

Characteristics of the oceanic MCC, continental MCC, and coastal MCC over the Indonesian maritime continent

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Abstract. This study explains the comparison of mesoscale convective complexes (MCC) characteristics in the oceans, land and in the coast over Indonesian maritime continent (IMC). MCCs were identified and tracked during 15-years (2001-2015) over IMC by infrared satellite imagery using an algorithm that combines criteria of cloud coverage, eccentricity, and cloud lifetime. Infrared satellite imagery was obtained from Himawari generation satellite data. This study showed most of the continental MCC found near the mountains and the high elevation areas. The frequency of MCC occurrences was larger over the land than over the ocean. The oceanic MCCs, which lasted for more than 12 hours, were longer-lived than the continental MCCs. The MCCs with small size most frequently occurred in the continent, in contrast, the MCC with the medium and large size were most concentrated over the ocean. Generally, the continental and coastal MCC initiation occurs in the late afternoon and reach maximum size around midnight before decaying the next morning. In contrast, the oceanic MCC dominantly develops in midnight, and reach maximum size in the morning and then MCC decayed and dissipated from noon until afternoon. The evolution of MCC development in the ocean, land, and in the coast has almost the same stages and ways.

1. Introduction

Maddox [1] defined Mesoscale Convective Complexes (MCC) is a very large of Mesoscale Convective System (MCS) observed around the globe. MCS is generally defined as an organized cluster of convective clouds that is larger than an individual cloud, but smaller than cyclone. MCC is a particular type of MCS; an MCC is a large, circular, long-lived cluster of the cloud systems identified by satellite. It often emerges out of other storm types during the late-night and early morning hours. MCCs can cover an entire state. Maddox [1] divided MCS into two types as linear and circular type, and MCC include as the circular type that found in midlatitude and tropics region included IMC. This system grows upscale from convective towers to a convective-stratiform coupled vertical circulation, ultimately meeting its demise as only a stratiform rain region [2].

MCC phenomenon has been studied by researchers for more than a decade in the world including IMC after Maddox [1] introducing the concept of the MCC. Laing and Fritsch [3] have studied the characteristics of MCCs globally. They found that more than 400 MCCs occurred 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 the events occurred over continents and the rest occurred over the ocean. In general, they came to a conclusion that, the life-cycle of MCCs in globe about 10 hours and most of them occurred in the night. In



principally, MCCs usually occurred over land or close to the coast. However, they are not described in detail the MCC characteristics in the ocean, inland, and in the coast. MCC does not only occur in the middle latitude region but also occurs in tropical regions including IMC [1].

Ismanto [4] and Trismidianto [5] have reported that there are many MCCs occurs in the Indonesian Maritime Continent, especially in the Indian Ocean and over Kalimantan Island. One example of the case of MCC event that occurred in ocean has been reported by Trismidianto [7]. In another paper, Trismidianto [6] have analyzed the MCCs that occurred on the Kalimantan Island. However, that papers did not describe in detail the MCC characteristics in the ocean, inland and in the coast over IMC. So that, the MCC characteristics that occurred on the ocean and inland over IMC have not been clearly reported. Therefore, the purposes of this paper were to explain in detail the MCC characteristics that occur in the oceans, inland, and along the coast.

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>.

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 [1] as shown in Table 1. This method was adapted the method from Ismanto [4] and Trismidianto [5] that based on the maximum spatial correlation tracking technique (MASCOTTE) method by Carvalho and Jones [8].

This program results in the MCC information consisted of MCC location, time of MCC, area for cloud shield and interior cloud, the eccentricity of cloud shield and interior cloud, and then the life-cycle of MCC found by the manual checking and tracking. The MCC information used to explain the MCC characteristics over the ocean, inland, and coastal regions. In this study, we defined the oceanic (continental) MCCs as a system that reaches maximum extent while positioned over the ocean (land) as the following method by Morel and Senesi [9] and Blamey and Reason [10]. This research follows the method by Ogino [11] and Mori [12] to define the coastal region. The coastal MCC is defined the MCCs that occurred near the coastal at between ocean and continent during MCC reaching maximum extent or mature stage.

Table 1. Physical characteristics of MCCs [1].

Size:	A-Cloud shield with continuously low $T_{BB} \leq -32^\circ\text{C}$ (241 K) must have an area $\geq 100,000 \text{ km}^2$ B-Interior cold cloud region with $T_{BB} \leq -52^\circ\text{C}$ (221 K) must have an area $\geq 50,000 \text{ km}^2$
Initiate:	Size definitions A and B are first satisfied
Duration:	Size definition A and B must be met for period of ≥ 6 hours
Maximum extent:	Contiguous cold cloud shield ($T_{BB} \leq -32^\circ\text{C}$ (241 K)) reaches a maximum size
Shape:	Eccentricity (minor axis/major axis) ≥ 0.7 at time of maximum extent
Terminate:	Size definitions A and B no longer satisfied

3. Result and Discussion

3.1. The frequency of MCC occurrences

This study has been found around 1028 MCCs during fifteen years from 2001 to 2015 as shown in figure 1a. The MCCs found separate in several areas, some of them were over coastal and ocean, and others were in high elevation areas over land. Figure 1a shows that the MCCs that occur in the mainland are frequently found in the high elevation areas or near the mountainous area, such as Central Kalimantan, East Kalimantan, Western Sumatra and Central Sulawesi. This result is similar with Ashley [13] and Laing and Fritsch [14] who reported that the mean location for the development of the MCCs in America was found on the lee side of the mountain. Morel [9] also reported that a large number of MCS over several areas of Europe found at mainly continental, strongly related with orography and the effect of topography. A mountain breeze and a valley breeze are two related, localized winds that occur one after the other on a daily cycle which also give a contribution to convective activity over the IMC due to IMC is a unique geographical region that 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 storm or MCC in Africa [15].

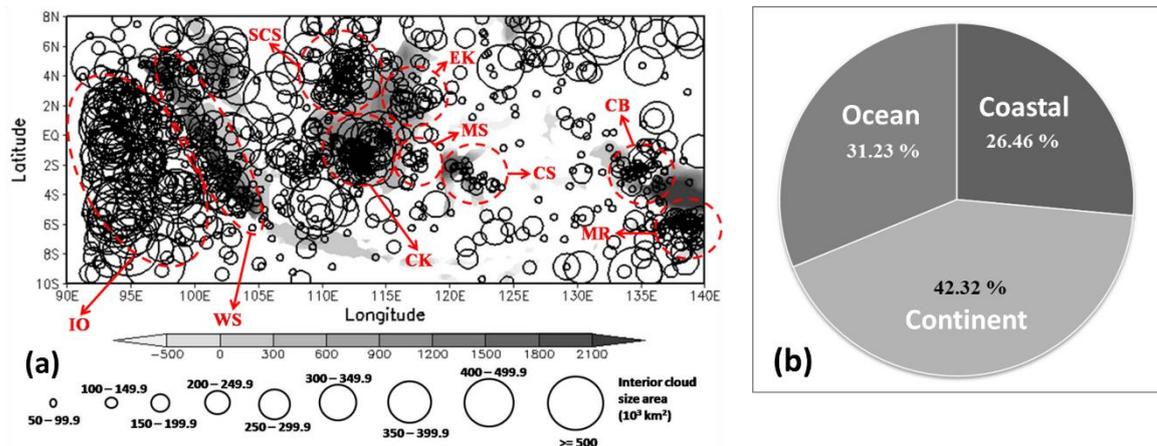


Figure 1. (a) Geographical distribution of the MCCs in the IMC in 15-years (2001-2015). The locations of MCC determined when the interior cloud size area of MCC reach maximum extent. The circles representing the interior cloud size area (10^3 km^2). The red broken line indicated the MCCs concentration region in IO (Indian Ocean), WS (Western Sumatra), SCS (South China Sea), CK (Central Kalimantan), EK (East Kalimantan), MS (Makassar Strait), CS (Central Sulawesi), CB (Cendrawasih Bay), and MR (Merauke). The color shaded refers to the elevation of the unit in meters (m). (b) Percentage of the MCC occurrences over the IMC in 15-years (i.e., 2001-2015) over the ocean, the coastal, and the continent.

The oceanic MCC mostly concentrated over the Indian Ocean, whereas the coastal MCCs concentrated over the Makassar Strait, Cendrawasih Bay, and the South China Sea near Kalimantan Island. Most of the oceanic MCCs concentrated over the Indian Ocean had large interior cloud size over $300,000 \text{ km}^2$ up to $500,000 \text{ km}^2$ since this area contained one of the biggest heat sources as the driving force for the global circulation in the tropics [16]. This area was also one of the regions where deep cumulus convection and heavy rainfall occurred most frequently in the tropics [17]. The oceanic MCCs with large size also occurred in the Pacific Ocean and the Java Sea. Moreover, an oceanic area with the lower MCC occurrences was found in the Molucca Sea and the Banda Sea.

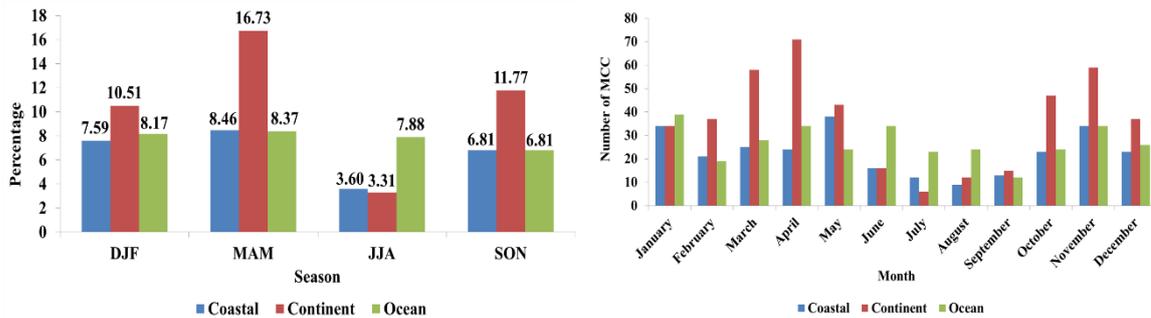


Figure 2. (a) Percentage of the MCC occurrences in coastal, continent and ocean over the IMC in 15-years (2001-2015) for each season in DJF (December, January and February), MAM (March, April and May), JJA (June, July and August), and SON (September, October and November). (b) A total of MCC occurrences over the IMC during 15-years (2001-2015) for each season in coastal, continent and ocean.

This result also supported by previous research, among other i.e., Trismidianto [5] that stated there were many MCC occurrences over the Indian Ocean near Sumatra and Ismanto [4] stated that one of concentration area for oceanic MCC was the Indian Ocean. Moreover, Mori [12] stated that IMC consists of many islands with very long coastlines, many narrow straits control the global (Pacific to Indian) ocean circulation and one of the major contributors to changes in tropical rainfall was the deep convection [18]. Land-sea breeze and mountain breeze play an important role in the tropical precipitation, include IMC so that most of the precipitation in IMC concentrated over the continent than over the ocean [19]. The rainfall outside the coastal region accounts for 52% and 14% on the ocean and the land, respectively. However, on the inside of the coastal region accounts for approximately 34% of the total over the entire tropics [11]. The percentage of MCC occurrences in the IMC was found greater over the continent (42.32%) than over the ocean (31.23%) and over the coastal region (26.46%) (figure 1b). Laing and Fritsch [3] found that most of the MCCs was located in continents (almost of 91%), however, it can occur over oceans.

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 (hereafter DJF) and dry seasons on June, July and August (hereafter JJA), however, there are two transition seasons. i.e., March, April, and May (hereafter MAM) as transition seasons from wet to dry seasons and September, October and November (hereafter SON) as transition seasons from dry to wet seasons. Figure 2a shows the comparison of the coastal, oceanic and continental MCCs, where 7.59%, 10.51% and 8.17% of MCCs occurred in the coastal, continent and ocean during DJF, respectively. The percentage of the MCC occurrence increased in MAM around 8.46%, 16.73% and 8.73% of MCCs found in coastal, continent and ocean, respectively. In contrast, during JJA, most of MCCs occurrence were the oceanic MCC with 7.88% events, while the percentage of the MCC which occurred in the continent and coastal are 3.31% and 3.60%, respectively. The percentage of MCC which occurred in the continent around 11.77% in SON, while the MCC which occurred in the oceanic and coastal have the same percentage around 6.81%.

The frequency of MCC occurrence in the ocean, land and in the coastal per month was shown in Figure 2b. As we can see that the peak of MCC occurrence in the land found in March, April, and November. It was possible due to likely linked to the synoptic-scale environment, which was more baroclinic in nature compared to the late summer months. It was similar to Tyson and Preston-Whyte [20] that stated the peak of MCC activity in southern Africa mostly occurred during the early before summer months. However, the MCC that occurred in the ocean was frequently found in June, July, and August. This result similar to Velasco and Fritsch [21] 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 [22] and in America [23]. The frequency of MCC events in the coastal was frequently found in January, May, and November, but less than the number of the continental MCC in the similar month.

3.2. Morphological characteristics of MCC

Figure 3a shows the greatest interior cloud size of MCC more than $1000 \times 10^3 \text{ km}^2$ occurred in April. The MCC with large size also occurred in March, July, September, and November with interior cloud size area more than $600 \times 10^3 \text{ km}^2$. Moreover, most of the MCC with medium size around $200 \times 10^3 \text{ km}^2$ occurred in July. The MCC with small size most frequently occurred in the land (continent), in contrast, the MCC with the medium and large size are most concentrated over the ocean as shown in figure 3b. The averaged of cloud shield size of MCC over ocean, land and in the coast were $387,865 \text{ km}^2$, $275,880 \text{ km}^2$, and $293,054 \text{ km}^2$, respectively. While the averaged of interior cloud size of MCC over the ocean, continent and in the coast were $188,590 \text{ km}^2$, $122,550 \text{ km}^2$, and $135,720 \text{ km}^2$, respectively. MCC with area size more than $500,000 \text{ km}^2$ frequently occurred in the ocean.

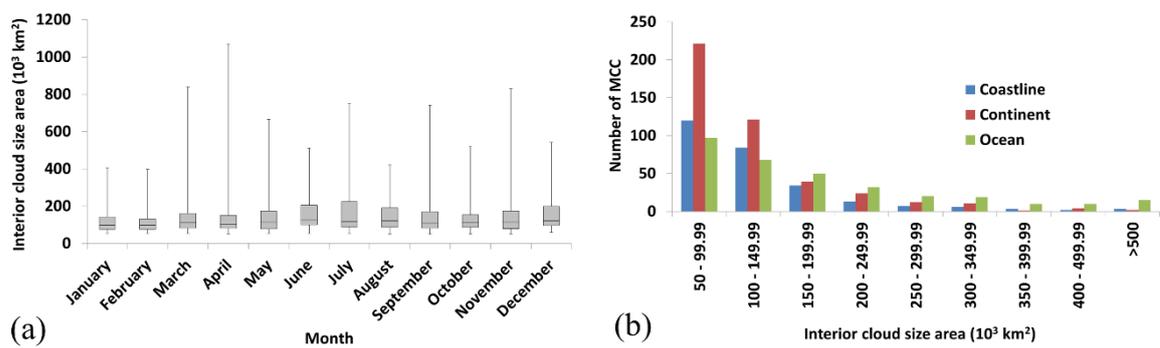


Figure 3. (a) Box and Whisker plot of interior cloud size area of MCC frequency by month during 15-years. (b) Frequency distribution of the MCCs interior cloud maximum area each month during 15-years.

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. Figure 4 displays the distribution of eccentricity at the time of maximum extent during mature stage. 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.

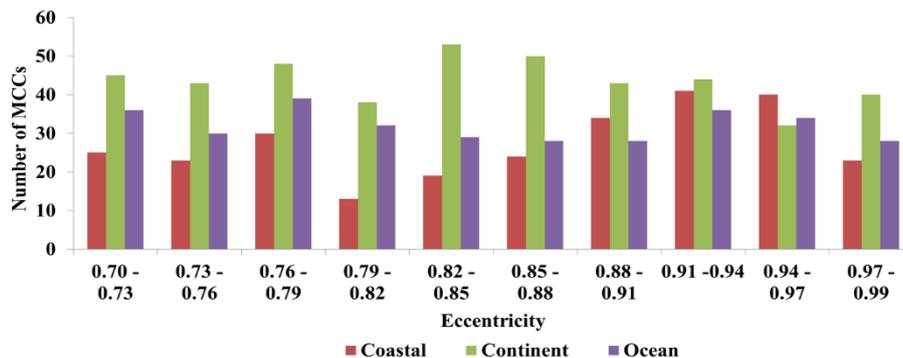


Figure 4. Number of MCC eccentricity at the time of maximum extent during 15-years (2001-2015).

This research found that averaged of eccentricity for all of the MCCs over the IMC was 0.85, with eccentricity averaged for the MCC which occurred in the continental, ocean and in the coast were 0.84, 0.85 and 0.86, respectively. It indicated that majority of MCCs over the IMC was more circular which similar to MCC over the USA [24]. In general, most of the MCCs has eccentricity between 0.91 - 0.94 and between 0.76 - 0.79, most of them occurred over the ocean as shown in figure 4. Most of the MCCs with large eccentricity more than 0.82 found over the ocean, while the majority of the small eccentricity occurred in the coastal region.

3.3. Duration and life-cycle of MCC

Figure 5 shows the comparison of the duration time of MCC which occurred in the continent, coastal, and the oceans. Most of the MCC with duration around 8 - 10 hours occurred on the land. The long-lived MCCs were most frequently concentrated in the ocean, while the short-lived MCCs were most frequently found in the land. Most of the coastal MCCs have duration around 8 -13 hours. This result similar to the global MCCs by Laing and Fritsch [3], where they stated that the oceanic MCCs have been found to be slightly larger and last longer than the continental MCCs. The average duration of the coastal, continental and oceanic MCCs was approximate ~11.5 hours, ~10 hours and ~12.5 hours, respectively. However, this averaged duration less than average for oceanic MCCs in southern Africa (~14 h; [10]).

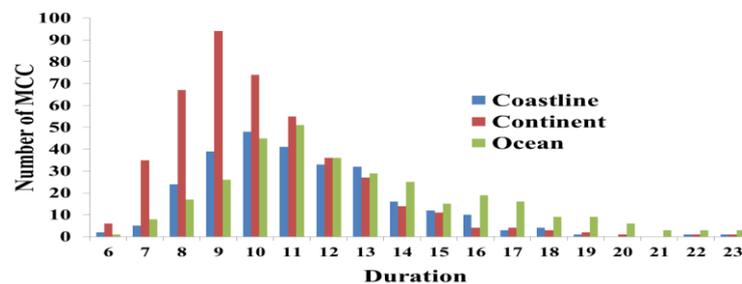


Figure 5. Frequency distribution of duration time of MCCs over the coastal, ocean, and continent during 15-years.

The comparison of MCC life-cycle in the ocean, land and in the coast was shown in figure 6. The MCC which occurred on the coast was usually started in the night to midnight around 1900 - 0000 LT and reached maximum size in the early morning around 0300 - 0700 LT. This system decayed in the morning, several hours after maximum extent, and then dissipated in the afternoon. While the MCC which occurred on the continent was also started in the night. The maximum size of the continental MCC is also predominantly in the early morning, but later than coastal around 0000 - 0400 LT. This system decayed and dissipated in the morning and daytime, respectively. In contrast, the frequency of MCC occurrences in the ocean for initiation, mature, decay and dissipation/post-MCC between 0000 - 0400 LT, 0400 - 0700 LT, 1000 - 1200 LT and 1400 -1800 LT, respectively. It indicated that most of the oceanic MCCs end much later in the morning than the continental MCCs. It is similar with Blamey and Reason [10].

3.4. The evolution of MCC development based on the case studies

The first case study in this research was the continental MCC as shown in figure 7. The MCC occurred on 14 – 15 April 2012 in transition seasons (MAM). Figure 7 shows that the MCC was generated in the Central Kalimantan is triggered by merging of the orographic cloud that migrated southward toward to the MCC area with the other group of the cloud that grew in near the MCC area. At 2100 LT, during the growth stage, this merger cloud expanded southward became grew with the larger size until reaches maximum extent in the midnight (2300 LT). This MCC started decaying in the morning around 0300 - 0700 LT. During decay stage, the new convective system was generated in the surrounding of the MCC area. The MCC was dissipated in the morning at 0700 - 0900 LT, and

then the new convective systems migrated to Sumatra, northern Kalimantan, and Java Island. A few hour after the MCC was dissipated, several cloud system appears over Java, eastern Sumatra, Malaysia and Brunei in northern Kalimantan. It indicated that the new convective systems and squall line induce the other cloud in its surrounding area during migration.

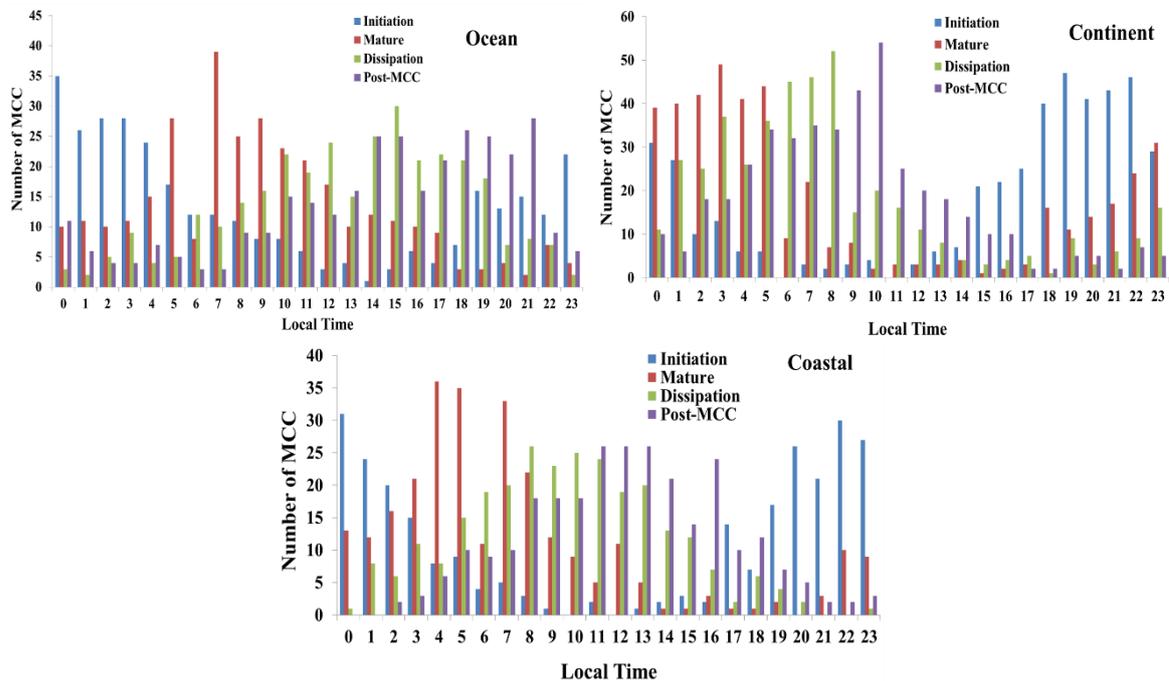


Figure 6. Frequency distribution of the oceanic, continent and coastal MCCs during critical stage (initial, mature, decay and dissipation or post-MCC stage).

The second case study in this research was the oceanic MCC in the Indian Ocean near Sumatra on 27–28 October 2007 and the third case study was the coastal MCC that occurred in the coastal of Sulawesi on 22 - 23 October 2011 as shown in figure 8. The second case study has been analyzed in detail by Trismidianto [7]. MCC in the second case began develops triggered by the cloud from the west and the coastal of the Sumatra in the midnight 0100 LT. The MCC reached maximum size in around the morning. The MCC was decayed and then dissipated in the afternoon. During the MCC dissipated, seem the cloud migrated to the west and predominantly to the east toward over the Sumatra. The MCC in the third case began from the small cloud in the coastline of Sulawesi in the midnight that continues grew rapidly to reaches maximum size in the morning. MCC decayed after several hours and then dissipated in the noon or afternoon. The MCC that occurred over the coastal of the Sulawesi tends to propagate to the Kalimantan Island after the MCC dissipated. It influenced the convective activity and rainfall over the Kalimantan.

This study has found around 1028 MCCs during fifteen years from 2001 to 2015. The greatest frequency of MCC occurrences was found in the continent that reached 42.32% from all events. Most of them were found in the Central Kalimantan. The MCC which occurred in the ocean and coastal was around 31.23% and 26.46%, respectively. The Indian Ocean is the favored region for the oceanic MCCs due to this area is one of the heat sources that interpreted as the driving force for the global circulation in the tropics. There are several favored region for the coastal MCCs. i.e., the coast of western of Sumatra, the South China Sea near the northern of Kalimantan, and the coastal of Merauke. The MCC with small size most frequently occurred in the continent. In contrast, the MCC with the medium and large size was most concentrated over the ocean. The MCC systems are longer lasting in the western Indonesian than in the central Indonesian and eastern Indonesian. Most of the

oceanic MCC concentrated over the Indian Ocean. Most of them have large interior cloud size over 300,000 km² even much going MCC which has a scale of 500,000 km². The majority of MCCs over the IMC was more circular due to the average of eccentricity for all of the MCCs over the IMC are 0.85. The oceanic MCCs are slightly larger and last longer than the continental and coastal MCCs. Almost half of MCC occurrences during MAM occurred on the continent. In contrast, during JJA, most of MCCs occurrences were the oceanic MCC.

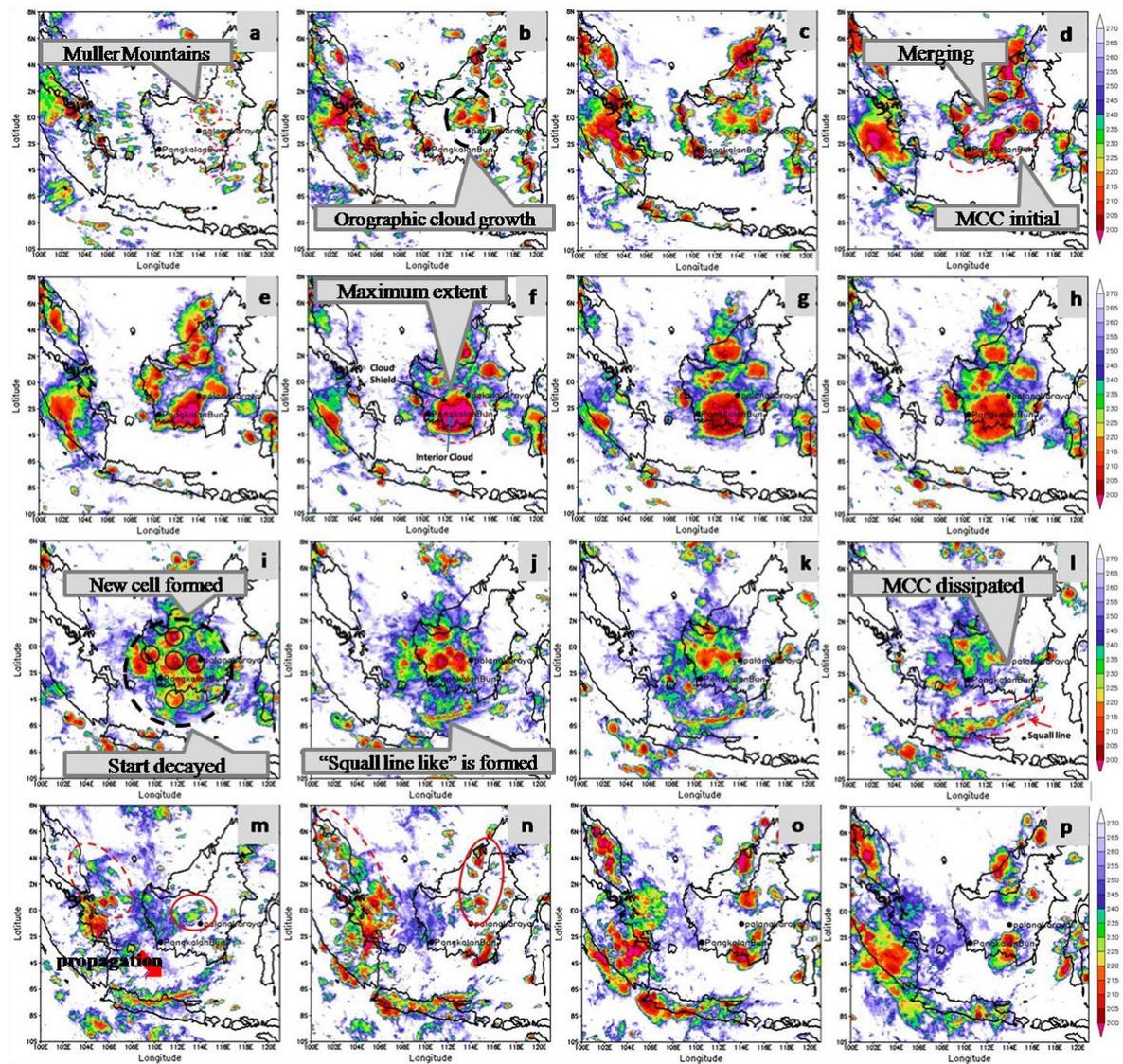


Figure 7. Horizontal distribution of T_{BB} for MCC criteria from infrared data obtained by MTSAT-1R over Kalimantan Island on 14-15 April 2012, showing the eight stages of MCC evolution: (a) MCC-12h or first storm stage (1300 LT), 14 April 2012; ((b),(c)) pre-MCC stage (1500 LT to 1700 LT), 14 April 2012; (d) initial stage (1900 LT), 14 April 2012; (e) growth stage (2100 LT), 14 April 2012; ((f),(g),(h)) mature stage (2300 LT, 0000 LT, 0100 LT), 14 April 2012; ((i),(j) and (k)) decay stage (0300 LT, 0500 LT and 0700 LT), 15 April 2012; (l) dissipation stage (0900 LT), 15 April 2012; (m) post-MCC stage (1300 LT) 15 April 2012; ((n),(o) and (p)), A few hours after MCC occur (1500 LT, 1700 LT and 1900 LT), 15 April 2012. Unit for T_{BB} is Kelvin.

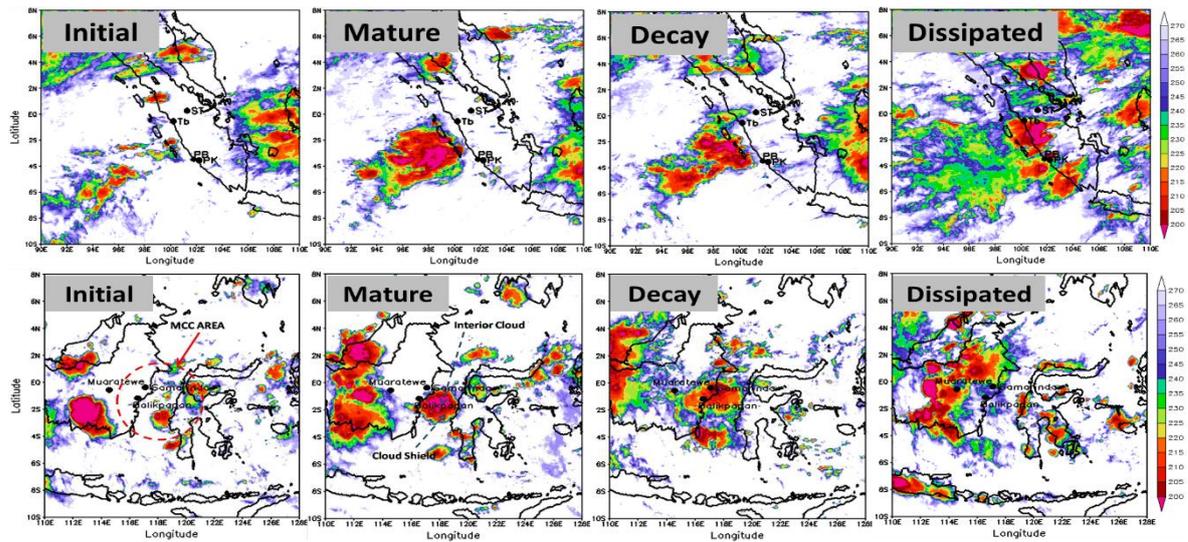


Figure 8. Horizontal distribution of T_{BB} for MCC criteria from infrared data obtained by MTSAT-1R; (Top) over the Indian Ocean near Sumatra on 27–28 October 2007 during initial stage (0100 LT), mature stage (0700 LT), decay stage (1300 LT) and dissipation stage (1600 LT), 28 October 2007. (Bottom) in the coastal of Sulawesi on 22 - 23 October 2011 during initial stage (0100 LT), mature stage (0600 LT), decay stage (1100 LT) and dissipation stage (1300 LT), 23 October 2011. The color indicates T_{BB} with unit Kelvin.

In general, the MCC started to begin occurring in the late afternoon and reached maximum size around midnight before decaying the next morning. The MCC was dissipated from the noon until the afternoon. The characteristics of the evolution of MCC in the coastal and continental was relative similar than the general MCC. In contrast, the oceanic MCC dominantly develops in midnight and reached maximum size in the morning and then MCC decayed and dissipated from noon until afternoon. The evolution of MCC development in the ocean, land and in the coast has almost the same stages and ways. MCC started to develop from the small cloud that continues grew rapidly to reach maximum size and then decayed after several hours. During decay stage, the new convective system was generated in the surrounding of the MCC area, after that, the MCC dissipated. The new convective systems propagated to its surrounding area and influenced the convective activity and rainfall over its surrounding area

4. Conclusion

A total of 1028 MCCs were identified and tracked during fifteen years for the 2001 – 2015 period. The largest frequency of occurrences of the MCC over the IMC was found over the continental (42.32%). While the MMCs frequency over the oceanic and the coastal regions were of 31.23% and 26.46%, respectively. The favored region for development of the continental MCC was found in the Central Kalimantan. The Indian Ocean was the favored region for the oceanic MCCs since this area was one of largest heat sources functioned as the driving force for the global circulation in the tropics. There were several favored regions for the coastal MCCs. i.e., the coastal of western of Sumatra, the South China Sea near the northern of Kalimantan, and the coastal of Merauke. The MCC with small size most frequently occurred over the continent. Meanwhile, the MCC with the medium and large size were most concentrated over the ocean. The MCC systems were longer lasting in the western Indonesian than in the central Indonesian and eastern Indonesian. Most of the oceanic MCC was concentrated over the Indian Ocean with large interior cloud size over 300,000 km² up to 500,000 km². The majority of MCCs over the IMC were more circular due to the average of eccentricity for all of the MCCs over the IMC of 0.85. The oceanic MCCs were slightly larger and

last longer than the continental and coastal MCCs. Almost half of MCC occurrences during MAM occurred on the continent. In contrast, during JJA, most of MCCs occurrences were the oceanic MCC

In general, MCC initiation occurred in the late afternoon or early evening and reach maximum size around midnight before decaying the next morning. The systems dissipated from the noon until the afternoon. The coastal and continental MCC was relative similar than the general MCC. In contrast, the oceanic MCC dominantly developed in midnight, and reach maximum size in the morning and then MCC decayed and dissipated from noon until afternoon. The evolution of MCC development in the ocean, land and in the coast had almost the same stages and ways. MCC development began from the small cloud that continues grew rapidly to reach maximum size, and then decayed after several hours. During decay stage, the new convective system was generated in the surrounding of the MCC area, after that, the MCC dissipated. The new convective systems propagated to its surrounding area and influenced the convective activity and rainfall over its surrounding area.

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