Influence of El Niño Southern Oscillation (ENSO) phenomena on Eddies Variability in the Western Pacific Ocean

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Abstract. Sea Surface Height (SSH), seawater temperature, and ocean currents are an important oceanographic variables that were used to identify the ocean eddies variability. This research aims to investigate the influence of ENSO on eddies variability in Western Pacific Ocean (WPO), by using the Automated Eddy Detection (AED). The results showed that cyclonic eddies are mostly formed in WPO from a total of 2024 eddies. Eddies total increases within the amount of the sea’s depth, at 200 m has the highest of eddy total. The temperature in eddy center mostly started changing at a depth of 150 m, which is at the cyclonic eddy has a lower value and at anticyclonic has a higher value. That has the large effect of changes SSH. During El Nino, sea level anomaly decreases down to -0.3 m, while sea level anomaly minimum decrease down to -0.1 m during La Niña. At the WPO, Mindanao Eddies formed along the year, whereas Halmahera Eddies were weakened in West Season. A periodic ENSO affects eddies variability, in general, the diameter, total and temperature center of eddies are smaller during El Niño, and greater during La Niña than normal condition.

1. Introduction
Western Pacific Ocean (WPO) in the last few decades has been a center for the attention of researchers meteorology and oceanography, because the waters had a very important role to incident El Niño and Southern Oscillation (ENSO) and is part the importance of “Great Conveyor Belt”. The eddies and low-latitude western boundary currents (WBC) addressed here are important aspects of these processes [1].

In Equator WPO between Mindanao and New Guinea there are two eddies [2], Mindanao Eddy (ME) and Halmahera Eddy (HE). The ME is a clockwise (or cyclone) eddy, while the HE is clockwise (or anticyclonic) eddy. In Northem hemisphere there are warm-core eddy and cold-core eddy. Warm-core eddy rotates clockwise or known as a anticyclonic eddy, while the cold-core eddy rotates counterclockwise or known as cyclonic eddy [put references]. The cyclonic eddy can drive upwelling in their interior and increasing marine primary production [3]. Ocean eddy can move at speeds of about 0.5 knots and may occasionally persist for many month [4]. Spatial distribution of eddy varies with the size. All eddies are categorized into two groups according to their size: a sub-mesoscale eddy is about 10-100 km, and a mesoscale eddy can reach more then 50-200 km [5].

El Nino Southern Oscillation (ENSO ) is ocean-atmosphere phenomenon in equatorial Pacific Ocean that influences climate variability over Indonesia region, as well as regional and global influences. ENSO phenomenon consists of two events as El Nino and La Nina. The ENSO events can be identified.
from an index of Southern Oscillation Index (SOI) [6]. ENSO phenomenon affects some of Indonesia's eastern waters, where the region is also affected by the Indian Ocean Dipole (IOD). These two phenomena can further influence ocean dynamics such as eddies currents in these waters [7].

Research on eddy variability in the WPO has been conducted by several researchers [8-13]. However, this study focused to investigate the variability of eddy current during normal year and ENSO year, using the Automated Eddy Detection (AED) developed by Nencioli et al. (2010) to analyze and identify vertical structures and eddies characteristics.

2. Methods

2.1. Study area

Study area is located in the WPO with coordinate 3° S – 10° N and 125° E– 140° E (figure 1). Data processing was carried out in Marine and Coastal Data Laboratory, Marine Research Center, Indonesian Ministry of Marine Affairs, and in Marine Research Laboratory (MEAL), Faculty of Fisheries and Marine Science, Padjadjaran University.

![Figure 1. Study Area in Western Pacific Ocean and the point of ME and HE [8,9,10].](image)

2.2. Material and method

The parameter that used to identify the eddy characteristic research are shown in table 1. The parameter distributions separated at 0 m, 75 m, 150 m, and 200 m. In detection the existence of eddy was using the Automated Eddy Detection algorithm which developed by Nencioli et al. (2010) [14]. The method is based on some of the features that characterize the velocity field associated with mesoscale eddies, such as minimum velocities in the proximity of the eddy center, and tangential velocities that increase approximately linearly with distance from the center before reaching a maximum value and then decaying [15]. This method was used by Tussadiah 2015 [16] showed the eddy vertical characteristic in Southern Java Indian Ocean. Geostrophic Current data is used for AED method with software Matlab 2013b, then to strengthen the analysis eddy visualization was overlaid with SSH and temperature to obtained eddy characteristic.
Table 1. Research materials.

| No  | Dataset             | Data Resolution | Source          |
|-----|---------------------|-----------------|-----------------|
| 1.  | Geostrophic Current | 8.8 km          | INDESO, HYCOM   |
| 2.  | Sea Surface Height  | 8.8 km          | INDESO, HYCOM   |
| 3.  | Temperature         | 8.8 km          | INDESO, HYCOM   |
| 4.  | SOI                 | -               | BOM             |

To know the condition of El Nino and La Nina, we used SOI from BOM. If the value of index greater than +7, then the condition is indicated La Nina year, but if index values smaller than -7 then indicated El Nino year. The period of time which indicated of ENSO phenomenon was used to compared the influence ENSO on Eddies Variability[17].

3. Results and discussion

3.1. Eddies variability

From the automated eddy detection analysis at four vertical levels (0 m, 75 m, 150 m, 200 m), it is shown that the number of eddies that have been detected in 2011 and between 2014-2016 were 2,024 eddies. Those are 1,119 cyclonic eddies and 892 anticyclonic eddies. Mostly the eddies formation increases at 200 m depth, which may be associated with differences of generating eddy vertically like wind stress, Kelvin and Rossby waves, topography, and baroclinic instability[18]. It is found eddies that can survive from depth 0 m to 200 m, but there is also a new eddy formed within the depth of 150-200 m. At the surface to bottom eddy has a variety diameter, dominated with the submesoscale eddy (30-500 km). The appearance of submesoscale, mesoscale and big eddy maybe come from drifter aggregation, maintained by converging Ekman currents and Coriolis force [18] and [19].

Eddies formation in October 2015, represented El Nino year (figure 1: right), shows 39 total eddies found at four depths, which are 23 cyclonic eddies and 16 anticyclonic eddies with variation of diameter ranges between 20-220 km. Based on the results of the eddies pattern in April 2011 which represents the La Niña event, it is known that the total of eddy cyclonic is 24 eddy, while the total eddy anticyclone type is 20 eddy, with varying diameters ranging from 30 - 450 km. In this month, it can be seen that Halmahera Eddy is formed at a depth of 75 m to a depth of 200 m.

In this month, it can be seen that Mindanao Eddy is only formed at a depth of 75 m and 200 m with a central point at 130-132 °E and 3.5 °N, while Halmahera Eddy is formed on four depth layers at 0 m, 75 m, 150 M and 200 m with the center point at 128.5 °E and 7.5 °N. The pattern of eddies formation will increases with the depth and when El Nino with total 39 eddies, but diameter of eddies become smaller. At normal eddy diameter measuring 30 - 300 km, while the occurrence of el nino phenomenon eddy diameter tends to decrease to 20-200 km. It may be caused at El Nino intensity, Mindanao currents as the caused of the formed of Eddy Mindanao weakened, otherwise North Equatorial Counter Current getting stronger marked with the movement of the warmpool of western Pacific to the eastern Pacific Ocean. Caused weakening of the wind moving toward the west in waters tropical Pacific.

During El Nino, showed that SSH decreased than normal with value ranges of 0.3-0.6 m. When cyclonic eddy formed at the coordinates of 130 °E and 7.5 °N has a lower value at eddy center of 0.3m. While on anticyclonic eddy has a higher value at the eddy center point with value ranges of 0.45 - 0.6 m. It shows that in the event of El Nino conditions in the Pacific Ocean sea surface height western part is lower than it would be in the eastern part of the Indian Ocean. It shows that in the event of El Nino conditions in the Pacific Ocean sea surface height western part is lower than it would be in the eastern part of the Indian Ocean [20].
Figure 2. Eddy visualisation in April 2011 (left) and October 2015 (right). Red (black) circles depict cyclonic (anticyclonic) eddies.

At depth 0 m center anticyclonic eddy has a temperature value of 29.36 °C greater than the temperature value at center cyclonic eddy of 29.30 °C. This showed that at a depth of 0 m starts to show upwelling and downwelling. At depths of 75 m and 150 m in eddy cyclonic type still has lower temperature values than antisyclyones eddy. The temperature value decreased drastically from 75 m to of 150 m, with value of 25.5 °C at a depth of 75 m and 16 °C at a depth of 150 m. It can be said that the
depth of 150 m including the depth of the thermocline layer, because at this depth a drastic temperature drop reaches 7 °C. At depths of 75 m and 150 m it is seen that values at the center point of the cyclonic and anticyclonic eddy type have significant differences ranging from 2-3 °C, this becaused in eddy cyclonic there is a divergence on the surface caused the layer of thermocline in the eddy cyclones is higher, whereas at anticyclonic eddy occurs a surface conyvergence that results in a deeper cyclonic layer of thermocline in eddy deeper.

The results of processing the formation of eddy in April 2011 represented La Nina condition shows that the total eddy at four depths of cyclonic eddy type are 24 eddies, while the total of anticyclonic eddy type are 20 eddy with total eddy formed of 44 Eddy. With variation diameter ranges from 30-450 km. In this month (figure 1: left) it can be seen that Mindanao Eddy is only formed at a depth of 75 m and 200 m with a central point at 130 °E and 5 °N, while Halmahera Eddy is formed on one depth layers at 0 m the center point at 128.5 °E and 7.5 °N. The pattern increases with the depth of the total eddy will tend to increase still occur at the time of La Nina phenomenon and, but during La Nina changed the size of diameter greater than the normal diameter. It maybe caused at El Nino intensity, Mindanao currents as the caused of the formed of Eddy Mindanao strengthenend, otherwise North Equatorial Counter Current getting weakened marked with the movement of the warmpool of eastern Pacific to the western Pacific. Caused strengthened of the wind moving toward the west in waters tropical Pacific.

During La Nina, showed that minimum SSH decreased than normal with value of 0.4 m. When cyclonic eddy formed has a lower with value ranges of 0.4 – 0.6 m. While on antisyliclonic eddy has a higher value at the eddy center point with value ranges of 0.4 - 0.85 m. During La nina phenomenon would be an increase in water mass volume, caused mass of water from the east is getting stronger to move western pacific marked with returned of the warmpool of western Pacific.

At depth 0 m center anticyclonic eddy has a temperature value of 29.97 °C greater than the temperature value at center cyclonic eddy of 29.12 °C. This showed that at a depth of 0 m starts to showed upwelling and downwelling. At depths of 75 m and 150 m in eddy cyclonic type still has lower temperature values than eddy anticyclones. The temperature value decreased drastically from 75 m to of 150 m, with value of 27.5°C at a depth of 75 m and 21.5 °C at a depth of 150 m. It can be said that the depth of 150 m including the depth of the thermocline layer, because at this depth a drastic temperature drop reaches 7°C. At depths of 75 m and 150 m it is seen that values at the center point of the cyclonic and anticyclonic eddy type have significant differences ranging from 3 °C. During La nina conditions has an effect of increasing value temperatures eddy center started at 75 m to 200 m [21].

The correlation value between SOI with total cyclonik and antiksilonik eddy, it is known that the highest correlation value in both types is at depth 0 m (0.31) and 200 m (-0.36). This is assumed caused ENSO phenomenon has a influence to total eddy that formed up to depth 200 m. The correlation value between SOI and the temperature at center cyclonic and anticyclonic eddy is known that the highest correlation value of both types is at 200 m depth in eddy anticyclonic (0.98) and at 75 m depth in eddy cyclonic (0.96). This is presumably because at the time of the ENSO phenomenon has a larger influence on the temperature at center eddy.

4. Conclusion
It can be concluded that ENSO conditions can affect on the eddies characteristics. Number of eddies increases with increase of depth, which has the large effect of SSH changes. The diameter, number of eddies and temperature center of eddies are decrease during El Niño, and increase during La Niña, compared to the normal year. The coefficient correlation between SOI and eddy diameter is high (-0.86), while coefficient correlation between SOI with total eddy is low (-0.36). The highest coefficient correlation is found between SOI and temperature center of eddy (0.98).

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