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Atmosphere Response to Tropical Cyclone Herman at Java Island

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Abstrak

Indonesia yang berada di daerah tropis mengakibatkan sering mengalami fenomena siklon tropis. Siklon tropis terjadi secara berulang setiap tahunnya dengan waktu kejadian antara bulan Februari sampai April yang bertahan selama 3-18 hari. Siklon tropis telah banyak terjadi di Indonesia seperti Siklon Tropis Cempaka, Aamang, dan Seroja. Fenomena alam berupa siklon yang akhir-akhir ini telah berlangsung di Indonesia, yaitu Siklon Tropis Herman. Penelitian ini bertujuan untuk menganalisis kondisi meteorologi selama terjadinya Siklon Tropis Herman serta dampaknya terjadap curah hujan di Pulau Jawa. Penggunaa data pada penelitian ini bersumber pada ERA-5 untuk parameter meteorologi,, citra satelit Himawari-9 band ke-13 (IR) untuk identifikasi Siklon Tropis Herman, serta identifikasi kejadian curah hujan dari GSMaP dari tanggal 29-31 Maret 2023 interval waktu 6 jam dengan metode yang digunakan berupa analisis deskriptif. Perkembangan Siklon Tropis Herman terbentuk pada 29 Maret 2023 dengan jarak terdekat dengan Pulau Jawa Ketika tanggal 30 Maret pukul 00:00 UTC sebesar 673 km yang kemudian bergerak menjauh dengan jarak terjauhnya mencapai 1093 km pada 31 Maret 2023 pukul 18:00 UTC. Siklon Tropis Herman dipicu oleh gerakan siklonik, kondisi S*ea Surface Temperature* (SST), *Monsoon Trough* (MT), dan *Intertropical Convergence Zone* (ITCZ). Hal ini menyebabkan *updraft* sehingga terjadi pertumbuhan dan kenaikan awan konvektif. Di sisi lain, Transpor kelembaban mendukung kondisi terbentuknya hujan di Pulau Jawa dengan kejadiannya setelah Siklon Tropis Herman. Dampak yang terasa berupa peningkatan curah hujan di Pulau Jawa terjadi pada 29 Maret pukul 06:00 UTC dan 12:00 UTC, 30 Maret pukul 00:00 UTC, 12:00 UTC, dan 18:00 UTC serta 31 Maret pukul 06:00 UTC sampai 18:00 UTC secara *remote effect.*
Kata kunci: Siklon Tropis Herman, Curah Hujan, Pulau Jawa, Himawari-9

Abstract

Indonesia, which is located in a tropical region, often experiences tropical cyclone phenomena. Tropical cyclones occur repeatedly every year with an occurrence time between February and April and last for 3-18 days. Many tropical cyclones have occurred in Indonesia, such as Tropical Cyclones Cempaka, Aamang, and Seroja. A natural phenomenon in the form of a cyclone that has recently occurred in Indonesia, namely Tropical Cyclone Herman. This research aims to analyze meteorological conditions during Tropical Cyclone Herman and its impact on rainfall on the island of Java. The data used in this research comes from ERA-5 for meteorological parameters, 13th band Himawari-9 satellite imagery (IR) for identification of Tropical Cyclone Herman, as well as identification of rainfall events from GSMaP from 29-31 March 2023 time interval 6 hours with the method used in the form of descriptive analysis. The development of Tropical Cyclone Herman was formed on March 29 2023 with the closest distance to Java Island on March 30 at 00:00 UTC of 673 km, which then moved further away with its furthest distance reaching 1093 km on March 31 2023 at 18:00 UTC. Tropical Cyclone Herman was triggered by cyclonic movements, Sea Surface Temperature (SST), Monsoon Trough (MT), and Intertropical Convergence Zone (ITCZ) conditions. This causes an updraft resulting in the growth and increase of convective clouds. On the other hand, moisture transport supports the conditions for the formation of rain on the island of Java which occurred after Tropical Cyclone Herman. The impact felt in the form of increased rainfall on the island of Java occurred on March 29 at 06:00 UTC and 12:00 UTC, March 30 at 00:00 UTC, 12:00 UTC and 18:00 UTC and March 31 at 06:00 UTC until 18:00 UTC with remote effect.
Keywords: *Tropical Cyclone Herman, Rainfall, Java Island, Himawari-9*

INTRODUCTION

Indonesia is situated in a tropical region, that receives more solar radiation compared to non-tropical regions. This is due to the larger incoming solar angle compared to mid-latitude to polar regions (Ismail et al., 2017). This condition results in higher sea surface temperatures in tropical regions. Tropical cyclones usually do not form below the 4° latitude line but rather in warm oceanic regions around the equator, specifically between 10°- 20° latitude (Gaol et al., 2019; Kuttippurath et al., 2021). The higher sea surface temperatures in tropical regions compared to non-tropical regions, leading to the formation of a low-pressure center that triggers the development of tropical cyclones (Emanuel, 1988). In Indonesia, tropical cyclones frequently traversed by tropical cyclones (Avrionesti et al., 2021) occur from February to April (Badan Metorologi Klimatologi dan Geofisika, 2023) and a duration ranging from 3 hours to 18 days (Kurniawan et al., 2021), impacting weather patterns with a 1.3% increase in average rainfall (Guzman & Jiang, 2021), extreme waves (Fang et al., 2017), landslide (Zinke, 2021), and flood (Zhang et al., 2017).

Several studies have examined the impact of tropical cyclone in Indonesia, such as Tropical Cyclone Cempaka, which affected rainfall on Java Island (Samrin et al., 2019), and Tropical Cyclone Amang, which influenced wind speed, salinity, sea surface temperature, and chlorophyll-a levels in waters around Sangihe Island (Rachim et al., 2021). Tropical Cyclone Seroja was the strongest cyclone near Timor Island, causing severe flooding (Latos et al., 2023). Recently, Tropical Cyclone Herman developed rapidly south of Java Island on March 29, 2023, and peaked on March 31, 2023 (Bureau of Meteorology, 2023). This study will analyze the meteorological conditions during the occurrence of Tropical Cyclone Herman and its influence on rainfall in Java Island.

RESEARCH METHODS

The research site is located on Java Island and its waters with coordinates ranging from 5° S to 20° S and 100° E to 116° E. The research period is from 29-31 March 2023.

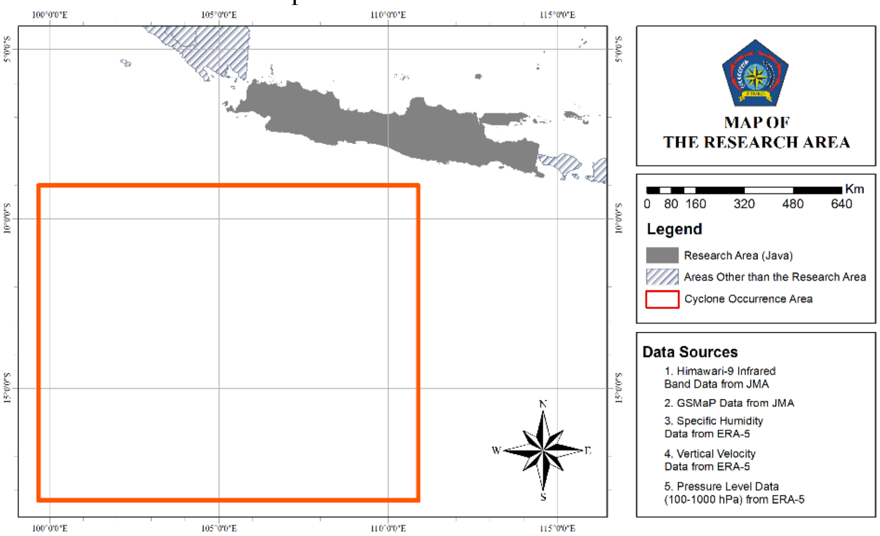


Figure 1. Research location (Source: Research Results, 2023)

In this research, the primary data utilized consists of brightness temperature data (T_{BB}), Meteorological parameters and rainfall data were processed using Climate Data Operator (CDO), SATAID, and GrADS. Brightness temperature data were obtained from the Himawari-9 satellite with a spatial resolution of 0.05°x0.05° and a temporal resolution of 10 minutes, operated by the Japan Meteorological Agency (JMA). In addition to being used for T_{BB}, the identification of Tropical Cyclone Herman was performed using Himawari-9 IR band data (Band 13) with a visual observation method based on T_{BB}values. T_{BB} values can determine the Convective Index (CI) (Adler & Negri, 1988; Mapes & Houze, 1995; Nitta & Sekine, 1994; Sakurai et al., 2005) In order to differentiate between surface temperature and high convective clouds (Samrin et al., 2019) with a threshold value of 253 K (Adler & Negri, 1988). This value can determine clouds that produce rain with the Convective Instability (CI) equation, indicating the occurrence of high convective clouds (Samrin et al., 2019).

$$(CI = Threshold - T_{BB}; T_{BB} < Threshold) \quad (1)$$

On the other hand, the equivalence of CI with the absence of high convective clouds

$$(CI = Threshold - T_{BB}; T_{BB} \geq Threshold) \quad (2)$$

Meteorological parameter data for observing atmospheric conditions during the occurrence of Tropical Cyclone Herman were obtained from ECMWF ERA-5, which has been demonstrated to exhibit superior spatial accuracy on a global scale (Hersbach et al., 2020) and the extensive use of historical data to estimate atmospheric conditions for greater accuracy (Meng et al., 2018). This data provides spatial and temporal resolution of higher quality compared to other secondary data products (He et al., 2020). The parameters utilized in this research include specific humidity, zonal wind, meridional wind, mean sea level pressure, and vertical velocity with air pressure ranging from 850-1000 hPa. Additionally, there is Low-Level Moisture Transport employing meteorological parameters with the following equation (Lélé et al., 2015).

$$\bar{Q} = \frac{1}{g}\int_{850}^{1000} q\bar{V}dp \quad (3)$$

With:
$\bar{Q}$ = Moisture Transport ($\text{kgm}^{-1}\text{s}^{-1}$)
g = Gravitational acceleration (ms^{-1})
q = Specific Humidity (gr/kg)
$\bar{V}$ = Horizontal Wind Vector

Other meteorological parameters utilized include Sea Surface Temperature (SST) and Anomaly Sea Surface Temperature (ASST) obtained from NOAA. SST is employed to investigate the causes of Tropical Cyclone Herman, with a threshold value of 26.5°C (Tory & Dare, 2015). The rainfall data utilized is derived from GSMap (Global Satellite Mapping of Precipitation) Rain Gauge satellite imagery with a spatial resolution of 0.1°x0.1° (Ramadhan et al., 2023) suitable for use in the Maritime Continent of Indonesia (MCI) as it possesses an average accuracy of 82.6% with Mean Error (ME) and Root Mean Squared Error (RMSE) values of 0.16 and 17.44, respectively (Fatkhuroyan & TrinahWati, 2018). The impact of Tropical Cyclone Herman on rainfall in Java Island can be observed through the visualization of estimated precipitation.

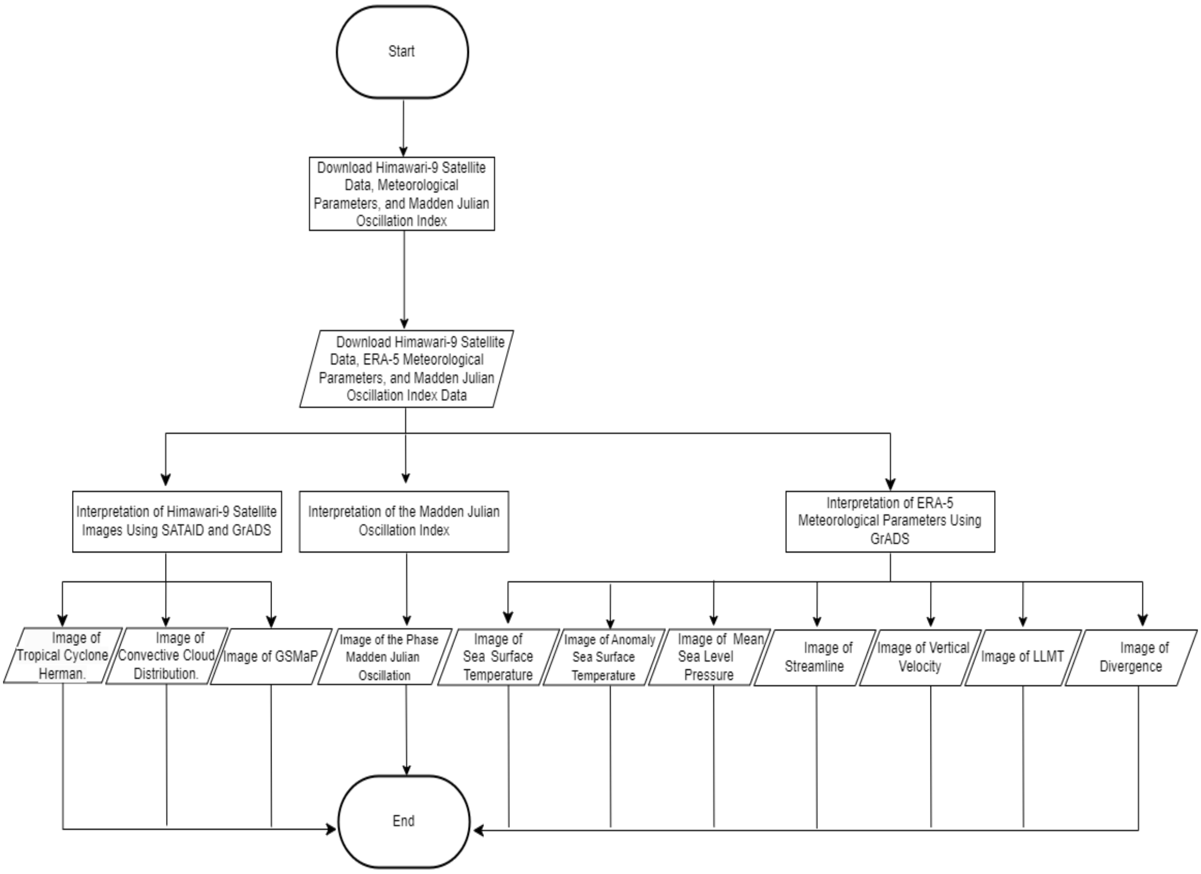


Figure 2. Flowchart (Source: Research Result, 2023)

RESULTS AND DISCUSSION

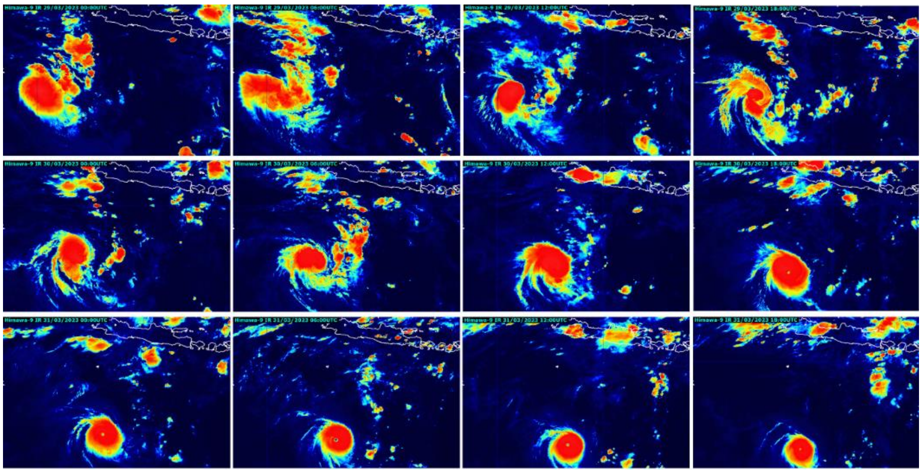


Figure 3. Tropical Cyclone Herman (Source: Research Results, 2023)

In Figure 3, the development of Tropical Cyclone Herman in the southern part of Java Island is observed from 29 to 31 March 2023 at 6-hour intervals starting from 00:00 UTC. The phenomenon is located approximately 796 km southwest of West Java Province, precisely at 11.96° S, 100.9° E at 00:00 UTC on 29 March 2023. The progression can be analyzed based on the T_{BB} satellite data indicating a value of 184.2 thereby suggesting convective clouds associated with rainfall (Adler & Negri, 1988). The closest distance of Tropical Cyclone Herman to Java Island occurred on 30 March 2023 at 00:00 UTC with a value of 673 km, while the farthest distance occurred on 31 March 2023 at 18:00 UTC with a value of 1039 km. The T_{BB} values from the beginning to the end of the cyclone in this study were below 253 K, with the lowest value being 182 K and the highest value being 196 K.

The clouds observed are indicated as Mesoscale Convective Complex (MCC) clouds, where the temperature is above 221 K and exhibits a circular shape (Maddox, 1980) With this MMC, it can act as a trigger for the occurrence of tropical cyclones (Trismidianto et al., 2017).

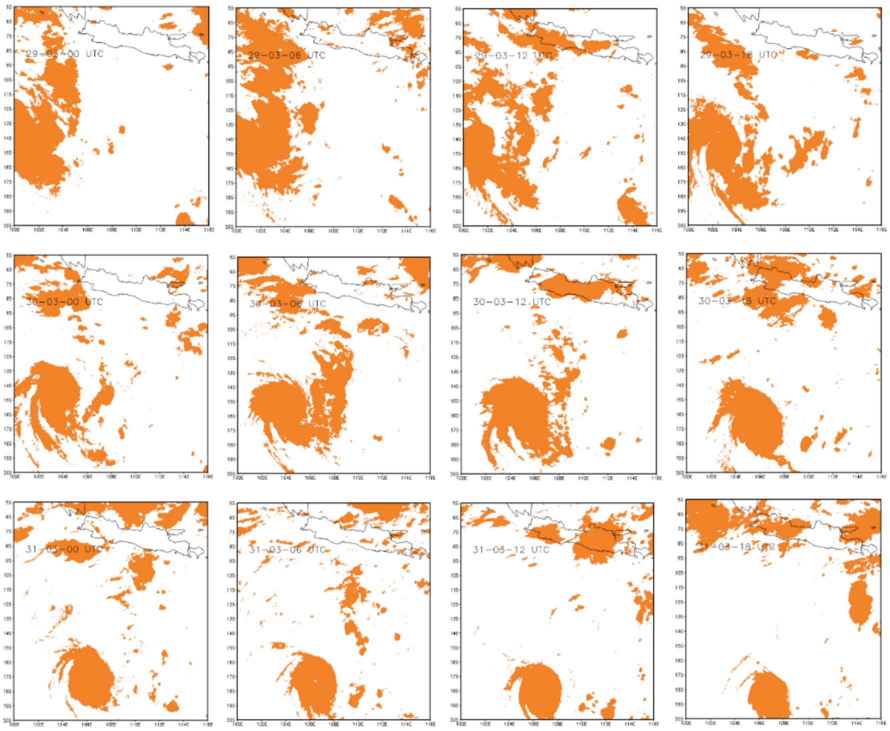


Figure 4. Distribution of Convective Clouds (Source: Research Results, 2023)

The distribution of clouds based on the established threshold for T_{BB} can be seen in Figure 4. The convective cloud swirl moves over the Indian Ocean towards Java Island on 29 March 2023 at 00:00 UTC and 06:00 UTC. By 12:00 UTC, the convective clouds are already positioned over Java Island. Subsequent distribution of convective clouds occurs on 30 March 2023 at 12:00 UTC covering Central Java Province, Yogyakarta, and parts of West Java and East Java Provinces.

Sea Surface Temperature

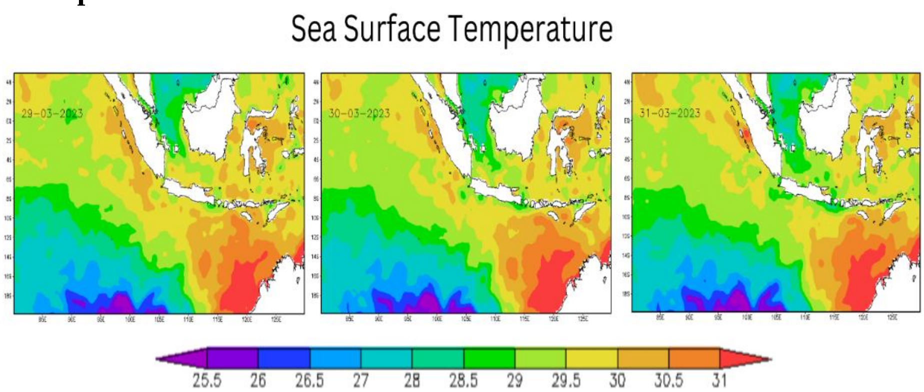


Figure 5. Sea Surface Temperature (Celcius) (Source: Research Results, 2023)

In Figure 5, the Sea Surface Temperature (SST) conditions during the occurrence of Tropical Cyclone Herman on 29-31 March 2023 are evident. The sea surface temperature values were above 26.5°C on 29-30 March 2023 as the tropical cyclone approached Java Island indicated by light blue to light green colors (26.5°C-28°C). Subsequently, when the tropical cyclone moved away from Java Island on 31 March 2023 the values dropped below 26.5°C marked by dark blue to purple colors and the cyclone intensity began to decrease. Based on this observation, Sea Surface Temperature (SST) contributes to the process of Tropical Cyclone Herman formation because this phenomenon requires high sea surface temperatures (Pillay & Fitchett, 2021) and meet the threshold.

Anomaly Sea Surface Temperature

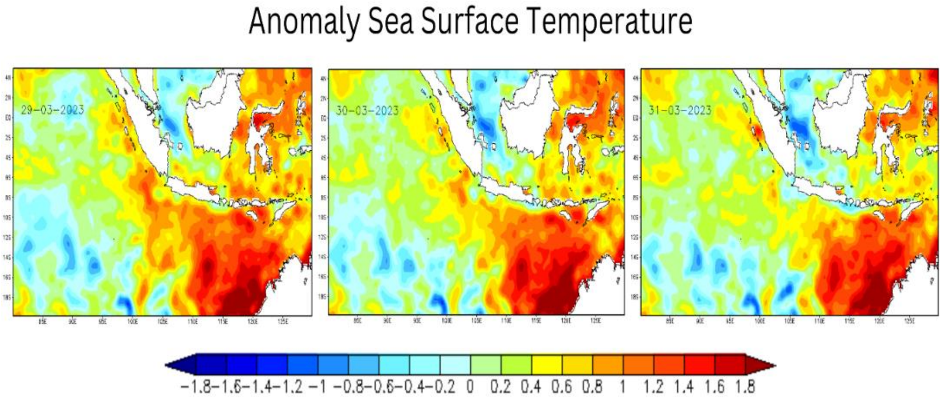


Figure 6. Anomaly Sea Surface Temperature (Celcius) (Source: Research Results, 2023)

Figure 6 illustrates the Anomaly Sea Surface Temperature (ASST) conditions during the phenomenon, as it has been proven to be used as an indication of Tropical Cyclone formation (Zhu et al., 2023). Positive anomalies signify that the Sea Surface Temperature (SST) conditions are above normal, and vice versa. It is evident that the location where Tropical Cyclone Herman occurred is highlighted in red, indicating a positive anomaly. This indicates that indeed sea surface temperature contributes to the formation of tropical cyclones due to the positive Anomaly Sea Surface Temperature (ASST), making it warmer than normal conditions.

Streamline

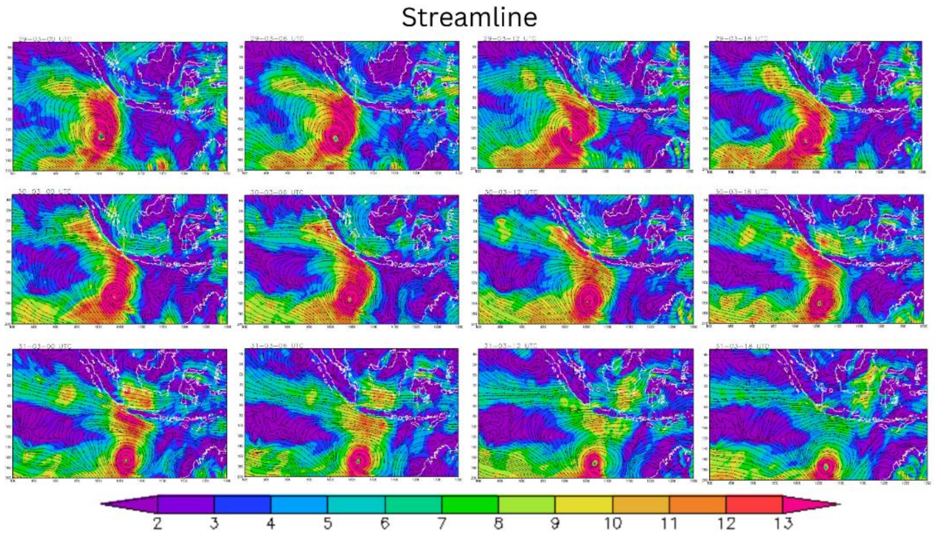


Figure 7. Streamline (m/s) (Source: Research Results, 2023)

In Figure 7, the movement of streamlines during the occurrence of Tropical Cyclone Herman is observed. The time of the event is in March, indicating the transition period between the westerly monsoon and the easterly monsoon. This is evident in the wind directions originating from the continents of Australia and Asia. Both wind directions converge in the south of Java Island, supported by warm sea surface temperatures, leading to the formation of the Intertropical Convergence Zone (ITCZ) (Yan, 2005). Therefore, the ITCZ contributes to the formation of Tropical Cyclone Herman.

Mean Sea Level Pressure

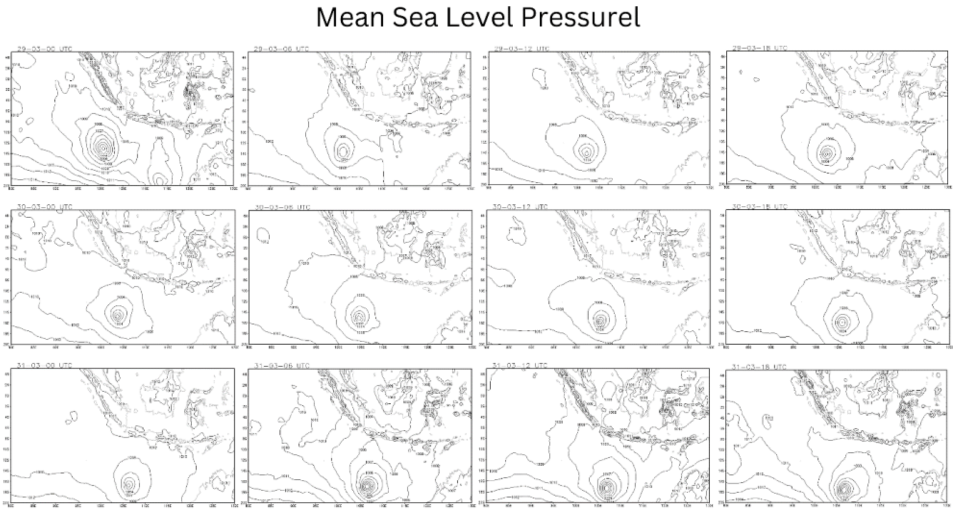


Figure 8. Mean Sea Level Pressure (hPa) (Source: Research Results, 2023)

In Figure 8, the Mean Sea Level Pressure (MSLP) conditions are observed to identify indications of the causes of Tropical Cyclone Herman. With the presence of this meteorological parameter, insights can be gained regarding the Monsoon Ridge (MR) and Monsoon Trough (MT) that can influence the formation of Tropical Cyclones (Zong & Wu, 2023). In this case, the Monsoon Trough (MT) occurs, marked by a low-pressure area in the tropical cyclone, thereby contributing to the formation of Tropical Cyclone Herman.

Madden Julian Oscillattion

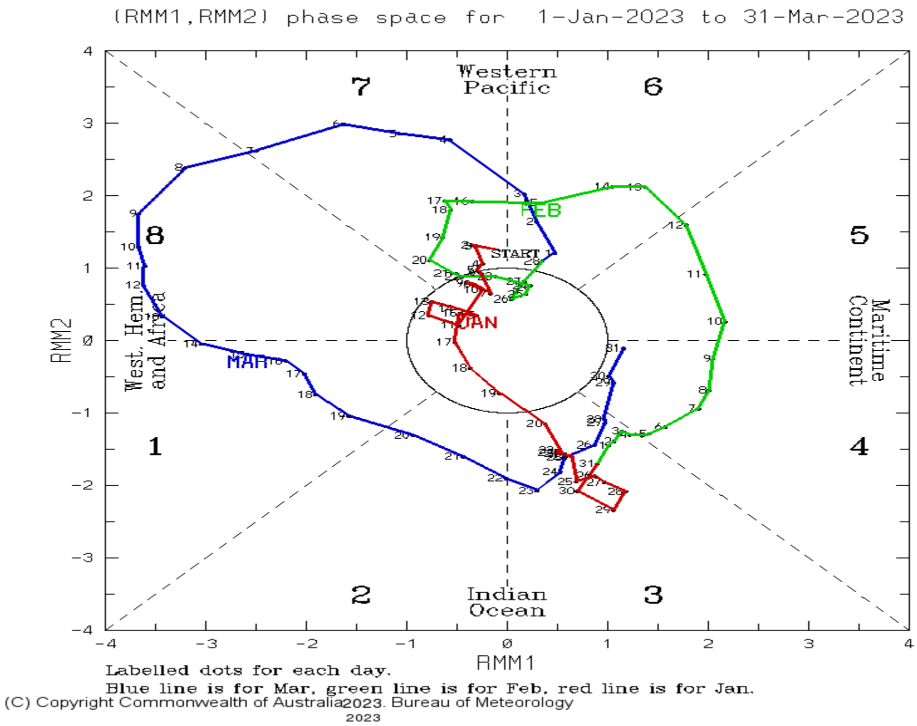


Figure 9. *Madden Julian Oscillation* (Sumber: http://www.bom.gov.au/climate/mjo/)

Observed in Figure 9 is the Maden Julian Oscillation (MJO) condition during the occurrence of Tropical Cyclone Herman. From 29 to 31 March 2023 the MJO wave was in a non-active or weak phase, indicated by its position inside the circle (with an amplitude less than one) (Purwaningsih et al., 2020) As a result, the Madden-Julian Oscillation (MJO) does not contribute to the formation of Tropical Cyclone Herman.

Vertical Velocity

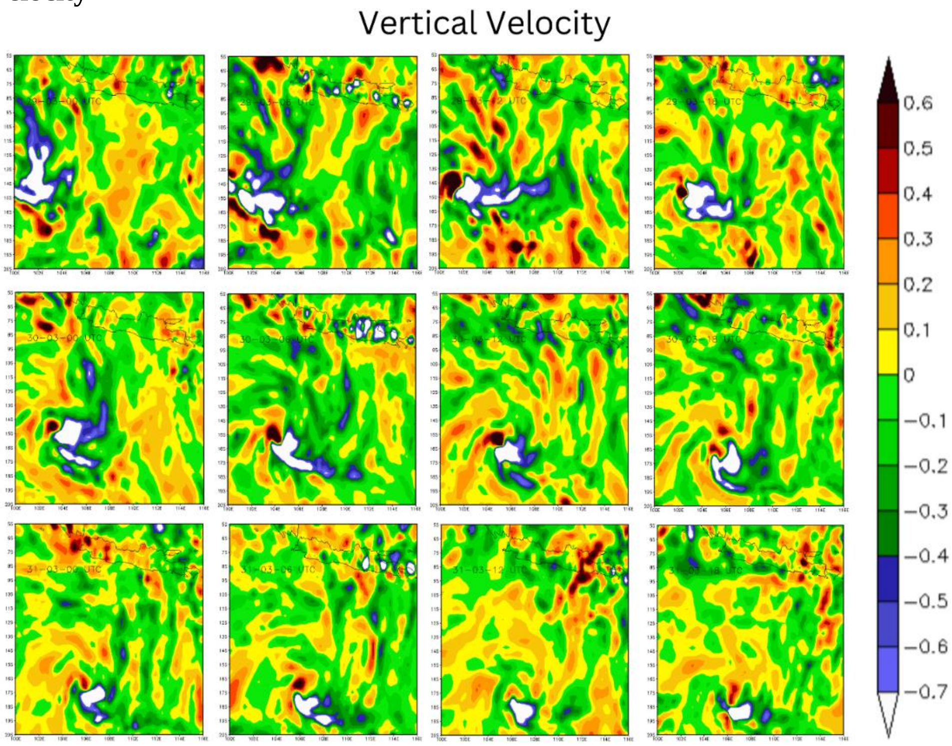


Figure 5. Vertical Velocity 850 hPa (Pa/s) (Source: Research Results, 2023)

In Figure 5, a change in the vertical velocity values over time is observed with decreasing values indicating updraft that carries air masses to higher layers and vice versa (Pujiastuti & Nurjaman, 2019). This will result in an increase in the growth of convective clouds (Dewi & Kristianto, 2018) With a minimum value of -4.7234 Pa/s and a maximum of 1.8658 Pa/s the spot vertical velocity first became apparent in Probolinggo Regency on 29 March 2023 at 00:00 UTC indicated by white and blue coloring. Subsequently, there was a development in the distribution of points indicating vertical velocity on 29 March 2023 at 06:00 UTC in Java Island specifically in DKI Jakarta, Cilacap Regency, Semarang, Situbondo, and Banyuwangi. The distribution of vertical velocity further increased in East Java Province on 30 March 2023 at 06:00 UTC and occurred again on 31 March 2023 at 06:00 UTC.

Low-Level Moisture Transport (LLMT)

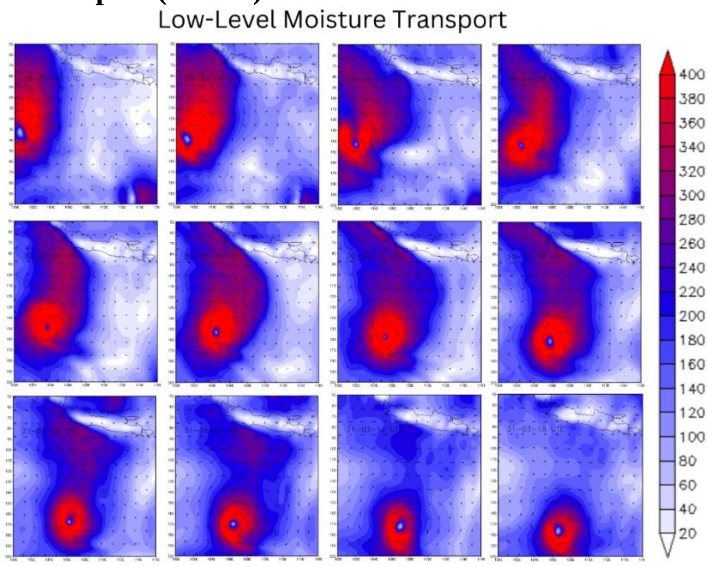


Figure 6. LLMT 850 hPa (kg$m^{-1}s^{-1}$) (Source: Research Results, 2023)

The analysis of moisture transport occurring in Java Island needs to be considered as a dominant factor in the increase of precipitation. With higher moisture values, the potential for rainfall occurrence becomes more significant (Eryani et al., 2022). Observed in Figure 6, Tropical Cyclone Herman influences moisture transport in the southern part of Java Island with its most significant impact in the southern regions of Banten and West Java provinces indicated by the red and dark blue colors. Thus, as Tropical Cyclone Herman approaches Java Island, there will be an increase in humidity along the southern coast of Java Island, and a decrease will occur as the tropical cyclone moves away from Java Island.

Divergence

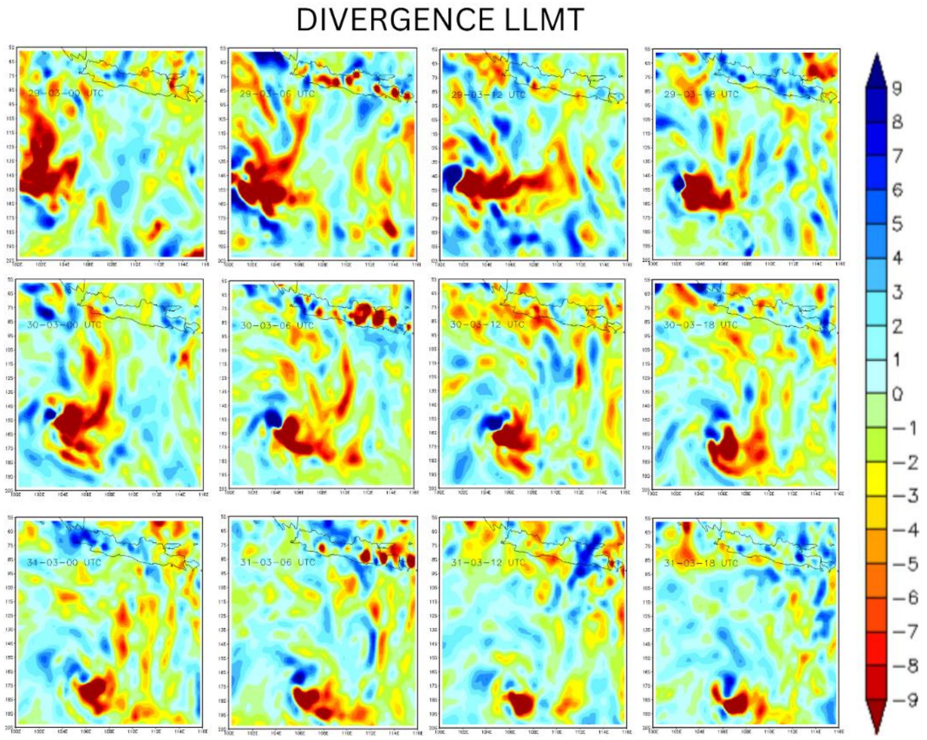
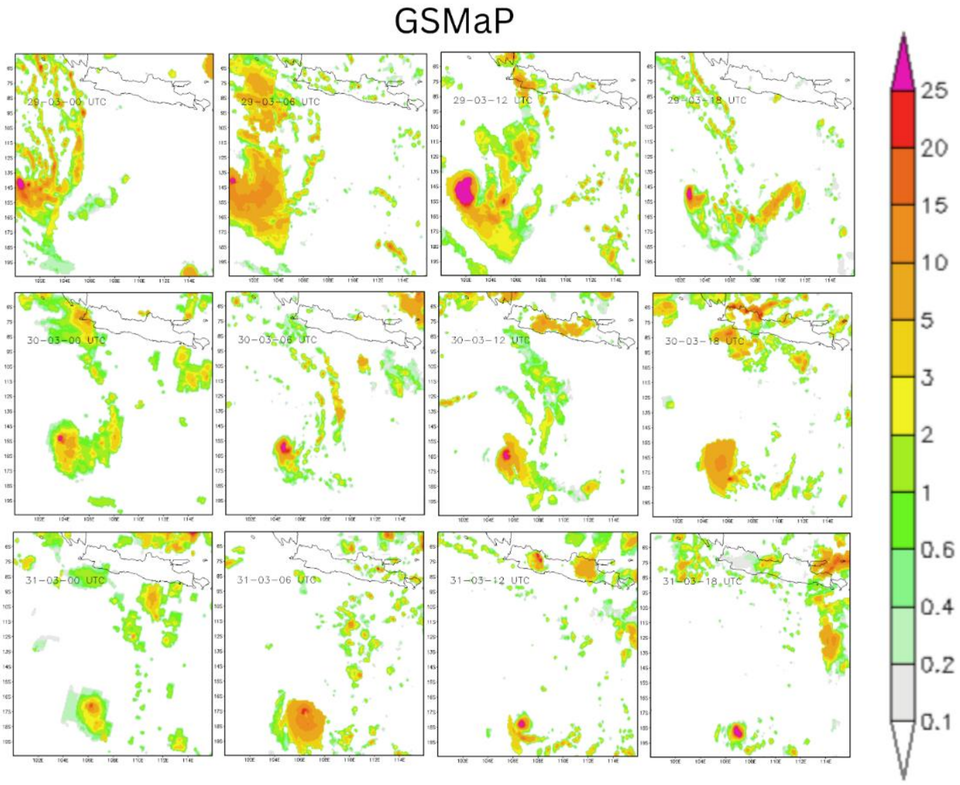


Figure 7. Divergence 850 hPa (/s) (Source: Research Results, 2023)

Figure 7 above illustrates the state of divergence that occurred during Tropical Cyclone Herman, showing changes in values over each time interval. A decreasing divergence value indicates the convergence of air masses (Ardiansyah, 2022) so an updraft occurs. This condition occurs when the divergence value increases or becomes positive, enhancing the potential for the formation of updrafts in small clouds. (Siregar et al., 2019). Convergence occurs on the island of Java particularly in the southern regions of Banten and Central Java as well as Surabaya indicated by the color blue

GSMaP

Rainfall intensity per hour can be categorized into four parts, namely light (1-5 mm/h), moderate (5-10 mm/h), heavy (10-20 mm/h), and very heavy (>20 mm/h) (Gustari et al., 2012).



Fgiure 8. GSMaP Rainfall Distribution (Source: Research Results, 2023)

Figure 8 above represents the distribution of rainfall that occurred on the island of Java. It can be observed that at the location of Tropical Cyclone Herman, there is rainfall with an intensity exceeding 25 mm per hour, indicating very heavy rainfall. The occurrence of rainfall is distributed across Java Island at each time interval, with significant distribution and intensity observed on 29 March 2023 at 06:00 UTC and 12:00 UTC, as well as on 30 March 2023 at 00:00 UTC, 12:00 UTC, and 18:00 UTC. For 31 March 2023, it occurred from 06:00 to 18:00 UTC.

CONCLUSION

The increase in rainfall in the southern part of Java Island during the occurrence of Tropical Cyclone Herman is triggered by cyclonic motion. This will result in updraft with low T_{BB} values, leading to the growth and ascent of convective clouds. On the other hand, Tropical Cyclone Herman can form due to the triggering factors of Sea Surface Temperature (SST), Monsoon Trough (MT), and Intertropical Convergence Zone (ITCZ).

The moisture transport facilitated by Tropical Cyclone Herman enhances the supply of water vapor in the coastal regions of Java Island. Consequently, there is an increase in rainfall, as observed on 30 March 2023 at 12:00 UTC in the city of Banjar, West Java.

The influence of Tropical Cyclone Herman on meteorological parameters in Java Island occurs through a remote effect, as evidenced by the observation that the updraft and rainfall events took place after the tropical cyclone occurrence, not during the cyclone event itself. This is evident in the convergence event in Surabaya on 30 March 2023 at 06:00 UTC with rainfall occurring at 12:00 UTC on the same day.

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