

Mesoscale Convective Complexes (MCCs) over the Indonesian Maritime Continent during the ENSO events

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Abstract. This study analyzed the mesoscale convective complexes (MCCs) over the Indonesian Maritime Continent (IMC) during the El Niño/Southern Oscillation (ENSO) events for the 15-year period from 2001 to 2015. The MCCs identified by infrared satellite imagery that obtained from the Himawari generation satellite data. This study has reported that the frequencies of the MCC occurrences at the El Niño and La Niña were higher than that of neutral conditions during DJF. Peak of MCC occurrences during DJF at La Niña and neutral condition is in February, while El Niño is in January. ENSO strongly affects the occurrence of MCC during the DJF season. The existences of the MCC were also accompanied by increased rainfall intensity at the locations of the MCC occurrences for all ENSO events. During JJA seasons, the MCC occurrences are always found during neutral conditions, El Niño and La Niña in Indian Ocean. MCC occurring during the JJA season on El Niño and neutral conditions averaged much longer than during the DJF season. In contrast, MCCs occurring in La Niña conditions during the JJA season are more rapidly extinct than during the DJF. It indicates that the influence of MCC during La Niña during the DJF season is stronger than during the JJA season.

1. Introduction

IMC lies at the heart of tropical region's warm pool. It is one of the world's most convectively active areas and thereby plays an important role in the variability of the tropical and global climate system. It is located between two continents (Asia and Australia) and between two oceans (Indian and the Pacific Ocean) [1]. Convection over the IMC consists of various spatial and temporal scales ranging from local circulation to large-scale disturbance in the tropical oceans near of IMC [2]. One of the types of convection system over IMC is the Mesoscale Convective System (MCS) as an organized cluster of convective clouds that is larger than an individual cloud, but smaller than cyclone. A very largest of MCS that are widely observed around the globe is defined as Mesoscale Convective Complex (MCC), which represents a class of MCS with a huge, near-circular, long-lasting cold cloud shield [3].

Houze [4] stated that MCCs have the important role in the rainfall changes in the tropics include IMC. MCCs are primary contributors to tropical rainfall [5]. Trismidianto [6] found that the contribution of MCC to total rainfall over the IMC during fifteen years reached 20%. Most studies have also reported that MCCs producing the heavy rainfall as a cause of the flooding, localized flash floods, mudslides, and property and crop damage (e.g., [3,7]). Trismidianto [8] have also reported that MCC in the Indian Ocean near of Sumatra Island influencing weather pattern in several regions over Sumatra Island.



The rainfall of IMC has also been considered to be closely linked to El Niño-Southern Oscillation (ENSO) in the Pacific Ocean. For example, the transition season anomalies in IMC region were found to be related with a drier condition over most part of the country during El Niño or the warm phase of ENSO [9,10]. ENSO is a naturally occurring phenomenon involving fluctuating ocean temperatures in the central and eastern equatorial Pacific, coupled with changes in the atmosphere. Indonesia is strongly influenced by the ENSO on rainfall in dry season and weakly influenced in wet season [11].

The linked of ENSO and MCC has been reported by some previous researchers but has not been described in detail, for example; Velasco and Fritsch [12] suggested that El Niño might play a role in MCC activity. Laing and Fritsch [13] also suggested the possibility of a relationship between El Niño and MCCs. Although there have been assertions in the literature of a connection between MCCs and El Niño, there has not been a general study directly addressing the changes in MCC related to the ENSO. Given that the climate of IMC is influenced by ENSO, while MCC are primary contributors to tropical rainfall. For that reason, it is important to know how they change between El Niño and La Niña. So that, this study focuses on the role of ENSO in modulating the spatial and temporal distribution of MCC events.

2. Data and method

This research utilized brightness temperature (T_{BB}) from the Himawari geostationary satellites, provided by the Japan Meteorological Agency (JMA). In detail, the data consists of Himawari-5/GMS-5 for data from January 2001-April 2003, Pacific GOES/GOES-9 for data from May 2003- June 2005, Himawari-6/MTSAT-1R for data from July 2005 - June 2010, Himawari-7/MTSAT-2 for data from July 2010 - June 2015, and Himawari-8 for data from July 2015 - December 2015. This satellite data has spatial and time resolutions $0.05^\circ \times 0.05^\circ$ and one hour, respectively that could be downloaded from <http://weather.is.kochiu.ac.jp>. This study used Nino 3.4 index to the analysis of the ENSO. This index can be downloaded free from https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/nino34/. The estimated rainfall data, corresponding to the MCCs and ENSO in this research, were obtained from the Real-Time TRMM TMPA (TMPA-RT) 3B41RT v7 dataset, which has hourly temporal resolution and $0.25^\circ \times 0.25^\circ$ spatial resolution. These data could be downloaded free from <ftp://disc2.nascom.nasa.gov/data/TRMM/Gridded/3B41RT/>.

MCC identified by input the temperature, latitude, and longitude values for each cloud shield pixel that obtained from infrared (IR) to a modified version of a computerized MCC program using MATLAB based on characteristics of MCCs [3]. He stated that MCC have cloud shield with continuously brightness temperature or black body temperature (hereafter T_{BB}) $\leq -32^\circ\text{C}$ (in this study converted to 241 K) and must have an area $\geq 100,000 \text{ km}^2$. The interior cold cloud has $T_{BB} \leq -52^\circ\text{C}$ (in this study converted to 221 K) and must have an area $\geq 50,000 \text{ km}^2$ for over six hours, although the cloud shield does not have to maintain an eccentricity of ≥ 0.7 for its entire life cycle. The eccentricity is also important to distinguish MCC from the other MCS type, for example; squall line, bow echo, CC and the others. The areal extent and eccentricity values used to determine the duration and life cycle of the MCCs, while the centroid position indicated the path of propagation of the systems.

This method adapts the method from Ismanto [14] and Trismidianto [8] that based on the maximum spatial correlation tracking technique (MASCOTTE) method by Carvalho and Jones [15]. This program results in the MCC information consists of MCC location, time of MCC, area size for cloud shield and interior cloud and the eccentricity of cloud shield and interior cloud, and then by the manual checking and tracking, we get the life cycle of MCC.

MCC events are grouped according to the ENSO events that occurs. The ENSO event is divided into three categories based on the SST anomalous value for the Nino 3.4 area, ie neutral conditions, El Niño and La Niña. The division of the ENSO category based on the anomalous SST Nino 3.4 is described in table 1. The anomalous value of SST Nino 3.4 has a monthly temporal resolution, whereas the analysis performed in this study is three monthly or seasonal, hence the average of three months before the value of anomalous SST Nino 3.4. Due to IMC is one of monsoon region, the seasons of IMC divided into two seasons. i.e., wet seasons on December, January and February (DJF)

and dry seasons on June, July and August (JJA), however, there are two transition seasons. i.e., March, April, and May (MAM) as transition seasons from wet to dry seasons and September, October and November (SON) as transition seasons from dry to wet seasons.

Table 1. The 3-monthly mean of the sea surface temperature anomaly in Nino 3.4 region, which are: green represents La Niña, yellow represents neutral and red representing the El Niño condition.

Year/Season	DJF	MAM	JJA	SON
2000	-1,7	-1,0	-0,6	-0,6
2001	-0,8	-0,4	-0,1	-0,3
2002	-0,2	0,2	0,7	1,1
2003	1,0	0,0	0,0	0,3
2004	0,3	0,0	0,4	0,7
2005	0,5	0,3	0,1	-0,2
2006	-0,8	-0,4	0,2	0,8
2007	0,6	-0,2	-0,4	-1,3
2008	-1,7	-0,9	-0,2	-0,3
2009	-0,9	-0,3	0,6	1,0
2010	1,5	0,5	-0,9	-1,6
2011	-1,5	-0,8	-0,4	-0,9
2012	-0,9	-0,3	0,4	0,3
2013	-0,3	-0,2	-0,3	-0,1
2014	-0,3	0,2	0,3	0,6
2015	0,6	0,8	1,6	2,3

3. Result and Discussion

3.1. The Influence of the MCCs to rainfall while ENSO occurred in December-January-February (DJF) Period

A climatological study of MCCs during 2001 - 2015 over IMC has been identified using IR satellite imagery with creating an algorithm that combines criteria of cloud coverage, eccentricity, and cloud lifetime. This study used the MCC data which has been found by Trismidianto [6] around 1028 MCCs during fifteen years from 2001 to 2015. This research was a continuation of the research conducted by Trismidianto [6] with grouping and analyzing the MCC occurrences when the ENSO phenomena during 2001 - 2015 periods in DJF and JJA season.

Table 2. The occurrences of MCC according to the three conditions of ENSO.

Month/ENSO condition	Neutral	El Niño	La Niña
December	27	24	26
January	26	35	30
February	35	32	35
Total MCC	88	91	91

Variations in actual MCC totals per ENSO phenomenon during DJF season has been observed with a peak of MCC activity occurred during La Niña and El Niño condition which has the same

number of events that is about 91 events as shown in table 2. While the MCC occurrences at the time of neutral condition are 88 events. The peak of MCC occurrences during DJF season at the time of La Niña and the neutral condition is in February, while El Niño is in January. It is due to the peak of diurnal convective activity and rainy season over IMC at the time of DJF is in February, where according to Trismidianto [16] that diurnal convective is also associated with MCC formation above IMC

Table 3. The physical parameters of MCC in three conditions of the ENSO during December-January-February for 2000 – 2015 periods.

	Eccentricity	Cloud Shield Area Size (km ²)	Interior Cloud Area Size (km ²)	Duration (Hours)
Neutral	0.84	371009.5	157434.7	11.5
El Niño	0.85	257748.6	119463.3	11.2
La Niña	0.86	321722.6	145679.6	11.3

During the DJF season, the number of MCCs occurring at the time of the neutral conditions is less than the number of MCC that occurred during El Niño and La Niña condition, but MCCs that occur during neutral conditions have larger average sizes than El Niño and La Niña as shown in table 3. The average of cloud shield and interior cloud area size of MCCs is around 371009.5 km² and 157434.7 km², respectively. It is more than MCC that occurred during El Niño and La Niña condition with the average of cloud shield area size of MCCs is 257748.6 km² and 321722.6 km², respectively. This indicates that the El Niño phenomenon at DJF has an effect on the MCC physical characteristics and does not significantly affect the number of MCC events in IMC.

The MCC that occurred during El Niño condition is slightly less than with global MCC by Laing and Fritsch [13] that reported the MCC for the global population is 354,000 km². However, the MCCs in IMC is more than from MCC in the western Pacific region that has the greatest frequency of MCC between 2 x 10⁵ km² until 3 x 10⁵ km² as reported by Miller and Fritsch [17]. This MCC is also more than with MCC over subtropical South America that has cloud size area 256,500 km² [18]. Although some MCCs produce cold cloud shields that extend over a million km², the size, and duration of MCSs and MCCs are positively correlated, i.e., larger systems tend to last longer [19,20,13].

Most climatologies of MCSs concern MCCs, and hence make use of a measure of cloud-shield shape with calculating eccentricity. The eccentricity is very important to distinguish MCC with the other type of MCS. The eccentricity defined as the ratio of the minor axis to the major axis of the MCC best-fitting ellipse at the time of maximum extent. This research found that average of eccentricity for all of the MCCs over the IMC during neutral, El Niño, and La Niña condition is 0.84, 0.85 and 0.86, respectively as shown in table 3. It indicated that majority of MCCs over the IMC are more circular which similar to MCCs over the USA [21]. In general, most of the MCCs has eccentricity between 0.91 - 0.94 and between 0.76 - 0.79.

In this study, we define the MCC duration as the duration between the time of initial stage and the time of dissipation stage. The frequency of distribution of the duration of all MCC systems that occurred at the ENSO event is shown in table 3. The average duration of the MCC that occurred during neutral, El Niño and La Niña condition was approximate 11.5 hours, 11.2 hours and 11.3 hours, respectively. It is more than average for MCCs in southern Africa which average duration around 9.5 hours [22]. Also, it is slightly longer than the global average around 10 hours [13] and much less than those found in subtropical South America which duration around 14 hours [18].

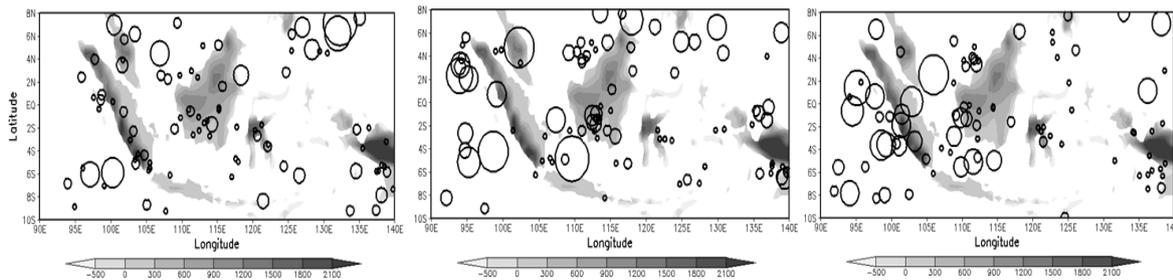


Figure 1. Frequency distribution of the MCC occurrences over IMC during fifteen years from 2001 to 2015 in wet seasons or DJF, for; (a) El Niño, (b) La Niña, and (c) Neutral condition. The circles show the size and location of MCC when the mature stage at the time of the interior cloud size area of MCC reached the maximum extent (10^3 km^2). The color shaded refers to the elevation of the unit in meters (m).

Figure 1 shows that the ENSO influenced on MCC events in different places, such as in Kalimantan, Sumatra, Java, and Papua. At the time of El Niño, the MCC occurrences spread more in Sumatra and Kalimantan, while during La Niña, MCCs tended to spread in the Indian Ocean and the Java Sea, but some of MCC concentrated in Central Kalimantan. In the neutral condition, MCC spread in the ocean and continent. The MCC occurrences in Java only occurred at the time of neutral and La Niña conditions. At the time of El Niño, MCCs that occur in IMC is not as large as MCCs that occur during La Niña and neutral conditions. It is due to the reduced supply of water vapor to become rain-producing convective clouds in IMC. It appears that the largest MCCs at the time of DJF El Niño occurred in the southwestern waters of Sumatra (the eastern Indian Ocean), which is the most frequently formed area of large-scale MCC and the Pacific Pole (warm pole). What is interesting is the area with the small and small number of MCCs at the time of La Niña and Neutral, such as in the Banda Sea, Timor Sea and the Arafura Sea, precisely during El Niño many MCCs occur and have a larger scale. Walker's circulation shift at the time of El Niño occurs, possibly causing shifts and changes in the scale of MCCs further east. In addition, during the neutral DJF and La Niña periods, MCCs spreads mostly in land and sea, whereas in the El Niño DJF period, MCCs occur on land and very few MCCs are found in the oceans.

Figure 2 shows that the MCCs affects rainfall in some areas for example in the Indian Ocean that has high rainfall during neutral and La Niña conditions. MCC events during normal and La Niña also caused high rainfall in the Eastern Indian Ocean, while MCC events at the time of El Niño affected more rainfall in the mainland such as southern Sumatra, Central Kalimantan, Southeast Sulawesi and some area in Papua. In addition, El Niño conditions also reduce the number of MCC occurrences in the ocean which resulted in low rainfall in the area, such as in the Java Sea and the western coast of Sumatra. It results reinforces the results of research that has been reported by Trismidianto [6,16] that MCC is very important to contribute to the rainfall that occurs in IMC. MCC also affects not only the existing rainfall at the MCC location, but also affects rainfall around the MCC location through the formation of new convective cells when MCC begins to become dissipated. Numerous studies have demonstrated that ENSO can modulate the synoptic and mesoscale environments South America, which in turn can influence convective activity and precipitation patterns across the tropical and subtropical regions (e.g., [23,24,12]). Specifically, Velasco, and Fritsch [12] found that the number of MCCs doubled during the 1982/83 El Niño event. However, this research showed no apparent relationship between MCC frequency and ENSO that similar with Durkee and Mote [18] that analysis of ENSO and MCC cloud-top characteristics, longevity, and the distribution of MCC rainfall show no apparent relationship.

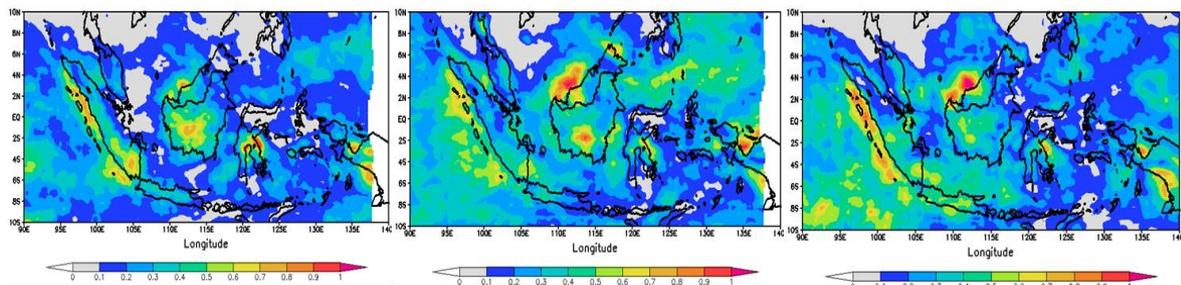


Figure 2. Rainfall accumulation per MCCs occurrences number in the IMC during fifteen years from 2001 to 2015 on DJF, for; El Niño (left), La Niña (middle), and Neutral condition (right). The color shaded refers to rain rate of the unit in millimeters (mm).

3.2. The influence of the MCCs to rainfall while ENSO occurred in June-July-August (JJA) period

Variations in actual MCC totals per ENSO phenomenon during JJA season has been observed as shown in table 4 with the peak of MCC activity occurred at the time of neutral condition with the number of MCC is 95 events, while the number of MCC that occurred during JJA at the time of La Nina is 30 events. MCC occurs at least few at the time of El Nino during the JJA season with about 19 events. The peak of MCC occurrences during JJA season during neutral, El Nino and La Niña is in June compared to July and August. This result almost similar with Tyson and Preston-Whyte [25] that stated the peak of MCC activity in southern Africa is mostly occur during the early before summer months due to likely linked to the synoptic-scale environment, which is more baroclinic in nature compared to the late summer months. Velasco and Fritsch [12] that reported the longer MCC season may be due to the influence of the oceans on the relatively smaller landmass. However, some of the previous paper stated that there is the effect of ENSO on MCC activity in Africa [26] and in America [27]. Comparison to DJF, the number of MCC events at JJA during neutral condition occurs more frequently. However, at the time of JJA, the phenomena of El Niño and La Niña had the effect of reducing the number of MCC occurrences in IMC, which at the time of the DJF was not so influential.

Table 4. Same as table 2, but for JJA.

Month/ENSO condition	Neutral	El Niño	La Niña
June	48	8	21
July	23	4	5
August	24	7	4
Total MCC	95	19	30

During the JJA season, the number of MCC events occurring at El Niño was smaller than the number of MCCs in neutral and La Niña conditions, however, the average of MCC that occurred at the time of El Niño larger than during neutral and La Niña conditions. The average of cloud shield and interior cloud area size of MCCs at the time of El Niño is around 444089.4 km² and 213422.4 km², respectively as shown in table 5. It is more than MCC that occurred at the time of the neutral and La Niña condition with the average of cloud shield area size of MCCs is 348253.1 km² and 253462.5 km², respectively. This indicates that the El Niño phenomenon at DJF has an effect on the MCC physical parameters and does not significantly affect the number of MCC events in IMC. MCC that occurs during El Nino is the large MCC compared to MCC in some regions of the world and more than with global MCC by Laing and Fritsch [13] that stated the mean cloud-top area for the global population is 354,000 km².

MCC occurring during the JJA season on El Niño and neutral conditions averaged much longer than during the DJF season, where the duration of MCC life-cycle when El Niño and neutral conditions were 12.9 and 11.6 hours, respectively. MCCs that occur during the JJA season at the time

of El Niño conditions is the long-lived MCC types. It indicates that El Niño also influences the development of MCC in IMC. In contrast, MCCs occurring in La Niña conditions during the JJA season are more rapidly extinct than during the DJF season with an average life-cycle duration of MCC ranging from 10.2 hours. It indicates that the influence of MCC during La Niña during the DJF season is stronger than during the JJA season. Almost similar with DJF season, this research also found that average of eccentricity for all of the MCCs over the IMC during neutral, El Niño, and La Niña condition during JJA seasons is circular types.

Table 5. Same as table 3, but for JJA.

	Eccentricity	Cloud shield area size (km ²)	Interior cloud area size (km ²)	Duration (Hours)
Neutral	0.88	348253.1	162834.7	11.6
El Niño	0.83	444089.4	213422.4	12.9
La Niña	0.84	253462.5	115142.8	10.2

Figure 3 shows that at the time of the neutral condition during JJA season, the MCC most frequently occurs if compared with El Niño and La Niña condition. However, the MCC, which is centered in the Indian Ocean at the time of JJA, is not affected by ENSO since MCC events are always found in neutral, El Niño and La Niña, although during El Niño and La Niña the number of MCC occurrences in the Indian Ocean is less. But in Indonesia, the influence of La Niña and El Niño is very strong at the time of JJA. This is indicated by the decreasing number of MCCs compared to the neutral condition. At the time of JJA in the IMC, MCC occurs mostly around the equator and north of equator while in the southern part of Indonesia there are few MCC events. In general, MCC at El Niño and La Niña are not as large as in neutral conditions.

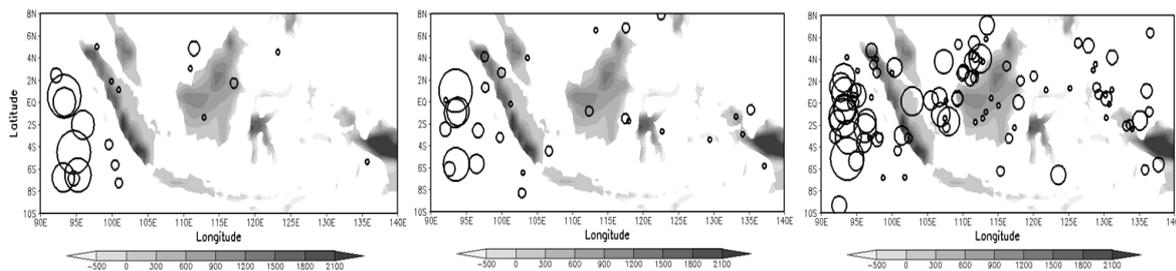


Figure 3. Same with figure 1, but for JJA.

During JJA period, rainfall under ENSO neutral and La Niña conditions are higher and more prevalent in IMC compared to El Niño. The highest rainfall is on the western coast of Sumatra, the western coast of Kalimantan and Papua. While low rainfall is seen in the southern region of Indonesia. However, at the time of El Niño, high rainfall occurred in the East Indian Ocean and the western coast of Sumatra while MCCs formed, comparing to La Niña and neutral conditions. While the reduction of rainfall at the time of El Niño occurred in South Kalimantan, Sulawesi, Maluku Islands and Papua. This is because the MCC occurrences at the time of El Niño is not so much, but it produces very high rainfall in the area. This is reasonable considering that MCCs that occur on JJA El Niño has a large scale (size) in the eastern Indian Ocean. But unlike the northern region of Kalimantan, because of high rainfall occurs despite the number of incidents MCCs are small and small scale. This indicates at the time of JJA El Niño, the presence of MCCs causes high rainfall in the area. While in the area of Papua, at the time of La Niña happened, rainfall in Papua area is very high although MCCs that happened little and with the small scale. This indicates the magnitude of the influence of MCCs at the time of JJA La Niña in the area. Even the effect is greater when compared to the JJA neutral which has a large number of occurrences and scale of MCCs. In general, the MCC occurrences at JJA neutral has an

effect to more widespread rainfall when compared to La Niña and El Niño which have a high rainfall effect focused on a particular area.

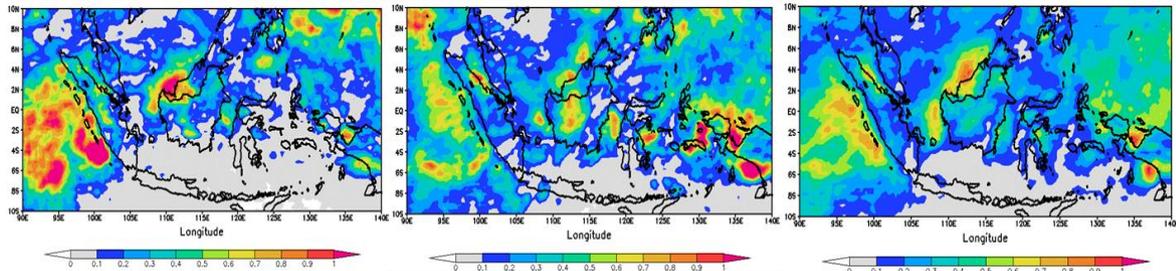


Figure 4. Same with figure 2, but for JJA.

4. Conclusion

During DJF seasons, the frequencies of the MCC occurrences during El Niño and La Niña conditions was higher than that of neutral conditions, but the size of MCCs at Neutral condition was larger than the other conditions. At the time of El Niño condition, the MCC occurrences frequently found spread in the southern of Sumatra and the Central Kalimantan. At the La Niña, the MCCs tended to spread in the Indian Ocean and the Java Sea, but also found concentrated in the Central Kalimantan. While at the neutral conditions, the MCC spread evenly in the oceans and the mainland of IMC. The MCC occurrences in the Java Sea and Java Island are just found in the neutral and La Niña conditions. It is generally concluded that ENSO strongly affects the occurrence of MCC during the DJF season. The existences of the MCC were also accompanied by increased rainfall intensity at the locations of the MCC occurrences for all ENSO events. The MCC occurrences at neutral and La Niña caused high rainfall in the Eastern Indian Ocean, whereas the MCC occurrences at El Niño affected more rainfall in the mainland of southern Sumatra. During JJA seasons, the MCCs which concentrated in the Indian Ocean are not affected by ENSO, whereas the MCC occurrences are always found during neutral conditions, La Niña and El Niño. The influence of MCC during La Niña during the DJF season is stronger than during the JJA season. Comparison to DJF, the number of MCC events at JJA at the time of neutral condition occurs more frequently. However, at the time of JJA, the phenomena of La Niña and El Niño had the effect of reducing the number of MCC occurrences in IMC, which at the time of the DJF was not so influential. This research found that average of eccentricity for all of the MCCs over the IMC at the time of neutral, La Niña, and El Niño condition during JJA and DJF seasons is tend to circular types.

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