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DISTRIBUTION AND CHARACTERISTICS OF EDDIES IN INDONESIAN SEAS

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ABSTRACT

Eddies has an influence in the transporting and mixing of water masses which have an important role because it transports chemical elements, dissolved substances, nutrients, small organisms, and heat. Eddies can be observed based on the high intensity of eddies kinetic energy (EKE). The purpose of this study was to determine the distribution and characteristics of eddies in Indonesian seas. The data used is obtained from HYCOM (Hybrid Coordinate Ocean Model) in the form of current data consisting of components u and v with daily datasets from January to December 2016. The study area covers Indonesian waters with coordinates 11ºN – 11ºLS and 91°E – 141.5 °BT, then processed using MATLAB software. Automated Eddies Detection (AED) method for eddies detection. Current data is also calculated to get the EKE value and overlay with eddies detection results. The results showed that the most eddies distribution occurred in the western of Sumatra sea, southern Java sea, and the Indian Ocean with 107 occurrences and the north of Papua to Pacific Ocean with 101 events. The average diameter of the eddies is 90.626 km for cyclonic eddies and 95.834 km for anticyclonic eddies. The highest EKE values occur in the waters north of Papua to Pacific Ocean. Average EKE value at the central point is 395,086 cm^2/s^2 for eddies cyclonic and 444.126 cm^2/s^2 for eddies anticyclonic.

Keywords : Anticyclonic eddies, Cyclonic eddies, EKE, Indonesian Seas

1. INTRODUCTION

Eddies is a circular current that is separate from the main current, this current can form in any ocean with a spatial scale ranging from tens to hundreds of kilometers and a temporal scale ranging from weeks to months. Eddies can be formed due to the presence of two main forces, horizontal pressure gradient and Coriolis force. In addition to these two forces the interaction with topography [1], surface winds [2] and current systems [3]. According to [4] eddies can be observed based on the high intensity of eddies kinetic energy (EKE). EKE circulation system is dominated by geostrophic motion which is formed due to an imbalance of pressure gradient forces and Coriolis forces [5]. In the ocean, EKE can be formed due to wind forces or baroclinic instability [6]. Eddies has an influence in transporting and mixing water masses which has an important role because it transports chemical elements, dissolved substances, nutrients, small organisms, and heat.

Eddies research in Indonesian waters has been carried out by several people. In 2014 eddies were found in the waters south of Java to the Indian Ocean [7]. Eddies has detected in the Java Sea during the transitional season [8]. In the Makassar Strait to the Flores Sea in 2008-2012 52 eddies has found [9]. According [10] found a number of eddies with a time span from 1993-2004 in the Lombok Strait, Flores Strait, South Sulawesi Waters, and West Nusa Tenggara Waters. The influence of the ENSO phenomenon with the emergence of Halmahera Eddies and even Mindanao Eddies [11]. A number of eddies can also be seen in the waters south of the South China Sea to the Malacca Strait [12]. The purpose of this study was to determine the distribution and characteristics of eddies in Indonesian waters.

2. MATERIALS AND METHODS

The data used in this study is secondary data obtained from the HYCOM (Hybrid Coordinate Ocean Model) in the form of current data consisting of components u and v in Indonesian waters with daily datasets from January to December 2016. The study area covers Indonesian waters with coordinates 11ºN – 11ºS and 91°E – 141.5°E. Research and processing is carried out at the Marine Research Center, North Jakarta and the Laboratory of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, University Padjadjaran from March to April 2018. Identification of the presence of eddies is carried out using the Automated Eddies Detection (AED) method and will produces an eddies spatial distribution and statistical data consisting of the position of the eddies center point, eddies frequency, radius, and type of eddies. The current data is also calculated to get the EKE value overlay horizontally with the results of monthly eddies detection which is then searched for the EKE value at the eddies center point. EKE calculation can be done with the following equation [13]:

$$EKE = (U^2 + V^2)$$

Description:
EKE : Eddies Kinetic Energy (cm^2/s^2)
U : Eastward Sea Water Velocity (cm/s)
V : Northward Sea Water Velocity (cm/s)

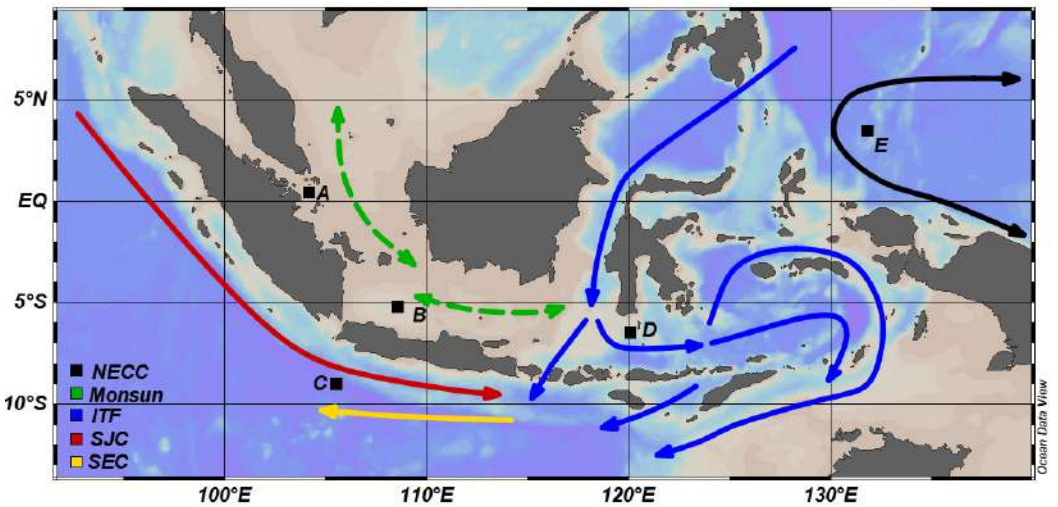

Figure 1. Research Area and Previous Study A= Zhang (2016), B= Ismoyo (2014), C= Pranowo & Tussadiah (2016), D= Kartadikaria dan Nuzula (2012), E= Simanungkalit (2017)

3. RESULTS AND DISCUSSION
3.1. EDDIES DETECTION AND DISTRIBUTION

The eddies detection results that are formed will be marked with red color if it is cyclonic eddies (SE) and black if anticyclonic (AE). The black dot in the middle of the circle is the eddies's center point. Throughout 2016, 578 eddies were formed (302 SE and 276 AE) with diameters ranging from 8.13 to 622.5 km. The most Eddies incidents occurred in December with 61 incidents, while the least occurred in August with 38 incidents. Spatially, eddies are mostly formed in northern waters and southern waters (Figure 2).

In western of Sumatra, southern of Java, to the Indian Ocean, 179 eddies are formed (104 SE and 75 AE). The diameter of the eddies formed varied, ranging from 51.53 to 146.18 km. From January to May, the eddies formed tends to be in the waters south of Java to the south of Flores. This happens because during the west monsoon the ITF is weaker than the JCC (Java Coastal Current) flow in the southern of Java. Java Coastal Current flow during December to March in the southern of Java moves closer to the coast at high speed, while in the western of Sumatra the current flows is weak [7]. From July to August, the eddies formed tends to be closer to the Sumatra island around 2º – 8º South Latitude and 95 – 105 East Longitude. This happens because the influence of the east monsoon on JCC makes the currents of the southern waters of Java move towards the northwest [14].

In the northern of Papua to the Pacific Ocean, 101 eddies were formed (48 SE and 53 AE). The diameter formed is 56.12 – 229.37 km. There are semi-permanent eddies, namely Halmahera Eddies and Mindanao Eddies (2º – 7º North Latitude and 128º – 132º East Longitude). Eddies is most formed in the east monsoon when the currents in these waters are stronger. During the East Transition (June-October) the flow of the NECC and NGCC currents made Halmahera Eddies experience strengthening because the NGCC current was driven by winds moving from southeast to southwest [15].

In the Sulawesi Sea, the Makassar Strait, and the Flores Sea, 69 eddies events were formed (25 SE and 44 AE). There is an eddies cyclonic which is always there every year except in July and December which is an anticyclonic type. In the Makassar Strait there is an eddies anticyclonic which is located close to the islands of Sulawesi and Kalimantan in certain months and does not stay. In the Flores sea, eddies only form in July, September and November. The formation of eddies in these waters is because these waters are the main entry point for the flow of the Indonesian Through Flow (ITF) with a strong mass of water. On the north and south sides of the ITF main current axis in Sulawesi waters, recirculation of currents can be formed that moves clockwise (clockwise) and anti-clockwise (anti-clockwise) [16].

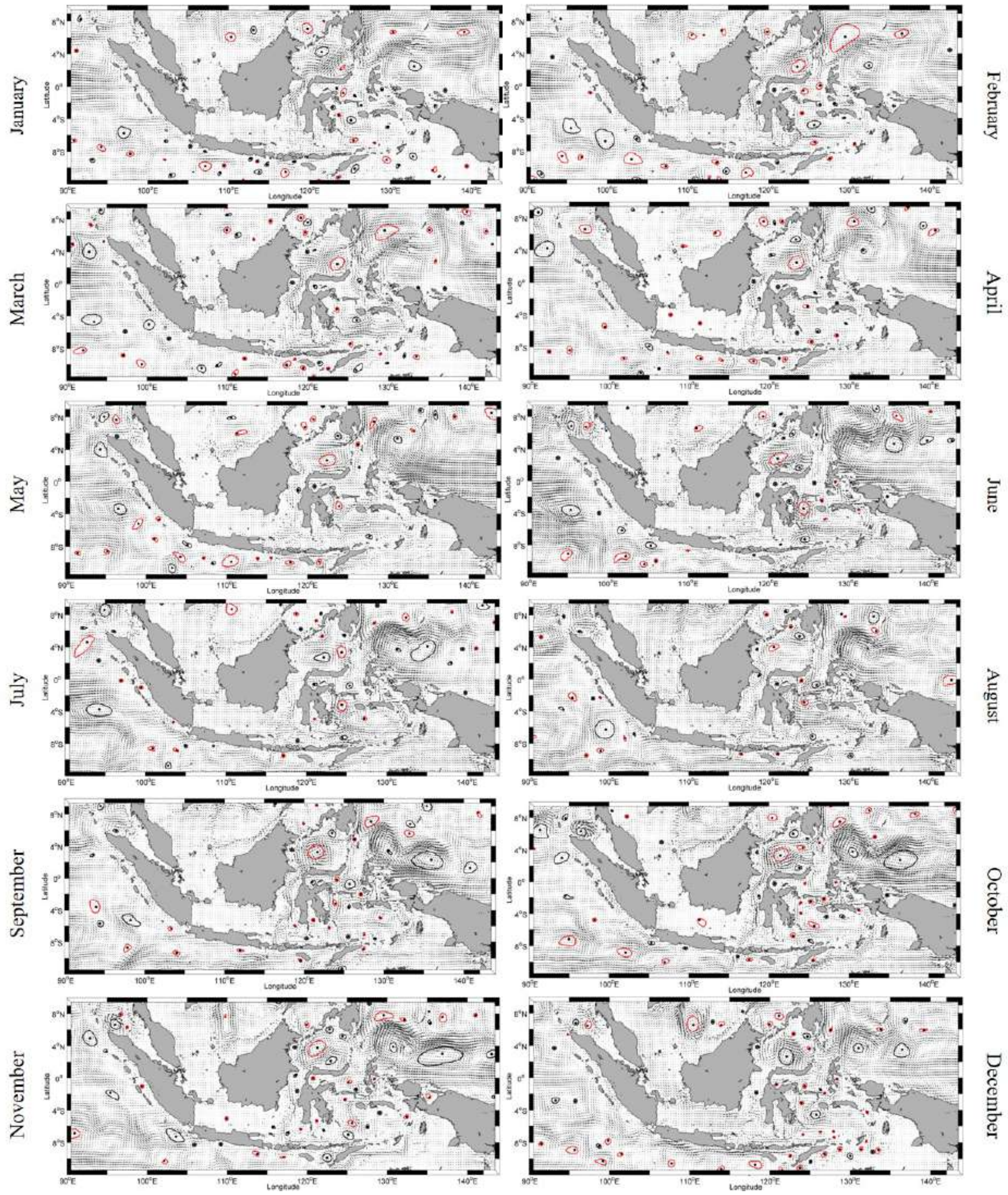

Figure 2. Distribution of Eddies in January – December 2016 in Indonesia Seas

In the Banda Sea, Maluku Sea, Halmahera Sea, and Seram Sea, 104 eddies events were formed (55 SE and 49 AE). The eddies formed in these waters are scattered throughout the year with varying numbers, diameters and locations. Eddies cyclonic formations are seen throughout the year around the east of Sulawesi around 4º South Latitude and 125 East Longitude and in Tomini Bay 1º South Latitude and 123 East Longitude with an anticyclonic type. The formation of eddies in these waters is because these waters are also the entrance for ITF which passes through the Maluku Sea and Halmahera Sea to the Banda Sea and meets the topography of the islands around these waters. In the Arafura Sea, Timor Sea, and Sawu Sea, 38 eddies events were formed (21 SE and 17 AE). December is the month with the most eddies formed. In these waters there is no eddies formed with the same location. Eddies in these waters is caused by the confluence of ITF, which originates from the Banda Sea and which passes south of Papua through the Timor Sea and the Arafura Sea. Currents in the waters of Arafura and Timor experience a lot of current rotation both counterclockwise (anticyclonic) and clockwise (cyclonic). The presence of a meeting between ITF water masses brought from the Seram Sea and Banda Sea also causes turbulence to form counterclockwise recirculation [17].

In the Java Sea, only 4 eddies cyclonic eddies are formed with diameters ranging from 53.38 to 123.76 km. Eddies formed occurs in April, October, and November. Eddies in the Java Sea can occur in transitional seasons and is strongly influenced by sea level anomalies and wind speed. In the non-transitional season (west monsoon and east monsoon) eddies are not formed in the Java Sea due to the constant wind direction. In the South China Sea to the Karimata Strait, 34 eddies events were formed (20 SE and 14 AE). Throughout the year in these seas eddies are formed except in August with different diameters and locations. The eddies formed is around 4º – 8º North Latitude and 108 – 115º East Longitude. In the Sulu Sea eddies also formed as many as 27 events (18 SE and 9 AE). In general, eddies are formed in the South China Sea and the Sulu Sea due to the influence of the mass flow of water originating from the Pacific Ocean that passes through the South China Sea and can also turn into the Sulu Sea and finally to the Sulawesi Sea. In the Andaman Sea to the Malacca Strait, 22 eddies events were formed (7 SE and 15 AE). In general, the eddies formed in these waters have an anticyclonic type from February to December, except in April only cyclonic eddies are formed. The formation of eddies in these waters is due to the influence of monsoon currents and northern equatorial currents that enter the Malacca Strait.

3.2. EDDIES KINETIC ENERGY CHARACTERISTICS

In general, Eddies Kinetic Energy (EKE) in Indonesian waters in 2016 had a high value in waters with strong currents such as northern waters and southern waters (Figure 3). High EKE values will be marked in dark purple and low EKE values will be indicated in light blue. A high EKE value can indicate an eddies event, but a low value does not mean there is no the eddies incident because there are other factors in the formation of the eddies. The EKE value will be higher in the main stream compared to the eddies center point. The average EKE value at the eddies center in a year is 395.08 cm^2/s^2 (SE) and 444.12 cm^2/s^2 (AE).

The EKE value in the waters north of Papua to the Pacific Ocean throughout the year has a range of 500 – 5000 cm^2/s^2. It can be seen that the high EKE values in these waters are at 2º – 8º North Latitude and 126º – 132º East Longitude and 0º – 2º North Latitude and 130º – 145º East Longitude during the transitional seasons. This area is the main water mass flow path that flows throughout the year in the northern waters of Papua to the Pacific Ocean. The water mass flows are the North Equatorial Current (NEC) and South Equatorial Current (SEC), the NEC water mass moves southward into the Mindanao current while the SEC water mass is carried by the New Guinea Coastal Current (NGCC). The high EKE value results in a large number of eddies being formed in these waters. The average EKE values at the center of the eddies are 455.93 cm^2/s^2 (SE) and 508.03 cm^2/s^2 (AE).

The Sulawesi Sea, Makassar Strait, and Flores Sea have EKE values in the range of 500 – 5000 cm^2/s^2. It can be seen that the high EKE value was more dominant in the Sulawesi Sea throughout 2016. In the Makassar Strait, the high EKE value occurred in January – April and weakened in May – August. Meanwhile, in the Flores Sea, the EKE value tends to have a value that is not too high. The Sulawesi Sea and the Makassar Strait have high EKE values because these waters are the main entry points for Indonesian through flow (ITF). According to [18], the main current in the Sulawesi Sea dominantly carries water masses into the Makassar Strait. The main current is a branch of the strong Mindanao current which is the base of ITF which has a major influence on water mass transportation in the Sulawesi Sea. The high EKE value in these waters causes frequent eddies formations with the highest EKE center point value. The average EKE value at the center of the eddies is 613.80 cm^2/s^2 (SE) and 613.06 cm^2/s^2 (AE).

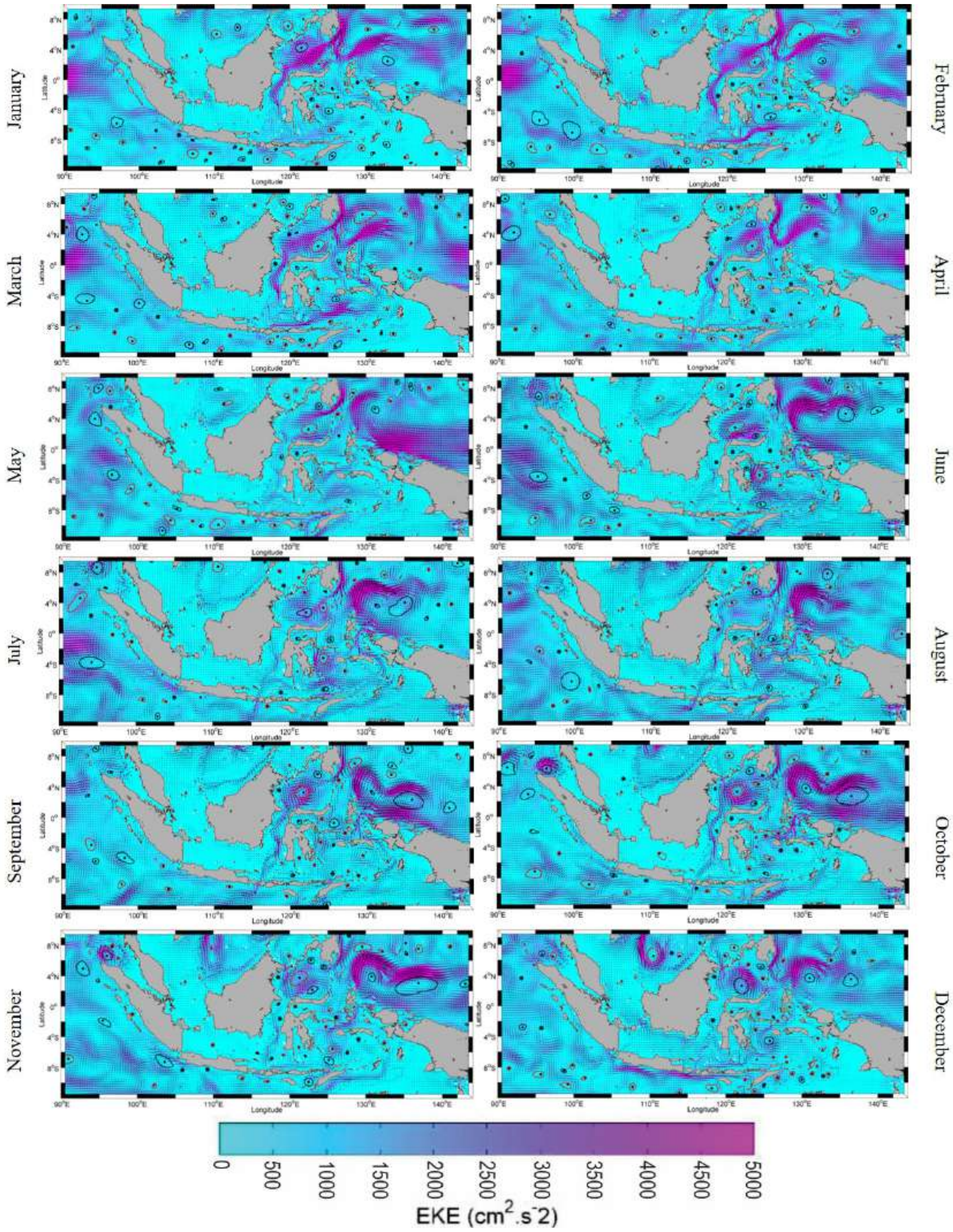

Figure 3. Distribution of Eddies Kinetic Energy in January – December 2016 in Indonesian Seas

The Banda Sea, Maluku Sea, Halmahera Sea, and Seram Sea have EKE values in the range of 500 – 4500 cm ^{2}/s ^{2}. Seen in the Banda Sea in February – March the high EKE values are at 6º – 8º South Latitude and 118º – 130º East Longitude, in June – August around the eddies cyclonic 4º South Latitude and 127 East Longitude. The high EKE value in the Banda Sea is because the Banda Sea is the waters where the ITF water mass meets the Celebes sea entrance and the Maluku sea entrance. Meanwhile, the Halmahera Sea tends to have a high EKE value and the peak occurs in October. This happens because there is a mass movement of water from the South Pacific carried by the New Guinea Coastal Current (NGCC) directly into the Halmahera Sea. The average EKE value at the center of the eddies is 414.56 cm ^{2}/s ^{2} cm ^{2}/s ^{2} (SE) and 366.10 cm ^{2}/s ^{2} (AE). In the Arafura Sea and Timor Sea, the EKE values are in the range of 500 – 3500 cm ^{2}/s $^{2.}$ In general, the surface geostrophic currents in the Arafura Sea move southwest to the Timor Sea and west to the Banda Sea. In the Timor Sea, the current moves southwest towards the Indian Ocean. While the current does not have a strong EKE value. The average EKE value at the center of the eddies is 412.82 cm^2/s^2 (SE) and 311.19 cm^2/s^2 (AE).

In the waters of West Sumatra, South Java, to the Indian Ocean, the EKE values are in the range of 500 – 3500 cm^2/s^2. High EKE values are at 0º – 2º North Latitude and 90º – 95º East Longitude in January – March, then shift towards 0º – 2º South Latitude in June – July. High EKE values can also be seen in the Java Coastal Current (JCC) at 2º – 8º South Latitude and 90º – 110º East Longitude in January – February, as well as at 8 South Latitude and 105º – 120º or south of Java to Sumba in December. This is because when the west season the JCC flows strongly as in the statement by [19] that the JCC reaches its peak around January–February when the winds that change direction periodically (monsoon) northwest in the south of Java–Sumbawa reach their peak. The average EKE values at the center of the eddies are 336.81 cm^2/s^2 (SE) and 410.63 cm^2/s^2 (AE).

In the Andaman Sea to the Malacca Strait, the EKE values are in the range of 500 – 3500 cm^2/s^2. High EKE values occur in October and November around the eddies which occurs at 7º – 8º North Latitude and 95 – 97º East Longitude. While the average value of EKE at the eddies center point is 570.98 cm^2/s^2 (SE) and 638.28 cm^2/s^2 (AE). In the South China Sea, the EKE values are in the range of 500 – 3500 cm^2/s^2. In these waters, high EKE values can only be seen from October to December around the eddies formed at 6º – 10º North Latitude and 110º East Longitude. The average EKE values at the center of the eddies are 348.37 cm^2/s^2 (SE) and 319.91 cm^2/s^2 (AE). In Sulu, EKE values tend to be low in the range of 500 – 2000 cm^2/s^2. The eddies formed in these waters have a fairly low EKE value in the main current. While the average value of EKE at the eddies center is 202.06 cm^2/s^2 (SE) and 244.22 cm^2/s^2 (AE).

The Java Sea has a very low EKE value with a range of 0 – 500 $cm^2/s^{2.}$ While the average EKE value at the eddies center point is 40.94 cm^2/s^2 (SE). The low EKE value is because in these waters it is only influenced by the Indonesian monsoon current (Armondo) while the Armondo is a current that is not so strong compared to other currents in Indonesian waters.

4. CONCLUSION

Based on the results of the research that has been carried out, it can be concluded that the distribution of eddies mostly occurs in the western waters of Sumatra, southern Java, to the Indian Ocean with 107 occurrences and the northern waters of Papua to the Pacific Ocean with 101 events. The average eddies diameter is 90.626 km for eddies cyclonic and 95.834 km anticyclonic eddies. The highest EKE values occur in the waters north of Papua to the Pacific Ocean and the average EKE value at the central point is 395,086 cm^2/s^2 for eddies cyclonics and 444.126 for eddies anticyclonics.

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