# IDENTIFICATION OF TROPICAL SQUALL LINE USING INFRARED CHANNEL HIMAWARI-8 SATELLITE IMAGERY (CASE STUDY OF 6-7 DECEMBER 2020 IN THE INDIAN OCEAN)

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**ABSTRACT**

Tropical squall line is a linear type of Mesoscale Convective Systems (MCS) phenomenon. They have regions of both convective and stratiform precipitation. In some cases, the stratiform region of tropical squall also occurs the middle-level vortex, and may contribute to tropical cyclone development. Therefore, the identification of that phenomenon is important. However, the identification of MCS needs observational data which has high time resolution. The next generation of MTSAT satellites (Himawari-8) with better spatiotemporal resolution can be utilized in this study. This study aims to identify the characteristics of cloud line identified as the tropical squall line that occurs in the Indian Ocean south of West Java on December 6-7, 2020 using Himawari-8 Infrared (IR1) satellite imagery. Satellites data are processed using an algorithm adapted to the MCC Maddox criteria. The Maddox criteria describes tropical squall line identified by area coverage of cloud shield more than 100.000 $Km^2$ and area coverage of interior cold cloud more than 50.000 $Km^2$. Furthermore, a subjective interpretation is carried out on the data based on the criteria from previous studies. The result shows that the tropical squall occurred for 19 hours with the initial type of formation as an intersecting convective band and propagating west to southeast around 108.2°E 9.9°S. In the mature stage, the precipitation regions develop an asymmetric pattern and shows a vortex (Mesoscale Convective Vortices) that forms inside the stratiform region. The rainfall distribution using the GSMaP model shows a category of heavy rain exceeding 10 mm per hour.

**Keywords:** Himawari-8, tropical squall line, mesoscale convective vortices

## 1. Introduction

Mesoscale Convective Systems (MCS) is a group of Cumulonimbus (CB) clouds that are organized to produce an area of precipitation in one direction at least 100 km long [1]. According to the physical characteristics, organization, and location of occurrence, MCS with 250-2500 km length and time scales > 6 hours divided into two main types: Linear and Circular [2]. Furthermore, Maddox [2] divides the linear type of MCS into two types: squall line that occurs in the midlatitude and tropical squall which occurs in tropical regions.

There are four stages of the MCS life cycle: formative, intensive, mature, and decay [3]. The precipitation structure of MCS observed by Leary and Houze [3] generally refers to the linear type; squall line which has a line of convective and stratiform precipitation area [4]. The convective precipitation line developed a group of clouds in the shape of an arc, convex towards the leading edge, the orientation of the lines is generally northeast-southwest, moving rapidly to the east and or south (>10 $ms^{-1}$), and in the form of elongated cells oriented 45 – 90◦ with respect to the line. Meanwhile, the stratiform precipitation region is characterized by an extensive cloud area (> $10^4$ $km^2$ in horizontal area) and concave on the back edge [5]. Furthermore, based on research during heavy rain events over 6 years in Oklahoma [5], two prominent patterns of MCS linear precipitation structures at the mature stage were identified: symmetric (figure 1a) and asymmetric (figure 1b).

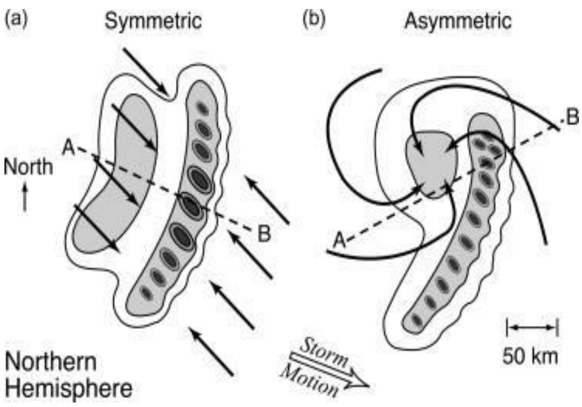


**Figure 1. Precipitation structure of MCS linear in Northern Hemisphere, (a) shows the symmetric pattern and (b) shows the asymmetric pattern [5].**

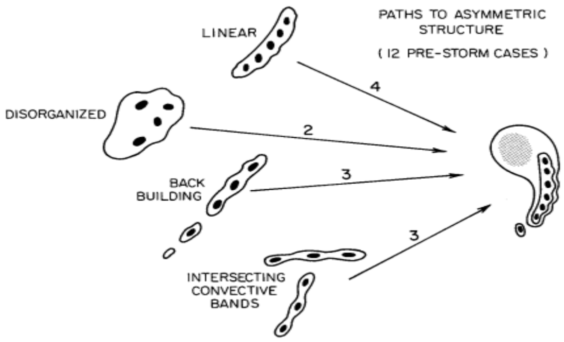


**Figure 2. The evolution of 12 MCS cases on their PRE-STORM Stages that changed into an asymmetric pattern during 1985 was observed by Loehrer & Johnson [6] and the scheme made by Hilgendorf & Johnson [7].**

The discovery of Houze et al. [5], was extended by Loehrer and Johnson [6]. They found that among identified MCSs on stage PRE-STORM, 75% of them evolved from originally varied structures to an asymmetric pattern during their mature stages. Four modes of the initial shape were identified: linear, back-building, disorganized, and intersecting convective bands (Figure 2) [6], [7]. The tendency to evolve became an asymmetric structure is influenced by two main factors: 1) the Coriolis force acting on the ascending front-to-back flow in the convective line, rotating northward towards the stratiform region, and 2) the Coriolis force acting on back-to-front flow on the surface cold pool, directs cold air to the south and produces new cells that are usually at the southern end of the line [7], [8]. The Coriolis force arouses vortex formation called Mesoscale Convective Vortices (MCV) in the asymmetric structure. MCV is a low-pressure cyclonic vortex with a warm core that develops within the MCS stratiform area. Using IR satellite imagery, the MCV moved around 700-500 mb and has a horizontal diameter of 50-100 km [9], [10].

The development of MCV in the stratiform region of an MCS was first noticed in tropics [4]. However, it is more common in the midlatitudes MCSs [11]. Zhang and Fritsch [12] pointed out that a middle level MCV can develop in mature and later stages of MCC. Some previous studies have been suggested that the MCV in the stratiform region evolves into a deep tropical cyclone circulation [13], [14]. Bister and Emanuel [15] proposed that when the cooling-induced MCV extended low enough, it might develop into a tropical cyclone by combining with the boundary layer as a tropical cyclone seed. However, the mechanism by which the developing cyclone builds downward and connects with the surface layer remains unclear. Therefore, identification of this phenomena is important to understand the characteristics of tropical squall line that may contribute into tropical cyclone development.

The characteristic of the tropical squall line in Indonesia has an area of about 100 km and a lifetime of about 6 hours [16]. This characteristic causes tropical squall lines to be difficult to identify only with surface observation data. Therefore, meteorological satellites with high spatial and temporal resolution will be able to identify that phenomenon clearly. Himawari-8 is one of the geostationary satellites which has high time resolution and advanced spatial resolution [17]. The last study states that Himawari-8 channel IR1 can identify coverage regions of tropical squall lines [16]. However, that research showed propagation of tropical squall lines by only weather radar data.

Plenty of studies related to squall lines were discussed cases that occurred in the midlatitude of the northern hemisphere rather than in the tropical region of the southern hemisphere. In this study, we examine squall line characteristics in the tropical region of the southern hemisphere. Tropical squall is an MCS phenomenon that rarely occurs in Indonesia due to the complexity of the atmosphere dynamics influenced by geographic location [16], [18], [19]. Nevertheless, on December 6-7, 2020, IR1 Himawari-8 satellite image in the Indian Ocean of the Indonesian region, shows a cloud line identified as the tropical squall line. Therefore, the purpose of this study is to examine the characteristics of that phenomenon by optimizing the use of the infrared channel of Himawari-8 satellite imagery. It is important to understand the characteristics of these disturbances to provide broader insight into weather forecasting skills and provide an opportunity to conduct further research on this rare MCS phenomenon.

## 2. Methods

The squall line is a type of Meso Convective Systems (MCS) with an elongated pattern that is initiated by low air pressure [20]. On the 7th December 2020, Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) observed a tropical cyclone seed indicated by low air pressure, 1004 hPA in the Indian Ocean region on the southern part of West Java at 9.9°S and 108.2°E. However, BMKG announced that the potential to develop into a tropical cyclone in the next 24 hours is low and after several hours of maintenance, the tropical cyclone seeds decay and failed to become a tropical cyclone [21]. Therefore, this study investigated those phenomena around 8°S – 14°S and 100°E – 111°E. Further information about the research sites can be seen in Figure 3. This research used the Infrared channel (IR1) of Himawari-8 satellite image data in netCDF format with a spatial resolution of 0.02° x 0.02° every hour from December the 6th 2020 at 20.00 UTC to the 7th December 2020 at 12.00 UTC. To identify the MCV that are formed in the asymmetric squall line structure, the 700 hPA and 500 hPA layer wind component data are used at the same hour as the satellite imagery. Wind component data (U and V wind components) having a spatial resolution of 0.25° x 0.25° and an hour temporal resolution obtained from ERA5 Copernicus Reanalysis hourly data on single levels which can be downloaded via the following link https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5. In addition, Global Satellite Mapping (GSMaP) imagery rainfall data were used with a spatial resolution of 0.1° x 0.1° and a temporal resolution of 1 hour to determine the distribution of rainfall during the tropical squall event.

The first step in this study after finding the indication of the squall line pattern on the Himawari-8 satellite image was to collect the Himawari-8 satellite image data. The satellite image data is used to define the squall line using the criteria made by Maddox in identifying MCC with the IR channel of the satellite image. The MCC system occurs for a minimum of > 6 hours [2]. Utilized the modification of MCC criteria, the squall line system will be formed if it fulfils the criteria shown in Table 1. To obtain the satellite image data in accordance with the characteristics above, Matlab software is used. Then the satellite image data is processed using the Grid Analysis and Display System (GrADS) software to display the infrared satellite image data. Furthermore, the stratiform area of the squall line system that forms a vortex (MCV) is calculated for its horizontal diameter based on the criteria [9], [10] which is fulfilled if the minimum diameter is ≥ 50 km. The satellite data also utilized to identify MCV using the subjective process suggested by Bartels and Maddox 1991 [22] The "beginning" of MCV was the time of the satellite image on which vortex structure was first apparent and the end of MCV occurred when no perceivable clouds remained [22

**Table 1. The tropical squall line characteristics based on IR satellite analysis [16] were adapted from Maddox characteristics of MCCs [2].**

| Physical Characteristic | TBB (IR black-body temperature) | Area coverage |
|---|---|---|
| Cloud Shield | ≤ -32 ºC | ≥ 100 000 km$^2$ |
| Interior Cold Cloud | ≤ -52ºC | ≥ 50 000 km$^2$ |

This study visualized and manipulated the Himawari image. Furthermore, it clustered Infrared Himawari-8 product to be two regions like as table 1, then calculated area coverage of cloud shield and interior cold cloud. This study also analyze streamline to identify wind pattern such as vortex as cause of MCS.

## 3. Result and Discussion

**Identification of Tropical Squall Line.** The tropical squall over the Indian Ocean was observed using Himawari-8 infrared satellite imagery. The infrared satellite images at 16.00 UTC and 20.00 UTC (Figure 4) were matched to the classification of the PRE-STROM stage according to Loehrer and Johnson's research [6] as the intersecting convective band types (Figure 2). Those initial type indicated by the presence of two lines in the form of separate convective clouds that intersect each other. The line area of the convective clouds is shown as a yellow circle in Figure 4. This type of initiation indicates that a tropical squall may develop into an asymmetric precipitation structure at mature stage.

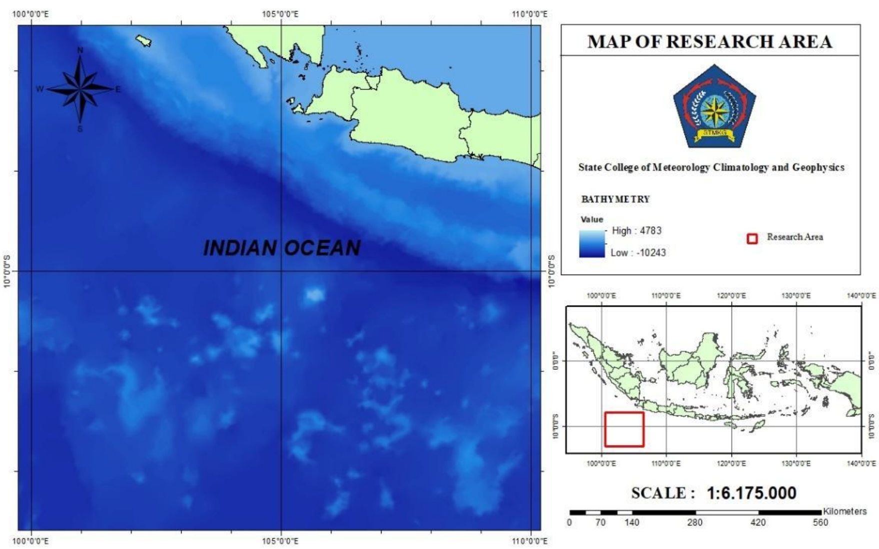


**Figure 3. Map of the research area. The red box shows the area where the tropical squall occurs.**

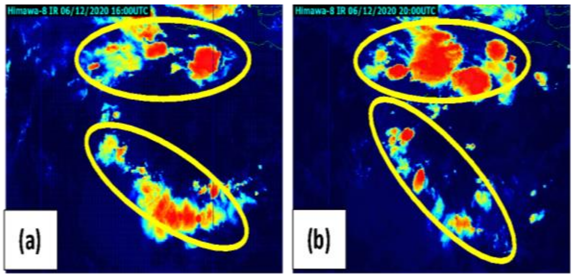


**Figure 4. The Himawari-8 IR satellite image shows the initiation stage of Tropical Squall on December 6, 2020, (a) at 16.00 UTC and (b) at 20.00 UTC. Red indicates convective clouds.**

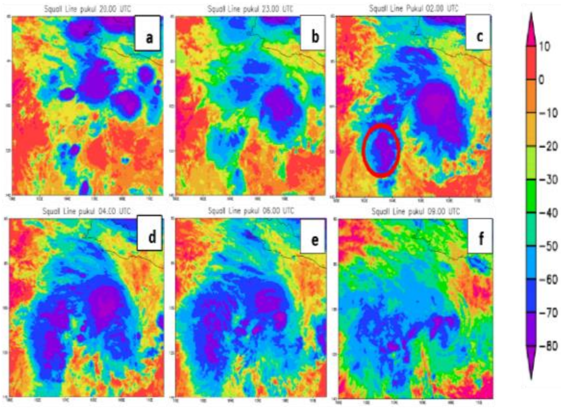


**Figure 5. Distribution and evolution of Tropical Squall based on TBB (IR black-body temperature) in degrees Celsius by Himawari-8 satellite imagery. (a), (b) Tropical squall conditions in the PRE-STORM / initiation stage at 20.00 UTC and 23.00 UTC. (c), (d), (e) Tropical Squall on its mature stage at 02, 04, and 06 UTC. (f) Tropical Squall decayed at 09.00 UTC.**

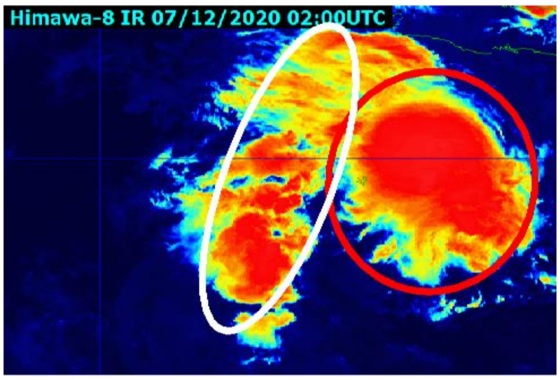


**Figure 6. The infrared Himawari-8 satellite image at the mature stage on 7 December 2020 at 02.00 UTC. The red circle shows the stratiform precipitation area and the white circle shows the convective precipitation area.**

**Tropical Squall Line Characteristic Observation.** A Tropical squall is officially formed if it qualifies the criteria according to Table 1 with a minimum duration of ≥ 6 hours [2]. Based on Table 2 data, on December the 6th 2020, at 15.00 UTC, it was not eligible as the initiation stage because the area of the tropical squall core had not reached 50000 $km^2$ although the area of the cloud shield had adequate. On the same date at 16.00 UTC, the area of the tropical square core and the area of the cloud shield value have attained the given criteria. Tropical squall started to form at 16.00 UTC with the type of initiation is the intersecting convective band as described in the previous section.

The initiation stage lasted for about 6-9 hours until it reached the mature stage on the 7th December at 02.00 UTC with a core area of 190325 $km^2$ and the total cloud coverage reached 366293 $km^2$. During the mature stage, it appears that the tropical squall precipitation structure is classified as an asymmetrical type characterized by a stronger convective precipitation line area at the southern end which is located at 11º LS-13º LS (red circle in Figure 5c).

In accordance with the characteristics expressed by Houze [5], subjective observations were made through the Himawari-8 IR satellite imagery to determine the convective and stratiform precipitation area. In this case, the convective precipitation structure is indicated by the area inside the white circle as shown in Figure 6. Meanwhile, the red circle in Figure 6 shows a stratiform precipitation area characterized by a large cloud area (> 104 $km^2$) and a concave back edge [5].

Cloud top temperature (IR black-body temperature) around the tropical squall area at the mature stage ranges from -50°C to -80°C, even at the core of the convective rain area the temperature could reach <-80°C. This cloud top temperature results are in accordance with tropical squalls that were examined by Hidayat et.al. [16]. The convective system of those tropical squalls also varied around -50°C to -80°C with the average cloud top temperature around -67.8°C in South Sumatra Region, -45°C and -50.9°C average cloud top temperature in Jawa Sea. Its minimum temperature reached -86.8°C in South Sumatra Region [16].

The convective precipitation area that is shaped like an arc in asymmetric structures is influenced by the Coriolis force [8]. The Coriolis force triggers the formation of a vortex called Mesoscale Convective Vortices (MCV). MCV is a low-pressure cyclonic vortex with a warm core that develops within the MCS stratiform area [9], [10]. Previous studies have described the MCS (squall line) phenomenon with an asymmetric precipitation structure that occurs in the Northern Hemisphere [5], [6] characterized by the presence of cyclonic vortex in the Northern Hemisphere (Figure 1b) and anticyclones in the Southern Hemisphere [6], [8], [23]. The cyclonic vortex in the low pressures area that occurs in the Northern Hemisphere will rotate counterclockwise marked by the incoming air flow around the center of the low pressure. Meanwhile, the vortex that are formed in the low pressures area in the Southern Hemisphere will rotate clockwise because they are influenced by the Coriolis force due to the earth's rotation [24]. Based on the 700 mb and 500 mb streamline winds at the maturation and decay phases of the tropical squall (Figure 7), a clockwise MCV was observed around the low pressures area of the stratiform precipitation region.

The MCV moved eastward during the mature stage, and to the southeast at the decay stage. The Pre-Vortex has been found on 500 mb and 700 mb streamline at the initiation phase on the 6th December at 16.00 UTC. There were two vortex cores that formed at the initiation stage in the 500 mb layer. The 500 mb layer streamline showed a significant and irregular pattern of changes in wind direction around the vortex core (Figure 7a and 7b). Meanwhile, the 700 mb layer showed a more regular vortex.

The mature stage of tropical squall lasts for 6 hours started on the 7th December 2020, at 02.00 UTC - 08.00 UTC with the asymmetric pattern (Figure 5), the presence of a strong MCV (Figure 7b and 7e), and the diameter of the horizontal area overcoming the stratiform already exceeds 50 km. The tropical squall decay phase began at 09.00 UTC with the warming of TBB (Figure 5f), decreasing cloud area (Table 2), and converging convective and stratiform precipitation areas. The MCV was still visible at the decay phase with a movement to the southeast. The last tropical squall that meets the criteria was at 11.00 UTC (Table 2). Therefore, tropical squall occurred in the region for 19 hours.

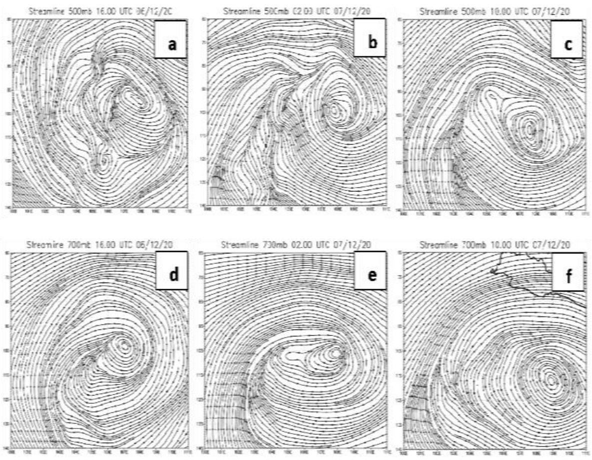

**Figure 7. Streamline during the Tropical Squall life cycle indicate the presence of vortex (MCV). Wind in the initiation stage at 16.00 UTC (a) 500 mb layer and (d) 700 mb layer. Wind current in mature stage at 02.00 UTC (b) 500 mb layer and (e) 700 mb layer. Wind current in decay stage at 10.00 UTC (c) 500 mb layer and (f) 700 mb layer.**

**Table 2. The output of satellite data processing using Matlab software and algorithms adapted to the characteristics of MCC.**

| **Time** | | **Interior cold cloud TBB <-52ºC, area >50 000 km²** | | | **Cloud shiled TBB <-32ºC, area > 100 000 km²** | | |
|---|---|---|---|---|---|---|---|
| Date | Hour | Tropical Squall core area | Latitude | Longitude | Cloud shield coverage | Latitude | Longitude |
| 6 | 15 | 48840 | -8.28 | 112.45 | 106902 | -8.18 | 111.38 |
| 6 | 16 | 111170 | -9.47 | 108.28 | 223838 | -9.19 | 107.63 |
| 6 | 18 | 149158 | -9.29 | 108.46 | 361464 | -8.93 | 108.87 |
| 6 | 20 | 175471 | -9.32 | 108.17 | 278514 | -9.21 | 108.03 |
| 6 | 21 | 196416 | -9.32 | 108.15 | 364145 | -9.04 | 109.09 |
| 6 | 22 | 243621 | -9.23 | 109.00 | 398693 | -9.01 | 109.10 |
| 7 | 2 | 190325 | -9.15 | 109.56 | 366293 | -9.05 | 108.99 |
| 7 | 6 | 142401 | -9.16 | 108.52 | 422137 | -8.95 | 108.53 |
| 7 | 7 | 155289 | -9.04 | 108.54 | 465675 | -8.85 | 108.39 |
| 7 | 8 | 149705 | -9.00 | 108.60 | 457020 | -8.82 | 108.16 |
| 7 | 9 | 131253 | -8.77 | 108.26 | 431412 | -8.75 | 108.09 |
| 7 | 11 | 112885 | -8.47 | 107.64 | 379107 | -8.80 | 108.13 |

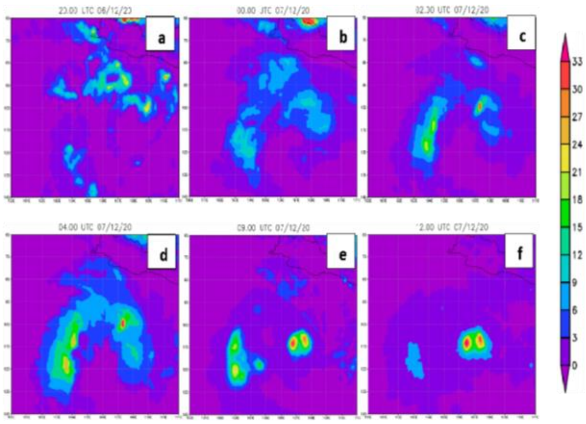

**Figure 8. GSMap rainfall distribution around tropical squall areas. (a), (b) The initiation stage at 20 and 00 UTC. (c), (d) The mature stage at 02 and 04 UTC. (e), (f) The decay stage at 09 and 12 UTC.**

**Rainfall Distribution Based on GSMap Imagery.** Rainfall distribution GSMap images that represent the initiation, maturation and decay phases of tropical squall are shown in Figure 8. The rainfall distribution during the tropical squall occurred around convective and stratiform precipitation areas. According to BMKG [25], the criteria for heavy rainfall in the Indonesian territory are if the measured rainfall has an intensity of 10-20 mm per hour or 50-100 mm per day. Rainfall accumulation that occurred in tropical squall system ranges from 3 - 33 mm per hour. The highest accumulation of precipitation occurred around the convective precipitation area during the mature phase at 02.00 UTC and 04.00 UTC (Figure 8c and 8d) and during the decay phase (Figure 8e) with rainfall reached the range of 24-30 mm per hour.

Meanwhile, the distribution of rainfall decreases at 12.00 UTC, with a range of 3 - 9 mm per hour, except at the MCV's core there was still rain with a heavy intensity of up to 30 mm per hour (Figure 8f). Rainfall that occurs during the tropical squall phenomenon is classified as a heavy rain category according to the BMKG rainfall criteria in the Indonesian region.

## 4. Conclusion

Based on the analysis in the previous section, the tropical squall line that formed over the Indian Ocean south of West Java on December 6-7, 2020 inherit the same initial pattern from Loehrer and Johnson's findings as intersecting convective band types and formed into an asymmetric pattern in the mature stage. In general, the diameter of the stratiform precipitation area reached 326 km in horizontal on 7 December 2020 at 04.00 UTC. The vortex (MCV) pattern identified in streamline analysis in stratiform precipitation region. MCV in tropical squalls rotated clockwise with eastward propagation at the mature stage and southeast at the decay stage. The tropical squall life phase from the initiation stage to the decay that meets the criteria started on December 6, 2020, at 16.00 UTC until December 7, 2020, at 11.00 UTC for 19 hours.

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