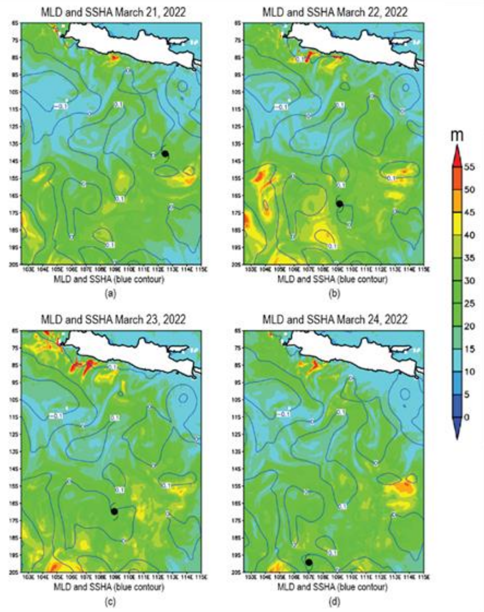

Figure 5. Conditions of MLD and Sea Surface Height Anomaly Parameters (blue contours) Before the Tropical Cyclone (March 17-20, 2022)

3.4. After Tropical Cyclone

The condition of SST and chlorophyll-a parameters at the research location during the period after Tropical Cyclone Charlotte ended can be seen in Figure 6, it is generally known that SST remains within the range of 27.5-30°C. There is no evidence of any temperature drop at the research location that can be attributed to Tropical Cyclone Charlotte. Instead, SST has increased compared to the conditions during the passage of Tropical Cyclone Charlotte (Figure 5). The SST in the research location warmed up after the end of Tropical Cyclone Charlotte.

There was no significant change in the quantity of chlorophyll-α concentration at the research location after the end of Tropical Cyclone Charlotte. The concentration of chlorophyll-a offshore remained relatively low, ranging below 0.1 mg/m^3. Along the coastal area, the concentration of chlorophyll-α also remained unchanged, with values of approximately >0.2 mg/m^3. This indicates that there was no significant change in chlorophyll-α concentration from before, during, to after Tropical Cyclone Charlotte ended.

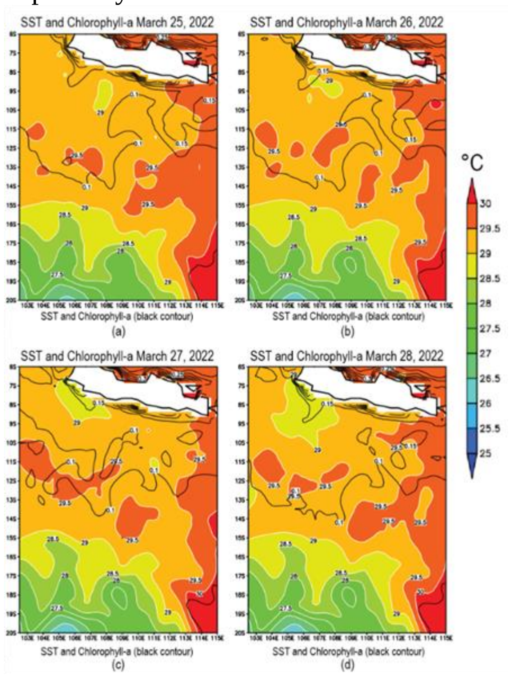

Figure 6. Conditions of SST and Chlorophyll-α Parameters After the End of the Tropical Cyclone (March 25-27, 2022)

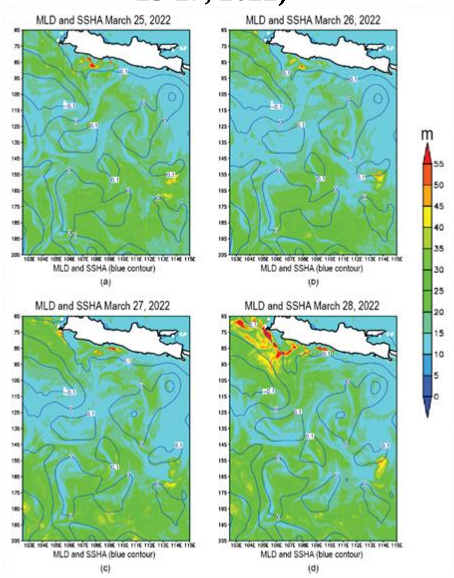

Figure 7. Conditions of MLD and Sea Surface Height Anomaly Parameters (blue contours) After the End of the Tropical Cyclone (March 25-27, 2022)

Figure 7 illustrates the condition of MLD and Sea Surface Height Anomaly parameters at the research location during the period after the end of Tropical Cyclone Charlotte. In this period, as shown in Figure 7, there is no longer wind-induced mixing by Tropical Cyclone Charlotte. However, remnants of the mixing effects are still visible with MLD ranging from approximately 15-40 m. These values are smaller than when the cyclone was active but larger than the period before the cyclone occurred.

4. Conclusion

Upwelling was not identified at the research location during the period before Tropical Cyclone Charlotte occurred until the cyclone ended. The absence of upwelling is indicated by the high sea surface temperature with values between 28.5-29.5°C and a low chlorophyll-α concentration of around <0.15 mg/m^3. This is further supported by the Sea Surface Height Anomaly parameter, which shows an increase in sea level height of up to 0.1 m despite surface mixing activity during the cyclone, as evident from the thick mixed layer depth (MLD) during the cyclone. The increase in sea level height by 0.1 m indicates that there is an accumulation of water mass at the sea surface, preventing water from rising to the surface. As a result, there is no significant decrease in sea surface temperature and an increase in chlorophyll-α concentration.

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