Indonesian Physical Review

Volume 6 Issue 3, September 2023

P-ISSN: 2615-1278, E-ISSN: 2614-7904

Identification of Mesoscale Convective Complex (MCCs) at Southern Papua for The Period of December 2017 – November 2022

Daffa Adhitiansyah[1*], Desak Putu Okta Veanti[2*], Dedi Sucahyono Sosaidi[1], Ahmad Fadlan[1]

[1] *Meteorology Department, State College of Meteorology Climatology and Geophysics (STMKG), Jakarta, Indonesia*

[2] *Climatology Department, State College of Meteorology Climatology and Geophysics (STMKG), Jakarta, Indonesia*

Corresponding Authors E-mail: okta.veanti@stmkg.ac.id

Article Info

Article info:

Received: 20-07-2023

Revised: 25-08-2023

Accepted: 13-09-2023

Keywords:

Mesoscale Convective Complex (MCC); Himawari-8 satellite, rainfall, Papua's weather

How To Cite:

D. Adhitiansyah, D. P. O. Veanti, D. S. Sosaidi, and A. Fadlan, "Identification of Mesoscale Convective Complex (MCCs) at Southern Papua for The Period of December 2017 – November 2022", Indonesian Physical Review, vol. 6, no. 3, p 346-359, 2023.

DOI:

https://doi.org/10.29303/ipr.v6i3.256

Abstract

One factor contributing to rainfall in a certain region is the presence of convective cloud growth. Extensive convective clouds can trigger extreme weather conditions and the occurrence of Mesoscale Convective Complex (MCC) phenomena. MCCs phenomena are characterized by circular cloud cover with eccentricity ≥ 0.7, core cloud area ≥ 50,000 km², cloud cover area ≥ 100,000 km², and cloud top temperature ≤ -52 °C or 221 K. This study aims to identify the spatial and diurnal of MCC in the Southern Papua and for the period of December 2017 to November 2022, as well as to assess its impacts on rainfall during MCC events. Satellite data from Himawari-8 in IR channel was used to analyze MCCs criteria, which were then plotted using a geographic visualization software. Rainfall data in GSMaP was processed using GrADS to display rainfall values. The data processing procedure is carried out using an algorithm based on the study conducted by Maddox. The results of the spatial distribution analysis showed that there were 20 MCC events that occurred during the 5-year period, with dominant growth in inland areas near mountainous and high-topography regions. Seasonally, MCC events predominantly occurred during the MAM period and were least frequent in the JJA period. The diurnal distribution revealed that MCC events had a nocturnal life cycle, forming during the nighttime until early morning. Analysis of the GSMaP rainfall data indicated that the dominant rainfall intensity caused by MCC events was heavy rain (20 – 50 mm/hr).

Introduction

MCC refers to a collection of convective cloud systems that can persist for over six hours, characterized by specific features initially introduced by Maddox in 1980 based on the analysis of infrared (IR) satellite images [1]. A cloud system is classified as an MCC if it has an eccentricity ≥ 0.7, cloud cover area or cloud shield (CS) ≥ 100,000 km², core cloud area or interior cloud (IC) ≥ 50,000 km², cloud top temperature within CS ≤ –32 °C (241 K), and within IC ≤ –52 °C (221 K) [1]. MCCs play a role in about 20% of the overall rainfall across the

Indonesian Maritime Continent (IMC), with the most significant impact observed in Central Kalimantan, the South China Sea, the Indian Ocean, and Papua Island [2].

The MCCs phenomena are a frequently observed events in Indonesia. Based on the geographic and diurnal distribution of MCCs from 2001 to 2015, there were nine regions within the MCI that served as common locations for MCCs growth [3]. These regions encompassed the Indian Ocean near Sumatra Island, the western coast of Sumatra, the South China Sea near Kalimantan, the Central Kalimantan, the Eastern Kalimantan, Makassar Strait near the Kalimantan coastline, the Central Sulawesi, the Cendrawasih Bay, and Merauke. MCCs display distinctive characteristics where the size and duration are significantly influenced by the location of MCCs formation. Research conducted by Trismidianto on the characteristics of MCC formed over land and sea in the MCI indicated that MCC size and lifespan are comparatively smaller over land than those formed over the sea [4].

MCCs can be detected using remote sensing techniques, particularly through weather satellites. Studies on MCCs in Indonesia are often conducted using Himawari-8 satellite imagery. The Himawari-8 satellite is equipped with the Advanced Himawari Imager (AHI) sensor, which features enhanced temporal, spectral, and spatial resolution specifications compared to its predecessor series [5]. Diniyati and Haryanto (2019) and Perdana, et al. (2019) utilized the Himawari-8 satellite to examine MCC event in the Karimata Strait for September 19-20, 2020 and Southern Papua regions for Mei 9, 2018 [6,7]. Then, research by Saragih (2021) investigated the MCC phenomenon in the Makassar Strait on September 4, 2021, utilizing Himawari-8 satellite imagery. The study revealed the presence of MCC cloud cover growing over the Makassar Strait with a lifespan of 8 hours [8].

MCCs can contribute to a significant increase in rainfall, leading to prolonged periods of precipitation in the areas it traverse. Such rainfall can result in various impacts such as floods and landslides [7,9]. Trapp (2013) revealed that MCCs phenomena can lead to severe weather conditions, including tornadoes, hailstorms, and strong winds [10]. The formation of MCC in Cilacap on September 16-17, 2016, also resulted in increased rainfall accompanied by strong winds in the region. Maximum rainfall recorded by Cilacap Meteorological Station is about 108 mm/3 hours during the mature phase [11].

Research on MCCs identification using the Himawari-8 satellite has been conducted in several regions of Indonesia, such as Central Kalimantan by Yulishatin et al. [12] and Papua Island by Saragih et al. conducted only for 1 year [13]. Therefore, we want to extend the study period to 5 years to get more comprehensive understanding about MCC in Southern Papua region using Himawari-8 satellite imagery in the IR channel, as well as its impacts on rainfall over a period of 5 years from December 2017 to November 2022. The northern part of the Southern Papua is dominated by mountainous area, while the southern part are low plateau. The northern part of the South Papua region experiences an equatorial rainfall type, while the northwestern part has a local rainfall type, and its southern part experiences a monsoonal rainfall type [14]. The selection of the research location was based on the high probability of MCCs growth in the Merauke region and its surroundings (Southern Papua), as well as areas with significant MCCs contribution to rainfall [2,3].

Theory and Calculation

MCCs was defined by Maddox using the physical characteristics observable in infrared satellite imagery, particularly in the IR channel. It is categorized as a type of MCS (Mesoscale Convective System), which can be classified based on its distinct physical attributes. Based on the infrared satellite imagery from Maddox's research, the physical characteristics of MCCs are depicted in Table 1 [1] .

Table 1. MCC characteristics observed from infrared channel satellite imagery [1].

Physical characteristics	
Size	A: Cloud shield (CS) with continuously low IR temperature ≤ –32 °C must have an area ≥ 100.000 km² B: Interior cold cloud (IC) region with temperature ≤ –52 °C must have an area ≥ 50.000 km²
Initiate	Size definitions A and B are first satisfied
Duration	Size definitions A and B must be met for a period ≥ 6 hours
Maximum extent	Contigous cold cloud shiel (IR temperature ≤ –32 °C) reaches maximum size
Shape	Eccentricity ≥ 0.7 at time of maximum extent
Terminate	Size definitions A and B no longer satisfied

In the study by Trismidianto, out of a total of 1028 MCC events that occurred in the MCI, the majority of MCCs had a lifespan ranging from 8 to 12 hours [3]. Only 20 MCC events had longer lifespans exceeding 20 hours, while 57 events exhibited MCCs with a lifespan of 6 to 7 hours. Consistent with [3], research by Septiadi & Septiadi indicated that the lifespan of MCCs in Indonesia throughout 2018 ranged from 8 to 15 hours [15]. A study by Rustiana et al. stated that the Indian Ocean Dipole (IOD) can influence the lifespan of MCCs in Indonesia, particularly the negative phase of IOD, which can lead to longer MCC durations [16]. Additionally, the La Niña and El Niño phenomena during the DJF period resulted in a higher frequency of MCC events in MCI compared to the neutral phase, but with smaller MCC sizes compared to MCCs during the neutral phase [17]. Manurung & Mulsandi showed that generally, during La Niña periods, there were more MCC events compared to the neutral phase, with MCCs formation being more active in the northern part of Indonesia than in the southern part [18]. MCCs not only contribute to significant increases in rainfall in the areas they pass through but also affect their surrounding regions [2].

Rainfall is the amount of water that falls onto the Earth's surface or a flat area within a specific period, measured in millimeters (mm). Tjasyono stated that a rainfall measurement of 1 mm indicates the height of rainfall that covers an area without being absorbed into the ground, evaporated into the atmosphere, or drained elsewhere [19]. BMKG categorizes rainfall intensity in Indonesia as shown in Table 2 [20].

Table 2. Rainfall categories according to BMKG [20].

Rainfall intensity	Total rainfall	
	Hourly	Daily
Light	1 – 5	0,5 – 20
Moderate	5 – 10	20 – 50
Heavy	10 – 20	50 – 100
Very heavy	20 – 50	100 – 150
Extreme	> 50	> 150

Experimental Method

The research location for this study was the Souther Papua, spanning coordinates 5° - 9° S and 135° - 141° E (highlighted in the red box in Figure 1) based on research by Trismidianto [3]. The study period encompassed from December 2017 to November 2022.

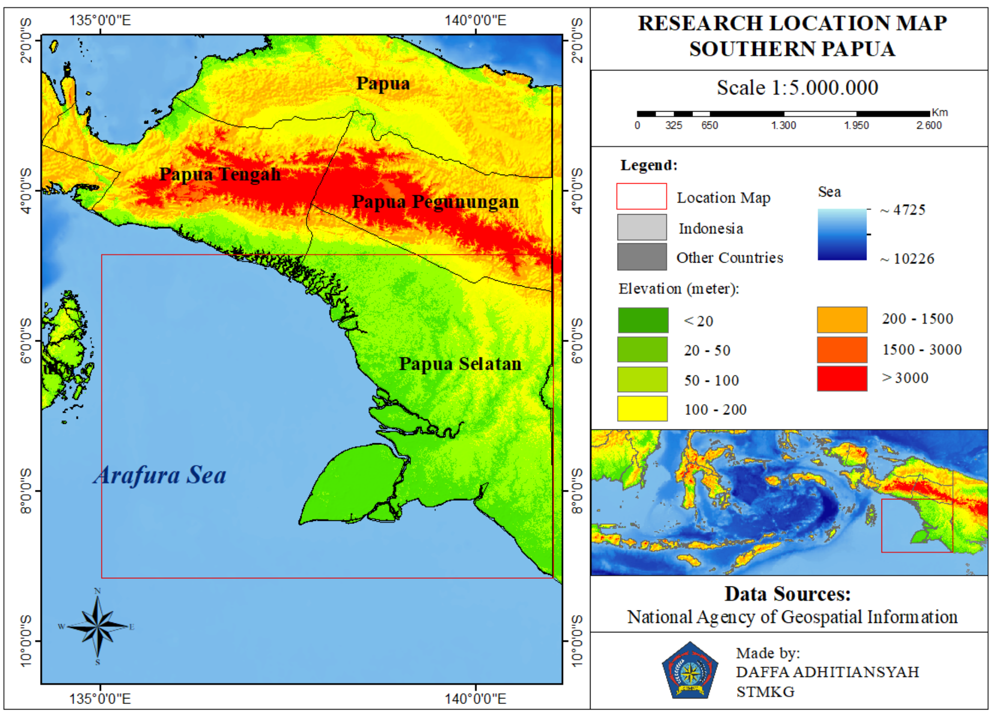

Figure 1. Map of the research location (red box) in Southern Papua.

This study employed Himawari-8 satellite imagery data, band 13, in .nc format, downloaded from ftp://202.90.199.64, with a spatial resolution of 0.02° and hourly temporal resolution. The data covered the period from December 2017 to November 2022 and served as input for data processing. Additionally, GSMaP rainfall data in .nc format with a spatial resolution of 0.1° and hourly temporal resolution, also downloaded from ftp://202.90.199.64 [21], was processed using GrADS to display precipitation values during the maximum MCCs extent phase. The Grid Analysis and Display System (GrADS) is an interactive desktop tool utilized to facilitate convenient access, manipulation, and visualization of data related to earth science [22]. However, data for specific dates (May 8-9, 2018, November 26, 2018, and September 21, 2022) had to be obtained from ftp://hokusai.eorc.jaxa.jp in .dat format due to data limitations. The steps to be taken in this research are depicted in the research flowchart shown in Figure 2.

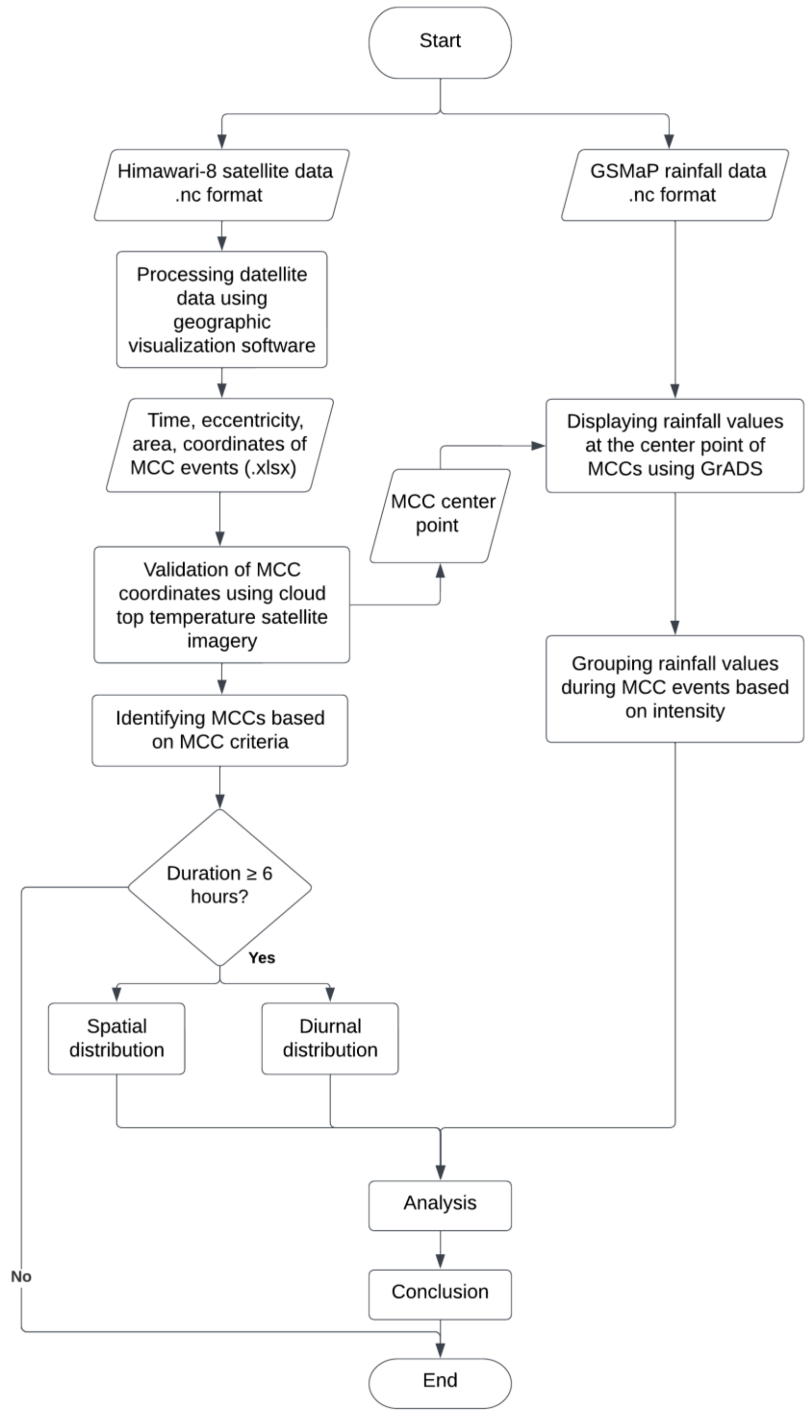

Figure 2. Research flowchart.

The data processing procedures and techniques in this study were conducted as follows:

1. Collecting the necessary data for the research, including Himawari-8 satellite imagery data and GSMaP rainfall data.
2. Processing the Himawari-8 satellite data in .nc format using algorithms tailored to the MCCs criteria based on Maddox's research [1], including:
   a. Selecting the Himawari-8 satellite data to obtain temperatures with CS ≤ -32 °C (241 K) and IC ≤ -52 °C (221 K).
   b. Performing area selection based on CS ≥ 100,000 km² and IC ≥ 50,000 km².
   c. Determining the center point of the selected area using the mass-weighted centroid formula based on Carvalho & Jones [23]:

$$X_0 = \frac{\sum_i^N X_i}{N} \text{ and } Y_0 = \frac{\sum_i^N Y_i}{N} \tag{1}$$

   where X_0 = center (longitude) and Y_0 = center (latitude), X_i = the I-th pixel on the X-axis, Y_i = the I-th pixel on the Y-axis, and N = area or total pixels.
   d. Defining the area with an eccentricity value more than ≥ 0.7 for MCCs phenomena. The eccentricity value indicates the elongation level of the cloud system.
3. Validating the location of IC center point from the output of MCC identification using satellite image visualizations through Satellite Animation and Interactive Diagnosis (SATAID). SATAID comprises CAL software designed for MS-Windows, allowing the utilization of diverse meteorological data emphasizing satellite images, numerical weather prediction (NWP) outputs, observational findings, and data [24]. Validation was performed by comparing the contour features of cloud top temperatures to identify the minimum cloud top temperature during MCC events. This validation aimed to ensure the coherence between the MCCs coordinate data processed in Step 2 and the satellite images from SATAID.
4. If the above criteria were met, plot the spatial distribution of MCCs for each season (DJF, MAM, JJA, SON) using ArcGIS to create maps [3].
5. Creating diurnal distribution graphs of MCCs. The diurnal distribution graphs were based on the MCC life cycle phases: initiation, maturity, and dissipation. The time periods were grouped into 6 intervals of 4 hours each: 00–03 UTC (09-12 LT), 04–07 UTC (13-16 LT), 08–11 UTC (17-20 LT), 12–15 UTC (21-00 LT), 16–19 UTC (01-04 LT), and 20–23 UTC (05-08 LT) [3].
6. Processing GSMaP rainfall data in .nc format using GrADS to display the precipitation values at the center points of MCCs during the maximum extent phase. The rainfall data would be classified based on rainfall intensity values (mm/hour) provided by BMKG [20] and presented in graphs for all MCC events and for each season.

Result and Discussion

The analysis of Himawari-8 satellite data using geographic visualization software indicated that there were a total of 20 MCC events observed in the Southern Papua from December 2017 to November 2022. Throughout the year 2018, there were 3 occurrences of MCC; in the year 2019, there was 1 MCC event; in the year 2020, there were 3 MCC events; in the year 2021, there were 5 MCC events; and in the year 2022, there were 8 MCC events (Figure 3).

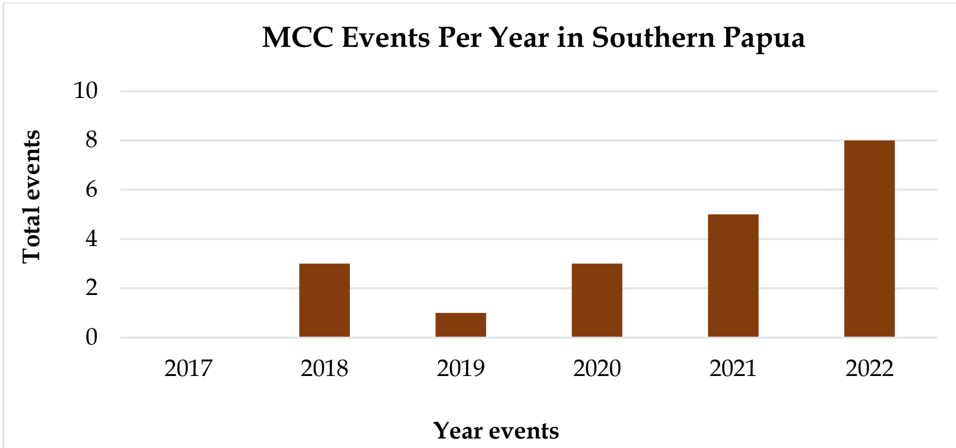

Figure 3. Distribution of MCC events per year in the South Papua region for the period of December 2017 – November 2022

The average core area of MCC events in the Southern Papua is 96,114.2 km². The maximum core area recorded was 234,133.499 km² on May 9, 2018, at coordinates 7.12° S and 138.32° E. Meanwhile, the minimum core area observed was 50,220.39 km2 on March 12, 2021, at coordinates 3.94° S and 137.66° E. The average eccentricity value for all MCC events during the 5-year period is 0.87, with a minimum value of 0.71 and a maximum value of 0.99. The average extent of the MCC's cloud cover is 161,649 km². The largest extent observed was 283,139 km², while the smallest extent occurred on December 26, 2018, measuring 101,456 km². The MCC's life cycle varies depending on the season, with the DJF and SON periods lasting from 21-12 LT, the MAM period from 21-16 LT, and the JJA period from 21-08 LT (Table 3).

Table 3. Characteristics of MCC in the Southern Papua for the period of December 2017 to November 2022. Inside the bracket is the range of the data.

Events periode	SpatialDistribution				Diurnal Distribution	
	Number of events	Eccentricity	Core area (km²)	Shield area (km²)	Life cycle (LT)	Duration (hour)
DJF	4	0,913 (0,73-0,99)	100.400 (51.132-151.036)	171.315 (114.600-234.148)	21–12	8,5 (6-11)
MAM	9	0,874 (0,73-0,99)	95.382 (50.220-234.133)	154.470 (101.618-283138)	21–16	8 (6-11)
JJA	2	0,918 (0,81-0,99)	120.406 (80.771-148.251)	213.112 (167.846-254.793)	21–08	7,5 (7-8)
SON	5	0,830 (0,71-0,97)	84.495 (52.714-150.888)	146.929 (101.456-215.110)	21–12	7,8 (6-9)

Spatial Distribution of MCCs

The seasonal distribution of MCC events over a 5-year period indicates that MCCs predominantly occurs during the MAM period, with a total of 9 occurrences, while the fewest events occur during the JJA period, with 2 occurrences. In the DJF period, there were 4 occurrences, and in the SON period, there were 5 occurrences (Figure 4). This aligns with MCCs population in MCI over a span of 15 years, which revealed that MCC events are most frequent during the MAM period (early transition season) with a percentage of 33.56%, while the least number of MCC events occur during the JJA period (dry season) with a percentage of 14.79% [3]. Septiadi & Septiadi's study on MCCs in MCI throughout 2018 also indicated that 83% of MCC events occurred during the MAM and SON periods, while 17% of MCC events occurred during the DJF period based on 6 MCC events in that year [15].

In terms of location, there were 14 MCC events that occurred on land, while 6 MCC events occurred at sea (Figure 4). The majority of MCC events were concentrated in the northern part of research location, which is characterized by mountains and high topography. The presence of onshore winds carrying moisture towards the land, encountering mountains acting as barriers, further induces the upward movement of air, enhancing the convective processes. This process usually takes place during the night. This observation is consistent with the formation of MCC in the MCI region, where a larger proportion of MCC events (42.32%) occurred on land compared to those at sea (31.23%) and in coastal areas (26.46%) [4]. These MCC events predominantly occurred in inland areas, particularly near mountains, which exhibit similar characteristics to the population distribution in MCI [3].

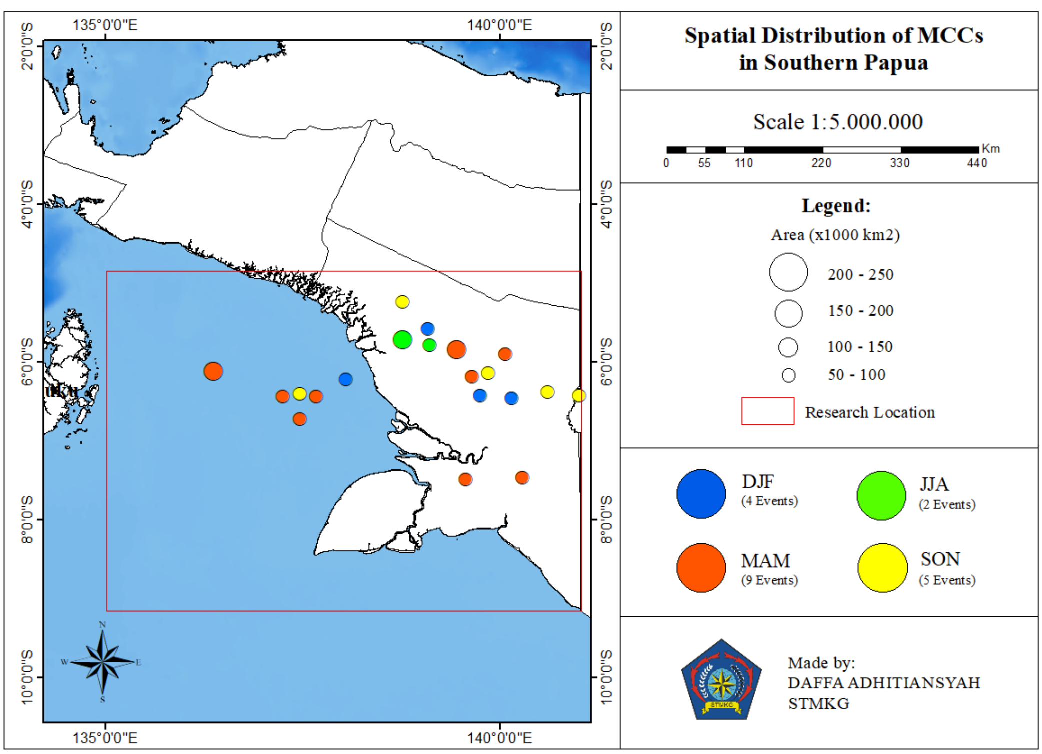

Figure 4. Spatial distribution of MCCs in Southern Papua from December 2017 to November 2022.

Diurnal Distribution of MCC Events

The diurnal distribution of all MCC events over the 5-year period indicates that the initiation phase of MCC occurs during the night until early morning (21-08 LT), reaches its peak phase around midnight until early morning (21-08 LT), and then enters the decay phase during the morning until noon (05-16 LT) (Figure 5). The average duration of an MCC event within one cycle is 8 hours.

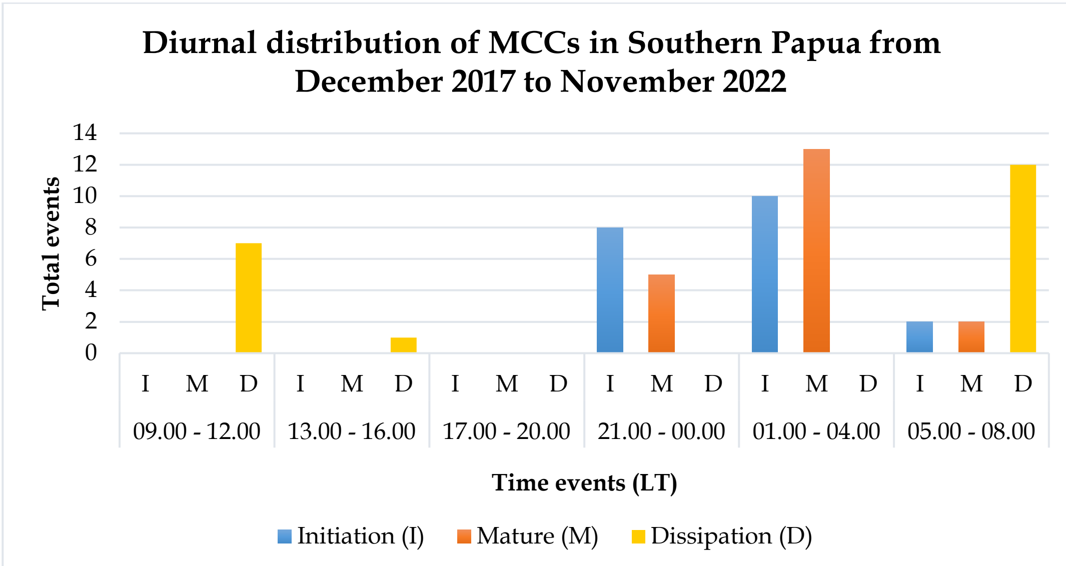

Figure 5. Diurnal distribution of MCCs in Southern Papua from December 2017 to November 2022.

In terms of seasons, the diurnal distribution pattern of MCC events remains relatively consistent across each period, but the average duration of MCC events varies. Specifically, during the DJF period, the average duration is 8.5 hours, during MAM it is 8 hours, during JJA it is 7.5 hours, and during SON it is 7.8 hours (Figure 6). This is aligns to Trismidianto's research [3] indicates that MCC events in the MCI region generally have a lifespan ranging from 8 to 12 hours. MCC formation typically occurs in the late afternoon to evening, reaching its peak phase during the night until early morning, and experiencing decay from morning to noon in the MCI region [15]. The convective process generally initiates in the late afternoon, while the air cooling process becomes more intensive during the night. This is why phenomena like MCCs which require more time to mature, typically happening during the nighttime. The nocturnal life cycle of MCC events in the MCI region, characterized by growth in the late afternoon to evening, a peak after midnight, and dissipation shortly after morning [3].

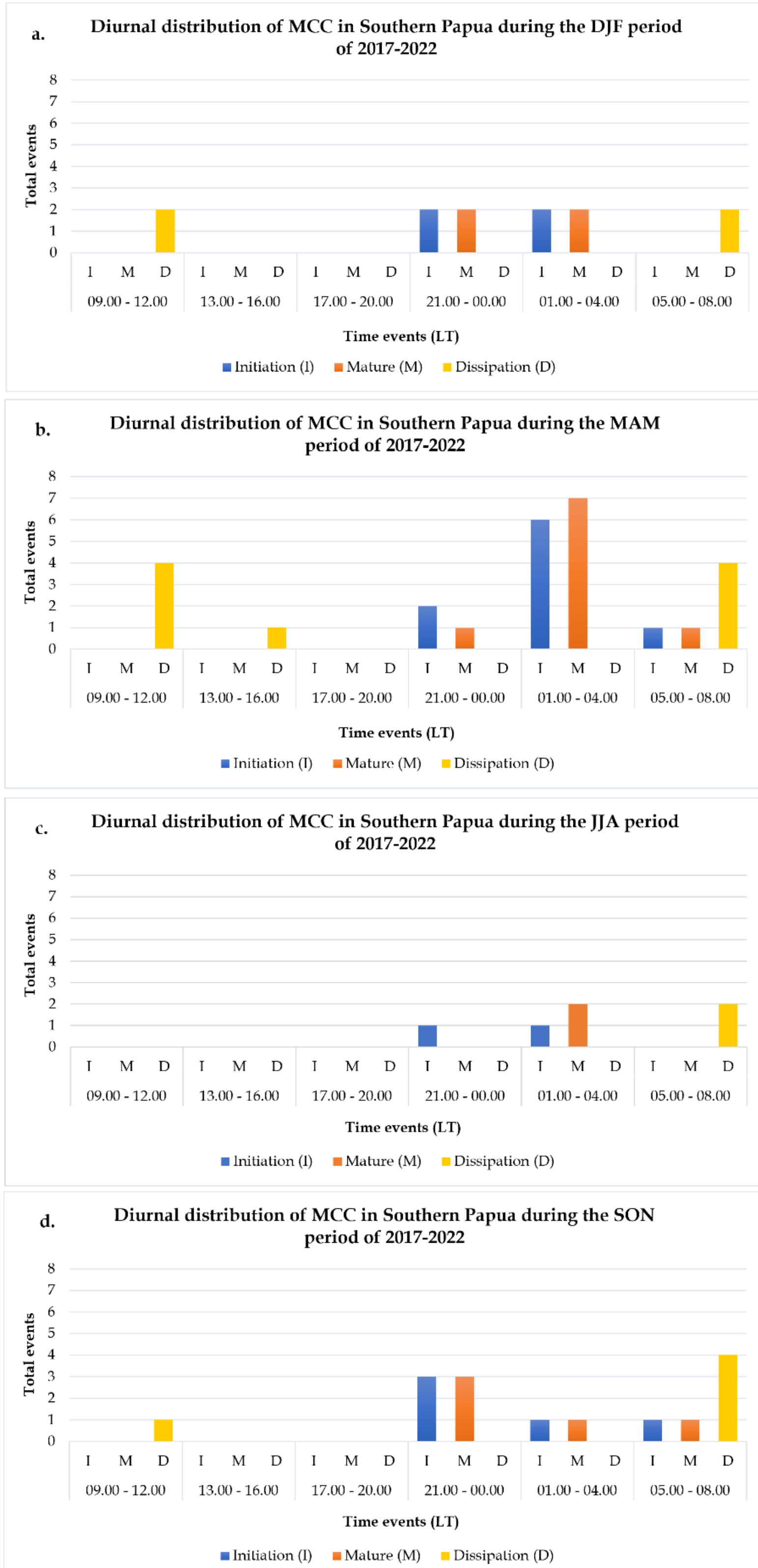

Figure 6. Diurnal distribution of MCCs in Southern Papua December 2017 to November 2022 for: (a) DJF; (b) MAM; (c) JJA; (d) SON.

Rainfall Distribution of MCC Events

Out of the total 20 MCC events that occurred in Southern Papua from December 2017 to November 2022, the majority of them were associated with heavy rainfall, accounting for 7 events. Additionally, there were 5 events with moderate rainfall and 4 events with very heavy rainfall. On the other hand, occurrences of light and extreme rainfall were relatively less frequent, with 2 events each (Figure 7).

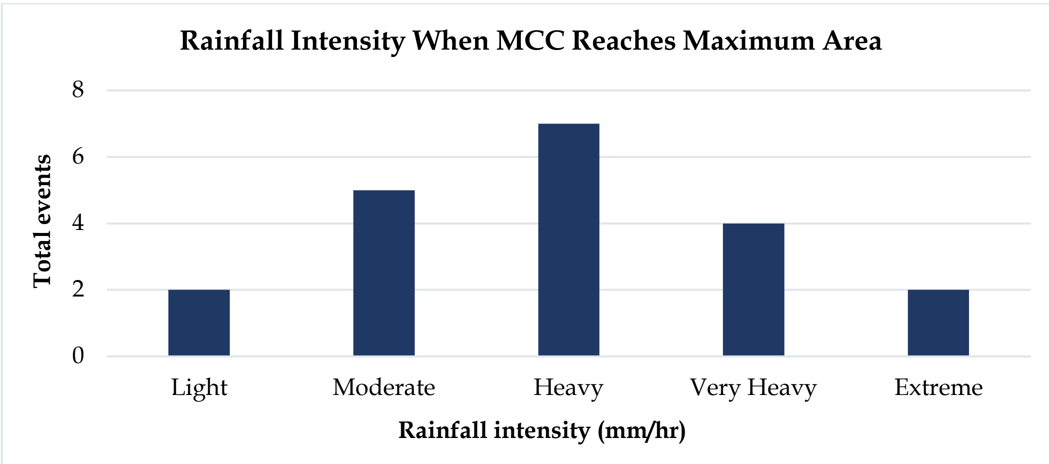

Figure 7. Rainfall distribution during MCC events in Southern Papua from December 2017 to November 2022.

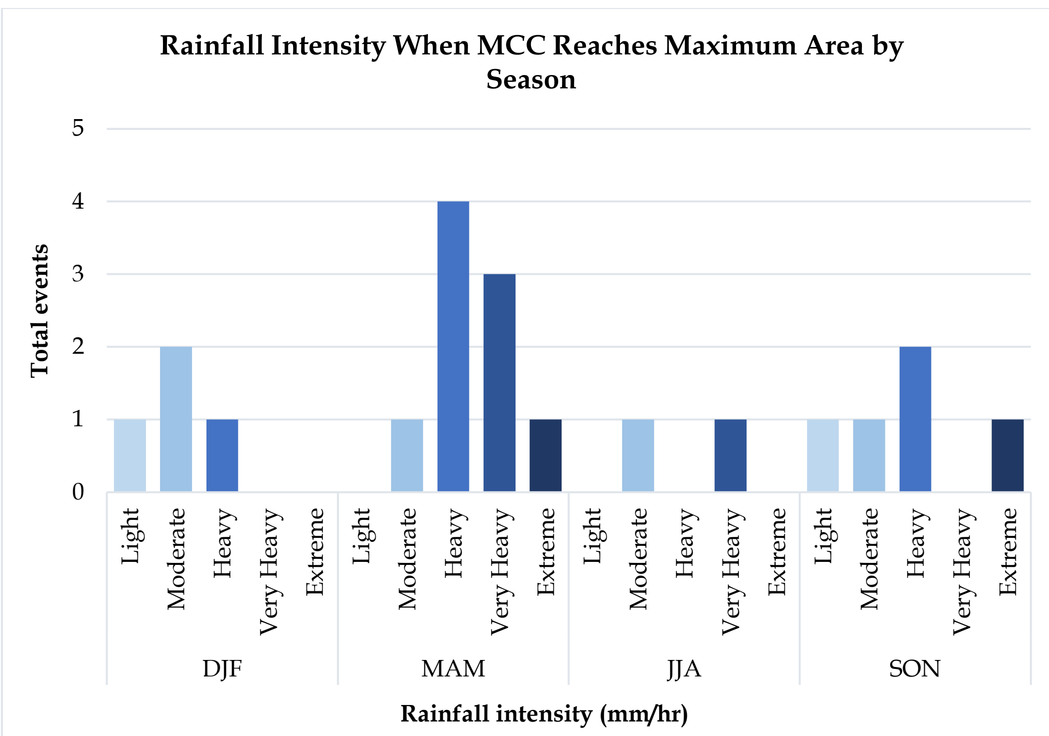

Figure 8. Rainfall distribution during MCC events in Southern Papua from December 2017 to November 2022 by season.

Trismidianto [2] stated in their study that MCC events in the MCI region contribute over 20% to the overall precipitation, with a specific range of 14-18% for the Merauke area (Southern Papua). However, the study did not mention the specific rainfall intensities attributed to MCC events. Regarding the seasonal pattern, MCC rainfall made the largest contribution during the MAM period, followed by SON (Figure 8). The highest rainfall contribution in the MCI region occurs during the MAM period, accounting for approximately 16-20% in the vicinity of Southern Papua.

Conclusion

The spatial distribution of MCC events reveals that there were 20 occurrences of MCC growth during December 2017 to November 2022, with a predominant growth pattern observed in inland areas near mountains and high topography compared to coastal regions. MCC events were most frequent during the MAM period and least frequent during the JJA period. The diurnal distribution of MCC events shows that over the 5-year period, MCC formation primarily occurred during the night to early morning hours at 21.00 – 08.00 LT (nocturnal life cycle) and dissipated during the morning to afternoon hours at 05.00 – 16.00 LT. The average lifespan of MCC events within one cycle was 8 hours, with the longest average lifespan observed during the DJF period at 8.5 hours and the shortest average lifespan during the JJA period at 7.5 hours. The dominant intensity of rainfall resulting from MCC events was heavy rainfall (20 – 50 mm/hr). Seasonally, the frequency of heavy to very heavy rainfall predominantly occurs during the MAM and SON seasons rather than DJF and JJA.

Acknowledgment

Thanks to the State Collage of Meteorology, Climatology and Geophysics (STMKG) and Meteorology, Climatology, and Geophysics Agency (BMKG) for the availability of data that we used in this research.

References

[1] R. Maddox, "Mesoscale Convective Complexes," *Bull. Am. Meteorol. Soc.*, pp. 1374–1387, 1980.

[2] Trismidianto, E. Yulishatin, H. Satyawardhana, J. T. Nugroho, and S. Ishida, "The Contribution of the Mesoscale Convective Complexes (MCCs) to total rainfall over Indonesian Maritime Continent," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 755, no. 1, 2017, doi: 10.1088/1742-6596/755/1/011001.

[3] Trismidianto, "The Global Population of Mesoscale Convective Complexes (MCCs) over Indonesian Maritime Continent during 15 Years," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 166, no. 1, 2018, doi: 10.1088/1755-1315/166/1/012040.

[4] Trismidianto, "Characteristics of the oceanic MCC, continental MCC, and coastal MCC over the Indonesian maritime continent," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 149, no. 1, 2018, doi: 10.1088/1755-1315/149/1/012024.

[5] D. Kushardono, "Kajian Satelit Penginderaan Jauh Cuaca Generasi Baru Himawari 8 dan 9," *Pus. Teknol. dan Data Penginderaan Jauh – Lemb. Penerbangan dan Antariksa Nas.*, vol. 3, no. 5, p. 48, 2012.

[6] E. Diniyati and Y. D. Haryanto, "Identifikasi Fenomena Mesoscale Convective System

(MCC) di Selat Karimata," *KELUWIH J. Sains dan Teknol.*, vol. 2, no. 2, pp. 103–111, 2021, doi: 10.24123/saintek.v2i2.4541.

[7] I. F. P. Perdana, Y. I. Rismana, F. A. Prasetya, and A. Mulsandi, "Studi Kejadian Mesoscale Convective Complex (MCC) di Wilayah Papua Bagian Selatan Pada 9-10 Mei 2018," *J. Meteorol. Klimatologi dan Geofis.*, vol. 6, no. 1, pp. 58–66, 2019, doi: 10.36754/jmkg.v6i1.115.

[8] R. W. Saragih, "Identifikasi Karakteristik Mesoscale Convective Complex (MCC) di Selat Makassar," *J. Ilm. Giga*, vol. 24, no. 2, p. 55, 2021, doi: 10.47313/jig.v24i2.1395.

[9] D. E. Nuryanto, H. Pawitan, R. Hidayat, and E. Aldiran, "Propagation of Convective Complex Systems Triggering Potential Flooding Rainfall of Greater Jakarta Using Satellite Data," *J. Phys. Conf. Ser.*, vol. 755, no. 1, 2016, doi: 10.1088/1742-6596/755/1/011001.

[10] R. J. Trapp, *Mesoscale-Convective Processes in the Atmosphere*. Cambridge University Press, 2013.

[11] L. F. Aiqiu, A. Zakir, and Trismidianto, "Analysis of Mesoscale Convective Complex during Madden Julian Oscillation Phase 4 (Case Study: Heavy rain in Cilacap on Sept 16-17, 2016)," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 303, no. 1, 2019, doi: 10.1088/1755-1315/303/1/012063.

[12] E. Yulishatin, H. Satyawardhana, and S. Ishida, "A Composite Analysis of The Mesoscale Convective Complexes (MCCs) Development Over The Central Kalimantan and Its Relation with The Propagation of The Rainfall Systems," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 755, no. 1, 2017, doi: 10.1088/1742-6596/755/1/011001.

[13] R. W. Saragih, J. D. Malago, and Subaer, "Identifikasi Karakteristik Mesoscale Convective Complex (MCC) di Wilayah Papua dan Sekitarnya," vol. 12, no. 2, pp. 42–54, 2022.

[14] BMKG, *Pemutakhiran Zona Musim Indonesia Periode 1991-2020*. 2022.

[15] D. Septiadi and Y. N. Septiadi, "Identifikasi Mesoscale Convective Complex (MCC) dan Dampaknya terhadap Curah Hujan di Benua Maritim Indonesia (BMI) Sepanjang Tahun 2018," *J. Meteorol. dan Geofis.*, vol. 20, no. 2, p. 73, 2020, doi: 10.31172/jmg.v20i2.645.

[16] S. Rustiana, Trismidianto, and H. Satyawardhana, "The Influence of ENSO and IOD during Mesoscale Convective Complex (MCC) to Rainfall in Indonesia," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 303, no. 1, 2019, doi: 10.1088/1755-1315/303/1/012006.

[17] Trismidianto and H. Satyawardhana, "Mesoscale Convective Complexes (MCCs) over the Indonesian Maritime Continent during the ENSO events," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 149, no. 1, 2018, doi: 10.1088/1755-1315/149/1/012025.

[18] E. V. I. Manurung and A. Mulsandi, "Analisis Mesoscale Convective Complex (MCC) di Benua Maritim Indonesia saat Tahun La Nina Kuat," *J. Meteorol. Klimatologi dan Geofis.*, 2015.

[19] B. Tjasyono, *Klimatologi*, 2nd ed. Bandung: Institut Teknologi Bandung (ITB), 2004.

[20] BMKG, "SOP Pengelolaan Informasi Peringatan Dini Cuaca Ekstrem Nowcasting dan

Mekanisme Koordinasi ketika Terjadi Bencana Akibat Cuaca Ekstrem," 2020.

[21] T. Kubota *et al.*, "Global precipitation map using satelliteborne microwave radiometers by the GSMaP project: Production and validation," *Int. Geosci. Remote Sens. Symp.*, vol. 45, no. 7, pp. 2584–2587, 2006, doi: 10.1109/IGARSS.2006.668.

[22] P. Tsai and B. E. Doty, "A Prototype Java Interface for the Grid Analysis and Display System (GrADS)," *Fourteenth Int. Conf. Interact. Inf. Process. Syst.*, 1998.

[23] L. M. V. Carvalho and C. Jones, "A satellite method to identify structural properties of mesoscale convective systems based on the maximum spatial correlation tracking technique (MASCOTTE)," *J. Appl. Meteorol.*, vol. 40, no. 10, pp. 1683–1701, 2001, doi: 10.1175/1520-0450(2001)040<1683:ASMTIS>2.0.CO;2.

[24] JMA, "SATAID Data." https://www.data.jma.go.jp/mscweb/en/himawari89/space_segment/sample_sataid.html# (accessed on August 19, 2023).