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The El Niño Southern Oscillation (ENSO) Effect on Upwelling in The North Maluku Sea

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Abstract. The north Maluku Sea has a high wind speed in the southeast season caused an increase in the Ekman transport at the coastal area so affects in rising of chlorophyll-a and the Sea Surface Temperature (SST) is cooling, who indicates the upwelling phenomenon. Upwelling in the North Maluku Sea is a type of coastal Upwelling where it occurs on the coast with a depth of more than 1500 m. The intensity of Upwelling is influenced by climate variability, one of which is El Niño Southern Oscillation (ENSO). By using remote sensing is chlorophyll-a data, SST, wind obtained from satellite imagery, and the value Ekman Mass Transport (EMT) with method composite formula. This research aims to know the influence of climate variability ENSO against the phenomenon of upwelling that occurred in the North Maluku Sea in the southeast season. Effect of climate variability ENSO at the time of El Niño (La Niña), chlorophyll-a concentration has positive (negative) anomalies, negative (positive) SST anomaly and wind conditions thus causing EMT energy to increase (decrease).

1. Introduction

The Maluku Sea is one of the eastern waters of Indonesia which has the deepest depths of water up to 4.500 meters and more than 1.500 meters for the Maluku Sea near the coast of Sulawesi Island [1,2]. The waters were part of the Lifamatola as the deepest entrances of the Southern Pacific Ocean water masses with low currents as the connector of the Pacific Ocean with Indonesian waters [2,3]. Its location in the equator made the influence of the Coriolis effect reduced, but in the region of the North Maluku Sea has a high wind speed [4] with the high Ekman transport [1] that can cause upwelling.

Upwelling is one of the phenomena in the ocean characterized by rising mass seawater from the deep sea ranges from 100 – 300 meters. This process can lead to increased nutrient content on the water surface, thus having high primary productivity potential [5]. The types of upwelling in the northern Maluku Sea includes the Coastal upwelling where it occurs in the coastal area [6]. Coastal upwelling occurs because of the emptiness layer of the water that is on the surface due to influences from the wind. The wind that blows firmly will cause an Ekman transport continuously from a certain depth, allowing



a pressure gradient along the coastline transporting water masses from within the water following the basic slope of the waters and moving onto it [7].

The high transport of Ekman in the North Maluku Sea [1] Raises the characteristics of upwelling in this water with the highest chlorophyll-a occurring when the southeast season is on the coast around Banggai Island [8]. Then the high chlorophyll-a also occurs on the coastal Maluku Sea around North Sulawesi Island and the coast of South Halmahera Island, especially in August [4]. In addition, its a cold water surface that has an increase in chlorophyll-a becomes characteristic of upwelling occurring in the Sea of Maluku [8,9]. The highest upwelling peak in August also occurred in research [10] marked by an increase in chlorophyll-a concentration and a decrease in SST at Bone Bay.

The Indonesia's territorial waters tended to be largely influenced by ENSO [11]. So that the upwelling intensity can increases (decreases) when El Niño (La Niña) also affects the chlorophyll-a concentration and SST [10]. These event was influential on primary productivity of water [12]. The purpose of this study is to know how the ENSO effect as a climate variability against the phenomenon of upwelling that occurred in the North Maluku Sea (from $0^{\circ} - 1.7^{\circ}\text{N}$; $125.3^{\circ}\text{E} - 126^{\circ}\text{E}$) in the southeast season.

2. Data And Method

2.1. Data

The SST and chlorophyll-a data obtained from the Aqua MODIS L3 with Common Data File Net (NetCDF) format data and a spatial resolution of $0.04^{\circ} \times 0.04^{\circ}$, because this study uses ENSO climate data to see significant differences with at least ten years a composite data observation period from year 2006-2018 [13,14]. The SST MODIS data used is SST $11 \mu\text{m}$ with day and night observation data. Then for chlorophyll-a data using Chl-a MODIS data $11 \mu\text{m}$ from the year 2006-2018. The SST and chlorophyll-a data downloaded from <http://oceancolor.gsfc.nasa.gov/cms/page>.

Wind data obtained from Cross Calibrated Multi-Platform (CCMP) with a high-resolution grid analysis of $0.25^{\circ} \times 0.25^{\circ}$ [15] from a daily data of L3 for 13 years (January 2006 through December 2018) with a pick up every 6 hours is download through the <http://data.remss.com/ccmp/page>. This data has the best analysis of other data following the in situ observation data and has been widely used for various studies [15-18].

The climate variability data used is ONI index who obtained based on differences in SST anomalies in the West Pacific Ocean and East Pacific Ocean in the Nino 3.4 region ($5^{\circ}\text{N} - 5^{\circ}\text{S}$, $120^{\circ} - 170^{\circ}\text{W}$) downloaded from the http://www.cpc.noaa.gov/products/analysis_monitoring page.

2.2. Method

SST, chlorophyll-a, and daily winds data from 2006 to 2018 in extracts which will then display a daily SST and chlorophyll-a state with a data format (*. sav). Daily data is compressed with daily algorithms into monthly SST data, using a monthly composite formula, then composed into monthly data climatology with the following formula [4]:

$$Xb(x, y) = \frac{1}{mh} \sum_{j=1}^{mh} xi(x, y, t) \quad (1)$$

Where $Xb(x, y)$ is the mean monthly/climatology, mh is the number of composite data in monthly or climatology period, $j = 1$ is day 1/1st month observation period on the composite month $xi(x, y, t)$ is the daily data to- i /data observation period at position longitude (x), latitude (y), and time (t) [4].

Wind data processing is used also to calculate the value of Ekman Mass Transport (EMT) of the daily wind data in the format (*. sav) obtained the speed value in the direction U and V, then the data is stored in the program format (*. sav) to look for friction/stress value (τ) with the following formula:

$$\tau = \rho_a C_d U_{10}^2 \quad (2)$$

$$EMT_x = \frac{(\delta_{tx} + f_{ty})}{\rho_w (f^2 + \delta^2)} \quad (3)$$

$$EMT_y = \frac{(\delta_{ty} - f_{tx})}{\rho_w (f^2 + \delta^2)} \quad (4)$$

$$EMT = \sqrt{(EMT_x)^2 + (EMT_y)^2} \quad (5)$$

[1,19]

where τ is the stress of wind (N/m^2), ρ_a is air density (1.25 kg/m^3), C_d is the coefficient of friction, ρ_w of seawater density ($1.025 \times 10^3 \text{ kg/m}^3$), U_{10} is wind speed 10 m below the sea level, δ is friction ($1/(4.8 \times 24 \times 3600)$), f is the parameter Coriolis ($2\omega \sin\phi$). EMT_x and EMT_y show EMT in Zonal and meridional direction, C_d value:

$$1000 * C_d = 1.29 \text{ to } 0 \text{ m/s} < U_{10} < 7.5 \text{ m/s} \quad (6)$$

$$1000 * C_d = 0.8 + 0.0065 * U_{10} \text{ for } 7.5 \text{ m/s} < U_{10} < 50 \text{ m/s} \quad (7)$$

[20]

The data processing of ENSO variability carried out with the pattern of SST and chlorophyll-a monthly spread in the North Maluku Sea with the boundary from ($0^\circ - 1.7^\circ\text{N}$; $125.3^\circ\text{E} - 126^\circ\text{E}$). The method used to identify ENSO phenomena conducted with SST, chlorophyll-a, wind, and EMT monthly data from 2006-2018 based on the condition normal, El Niño, and La Niña that only reviewed in August because the peak of upwelling occurred in the month characterized by the high value of chlorophyll-A and the low-temperature value of sea level compared with the other month. The ONI Index used to sea level anomaly data in the region Niño3 4. If the ONI Index $> 0.5^\circ\text{C}$ then classed is an El Niño condition, and when the ONI Index of $< -0.5^\circ\text{C}$ is La Niña.

3. Result And Discussion

3.1. Variations of SST, chlorophyll-A, wind and EMT

The time series chart (Figure. 1) shows the average of SST, chlorophyll-A, wind velocity, and EMT monthly climatology as a result of the upwelling phenomenon occurring in the northern Maluku sea. The phenomenon of upwelling in the Maluku Sea has different variations according to the seasons of climate occurrence and influence [21]. Where the chlorophyll-a concentration, wind velocity, and EMT has a directly proportional relationship, while the three parameters have a relationship that is inversely proportional to SST.

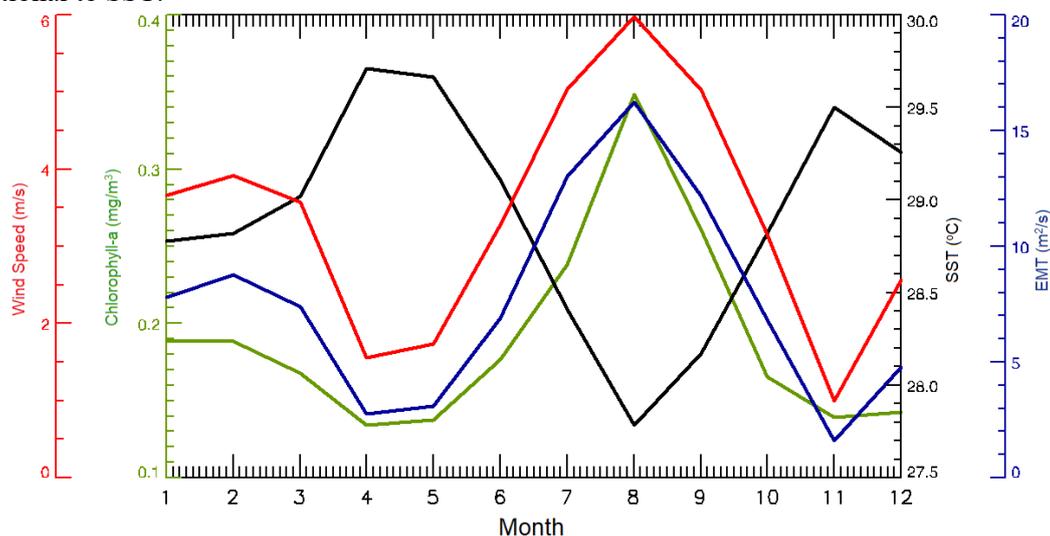


Figure 1. Time series graphs of chlorophyll-a (green line), SST (black line), wind (red line) and EMT (blue line) monthly climatology in Maluku Sea for 13 years (2006-2018).

The peak of upwelling events occurred during the southeast season, SST has the lowest value of 27.3°C (Figure. 2b) and the highest chlorophyll-a concentration reaches 0.32 mg/m^3 (Figure. 2a). The southeast season is characterized by wind gusts from the south (Australia) to the north (Asia) starting June to August. These wind gusts can cause sea level movement and Ekman transport. [9].

Low SST is influenced by high wind speeds that blow from the south of the Maluku Sea to a consistent north like previous studies [1,8]. The high wind speed reaches up to 6 m/s (Figure. 2c) which is located in the middle of North Maluku Sea because there are no obstacles from the island, while near the island of Sulawesi the low wind speed is blocked by the island as well as the speed of the wind

around the Halmahera Island. The wind direction is influenced by the southeast season known as the dry season in Indonesia, the monsoon wind is blowing from the southern hemisphere (Australian) to the north hemisphere (Asian) which is dry due to the air pressure distinction.

The high wind speed then generated the EMT along the coasts of the northern Sulawesi Island and the coastline of Halmahera Island. This type of phenomenon includes coastal upwelling because it occurs along the coast, which is caused by wind divergences and EMT that move away from the coastline. The rate of increase in the amount of chlorophyll-a increases (decreases) as the strengthening (weakening) of the wind velocity and the upwelling occurring in the North Maluku Sea is closer to the sea and the lower the upwelling intensity while near the higher shore because it is associated with EMT.

The mechanism of EMT is influenced by wind speeds so that EMT's power will diminish as depth increases. The direction of the EMT is also influenced by the style of Coriolis, at (Figure. 2d) indicating when the EMT movement turns towards the right direction from its wind as the North Maluku Sea includes the northern hemisphere [22]. EMT will then form an Ekman spiral from the base of the waters towards the surface so that it can cause seawater in the surface layer to move away from the beach because the wind is going to cause a mass void of water on the side of the beach and formed a pressure gradient so that the high water face at the side of the beach is lower than the water.

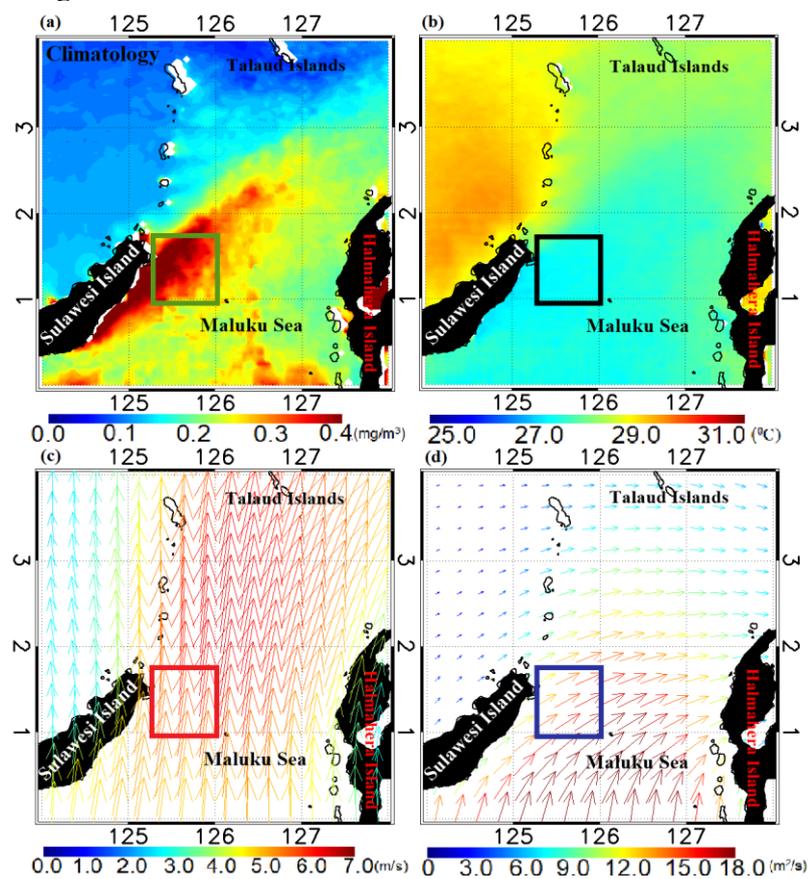


Figure 2. Spatial distribution of (a) chlorophyll-a concentrations, (b) SST, (c) Sea-level wind vectors, (d) vector Ekman Transport (EMT) in August is climatological from 2006 – 2018 in the Maluku Sea for 13 years (2006-2018)

Coastal upwelling events in the North Maluku Sea, in the graph and distribution of spatial decreased SST and an increase in the same concentration of chlorophyll in August (Figure. 1), the occurrence of indirect chlorophyll-A in the peak of upwelling in August, but gradually increased from the previous month. The coastal upwelling phenomenon is related to the water turbidity since material from the deeper layers of water containing nutrients will be carried away by an Ekman spiral to the sea. Where based on research [23], increased water turbidity due to the upwelling phenomenon will increase the

amount of subglacial sediment where one of them can increase chlorophyll-a concentration in a water, thus making the Northern Maluku sea region rich in nutrients and causing muddiness as in the spatial spread when the chlorophyll-a concentration is increased. When an increase in chlorophyll-a at sea level, the phytoplankton will begin to actively consume biogenesis so that the high primary productivity value can increase the food chain level [24].

The chlorophyll-a distribution is influenced by Ekman's transport activities who making turbidity levels in the region well distributed. Ekman phenomenon can cause a cool water mass transport, so the area is in the same position as the region by having a high EMT because of the Ekman transport. The cool water mass moves along the coast following the slope of the Maluku sea towards the surface. These can cause raise upwelling on the coast of North Sulawesi Island moving towards the offshore. Mass EMT will be higher when the process of lifting seawater mass in the inner layer because it transports organic material from the seabed to the surface of the water.

3.2. Relations of Climate Variability (ENSO) and Upwelling

The ENSO climate variability can be known based on the ONI (Ocean Niño Index) index value. Figure 3b is a chart of the time series for the climate variability of the ENSO (shown in blue) over 13 years (2006 – 2018). In an ONI index which is worth more (+) 0.5°C is classified as El Niño condition, then if an ONI index is worth less (-) 0.5°C then is classified as La Niña condition and if its between (-) 0.5°C and (+) 0.5°C its considered normal condition. Hovmoller Diagram (Figure. 3) shows inter-annual temporal variability of chlorophyll-a and SST linked to the ONI index (NIÑO3.4) on the north coast of Sulawesi Island with the same longitude ($125.56249^{\circ}\text{E}$) and Latitude of $1.0208^{\circ}\text{N} - 1.7708^{\circ}\text{N}$.

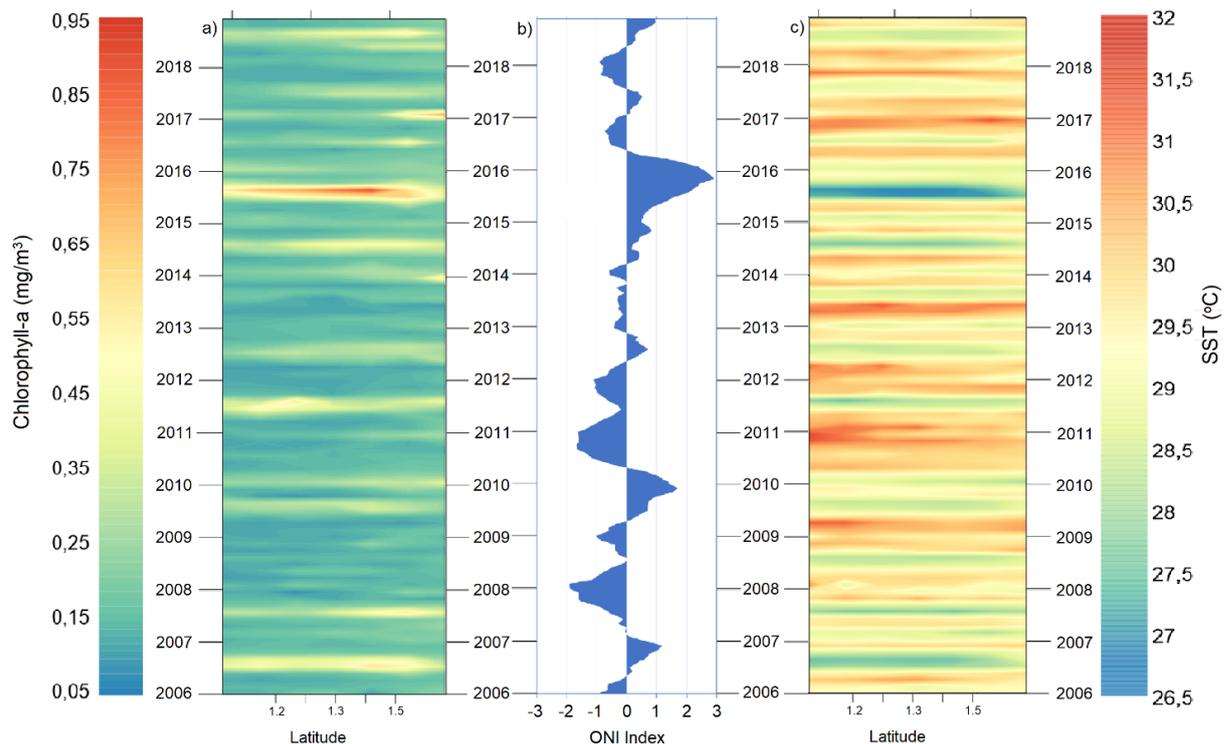


Figure 3. Temporal variability of (a) chlorophyll-a and (c) SST along the northern coastline of northern Sulawesi Island ($125.56249^{\circ}\text{E}$; $1.0208^{\circ}\text{N} - 1.7708^{\circ}\text{N}$) with (b) an ONI index

The image shows the high and low of chlorophyll-A and SST due to ENSO climate variation. The highest chlorophyll-a concentration is in the year 2015 with a value of around 0.9 mg/m^3 which is influenced by the El Niño event and annually the chlorophyll-a concentration has varying values each time due to climate and monsoon. While the lowest value of chlorophyll-a concentration has approximately less than 0.05 mg/m^3 . The interannual variation of the SST has varying numbers, the lowest of the SST, which is about less than 26.8°C which is in 2015, while the highest SST in the year 2011 with a value of more than 31.8°C .

Anomaly conditions occur due to the increase and decrease in the value of SST more or less than the normal limit due to the influence of climate variability in three conditions El Niño, La Niña, and normal. The ENSO affects the magnitude of a region and does not change from its affected location [4]. Chlorophyll-a anomalies occurring in August have a positive effect on ENSO (dominant when El Niño conditions) have a positive value of up to (+) 0.3 mg/m³ (Figure. 4e) indicating an increase of the chlorophyll-a concentration which is evenly distributed throughout the Maluku sea, SST anomaly values when El Niño (Figure. 4f) has a negative value that indicates that there is a decrease in SST from its normal state to be cooler. The state of the wind speed anomaly has a higher anomaly value (Figure. 4g) than in normal conditions, the condition is known from the direction of the vector wind that moves like the normal direction and the wind vector shape is longer than during the condition of La Niña. Then the EMT value anomalies also increase where is higher and spread wider than normal conditions with a longer vector shape than when La Niña conditions so that upwelling will be strengthened when El Niño conditions (Figure. 4h).

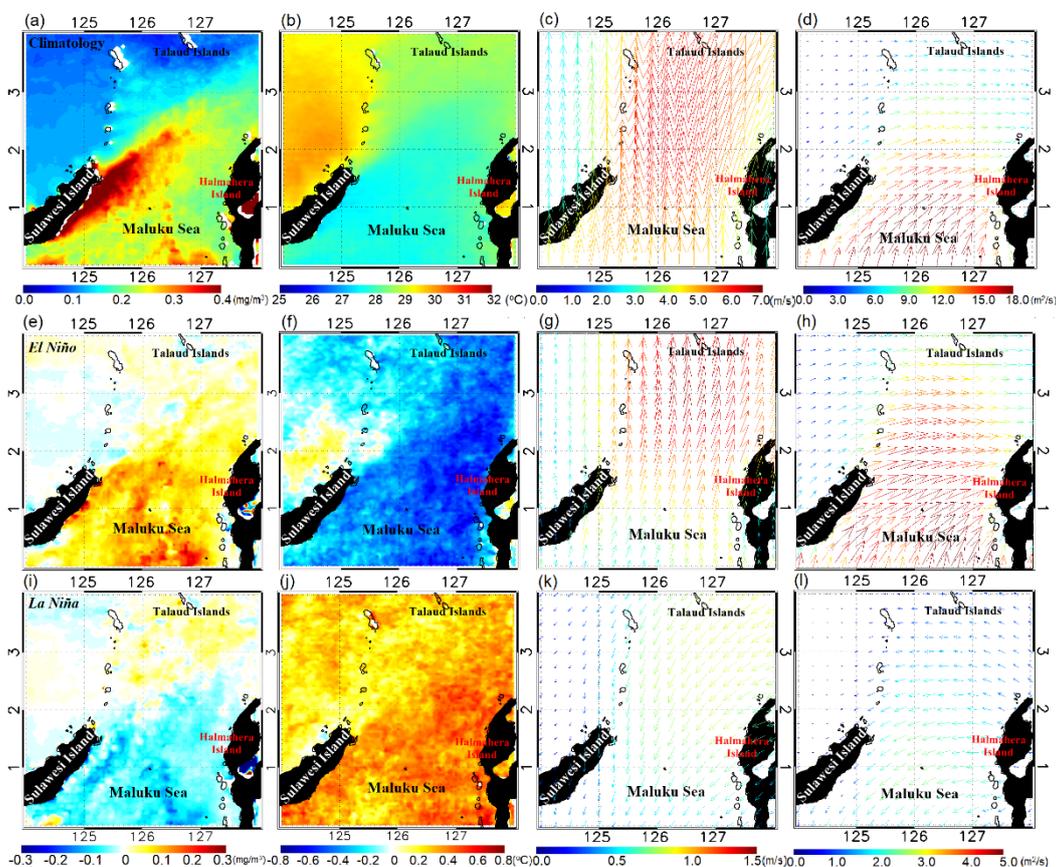


Figure 4. Spatial distribution of (a) chlorophyll-a concentrations, (b) SST, (c) wind vectors, and (d) vector Ekman Transport (EMT) in August is climatological from 2006 – 2018. (e)-(h) and (i)-(l) are anomaly states of concentrations of chlorophyll-a, SST, sea-surface wind vectors, and EMT vectors for El Niño Event and La Niña Event.

The ENSO influence has a negative anomaly to the chlorophyll-a concentration when the La Niña condition where the value will be lower than at normal (Figure. 4i). Then the anomaly distribution has a different spread, which the lower chlorophyll-a value in the southern sea of Maluku up to (-) 0.1 mg/m³, the area that has low anomaly due to the weakening of the wind velocity in the Maluku sea, so that when a low wind speed around the Talaud islands chlorophyll-a has a different anomaly value. When the wind speeds are low around Talaud-a islands, The Island will have a low Ekman transport and cause the chlorophyll value is lower than the surrounding area (Figure. 4l). The anomaly value of the high SST indicates that when the condition of La Niña SST at the sea level Maluku warmer (Figure.

4j) from normal conditions throughout the sea surface of the Maluku as a result of the weakening of the value of the wind speed seen from the condition of spatial is the direction of the wind vector in the opposite direction with normal conditions (Figure. 4k) and it is vector length The decreasing wind speed value makes the EMT power also decreases, as a result, the EMT vector will reverse direction from the normal direction and has a vector length also smaller and shorter so that the upwelling potential will be lower when the condition is La Niña (Figure. 4l).

4. Conclusion

The upwelling value in the North Maluku Sea in August has the positive effect which an increase in upwelling in the El Niño conditions where the chlorophyll concentration had a positive anomaly value of (+) 0.3 mg/m^3 , the negative SST anomaly value of (-) 0.7°C , positive wind anomaly (+) 1.5 m/s and positive EMT anomaly value of (+) 5 m^2 . While the negative influence of ENSO resulted in the decrease of upwelling intensity in the La Niña condition, where the chlorophyll-a concentration had a negative anomaly of (-) 0.1 mg/m^3 , positive SST anomaly value of (+) 0.6°C , positive wind anomaly value (+) 0.8 m/s and positive EMT anomaly value of (+) 2 m^2 .

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