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Eddy Vertical Structure in Southern Java Indian Ocean: Identification using Automated Eddies Detection

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Abstract: ***The eddy characteristic in Southern Java Indian Ocean has been investigated and discussed, but spesifically deals about the vertical structure of eddy is still not much. This research was conducted to determine the eddy vertical characteristic and to find out the biggest value of kinematic energy between the cyclonic and anticyclonic eddy. The data set was from NEMO model with parameter are current and temperature from 2014. By using an automated eddy detection the veertical eddies characteristic was set developed, it includes the statistical data of each eddy location, radius, kinematic energy, temperature, and SSH at four vertical levels. The results indicated that cyclonic eddy is mostly formed in Southern Java Indian Ocean in 2014. The temperature in eddy center mostly started changing at a depth of 109 m, which is at the cyclonic eddy has a lower value and at anticyclonic has a higher value.***

Keywords: Eddies, vertical structure, cyclonic eddy, anticyclonic eddy, kinematic energy**.**

1. Introduction

Indian Ocean waters has a unique and complex properties dynamics because the water system were affected by monsoon and trade wind system, unlike the Pacific Ocean and the Atlantic are only influenced by the trade wind system. In these waters there are several oceanography phenomena which have an important influence not only for oceanography but also for the atmosphere, such as Indian Ocean Dipole (IOD), upwelling, South Equatorial Current (SEC), South Java Current (SJC) and eddy [1].

An eddy is a loop of current that is cut off from the main current, or a small, spinning current. Ocean eddy can move at speeds of about 0.5 knots and may occasionally persist for many month [2]. Spatial distribution of eddy varies with the size. All eddy are categorized into two groups according to their size: a submesoscale eddy is about 10-100 km, and a mesoscale eddy can reach more then 50-200 km [3]. There are warm-core eddy and cold-core eddy. In southern hemisphere cold-core eddy rotate clockwise or known as a cyclonic eddy, while the warm-core eddy rotate counterclockwise or known as anticyclonic eddy. The cyclonic eddy can drive upwelling in their interior and increasing primary production [4].

Eddy are important because they have so much kinetic energy, and because they can transport momentum and trace water properties. They have deep „roots" that often reach 5 km or more downward, carrying energy and momentum to the seafloor. They are responsible for the irreversible mixing of waters with different properties. They may owe their existence to several sources other than meandering of strong currents: for example, direct generation by winds or cooling at the sea surface; flow over a rough seafloor or past islands and coastal promentories; or generation by mixing or waves of smaller scale [5].

Most of the former eddy studies in Southern Java Indian Ocean are focused on the surface and little is known about the vertical structures of eddies in the region. The first research about eddy in Southern Java was by Creswell and Golding in 1977 using drifter trajectories [2]. In this paper, we used a automated eddy detection developed by Nencioli et al. (2010) to analyze and identify the vertical eddy structures and characteristics.

2. Methodology

The study region extend from Southern Java Indian Ocean (0^o – 20^oS and 90^o - 120^oE). The data set was from NEMO Model from INDESO website (www.indeso.com). This model is forced at the surface using 3-hourly ECWMF atmospheric analysis and forecast fields and at the lateral open boundaries using Mercator Océan global operational analysis and forecast fields.

2.1 Ocean Model Data

The ocean model used by INDESO is a "regional" version of the OPA/NEMO global ocean circulation model. This regional model was developed by France (MERCATOR OCEAN) and is now used to simulate very accurately (at high resolution) ocean circulation around the world. The parameter that used to identify the eddy characteristic are vertical current (U and V component) and temperature with the resolution 0.08^{o} and daily composite data from 2014. It is distributions at four vertical level (5 m, 109 m, 155 m, and 222 m).

2.2 Eddy Kinetic Energy

To get the value of eddy kinetic energy, it is computed from velocity components using the classical relation:

$$EKE = \frac{1}{2} (U^2 + V^2) \quad (6)$$

Where:

EKE = Eddy kinetic energy
U = u current vector / zonal (cm/s)
V = v current vector / meridional (cm/s)

2.3 Automated Eddy Detection Scheme

In detection the existence of eddy was using the automated eddy detection algorithm which developed by Nencioli et al. (2010). The method can be applied to any velocity field. It has been applied to eddy detection in Hawaiian Islands wake by Dong et al. (2009). 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 [7]. Four constraints were derived in conformance with the eddy velocity field definition and characteristics described above. Eddy centers are determined at the points where all of the constraints are satisfied. The four constraints follow: [8]

(i) along an east–west (EW) section, meridional velocity (v) has to reverse in sign across the eddy center and its magnitude has to increase away from it,
(ii) along a north–south (NS) section, zonal celocity (u) has to reverse in sign across the eddy center and its magnitude has to increase away from it: the sense of rotation has to be the same as for v,
(iii) velocity magnitude has a local minimum at the eddy center, and
(iv) around the eddy center, the directions of the velocity vectors have to change with a constant sense of rotation and the directions of two neighboring velocity vectors have to lay within the same or two adjacent quadrants.

3. Results and Discussion

3.1 Eddy Frequency

With the application of automated eddy detection at four vertical levels, the occurence of eddy shows significant seasonal variation. The maximum total of cyclonic eddy occur in January – March and July – September, while the anticyclonic eddy in April – June and July – September. The formation of cyclonic eddy dominated in the Southern Java Indian Ocean during 2014, with total of cyclonic eddy are 1096 and anticyclonic are 1033. Mostly the formation of eddy increasing at 109 m – 222 m. The increasing of eddy at 109 m – 222 m maybe come from the differences of generating eddy vertically like wind stress, kelvin and rosby waves, topography, and baroclinic instability [9].

Figure 1 shows the formation eddy at four vertical levels during September 2014, which red (black) circle depict cyclonic (anticyclonic) eddy. A 186 total of eddy were identified during this month, with 98 were cyclonic eddy and 88 were anticyclonic eddy. Increasing of cyclonic eddy in September 2014 maybe caused by the instability of Indonesian Thorughflow (ITF) that reach maximum flow during Southeast Monsoon. Because of the high intensity of ITF, the formation of eddy driven into South Indian Ocean (14^{o} – 20^{o}S). At the surface eddy has a variety diameter, along 16^{o} – 20^{o}S dominated with the submesoscale eddy (50 – 100 km). The appearance of submesoscale eddy maybe come from drifter aggregation, maintained by converging ekman currents [10], [11]. At 109 m – 222 m eddy formation spread well in Southern Java Indian Ocean and mostly dominated by mesoscale eddy (80 – 200 km) and the larger eddy mostly formed in SEC pathways. There are several eddy that can formed well from surface to 222 m. Example an anticyclonic eddy with coordinate at 113.7^{o}E and 14.4^{o}S can reach to 222 m, this eddy have a variety diameter vertically. At surface the diameter is 241 km, while in 222 m is 291 km. This eddy also called as cone-shaped (an eddy has the largest size at the bottom).

During November and December 2014 the cyclonic and anticyclonic eddy fomation decreasing vertically. At the surface has a lower of total cyclonic and anticyclonic eddy. Decreasing of the eddy formation during November – December maybe affected by the lack of ITF flow. Furthermore during March 2014 the total cyclonic eddy has decreasing while the total anticyclonic eddy has increasing. Decreasing of cyclonic eddy maybe affected by the lack of SJC flow from Southwest Sumatra, while increasing of anticyclonic eddy maybe affected by other phenomenon occur in Indian Ocean such as kelvin wave. Kelvin waves leading to a shallower thermocline with lower sea surface height in the east Indian Ocean [12].

3.2 Temperature at Eddy

The temperature characteristic at eddy center shows at the cyclonic eddy has a lower value than anticylonic and its surrounding water. In the surface was covered with homogeneous warm water (28 – 30^{o}C). At surface (5 m) the existence of cold-core eddy (cyclonic eddy) and warm-core eddy (anticyclonic eddy) was invisible. It maybe caused by the time lag about 10 days between the increase of eddy from the bottom layer to the upper layer [13]. The temperature in the eddy center gradually decreased at 109 m and start fading at 222 m, so that in cyclonic eddy shows the existence of upwelling while anticyclonic eddy shows the existence of downwelling. Mean temperature at cyclonic eddy at 109 m was about 19.41^{o}C while at anticyclonic eddy was about 20.88^{o}C, and at 222 m the mean temperature has not significant difference which at cyclonic eddy was about 14.98^{o}C and at anticyclonic eddy was about 15.88^{o}C.

In September 2014 was a strongest intesity of temperature at eddy center, which at cyclonic eddy has a lower temperature than the other months. In the cyclonic eddy at 109 m the temperature was about 11.9^{o}C and in anticyclonic eddy the temperature was about 13.2^{o}C. Its indicated in September the upwelling generated by the cyclonic eddy has a maximum phase. And this upwelling can be seen up to 222 m, which the temperature at cyclonic eddy in 222 m was about 14.14°C while at anticyclonic was about 16.61°C. Furthermore, strong intensity during September maybe caused by the intense of upwelling phenomenon occur in Southern Java Water during Southeast Monsoon, also maybe caused by the ENSO. During El Nino events, sea surface temperature showed lower (24-27°C) occured in the coastal to offshore regions of the Eastern Indian Ocean off Java, and warmer waters (29°C) appeared in the eastern part of the Eastern Indian Ocean off Java [14].

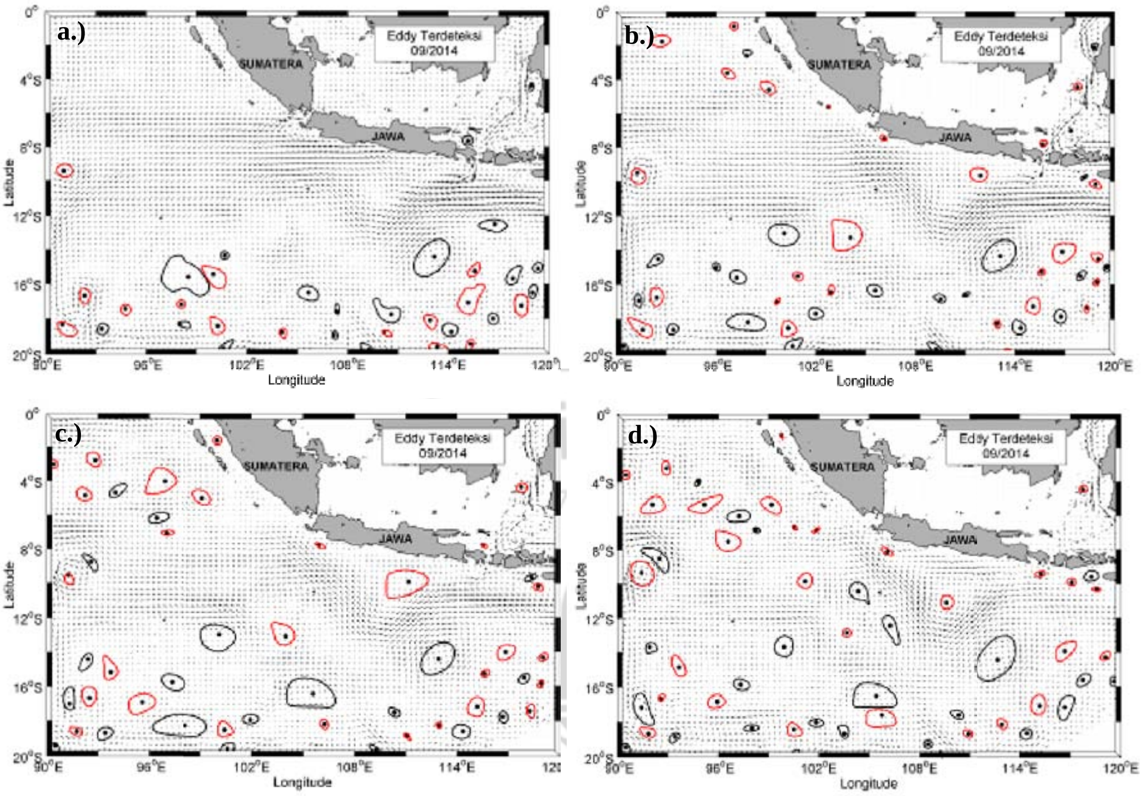

Figure 1: Eddy visualisation in September 2014 at four vertical levels a.) 5 m, b.) 109 m, c.) 155 m, d.) 222 m

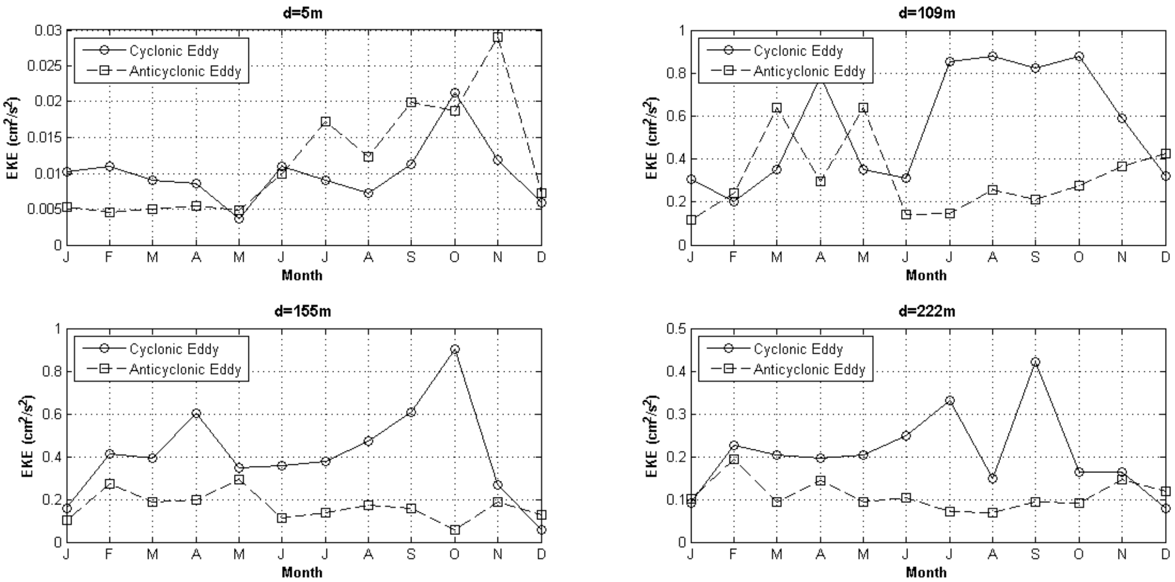

Figure 2: Mean EKE at four vertical levels during 2014

3.3 Eddy Kinetic Energy

EKE inside the eddy center mostly decrease within increasing of the depth. From 109 m to 222 m the EKE tend to decrease and at 155 m and 222 m the EKE has a constant value. From the Figure 2 showed that at 109 m has a higher EKE value. EKE values showed a seasonal cycle with a maximum during Southeast Monsoon (July – September) and minimum during Transition System and Northwest Monsoon (December – April). The increasing of EKE during Southeast Monsoon maybe caused by the instability of current system between SEC and ITF. ITF flow has a maximum intensity during

Southeast Monsoon compared to the Northwest Monsoon [15].

The modulation of EKE is mediated by baroclinic instability associated with seasonal current system and the underlying westward-flowing SEC system and that makes EKE has a maximum value during Southeast Monsoon [16]. From all of depth mostly at cyclonic eddy has a higher EKE (0.01 – 0.55 cm^2/s^2) then at anticyclonic eddy (0.01 – 0.31 cm^2/s^2). In August the EKE between cyclonic and anticyclonic eddy has a significant difference. In cyclonic eddy at 109 m with a mean EKE of 0.880 cm^2/s^2 while in anticyclonic 0.257 cm^2/s^2. Its showed that cyclonic eddy has higher energy in transporting water system.

In June and December the EKE value between cyclonic and anticyclonic has a minimum value. In June mean EKE at cyclonic eddy was about 0.233 cm^2/s^2, while at anticyclonic eddy was about 0.091 cm^2/s^2. In December mean EKE at cyclonic eddy was about 0.116 cm^2/s^2, while at anticyclonic eddy was about 0.171 cm^2/s^2. Decreasing of EKE in eddy center during June and December maybe cause by the peak of the monsoon transition period occured in June and December and has the transition system of current at Southern Java Indian Ocean. Because of the transition system that occured in Southern Java Indian Ocean during this month caused weak value of EKE at eddy center.

4. Conclusion

The formation of eddy in Southern Java Indian Ocean are associated with the SEC, SJC, and ITF pattern. Total maximum of cyclonic eddy happened in January-March and July-September, while the anticyclonic eddy in April-June and July-September. Its indicated that cyclonic eddy is mostly formed by the baroclinic instability associated with the surface-intensified ITF and SJC system. Anticyclonic eddy is mostly formed by the baroclinic instability associated with the SEC system, beside that there are several factor that caused on anticyclonic form which is kelvin and rosby waves, wind trends, and the topography.

Characteristic of temperature at eddy center has a different value between cyclonic and anticyclonic, which at cyclonic eddy has a lower value than anticyclonic eddy. The temperature in eddy center mostly started changing at a depth of 109 m and fading at 222 m. Characteristic of EKE at eddy center showed seasonal cycle with maximum in Southeast Monsoon and minimum in Transition and Northwest Monsoon. EKE at cyclonic eddy has a higher value (0.01 – 0.55 cm^2/s^2) then at anticyclonic (0.01 – 0.31 cm^2/s^2).

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Author Profile

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