Atmospheric dynamics and moisture transport forming tropical cyclones in Indonesia Maritime Continent

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Abstract. Indonesia's position in the tropics causing Indonesia has small potential to be directly affected by tropical cyclones. However, over the last 10 years a number of tropical cyclone phenomenon have occurred in the region of 0^o to 10^o LS and affect weather in Indonesian Maritime Continent region. They are Durga (2008), Kirrily (2009), Anggrek (2010), Bakung (2014), Cempaka (2017), Dahlia (2017) and Flamboyan (2018). Analysis of atmospheric dynamics during occurrence of these tropical cyclones needs to be done to obtain the characteristics of its growth in Indonesian maritime continent. The data used is reanalysis data of ECMWF include Sea Surface Temperature (SST), wind, vorticity, vertical velocity, and moisture transport with resolution 0.125^o x 0.125^o, vertical shear data from CIMSS. The results showed that supporting parameters of tropical cyclone growth such as SST reached more than 27^0C, the lowest pressure reached 984 mb, maximum wind speed reached 50 knots, vortices between -12 x 10^{-5}/s to -2x10^{-5}/s, vertical velocity ranges -1.4/s to -0.4/s, vertical shears ranging from 10 to 15 knots, and transport moisture ranges from 800 to 1600 kg/ms-1.

1. Introduction

The position of Indonesia which is located in a tropical area, lying between latitudes 11°25'S and 06°05'N, and longitudes 95°06'E and 141°41'E, and surrounded by the Indian and Western Pacific Oceans creates an interaction between the ocean and the atmosphere which affects the weather in Indonesia whether in global, regional and local scale. One of the regional scale weather phenomena which occurs in Indonesia is a tropical cyclone. It is defined as a storm which has large forces and occurs in the oceans with an average radius of 150 to 200 km. The formation of tropical cyclones is characterized by the reaching of more than 26.5^o C of sea's surface temperatures and it is generally formed in areas between 10^0 to 20^0 N or S [1]. The area where tropical cyclones formed is outside the 8^0 N or S from the equator [2]. In the other opinion, tropical cyclones only formed in the region of the ocean with a surface temperature of more than 26.5 ^{o}C and rarely form in areas located less than 5 ^{o} N or S [3].

However, in the past 10 years a number of tropical cyclone phenomena have occurred in regions of 0^0 to 10^0 S and caused significant weather in the Indonesian Maritime Continent (BMI). The tropical cyclones were tropical cyclones of Durga (2008), Kirrily (2009), Anggrek (2010), Bakung (2014), Cempaka (2017), Dahlia (2017) and Flamboyan (2018). The number of events of tropical cyclones mentioned above becomes the basis for conducting an analysement of atmospheric dynamics during the occurrence of tropical cyclones in order to identify the growth characteristics of tropical cyclones and water vapor transport in the Indonesian Maritime Continent.

The researches about the tropical cyclones formation has been already conducted several times, such as Gray (1975) who explained that the dominant parameters which support the formation of tropical cyclones are the Sea Surface Temperature (SST) which reaches more than 26.5^{0}C in depth of 60 meters, Relative Humidity (RH) in the intermediate layer more than 70%, relative under-strong vorticity, weak vertical windshear, and labil atmospheric conditions, where vortices are the most influencing parameters that influence the growth of tropical cyclones [4].

Vorticity is a parameter used to see the cyclonic or anticyclonic movements of a weather system. In the northern hemisphere (BBU), when vorticity is greater than zero ($\xi > 0$), it indicates that there is a cyclonic movement which causes the air mass movement upwards and vice versa, if the relative vorticity is less than zero ($\xi < 0$), then the will be an anticyclonic movement when the air will move down. In the southern hemisphere (BBS), it works otherwise, if vorticity is greater than zero ($\xi > 0$), then there is an anticyclonic movement when the air will downwards and if relative vorticity is less than zero ($\xi < 0$) then there is a cyclonic movement that causes the air will upwards [5].

Vertical velocity (vertical velocity) is a movement of air particles or air parcels that move up or down in the atmosphere. The pressure value will decrease by the increasing of altitude, so the positive value indicates the movement of the air mass decreases, while the negative indicates the movement of the increase in air mass with Pa/s units [6].

The source and distribution of water vapor is one of the main components in the formation of convective clouds that have the potential to produce rain. The water vapor transport has an important role in analyzing the impact of some weather disturbances on rainfall [7]. Water vapor transport is the movement of wind that carries a mass of water vapor [8]. In their research, Zhou and You limited the parameter data at altitude of 300 mb due to the large amount of data lost at altitudes above 300 mb which could potentially affect the results of vertical steam integration calculations. Water vapor transport is affected by zonal winds and meridional winds, namely wind components, wind components v, and specific humidity (q). The distribution of water vapor transport is different in each layer of the atmosphere, so to determine the movement of water vapor calculations are carried out from layers 1000-300 mb, 1000-700 mb, 700-500 mb, and 500-300 mb [9].

2. Data and method

This study, used Europian Center for Medium Range Weather Forecasting (ECMWF) reanalysis data in the form of vortices, vertical velocity, and water vapor transport where the data was taken when a tropical cyclone occurred in the format of netcdf file (* .nc) every 6 hours with the resolution of 0.125^0 x 0.125^0 from layer 1000 to 300 mb. In addition, vertical shear data was taken from the Tropical Cyclones Cooperative Institute for Meteorological Satellite Studies (CIMSS) with a time interval of every 6 hours. Then, supporting data such as coordinates and time of occurrence of tropical cyclones used the data from BMKG. After the data collection was complete, the data processing was done using the GrADS software to display the results of the analysis in the form of unit values then entered into Microsoft Excel and analyzed in graphical form. These results are then associated with supporting parameters that have been examined by Gray (1975). So that, the characteristics of the formation of tropical cyclones in the Indonesian Maritime Continent are gotten.

3. Result and Discussion

This study discusses about the atmospheric dynamics which is seen from several supporting parameters of tropical cyclone formation as stated by Gray (1975), namely SST, Vertical Velocity, Vorticity, and vertical shear. Then, the occurrence of a tropical cyclone needs to be seen from the condition of water vapor transport because it is related to the influence of convective cloud formation in the region through which it passes. The following will be discussed about the results of the supporting parameters for the formation of tropical cyclones in the Indonesian Maritime Continent.

3.1 Sea surface temperature, minimum pressure, and vertical shear

Based on Table 1., it can be seen that the SST value, minimum pressure, and vertical shear during the event of tropical cyclones at latitude 0 - 10^0S. SST is one of the factors supporting the availability of water vapor in the ocean, the higher the SST to a depth of 60 meters, the greater the latent energy produced as the main capital of tropical cyclone formation. Indonesia, which is in the tropics, causes SST in its waters to be warmer than its surroundings. The general SST value seen when the occurrence of tropical cyclones in the BMI is between 25.6 to 29.6^0C with SST values below 26.5^0C occurs when tropical cyclones are in the extinct phase.

Table 1. Tropical cyclone events

Tropical cyclones	Date of events	SST (^{0}C)	Minimum pressure (hPa)	Vertical shear (knot)
Durga	April 22– 26, 2008	26.7 – 28.7	984	10 – 20
Kirrily	April 24 – 30, 2009	28.8 – 29.6	999	5 – 10
Anggrek	October 30 – November 4, 2010	25.8 – 29.1	986	5 – 10
Bakung	December 11 – 13, 2014	28.2 – 28.7	991	5 – 10
Cempaka	November 25 – 29, 2017	28.4 – 28.9	998	5 – 25
Dahlia	November 26 – December 4, 2017	26.7 – 29.4	985	10 - 30
Flamboyan	April 28 – May 2, 2018	25,6 – 28.9	986	5 – 15

The increasing of SST causes the occurance of low pressure in the region, and air mass will form a convective cloud. In case of tropical cyclones, generally the minimum pressure value for each cyclone is below 1000 hPa with the lowest pressure value occurring in the tropical cyclone Durga. A significant pressure is drop and the formation of sharp and tight of low pressure gradients causes the mass of air to gather quickly and experience impulse so that a wind vortex is formed, and then develop intensively into a tropical cyclone. In addition to SST and pressure, one of the supporting parameters for the formation of other tropical cyclones is vertical shear. According to Gray (1975) Vertical shear is a change in wind both in terms of direction and speed vertically from layers 950 to 200 mb and if the vertical shear value is less than 20 knots, it can support the formation of tropical cyclones. Seen in Table 1, the vertical shear value in the region of tropical cyclone formation ranges from 5 to 25 knots generally, with the greater value entering the extinct phase. This shows that vertical shears are one of the supporting forms of tropical cyclones in BMI, although the Coriolis style is small.

3.2 *Vertical velocity and vorticity*

Vertical velocity is used to determine the movement of the rising and falling air masses. If vertical velocity is negative, it means that there is a vertical pressure reduction every second or in other words an increase in air mass. In Figure 1 shows the value of the lower vertical velocity layer (850 mb) in general from the 7 tropical cyclones that occur at BMI ranges from -0.2 to -1.5 Pa / s. Vertical velocity will be more positive with increasing altitude or reduced pressure, this indicates that in the lower layer, there is an increase in the air mass until the air mass is saturated and condensed. During a tropical cyclone, high vertical velocity will determine whether or not the growth of convective clouds is an important part of a tropical cyclone. Figure 1 shows that the largest vertical velocity is achieved by tropical cyclones Anggrek and Dahlia with values (-1.5) Pa / s, where the maximum vertical velocity is reached 12 hours before being declared a tropical cyclone or in other words occurs in the growth phase. This suggests that in the growth phase, high convective clouds as a major part of tropical cyclones will form within 12 hours.

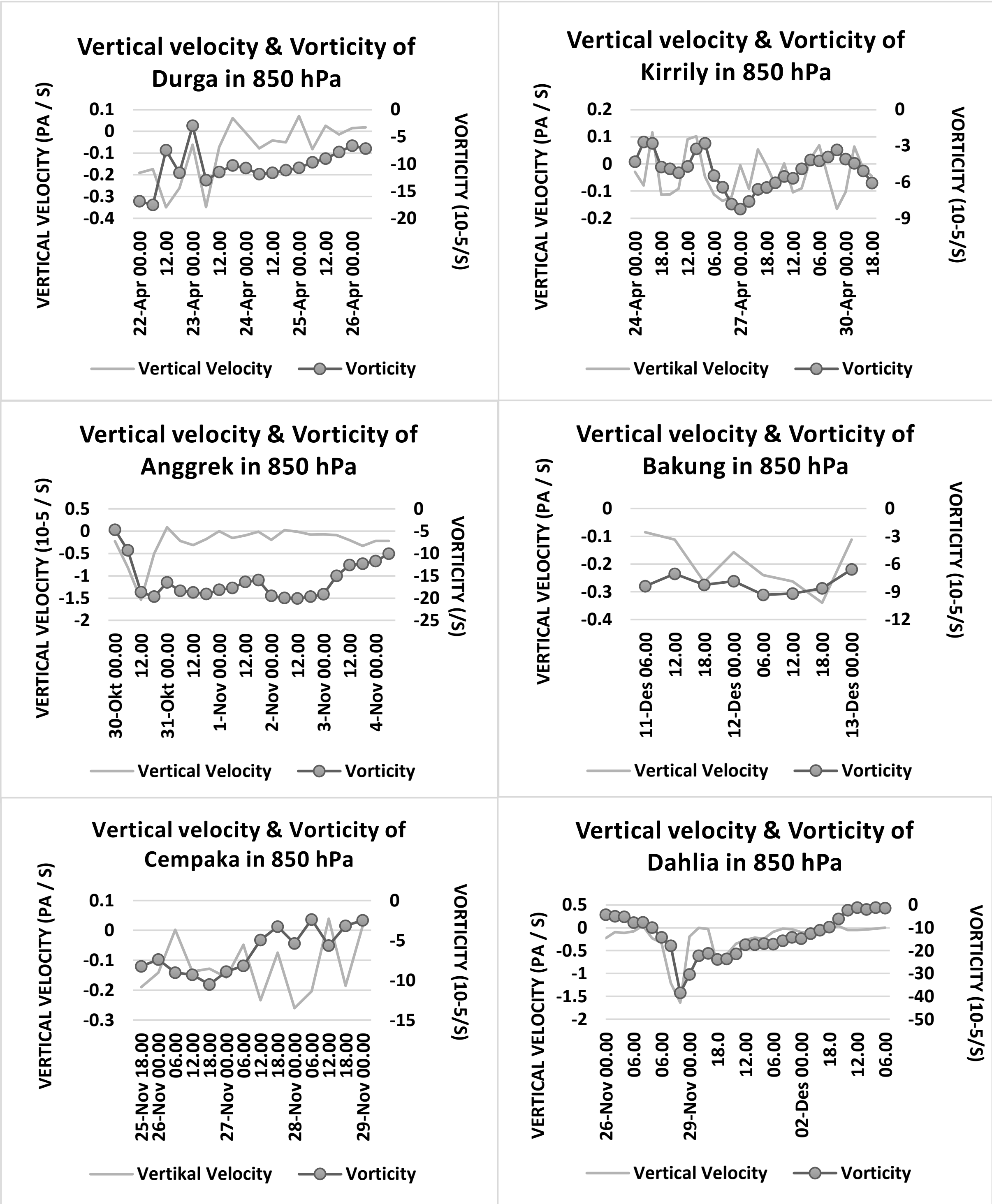

Figure 1. *Vertical velocity and vorticity value of tropical cyclones Durga, kirrily, Anggrek, Bakung, Cempaka, Dahlia*

Despite of vertical velocity, there are also vorticity parameters to determine the cyclonic or anticyclonic movements of a wind vortex. According to Holton (2004), if the value of vortices is negative in the southern hemisphere (BBS), it indicates the presence of cyclonic movements that cause an increase in air mass. Based on Figure 1, it can be seen that the vorticity and vertical velocity values are mutually supportive in the formation of tropical cyclones. In general, vorticity at the time of the occurrence of tropical cyclones in BMI is quite large, ranging from (-2) $x10^{-5}$ / s to (-38) $x10^{-5}$ / s, with dominating values ranging from (-8) $x10^{-5}$ / s to (-20) $x10^{-5}$ / s. The strongest vorticity values are generally in the mature phase or when low pressure system is declared a tropical cyclone. This Vorticity value also proves the theory of Gray (1975) that one of the conditions for the formation of tropical cyclones is the lower layer vortices (850 mb) which are low. Along with the development of tropical cyclones from the growth phase to extinction, this vortices value will weaken closer to the extinct phase. Tropical cyclones around the BMI have a short life span due to the small Coriolis force so that strong vortices only last for a short time.

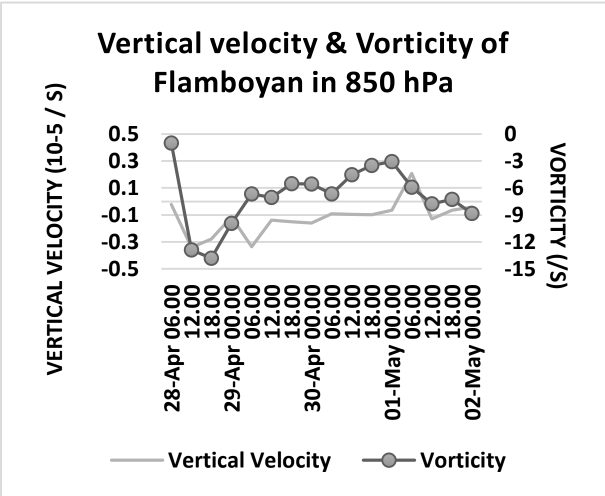

Figure 2. *Vertical velocity and vorticity value of tropical cyclones Flamboyan*

3.3 Gradient wind and moisture transport

The growth of tropical cyclones will greatly affect weather patterns in the surrounding area, one of which is wind direction and speed. The presence of significant pressure is drop and tight pressure gradient causes the wind to move from high pressure to low pressure at a considerable speed. This wind movement carries a mass of air and water vapor which will support the formation of convective clouds in the region through which it passes. Air speed is one of the parameters that determine the category of tropical cyclones, the higher the wind speed, the greater the impact of the tropical cyclone if it is close to the land, for example the tropical cyclone Kirrily and Cempaka. Based on Figure 3, it can be seen that the maximum wind speed in the cyclone wall area ranges from 25 to 70 knots, with a maximum wind speed of 45 to 70 knots achieved in tropical Flamboyant cyclones and a minimum speed of 25 to 35 dominant knots in tropical cyclones Kirrily and Cempaka. This happened because the two tropical cyclones were close to the mainland so that the water supply was relatively smaller than the other tropical cyclones that occurred at the BMI.

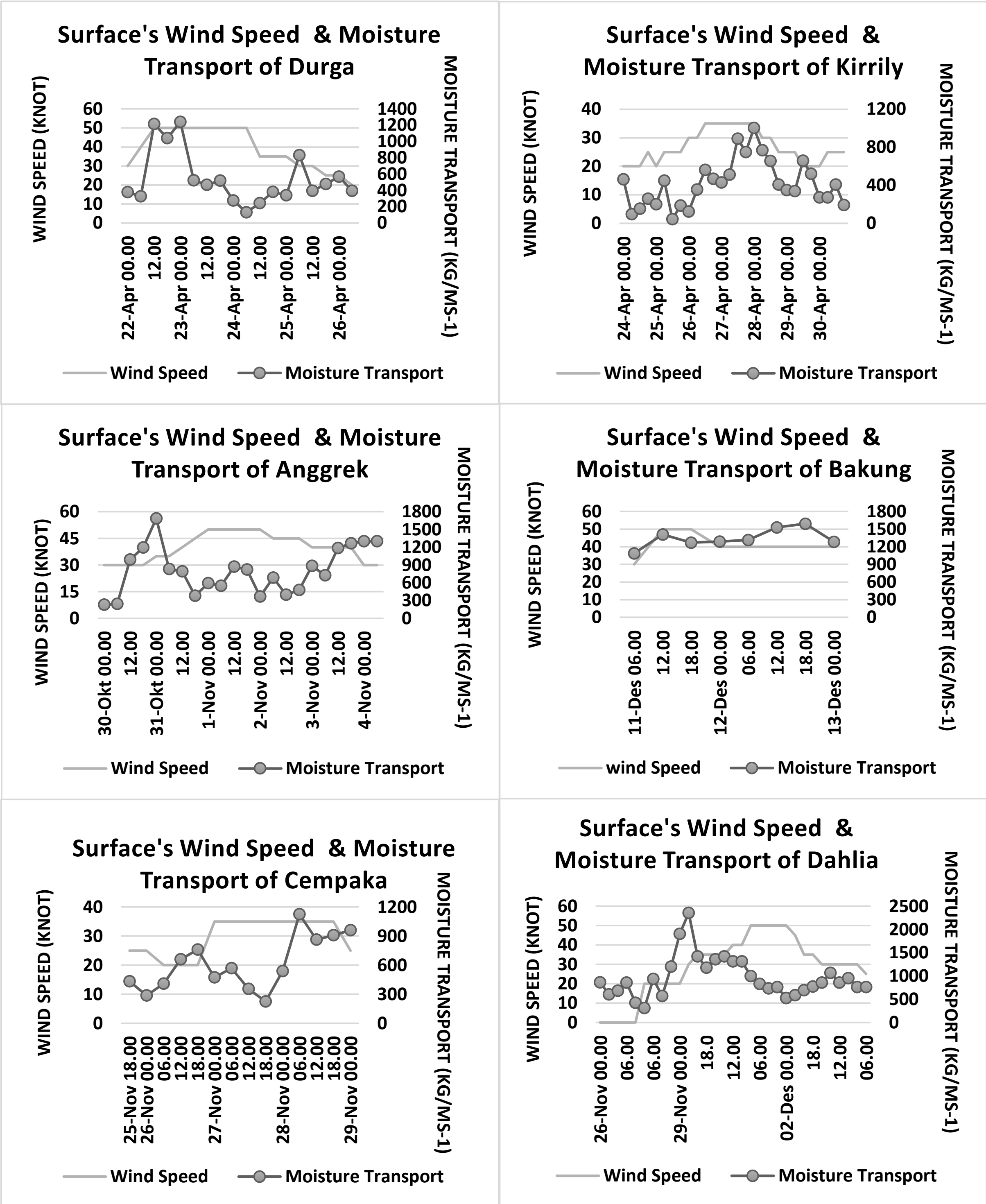

Figure 3. *Surface's wind speed and moisture of tropical cyclones Durga, Kirrily, Anggrek, Bakung, Cempaka, Dahlia*

Water vapor transport is the movement of wind that carries a mass of water vapor [7]. Water vapor transport is affected by zonal winds and meridional winds, named u wind components, v wind components, and specific humidity (q). Therefore, the value of water vapor transport depends on the speed of the wind moving in the region. The greater of wind speed, the moisture transport has a tendency to increase. The increase in moisture transport value will affect the formation of convective clouds in the region it passes. In Figure 3 and 4., it can be seen that moisture transport values in 7 tropical cyclones contained in BMI have values ranging from 200 to 2400 Kg / ms^{-1}, with a maximum moisture transport value of 1700 to 2400 Kg / ms^{-1} achieved by tropical Dahlia cyclones. when in the mature phase. In addition, the maximum value of each tropical cyclone is also achieved in the mature phase with different ranges of values. This shows that the maximum moisture transport value is in the mature phase of a tropical cyclone.

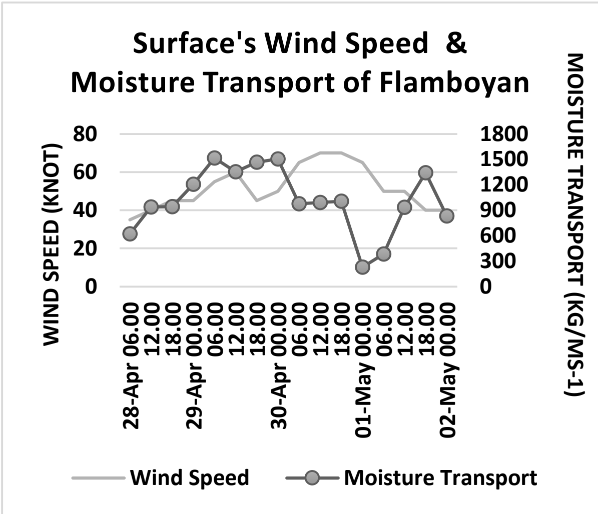

Figure 4. *Surface's wind speed and moisture of tropical cyclones Flamboyan*

3.4 Streamline at 925 hPa and 300 hPa

Streamline is a wind line that shows the movement and pattern of wind at a time in a region. Streamline datas show the shear patterns and convergent areas. Figure 5 shows the cyclonic movement pattern at 925 mb when a tropical cyclone occurs and the pattern of its disappears at 300 mb. This shows that at layer of 300 mb there has been a divergence or spread of air masses. This can be caused by the vorticity and vertical velocity values that have been weaken in this layer. The 300 mb layer show a shear pattern, but the cyclone pattern is already visible.

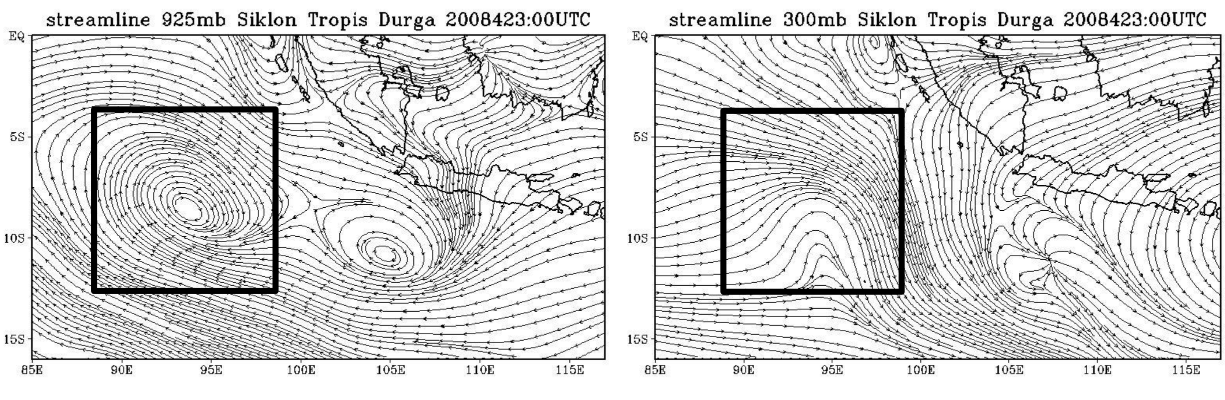

Figure 5. *Surface's wind speed and moisture of tropical cyclones Durga*

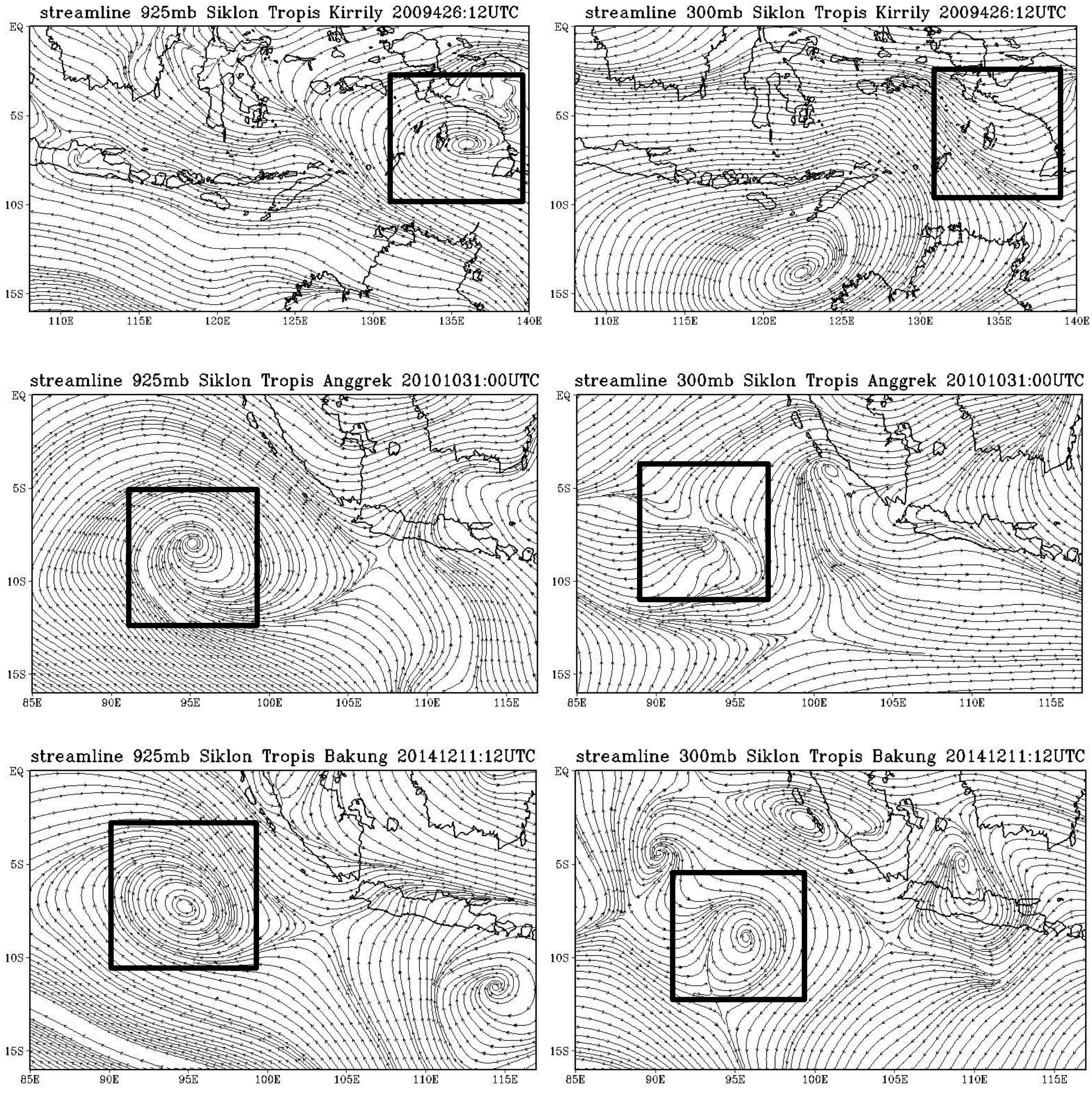

Figure 6. *Surface's wind speed and moisture of tropical cyclones Kirrily, Anggrek, Bakung*

As the Figure 6 and 7 show the wind pattern of 925 mb and 300 mb level at the time of the occurrence of the tropical cyclone Bakung and Dahlia the same pattern seen. At 925 mb layer, visible shear areas and also convergent which is a result of the presence of low pressure with a clockwise movement that indicates the presence of cyclonic currents in the wind vortex in the BBS. The convergence of the lower layer will be supported by vortices and vertical velocity to lift the air mass so that the formation of convective clouds can occur. At the 300 mb layer, the cyclone current still looks the same as the 925 mb layer. This indicates that at 300 mb layer, the convergent process still occurs accompanied by vorticity and vertical velocity still supports the occurrence of air mass lift.

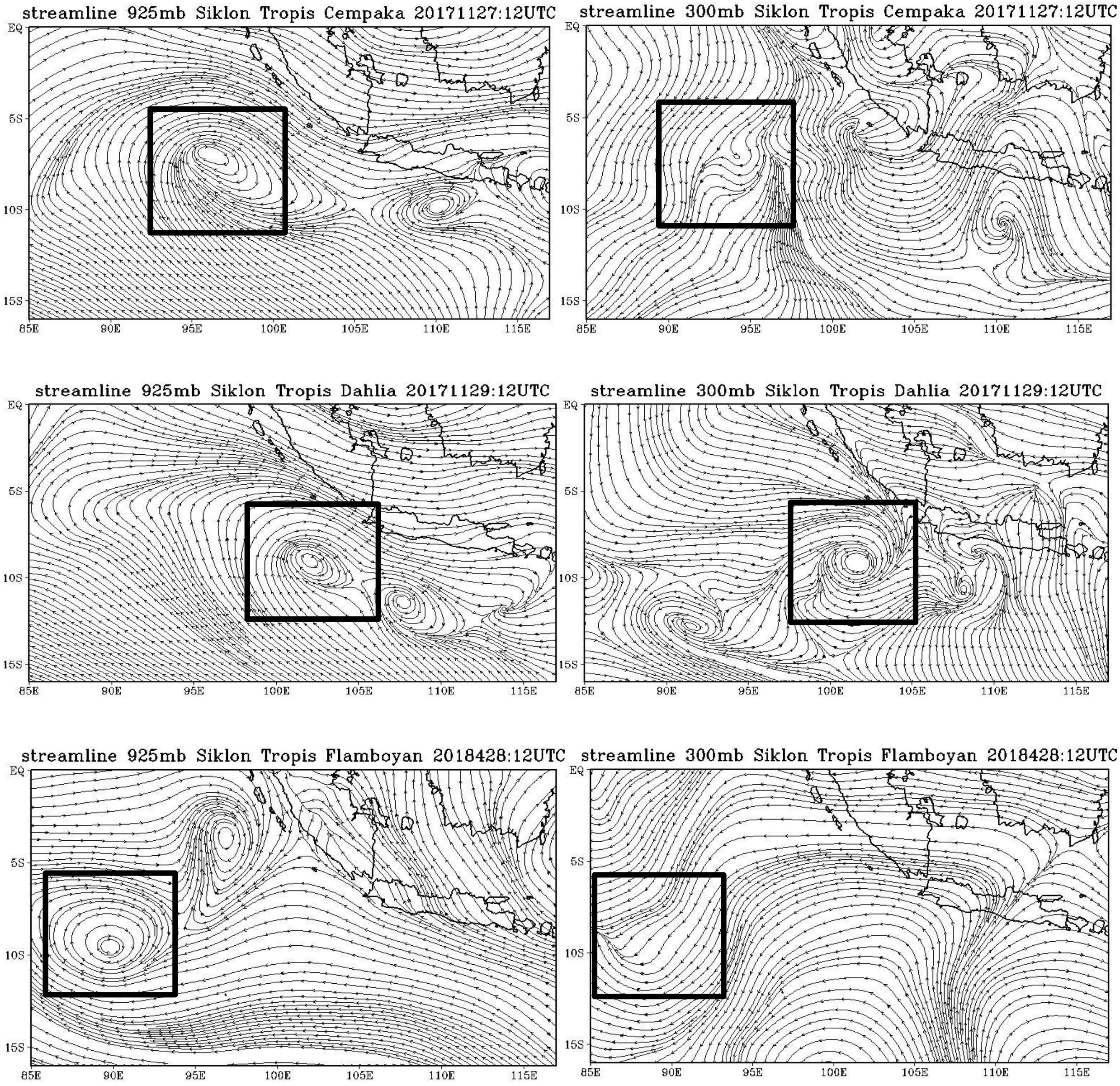

Figure 7. *Surface's wind speed and moisture of tropical cyclones Cempaka, Dahlia, Flamboyan*

4. Conclusion

Occurrence of tropical cyclones in Indonesia maritime continent are supported by several parameters, they are sea surface temperature that ranged between 26.7^0C to 29.6^0C. Wind speed occurs between 45 to 70 knots, minimum pressure recorded of 984 mb, vertical shear of 5 to 25 knots, value of vertical velocity between (-1.5) to (-0.2) Pa/s, then the vortices reaches (-20) to (-8) x 10^{-5}/s. tropical cyclones also affect the amount of transport of water vapor around of the events. During tropical cyclones in Indonesia maritime continent, the maximum water vapor transport shown between 1700 to 2400 kg/ms^{-1}, where the value is quite large and has the potential for convective cloud growth. The convergence process that occurrence of tropical cyclones region in Indonesia is also influenced by the movement of wind by the layer of 925 mb to 300 mb.

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