Investigation of Mesoscale Convective Systems over Indonesian Maritime Continent using Geostationary Meteorological Satellite

Yosik Norman\textsuperscript{1,2} and Nurjanna Joko Trilaksono\textsuperscript{3,4}

\textsuperscript{1}Graduate Student of Earth Science, Institut Teknologi Bandung, Indonesia
\textsuperscript{2}Meteorological, Climatological, and Geophysical Agency, Indonesia
\textsuperscript{3}Atmospheric Science Research Group, Institut Teknologi Bandung, Indonesia
\textsuperscript{4}Weather and Climate Prediction Laboratory, Indonesia

E-mail: yosikbrebes@gmail.com

Abstract. Variation of Mesoscale Convective Systems (MCSs) over Indonesian Maritime Continent (IMC) for 5 years in 2010-2014 were investigated using implementation of graph theory with hourly product from geostationary meteorological satellite infrared brightness temperature and Tropical Rainfall Measuring Mission (TRMM) precipitation data. Variations of MCSs are analyzed based on six criteria of convective cloud organization derived from area, duration and eccentricity characteristics. The result shows that monthly average of six types of MCSs in the IMC region forms a bimodal pattern with two peaks at March to May (MAM) and September to November (SON). A statistical analysis exhibit a maximum frequency occurrence of six types of MCSs in the region of equatorial rainfall type, which amount of events up to 40\%, where the greatest contribution concentrated in the Indian Ocean, Sumatra, Kalimantan, Sulawesi, and Papua. Diurnal pattern of MCSs in the IMC shows maturity time of MCSs mostly occurred in the evening to early morning. The typical occurrence of MCSs in this study is different compared to United States and China types, whereas IMC has balanced proportion amounts between linear and circular shape types, while United States and China region were dominated by linear type.

1. Introduction
Indonesian Maritime Continent (IMC) are the region that have influenced by a wide range of severe weather phenomena, such as frequent very heavy precipitation, thunderstorms, gale winds, and hailstorms. Severe weather phenomena produced by frequent convective activity are often associated with mesoscale convective systems (MCSs) \cite{7}. MCS is the organized thunderstorm that vary by the complexity of spatial, eccentricity and temporal characteristics \cite{8}. MCS are very important phenomena because MCSs bring very intense weather and they have greatest contribution to hydrometeorological disaster \cite{8}. Several previous study claimed that IMC is one of the most favourite location of MCSs on the world \cite{11,12,18,22}. Unfortunately, study of MCS over IMC were still limited by several earlier studies such as, \cite{18} were only focusing on the single type of
Mesoscale Convective Complexes (MCC). Spatial and monthly characteristics of Mesoscale Convective Complexes (MCCs), based on [18] results that favou location of MCC are mostly over equatorial region of IMC with the greatest period in transition of monsoon (MAM). Based on [22], MCS are vary by area, over western Sumatra and Western Pacific Ocean is the most occurence location of large connected MCSs. While in Middle of IMC, typical of MCSs are more separated. It is still not enough if characteristics of MCSs are only distinc ted by the complecity of horizontal area. While, in other study [8][21], MCSs are divided by complecity of horizontal area, eccentricity, and duration of the system and they are resulting six criterion of MCS. The six criterion are MCCs, Persistence Elongated Convective Systems (PECS), Meso Beta Circular Convective Systems (M\(\beta\)CCS), Meso Beta Elongated Convective Systems (M\(\beta\)ECS), Small Meso Beta Circular Convective Systems (SM\(\beta\)CCS), and Small Meso Beta Elongated Convective Systems (SM\(\beta\)ECS). Earlier study claimed that other types of MCCs, in region US and China, [8][21] are dominated by linear types with domination up to 80%. Eventhough, IMC are different geographicaly. It is still needed further variations of MCS investigation. In addition, this study is focus on investigating the spatial and temporal characteristics six criterion of MCS over IMC by satellite data. So that, the overarching goals of this study is to determine the original spatial and temporal pattern of six MCSs variation over IMC.

2. Data and Methods
The data in this research are using hourly Infrared (IR) Brightness Temperature (BT) from Himawari geostationary satellites. IR satellite data has spatial resolutions 0.05°×0.05°. and impact of MCS are identified by using precipitation rate data with spatial and temporal resolution 0.25°×0.25° and 3-hourly from Real-Time Tropical Rainfall Measuring Mission’s (TRMM) Multi-Satellite Precipitation Analysis (TMPA-RT) 3B41RT v7 dataset [6]. The length of data was 5 years from January 2010 till December 2014.

| MCS Criterion | Horizontal area and duration | Eccentricity (\(\varepsilon\)) |
|---------------|------------------------------|-------------------------------|
| MCCs          | Interior area BT \(-52^°C\) and cloud shield BT \(-32^°C\) with area minimum \(\geq 50.000\) and duration \(\geq 6\) hours | \(\varepsilon \geq 0.7\) |
| PECSSs        |                              | \(0.2 \geq \varepsilon \leq 0.7\) |
| M\(\beta\)CCSs| Interior area BT \(-52^°C\) and cloud shield BT \(-32^°C\) with developing system area \(\geq 35.000\) \(\text{km}^2\) area maturity \(\geq 50.000\) \(\text{km}^2\) and duration \(\geq 3\) hours | \(\varepsilon \geq 0.7\) |
| M\(\beta\)ECSs|                              | \(0.2 \geq \varepsilon \leq 0.7\) |
| SM\(\beta\)CCSs| Interior area BT \(-53^°C\) and cloud shield BT \(-33^°C\). With developing system area \(\geq 35000\) \(\text{km}^2\) area maturity \(\leq 50000\) \(\text{km}^2\) and duration \(\geq 3\) hours | \(\varepsilon \geq 0.7\) |
| SM\(\beta\)ECSs|                              | \(0.2 \geq \varepsilon \leq 0.7\) |

Variation of six MCSs are identied with automatic algorithm using grab em tag em graph (GTG). Temporal pattern of individual MCS are analyzed by graph theory implementation [20]. This algorithm are written in Python 2.7 programming language. for support fast programming, the algorithm is worked with CPU parallel computation using Python-Networx package on Linux operating system. Threshold of BT in this study are distinc ted by horizontal area criterion [13] which large types such as MCCs and PECSSs are using BT \(\leq -52^°C\) for interior area and cloud shield BT \(\leq -32^°C\). for smaller
types meso $\beta$ and small meso $\beta$ are using $BT \leq -53^\circ C$ for interior area and cloud shield $BT \leq -33^\circ C$. Detail of threshold information are available on Table 1.

3. Results and Discussion

3.1. Case study of MCSs
As the study of [22], MCSs over IMC are frequently merged and splitted. Earlier study found that large scale convective system existed over some region such as Makassar Strait, Sulawesi, Maluku [18]. Although, there are many report from Badan Meteorology, Klimatologi, dan Geofisika (BMKG) where this region are frequently exist of large convective activity. We assume that this information are having lack, it may due to identifitacion method which cannot track the merged and splitted pattern of convective systems. For further investigation. In this study, we imply the automatic method of GTG [20] for identifying MCSs. In this section, to convince that the method can be used for long term period. Firstly, we identify the single MCSs case. Date of case is based on study of [17].

![Figure 1](image)

**Figure 1.** Brightness temperature of single MCCs study 27-28 October 2007 : Initiation, maturation, and termination stage. Location and time of case study are similar to [17]

Figure 1 shows single MCC case over India Ocean - Sumatra (IOS). Some of disassociated clusters are removed by graph spatial temporal based algorithm. Multiple intersected cluster pattern as shown in figure 1 (c) is tracked automatically with implementation graph theory as the nearest graph to time dimension. It can explain the merged and splitted of the system. From this results, GTG method is well worked to catch single large MCS and also it can be implemented for tracking the each grid of precipitation by masking the BT data to the gridded precipitation data, see Figure 2. It seems that MCS are in termination stage by decreasing the precipitation pattern as shown in figure 2 (g).
Figure 2. Same as Figure 1 but for Precipitation inside cluster of MCSs.

Table 2. MCS types and numbers observed from 2010 to 2014

| Type     | MCCs | PECSs | MβCCSs | MβECSs | SMβCCSs | SMβECSs |
|----------|------|-------|--------|--------|---------|---------|
| Total    | 2811 | 2545  | 5197   | 4769   | 2708    | 2639    |

During periods of 2010 to 2014, 20669 MCSs over IMC are identified and classified as shown at table 2. Among all MCSs, 10716 systems are categorized as quasi-circular MCSs (MCCs, MβCCSs, and SMβCCSs) and the rest as elongated MCSs (PECSs, MβECSs, and SMβECSs), indicating that elongated systems account for nearly 51% of the MCSs during the studied period. Moreover, more systems belong to small-scale MCS categories (MβCCSs, MβECSs, SMβCCSs, and SMβECSs) compared to large ones (MCCs and PECSs). There are 15313 systems classified as small-scale convective systems with the greatest contributors are MβCCSs and MβECSs, while numbers of large-scale convective systems are 5356. Frequency of MCSs are very high over IMC. MCSs are not always single case in the particular area. At the same time, more than one different of MCSs can occur simultaneously. As the results of [22] that MCSs over some region such as, Papua, Western Pacific Ocean, and Indian Ocean-Sumatra, Connected MCSs are frequently occurred.

3.2. Spatial distribution of 6-MCSs

Figure 3 shows the all MCSs locations during the 5-yr period. The maximum frequency of location is observed around Indian Ocean - Sumatra (IOS), Kalimantan (KAL), Jawa (JAW), Philipinnes (PLP), Sulawesi (SUL), Australia (AUS), Papua (PAP), and Western Pacific Ocean (WPO).
Figure 3. Locations of MCSs over IMC in 2010-2014: (a) MCCs, (b) PECSs, (c) $M\beta$CCSs, (d)$M\beta$ECSs, (e) SM$\beta$CCSs and (f) SM$\beta$ECSs. The color shading shows the frequency of MCS occurrence in each grid.

MCSs location increases to the equator area. Papua is the most favour location in all MCSs type. Furthermore, MCSs with the same eccentricity type are having the same spatial pattern of MCSs. Quasi-circular are dominating over IOS, KAL, PLP, SUL, PAP, and WPO. Whereas, linear types are JAW, AUS, KAL, PLP, SUL, PAP, and WPO. High frequency location for MCSs are dominant over area of semi-annual rainfall pattern. This area are highly affected by the Inter-Tropical Convergence Zone (ITCZ)
3.3. Monthly distribution of MCSs

Figure 4. Monthly temporal pattern of all MCSs during 2010-2014: (a) Accumulation of MCSs, and (b) Percentage of total each MCS type (%). Note that, different colours on (a) and (b) are the same 6-MCSs type.

Monthly total of 6 MCSs as shown in figure 4 are consistent with total number of MCSs during 5-years. MβCCSs and MβECSs are the most frequent numbers of MCS. This mean that origin of convective systems over IMC are changable in size which can growth fastly in short duration. Annually, MCSs form bimodal pattern with two peaks on March, April, and May (MAM) and September, October, and November (SON). This pattern is considering as the origin of equatorial rainfall pattern [1] which has intensive of total rainfall in transition period of monsoon.

Monthly spatial distributions of MCS during 2012 as shown in figure 5 are consistent to the total period over meridional band. MCSs are centered over lower latitudes such as, IOS, KAL, PAP, and SUL (others year are not shown, technically period of 2012 are representing all of yearly pattern). It convince that the spatial pattern of MCSs are similar with equatorial rainfall spatial pattern. Outside of equatorial rainfall region such as, AUS and JAW, MCSs exists in southern hemisphere summer period on November, December, January, February, and March (NDJF). Whereas, in northern hemisphere such as, PLP and WPO exist on all months. PAP region in this study is the most frequent location of MCSs. Geographically, Papua is mountainous region and surrounded by western pacific warmpool. This condition supports the environment to keep convective activity exist in whole years [4][5].

Area of PLP and WPO are the most frequent location of typhoon. Existance of MCSs over that location are influenced by dynamics pattern of the typhoon. Even, typhoon dates are filtered they are still more frequent exist. IOS region exists large number but the distribution pattern are more spread over whole latitudes. In this study MCSs are dependent to the ITCZ movement. Monthly pattern only inform the background of favour condition related to the large phenomena. This results still need further investigation about characteristics of diurnal occurrence and the dominant shape characteristic over IMC compare to the other region.
Figure 5. Monthly spatial pattern of MCS (2012). Bubble colours are six types of MCS which colours are similar with Figure 4.a. Grey shaded inside of islands are the topograpical pattern.
3.4. Summary of MCS over IMC

The diurnal cycles of MCS occurrences are identical by maturity time of MCS. MCSs can reach maximum extent, and decay at any time of the day. A high frequency of large scale convective systems (MCCs) are reaching the highest frequency of maturity around late afternoon to early morning 18.00-23.00 LST and small scale convective systems are dominantly occurs from late night to morning. other large scale convective systems (PECSs) dominantly occur at afternoon. Mostly diurnal pattern over IMC are reaching the maximum stage at afternoon at coastal area. So we conclude that MCS are highly related to diurnal cycle of rainfall. This results are consistent to [13][21] that MCSs mostly occur as nocturnal phenomena. Dominant eccentricity as shown at figure 6 (d) in this study results balanced proportion between circular $\varepsilon \geq 0.7$ and linear $\varepsilon \geq 0.2$ and $\varepsilon \leq 0.7$ with proportion value is 51% and 49%. Dominant MCSs duration as shown at Figure 6(c) are mostly occurs less than 9 hours with percentage up to 80%. MCSs candidate for this duration are mostly small scale convective systems. Furthermore, In this study, as shown at figure 6 (e) we record precipitation fraction as the interior of MCSs. In this resuls, the most effective of MCSs can reach more than 50% up to 75% of the horizontal area of system with total precipitation reach greater than 700 mm/h up to 1000 mm/h for total grid masking data figure 6 (f).

Figure 6. Summary of total MCS events : (a) Maturity time, (b) Area of MCS, (c) MCSs Duration, (d) Eccentricity of all MCSs, (e) Percentage area precipitation fraction inside MCSs, and (f) Total precipitation of MCSs.
4. Conclusion

MCSs over IMC area are mostly dominated over equatorial rainfall type during transition phase of monsoon period (MAM and SON) with the greatest contributor Indian Ocean - Sumatra, Kalimantan, Jawa, Sulawesi, Papua, Western Pacific Ocean, and Australia. The significant different spatial pattern are divided by two kind of eccentricity which the same pattern of quasi-circular such as MCCs, MβCCSs, and SMβCCSs are frequently exist over Indian Ocean - Sumatra, Kalimantan, Sulawesi, Papua, and Western Pacific Ocean. While linear type such as PECSs, MβECSs, and SMβECSs are the same with quasi circular but more exist over Jawa and Australia. This results are considering that typical of whole type of MCSs over IMC are influenced by dynamics of ITCZ movement. Only region of Northern Australia and Jawa island where are more influenced by southern hemisphere summer. Papua is the most region of number of MCSs over IMC, this result is considering where Papua is surrounded by warmpool pacific region and Papua island is exist of complexes topography. Over that condition area, MCSs are dominantly favour to occur all along the year [5]. MCSs are mostly occured at evening to early morning nocturnal, except PECS (large linear type) at afternoon (12 to 17 LT). This results are indicating that MCS are influenced by diurnal pattern in IMC. The typical occurrence of MCSs in this study is different compared to United States and China types, whereas IMC has balanced proportion amount between linear and circular shape types, while United States and China region were dominated by linear type which the percentage amount is up to 80%.

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