The Global Population of Mesoscale Convective Complexes (MCCs) over Indonesian Maritime Continent during 15 Years

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Abstract. Mesoscale convective complexes (MCCs) were identified and tracked during 15-years over Indonesian Maritime Continent (IMC) by infrared satellite imagery using an algorithm that combines criteria of cloud coverage, eccentricity, and cloud lifetime. Infrared satellite imagery is obtained from the Himawari generation satellite data. This study results that there are several characteristics of MCC over the IMC, among others; Most of these MCCs were over the continental area, mainly near the mountains and the high elevation areas which have similar characteristic with the global population of MCCs in the world. The peak of MCC occurrence over the IMC is during MAM with around 33.56% due to likely linked to the synoptic-scale environment, which is more baroclinic in nature than in the late summer months. Around of 26.26% and 25.29%, MCC occurrences are found in DJF and SON, respectively. The season with fewer events is JJA, around of 14.79%. The average of cloud shield area size of MCCs is around 315,000 km². The average duration of the MCCs over IMC was approximately ~9.5 hours and the maximum duration was 10 hours. Those observed in this study were usually nocturnal and reached a maximum at midnight.

1. Introduction

According to Maddox [1], mesoscale convective complexes (MCCs) are a special case of mesoscale convective systems (MCSs), where MCS is portrayed as an organized ensemble of convective elements, whose lifecycle is longer than that of the individual convective elements, and the largest of the convective storms. He has divided MCS into two types as linear and circular type, and MCC includes as the circular type found in midlatitude and tropics region. Laing and Fritsch [2] have studied the characteristics of MCCs globally. They are of the view that, more than 400 MCCs occur at various locations around the globe each year, but mostly in tropical and mid-latitude locations, with approximately 66 percent of the occurrences in the Northern Hemisphere. They also found that 91% of MCCs occur over continents even though they can occur over oceans. The average duration of these systems is 10 hours with a cloud shield size of 354,000 km² at the time of maximum extent, but this
varies according to location. In general, the systems are long lasting in the Southern Hemisphere rather than in the Northern Hemisphere, and MCCs originating over the oceans are more long lasting than those originating over land. The typical MCC develops in the late afternoon, the maximum cloud-shield reaches its maximum size in the early morning hours of the following day, and the system dissipates just after sunrise.

Trismidianto et al [3,4] have reported that MCC in the Indian Ocean near of Sumatra Island influences weather pattern in several regions over Sumatra Island. The result has been posited that there is a role of cold pools during MCC in influencing the rainfall, but they only analyzed the present of new convective systems using convective index by spatial analysis, not only over the Indian Ocean but also over Indonesian Maritime Continent (IMC). Such that, the enthusiasm gives a deep understanding of the mechanism of MCC that relates to the land-sea breeze influencing the rainfall. For 10-years (i.e., 2000 - 2009), Trismidianto [3] also realized the greatest frequency of MCC occurrence in the transition season March, April, and May, and duration of the life cycle of MCC in the Indian Ocean about 12 to 15 hours.

The existence and characteristic of MCCs over IMC have been studied using infrared (IR) satellite imagery from geostationary meteorological satellite (GMS) observations of 5-years (i.e., 2001-2005) period cited by Ismanto [5]. He has reported that 36% of MCC was found in the Eastern Indian Ocean (including Sumatra Island), 15% in Papua Island, 13% in Northern Papua, 13% in Kalimantan Island, 9.5% in Northern Australian and 13.5% in the widespread area except those regions. He found that MCCs appearances are predominantly nocturnal with an average lifetime of 12.2 hours, but, Ismanto [5] only used short data to explain the characteristics of the MCC over the IMC. However, the climatology of MCCs has not been given attention in detail over IMC by the previous research. So that, the focus of this study is to provide a detailed description of the MCC characteristics in IMC using long period data for 15-years in the period of 2001-2015.

2. Data and Method

The previous study, such as Maddox [1], Anderson and Arrit [6], Durkee et al. [7] and others have utilized IR satellite image from Geostationary Operational Environmental Satellites (GOES). Laing and Fritsch [8,9], Morel and Senesi [10] and several others have utilized the METEOSAT IR images from the International Satellite Cloud Climatology Project (ISCCP) B3 stage radiance data. The METEOSAT is a geostationary meteorological satellite, operated by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), with multiple series. IR data provide the variable brightness temperature ($T_{BB}$) that gives information about the cloud temperature and altitude, where, as a general rule, the colder the object, the larger the altitude. $T_{BB}$ is uniquely related to the (sensed) wavelength.

This study utilized $T_{BB}$ from the Himawari geostationary satellites, provided by the Japan Meteorological Agency (JMA). Since the launch of GMS-1 (Himawari-1) in 1977, there have been three generations, including GMS (Geostationary Meteorological Satellite), MTSAT (Multi-functional Satellite imagery Transport SATellite), and Himawari 8/9. However, this research utilized data from Himawari-5 until Himawari-8 and added the data GOES-9 because from May 2003 to June 2005, JMA rented the GOES-9 satellite from the National Oceanic and Atmospheric Administration (NOAA) for observation of the western Pacific region to fill the gap between the operational periods of Himawari-5 and Himawari-6. In detail, the data consist 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.
MCC was identified by inputting the temperature, latitude, and longitude values for each cloud shield pixel obtained from IR to a modified version of a computerized MCC program using MATLAB based on characteristics of MCCs [1]. This method adapts the method from Ismanto [5] and Trismidianto [3] based on the maximum spatial correlation tracking technique (MASCOTTE) method by Carvalho and Jones [11]. Maddox [1] stated that MCC has cloud shield with continuously $T_{BB} \leq -32^\circ C$ (in this study converted to 241 K) and must have an area $\geq 100,000$ km$^2$. The interior cold cloud has $T_{BB} \leq -52^\circ C$ (in this study converted to 221 K) and must have an area $\geq 50,000$ km$^2$ for over six hours, although the cloud shield does not have to maintain an eccentricity of $\geq 0.7$ for its entire life cycle. The eccentricity is also important to distinguish MCC from the other MCS type, for example; squall line, bow echo, cloud cluster and the others. The areal extent and eccentricity values were used to determine the duration and life cycle of the MCCs, while the centroid position indicates the path of propagation of the systems. The explanation of MCC based on Maddox [1] criteria over IMC is still rarely found, so it becomes interesting to explore MCC over IMC based on Maddox [1].

3. Result and Discussion

3.1 Global distribution of MCC occurrences

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. A total of 1028 MCCs were identified and tracked during fifteen years for the 2001 – 2015 period as shown in Figure 1. The MCCs were developed in several concentrated areas; some of them were over the ocean and coastal areas, and others were over inland and high elevation areas. By examining the location of the interior cloud centroids for all MCCs, one can see that MCCs mostly frequently occurred in nine regions as shown in red dotted line in Figure 1. That nine regions are the Indian Ocean near Sumatra Island, along the western coastal of Sumatra Island, the South China Sea near Kalimantan Island, the Central Kalimantan around 3°S-1°N; 111° -115°E, the East Kalimantan around 1° - 4°N; 116° - 120°E, Makassar Strait near coasts of Kalimantan Island, the Central Sulawesi around 4° - 2°S; 120° - 123°E, Merauke over Papua Island in location around of 8° - 5°S and 135.5° - 140°E, and Cendrawasih Bay near coasts of Papua Island in location around of 132.5° - 136.5°E and 4° - 1°S.

![Figure 1](image-url)

**Figure 1.** Geographical distribution of the MCCs in the IMC during 15-years (2001-2015). Locations are for the MCC at the time of maximum extent of the interior cloud size area when the mature stage. The circles represent the interior cloud size area ($10^3$ km$^2$). The red dotted line indicates the MCCs concentration region, where IO,
WS, SCS, CK, EK, MS, CS, CB and MR refer to Indian Ocean, Western Sumatra, South China Sea, Central Kalimantan, East Kalimantan, Makassar Strait, Central Sulawesi, Cendrawasih Bay and Merauke, respectively. The color shaded refers to the elevation of the unit in meters (m).

Figure 1 shows that the MCC occurrences was frequently found in the near-equatorial regions in the range of latitude 5°S – 5°N. It is associated with the surplus of radiative energy in the tropics and a net deficit in middle and in high latitudes, requiring on average a poleward transport of energy by the atmospheric circulation. The fact is that this surplus energy heats the ocean and land surfaces and evaporates moisture. In turn, some of this heat lands its way into the atmosphere in the form of sensible and latent heat, and it is the energy of this type that is transported polewards by the atmospheric circulation. Cloud systems directly affect the surface energy budget through their modification of the net radiative fluxes. Clouds are also a key factor in the coupling between the atmosphere and the ocean through their influence in the surface radiative, heat, and momentum fluxes [12]. The energy associated with the equatorial maximum in solar radiation released through vigorous atmospheric convection is the ultimate driver of the mean position of the Hadley circulation [13]. Atmospheric convection cell warm air rises at the equator. As it rises, it cools and generates large amounts of precipitation. The development of the MCC over near-equatorial is also possibly related to the ITCZ as a belt of low pressure which circles the Earth generally near the equator where the trade winds of the Northern and Southern Hemispheres come together. It is characterized by convective activity which often generates vigorous thunderstorms over large areas. It is most active over continental land masses by day and relatively less active over the oceans.

Most of MCCs concentrated near the mountainous and high elevation areas. This result is similar to Ashley [14] and Laing and Fritsch [15] who reported that the mean location for the development of the MCCs in America was found on the lee side of the mountain. Morel and Senesi [10] also reported that a large number of MCS over a large part of Europe using satellite infrared imagery was found at mainly continental, strongly related to orography and in their majority are in phase with the diurnal radiative heating. MCC was frequently found near mountain because the effect of topography is important for the low level jet formation. The jet appears to contribute to the formation of the MCS (including MCC) structure in the northern part of the convective system and the formation of low-level intense wind. Additionally, the effect of the convective system on the formation of the jet could also be substantial because the convective system may hydrostatically reduce the low-level pressure behind it, thereby enhancing the horizontal pressure gradient force across the mountain range [16]. A mountain breeze and a valley breeze are two related; localized winds that occur one after the other on a daily cycle which also gives a contribution to convective activity over the IMC due to IMC is a unique geographical region composed of a complex system of mountainous islands. The interaction between the topography with the westerly wave propagation is assisted in the development of convective storms or MCC in Africa [17].

Variations in actual MCC totals per year as shown in Figure 2 have been observed with an obvious peak of MCC activity in 2004, 2005, 2011 and 2013 when more than 80 events occur each year. 2001, 2007, 2010, 2012, 2014 and 2015 are all above 70 events which occur each year. A total of 53 and 62 events occurred in 2003 and 2008, respectively. The only years notably fewer events are 2002, 2006 and 2009 with 45, 45, and 44 events, respectively. 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.,18,19,20]. Specifically, Velasco, and Fritsch [20] found that the number of MCCs doubled during the 1982/83 El Nino event. However, this research shows no apparent relationship between MCC frequency and
ENSO that is similar to Durkee and Mote’ analysis [21] that ENSO and MCC cloud-top characteristics, longevity, and the distribution of MCC rainfall show no apparent relationship.

![Figure 2](image.png)

**Figure 2.** A total of MCC occurrences over the IMC during 15-years (2001-2015) for each year.

This result is also supported by previous research, among other; Trismidianto [3] stated that there are many MCC occurrences over the Indian Ocean near Sumatra. In addition to that, Ismanto [5] stated that one of concentration areas for oceanic MCC is the Indian Ocean. Moreover, Mori et al. [22] stated that IMC consists of many large/small islands with very long coastlines, many narrow straits control the global (Pacific to Indian) ocean circulation and the deep convection is the major contributor to changes in tropical rainfall [23].

### 3.2 Seasonal distribution of MCC occurrences

The season in IMC is divided into four seasons, namely in December, January and February (DJF) as the wet season, March, April and May (MAM) as a transitional season from wet season to the dry season. June, July, and August (JJA) as dry season and September, October, and November (SON) as a season of transition from dry season to the wet season. **Figure 3** shows that the peak of MCC occurrence over the IMC is during MAM with around 33.56% MCC occur in this season. This result is similar to Tyson and Preston-Whyte [24] that stated the peak of MCC activity in southern Africa mostly occur during the early before summer months due to likely linked to the synoptic-scale environment, which is more baroclinic in nature than in the late summer months. Velasco and Fritsch [20] suggest that the longer MCC season maybe due to the influence of the oceans on the relatively smaller landmass. However, some of the previous paper stated that there is an effect of ENSO on MCC activity in Africa [25] and in America [7]. 26.26% and 25.29% MCC occurrences were found in DJF and SON, respectively. The season with fewer events is JJA, around of 14.79%.
Figure 3. Percentage of the MCC occurrences over the IMC during 15-years (2001-2015) for each season.

The location of the interior cloud centroid for each season was examined. In DJF, one can see MCCs are the most frequent concentrated in the continent in Central Kalimantan, the South China Sea near northern Kalimantan, Central Sulawesi and Merauke as shown in Figure 4(a). However, the MCCs that occurred in the continent have an interior cloud in small size around 50,000 - 149,999 km$^2$. In contrast, most of the MCC with large size was frequently found in the Indian Ocean near Sumatra Island. Most of them have an interior cloud in size more than 300,000 km$^2$. The MCC in medium size was also concentrated in the Pacific Ocean. During MAM as shown in Figure 4(b), the frequency of MCCs was almost similar to DJF, but MCCs over the Central Kalimantan became more widespread throughout to Kalimantan. Small-sized MCCs dominate MCCs that occurred over the Central Kalimantan during MAM, but several large-sized MCCs were also found. MCCs over Merauke also became more widespread until the Arafura Sea. Several MCCs with medium size around 200,000 - 300,000 km$^2$ were found over Sumatra Island and western coastal of Sumatra. The MCCs with large-sized were still found in the Indian Ocean. Several MCC in small-sized also occurred over the Java Island.

During JJA as shown in Figure 4(c), the MCCs occurred in the continent were just found in several areas, among others; Central Kalimantan and northern Sumatra in small frequency. The MCCs are more concentrated over the ocean with the greatest concentration are over the Indian Ocean. MCC never occurred along the Java Island until East Nusa Tenggara during JJA. There are five concentration regions of MCC events during SON as shown in Figure 4(d). i.e., over the Indian Ocean, the South China Sea near northern Kalimantan, Central Kalimantan, Cendrawasih Bay and Merauke. The MCC with large size was still concentrated over the Indian Ocean, while small size was concentrated over Kalimantan, especially central Kalimantan. Overall, the MCCs with large size more than 300,000 km$^2$ most frequently occurred over the Indian Ocean each season with the greatest frequency in SON season. The Central Kalimantan is one favored region for MCC occurrences each season, but most of the MCCs in this area have a small and medium size less than 300,000 km$^2$. MCCs are rarely found along of the Java Island to the East Nusa Tenggara. Figure 4 also shows that MCC most frequently occurs in region nearly equator around 2°S to 2°N. It is interesting to note that MCC is possible related with ITCZ.
Figure 4. Geographical distribution of MCCs in the IMC during 15-years (2001-2015) for each season; (a) DJF, (b) MAM, (c) JJA and (d) SON. Locations are for MCC at the time of maximum extent of the interior cloud size area when the mature stage. The circles represents the interior cloud size area ($10^3$ km$^2$). The color shaded refers to the elevation of the unit in meters (m).

3.3 Monthly distribution of MCC occurrences

Variations in actual MCC totals per month as shown in Figure 5 are reported with an obvious peak of MCC activity in April and November when more than 120 events occur each month. The frequency of MCC occurrences in January, March, and May is also great with 107, 111 and 105 events, respectively. A total of 77, 66, 94 and 86 events occurred in February, June, October, and December, respectively. The fewer events were found in July, August and September that have frequency 41, 45 and 40 events, respectively.

Figure 6 shows the monthly analysis of MCCs over the IMC during 15-years by plotting the location of the interior cloud centroid of MCCs for January until June. In January as shown in Figure 6(a), the MCCs are concentrated in the Central Kalimantan and Central Sulawesi but in small size less than 100,000 km$^2$. The MCCs with large size are predominantly the MCC that are most frequently found in the Indian Ocean. The MCC with small size were concentrated over the coastal of Merauke and the coastal of northern Kalimantan over the South China Sea. The frequency of MCCs over the Central Kalimantan during February as shown in Figure 6(b) became widespread until western Kalimantan. MCCs were also concentrated in Lampung, southern Sumatra, and several MCCs were found in the coastal of North Sumatra. The frequency of MCC over the Indian Ocean and the other ocean decreased, just occurred in a few events.
During March as shown in Figure 6(c), MCCs was just concentrated over the Central Kalimantan with the frequency of MCCs which is greater than February, dominantly with small size. MCC also occurred in Sumatra, Sulawesi, and Papua but the small frequency. A few of large-sized MCC was found in the Indian Ocean. The MCC with small size increased over the Central Kalimantan in April as shown in Figure 6(d). Most of MCCs were also located in along western of Sumatra Island. Most of them have medium size around 200,000 km². The MCC with medium size also occurred in the Indian Ocean near the coast of northern Sumatra. Several small-sized MCCs were also found over Papua and Java Island. Most of the MCCs that occurred in May as shown in Figure 6(e) has a large size and were located in the Indian Ocean. MCC was rarely found over Sulawesi, Papua, and Java. In June as shown in Figure 6(f), most of MCCs were concentrated over the ocean with the greatest frequency in the Indian Ocean. Only a few were found in the continent, such as in the Central Kalimantan and North Sumatra. Like May, MCC does not occur over Sulawesi, Java, and Papua.
The frequency of MCC in July as shown in Figure 7(a) was similar to June, where only found in the Indian Ocean in longitude 91° - 97°E. The MCC rarely occurred in the continent during this month. The frequency of the MCC with large size over the Indian Ocean increased in October and November as shown in Figure 7(d) and (e), while in August it was slightly same as in July as shown in Figure 7(b). However, this frequency decreased in September and December as shown in Figure 7(c) and (f). In August and September, the frequency of the MCC was slightly same as in July, only a few were found in the large island of MCC. In fact, almost never occur along of the Java Island to East Nusa Tenggara. The frequency of MCC over the Central Kalimantan increased in October and November as shown in Figure 7(d) and (e). However, this frequency decreased in August, September, and December as shown in Figure 7(b), (c) and (f). The MCC was more concentrated in coastal of Merauke from October until December. Overall, it is similar to seasonal that the MCCs with large size more than 300,000 km² most frequently occurred over the Indian Ocean each month with the greatest frequency in October and November. Central Kalimantan is one favored region for MCC occurrences each month except June until September, but most of the MCCs in this area have a small and medium size less than 300,000 km². Along Java Island to East Nusa Tenggara is the region where MCC events were rarely found.
3.4 Diurnal distribution of MCC occurrences

In the diurnal analysis, most of MCCs that occurred in the continent reached maximum extent or mature stage in the midnight until morning from 20.00 - 0700 LT as shown in Figure 8(f), (a) and (b) with the greatest frequency of the MCC was concentrated over the Central Kalimantan. The MCCs which occurred in the ocean reached the most frequent maximum extent in 0800 - 1100 LT as shown in Figure 8(c). During the daytime at 1200 - 1500 LT and the evening at 1600 - 1900 LT, the frequency of MCC occurrences was concentrated most frequent over the Indian Ocean as shown in Figure 8(d) and (e). MCCs rarely reached maximum extent at night in 2000 - 2300 LT.

Most of previous studies indicate that diurnal cycles of deep convection over land and sea show a distinct contrast. Convection over continents and large islands is most intense in late afternoon (around 19 LT). In contrast, convection over the seas near continents and large islands is most intense in the morning (around 03 LT); diurnal cycle over continents and large islands are likely forced by strong surface heating during the day, whereas diurnal cycles over adjacent maritime areas arise from interactions between sea-land breeze circulations and large-scale environmental flows [26, 27]. The other previous researcher, Sui et al. [28] found the average diurnal variation of rainfall from satellite infrared over an extensive tropical region that is in the central and eastern Pacific. It shows the maximum value in the afternoon (mid-afternoon) and the second peak approaching dawn. They also stated that the strongest convection on the surface of the continent occurred towards evening or afternoon depending on the dominance of diurnal cycle of heating surface, except in areas where the difference between land and sea is very real or orographic very powerful force. On top of the ocean
area that is free from the influence of the mainland, the coldest clouds and the maximum rainfall is often observed in the morning.

Figure 8. Diurnal distribution of MCCs in Indonesian Maritime Continent during 15-years (2001-2015); (a) 0000 - 0300 LT, (b) 0400 - 0700 LT, (c) 0800 - 1100 LT, (d) 1200 - 1500 LT, (e) 1600 - 1900 LT and (f) 2000 - 2300 LT. Locations are for the MCC at the time of maximum extent of the interior cloud size area when the mature stage. The circles represents the interior cloud size area \(10^3\) km\(^2\).

3.5 MCC maximum-extent distribution

The area size of cloud shield and an interior cloud of MCCs during the mature stage are shown in Figure 9. Most of the MCCs have cloud shield around 100 - 200 \(10^3\) km\(^2\) in a total of 433 events as shown in Figure 3.10(a) and interior cloud less than 200 \(10^3\) km\(^2\) in a total of 834 systems as shown in Figure 3.10(b). It indicates that most of the MCCs over the IMC are included in the category of small-sized MCCs. However, the large-sized MCCs with cloud size area more than 600 \(10^3\) km\(^2\) also occurred over the IMC. In fact, a total of 29 events have cloud shield more than 1000 \(10^3\) km\(^2\), and 20 events have interior cloud more than 500 \(10^3\) km\(^2\).

The average of cloud shield area size of MCCs is around 315,000 km\(^2\). It is slightly less than the global MCC by Laing and Fritsch [2] who stated the mean cloud-top area for the global population is 354,000 km\(^2\). However, the MCCs in IMC are more than from MCC in the western Pacific region that has the greatest frequency of MCC between 2 \(10^3\) km\(^2\) until 3 \(10^7\) km\(^2\) as reported by Miller and Fritsch [29]. This MCC is also more than MCC over subtropical South America that has cloud size area 256,500 km\(^2\) [21]. Although some MCCs produce cold cloud shields that extend over a million km\(^2\), the size, and duration of MCSs and MCCs are positively correlated, i.e., larger systems tend to last longer [30, 31, 2].


3.6 MCC duration

In this research, 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 is shown in Figure 10(a). The average duration is approximately ~9.5 hours, and the maximum duration is 10 hours. The distribution and average duration are very similar to the distribution and average for MCCs in the southern Africa (~9.5 h; [32]). However, it is slightly shorter than the global average (~10 h; [2]) and much less than those found in subtropical South America (14 h; [21]). Most of the MCCs around 686 events occurred during 8 - 12 hours as shown in Figure 10(a). Only 20 events are the long-lived MCCs that occurred during more than 20 hours. A total of 57 events indicate that short-lived MCCs has duration only 6 - 7 hours. The long-lived MCCs occurred in March, May, July, September and November as shown in Figure 10(b). Most of the short-lived MCCs occurred in March-May, July, September, and December.

Figure 10. (a) Frequency distribution of duration of MCCs over the IMC during 15-years. (b) Box and Whisker plot of the duration of MCC frequency during 15-years.

Figure 11(a) shows that there is no relation between the duration and MCC locations because the correlation is slight (r = 0.01). Figure 11(c) shows that the MCC locations are not related to a maximum area of MCCs (correlation coefficient r = 0.06). Figure 11(b) indicates that there is a tendency for relation of duration and maximum area of MCCs over the IMC that is positively correlated (correlation coefficient r = 0.58). It indicates that systems which generate large cold-cloud shields tend to persist longer than those which produce small shields. This result is similar to global MCC population by Laing and Fritsch [2] who stated there are relation between duration and

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**Figure 9.** Frequency distribution of; a) MCC cloud shield maximum area and b) MCC interior cloud maximum area during 15-years.
maximum area in the global population of MCCs that has correlation coefficient $r = 0.385$. Tollerud et al. [30] also found a similar relationship, although the relationship is weak. This result is also very similar to Durkee and Mote [21] who stated MCC maximum size and duration of subtropical South America exhibited a significant relationship with correlation coefficient $r = 0.56$.

![Figure 11](image)

Figure 11. Scatter plots show relationship between; (a) latitude and duration, (b) duration and interior cloud size and (c) latitude and interior cloud size. Latitude, duration and interior cloud size at the time of maximum extent or mature stage. Correlation coefficient $r$ is shown for each case.

3.7 MCC life-cycle

Figure 12 shows that in general, the MCCs in IMC usually develop in the late afternoon and by around sunset in a few times before the initial stage. The greatest frequency of occurrences for initiation occurred between 1900 – 2200 LT. The systems reached the maximum size extent after midnight or early morning in predominantly between 0100 - 0500 LT and then MCC started to decay in the morning a few hours after sunrise, predominantly around 0700 - 0900 LT. The systems dissipated from the daytime until the afternoon, around 1000 - 1500 LT. It indicates that characteristics of MCCs life-cycle tend to nocturnal characteristics. This result is similar to the previous studies that documented regional populations of MCCs were found to be nocturnal, among others; MCC in the Americas and the Western Pacific region, southern Africa [1, 20, 29, 21, 32]. It follows that global population is also predominantly nocturnal [2]. It is also strengthened by Sui et al [28] who stated that convective activity in the tropics has three variations. Using the results of observations, COARE TOGA (Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment) acquired three diurnal variations of atmospheric convective activity in the tropics. The three variations are warm cumulus morning, afternoon convective showers, and nocturnal convective systems. Rainfall afternoons are particularly true for convective cells, but nocturnal rainfall caused by cells deeper convective and stratiform clouds in a wide area. Further stated that convective precipitation afternoon (afternoon convective showers) is more apparent in the period of large-scale undisturbed than when the diurnal cycle of sea surface temperature occurs strongly. However, the nocturnal convective system (nocturnal convective systems) and cumulus morning (warm morning cumulus) are higher in the period disrupted when more moisture is available [28].
Figure 12. Frequency distribution of all MCCs during critical stage (initial, mature, decay and dissipation or post-MCC stage).

4. Conclusion

A total of 1028 MCCs were identified and tracked during the 15-year period from 2001 to 2015. Most of these MCCs were over the continental area, mainly near the mountains and the high elevation areas which have similar characteristic with the global population of MCCs in the world. There are nine favored regions of MCC occurrences, they are the Indian Ocean near Sumatra Island, along the western coastal of Sumatra Island, the South China Sea near Kalimantan Island, the Central Kalimantan around 3°S-1°N; 111° -115°E, the East Kalimantan around 1° - 4°N; 116° - 120°E, Makassar Strait near coasts of Kalimantan Island, the Central Sulawesi around 4° - 2°S; 120° - 123°E, Merauke over Papua Island in location around of 8° - 5°S and 135.5° - 140°E. The peak of MCC occurrence over the IMC is during MAM with around 33.56%. The season with fewer events is JJA, around of 14.79%. The average of cloud shield area size of MCCs is around 315,000 km² which slightly less than with global MCC in the world around of 354,000 km². However, the MCCs in the IMC are more than from MCC in the western Pacific region and subtropical South America. The average duration of the MCCs over IMC was approximate ~9.5 hours, and the maximum duration was 10 hours that very similar to the distribution and average for MCCs in the southern Africa (~9.5 h), but it is slightly shorter than the global average (~10 h) and much less than those found in subtropical South America (14 h). The long-lived MCCs with duration more than 20 hours occurred in March, May, July, September, and November and most of the short-lived MCCs with duration 6 - 7 hours occurred in March - May, July, September, and December. In general, the greatest frequency of occurrences for initiation occurred between 1900 – 2200 LT. The systems reached the maximum size extent after midnight or early morning in predominantly between 0100 - 0500 LT and then MCC started to decay in the morning a few hours after sunrise, predominantly around 0700 - 0900 LT. The systems dissipated from the daytime until the afternoon, around 1000 - 1500 LT. It indicates that the majority of MCCs over IMC exhibit a nocturnal life cycle that begins in the mid-to-late afternoon, peaks after midnight and ends shortly after daybreak. Nocturnal growth in convective storms has been hypothetically related to the differential radiative heating between the MCC and the environment, which leads to peripheral environmental subsidence and low-level convergence into the system.
5. Reference
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