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Characteristics and Influence of Squall Line on Moderate to Heavy Rain Phenomenon in Jambi Province

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Abstract
Introduction: *Jambi Province is a region prone to moderate to heavy rainfall events that are often triggered by mesoscale convective systems such as squall lines. This study aims to analyze atmospheric conditions, squall line characteristics, and their impact on surface rainfall. Three squall line events on May 7, 2024, June 21, 2024, and May 17, 2025, were selected as case studies.* ***Methods****: The research methods include analysis of 3000 ft wind data, 850–500 mb layer humidity, 925 mb air pressure, Himawari-08/09 satellite imagery, weather radar data, and AWS rainfall. Radar data were processed using Rainbow software, while satellite data were analyzed using Sataid.* ***Results and Discussion:*** *The results show that the three squall line events are supported by high air humidity (70–90%), wind deflection, and a low pressure center along Sumatra. Weather radar is able to clearly display the formation and decay of squall lines, with a linear convective structure that is not detected by satellite imagery. Measured rainfall varied from light to heavy rain in areas crossed by the squall line.* ***Conclusion:*** *Weather radar is the most effective instrument in identifying the squall line in Jambi, while satellite imagery only supports monitoring convective clouds. These results are important as a basis for improving the accuracy of early warnings for extreme weather.*

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Introduction

Jambi Province, located between 0°45'–2°45' South Latitude (SL) and 101°10'–104°55' East Longitude (EL) in the central part of Sumatra Island, Indonesia, is a region characterized by distinctive geographical features and a tropical climate. As an area with high development intensity and dense population, particularly in urban regions such as Jambi City, the threat of hydrometeorological disasters has become a critical issue (Yuningsih, Manessa, & Setiadi, 2024). One extreme weather phenomenon with the potential to cause significant impacts is moderate to heavy rainfall, which is often associated with the formation of mesoscale convective systems such as squall lines (Suhadi, Mabruroh, Wiyanto, & Ikra, 2023); (Tirtanegara, Himawan, Harisiwi, Sari, & Redha, n.d.)

Moderate rainfall is defined as precipitation with an intensity that is neither too light nor too heavy (Nabila, Tanjung, & Nasution, 2024). Typically, moderate rainfall has an intensity ranging from 10 mm to 50 mm per hour. It usually occurs over a relatively long duration and has a noticeable impact on daily activities, although outdoor activities may still be possible. Moderate rainfall generally does not cause flooding in a short period but can increase surface water accumulation. In contrast, heavy rainfall is characterized by high intensity, with precipitation exceeding 50 mm per hour. Heavy rainfall occurs very intensely and can rapidly inundate low-lying areas, potentially triggering hydrometeorological disasters such as floods and landslides, particularly in regions with poor drainage systems. (Windari & Sudarti, 2024); (Melinda, Utami, & Nuryanto, 2023); (Sinaga, Silvia, Arianti, Sinaga, & Purba, 2025); (Irawan, Hendra, Ikhsan, Atmaja, & Sari, 2020)

Squall lines are a type of mesoscale phenomenon in which multiple active thunderstorms are organized into an elongated linear pattern, extending over several hundred kilometers. When viewed from above, squall line systems exhibit a distinct linear structure. Squall lines form in unstable atmospheric environments, allowing air in the lower layers to rise freely after initial lifting to the level of condensation. According to Cotton et al. (2011), squall lines are indicative of severe weather conditions such as heavy rainfall and strong winds. These adverse weather conditions can lead to flooding and tornado-like events. Meteorological information is therefore essential in areas that serve as population centers and economic hubs to support community activities. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) is responsible for providing meteorological, climatological, and geophysical data and information services. The data, information, and services provided can be utilized by various user sectors to minimize disaster-related losses (BMKG, 2014); (Fitria, Sagita, & Cahyani, 2022); (Lopez-Bravo, Vincent, Huang, & Lane, 2023).

The characteristics of squall lines based on weather radar observations include the dominance of formation types such as broken line and back building. The convective cells within squall lines predominantly move toward the northeast, with dominant orientations in the southeast–northwest and east–west directions. These systems exhibit maximum reflectivity intensities ranging from 44.5 to 55 dBZ and reach maximum lengths of approximately 50–90 km. Squall lines typically form in the afternoon and have life spans ranging from 1.5 to 3 hours, with dominant vertical wind shear categorized as moderate to strong (Siregar, 2023).

Squall lines associated with strong shear tend to have longer life spans compared to those with moderate shear. Rainfall occurring during the mature phase of squall lines reaches maximum intensities exceeding 20 mm per hour, placing it within the category of very heavy rainfall. In order to enhance information dissemination and enable early identification of squall line phenomena, this study compares observations from weather radar and the Himawari-08 satellite. The issues examined include atmospheric conditions, squall line characteristics based on weather radar and Himawari-09 satellite observations, and surface rainfall conditions.

Method

The type of research used in analyzing the Squall Line includes Primary data and Secondary data, Quantitative data processing techniques and Squall line analysis techniques during moderate to heavy rain in Jambi Province. The research location is in Jambi Province by selecting Kerinci Regency, Sungai Penuh City, Bungo Regency, Merangin Regency, Sarolangun Regency, Tebo Regency, Batanghari Regency, West Tanjung Jabung Regency, East Tanjung Jabung Regency, Muaro Jambi Regency and Jambi City as the areas to be studied. Meanwhile, Kerinci Regency and Sungai Penuh City are not included in the studied area because the Weather Radar coverage of the Sultan Thaha Jambi Class I Meteorological Station is limited to Bungo Regency, Merangin Regency and Sarolangun Regency only. This research was conducted at the Sultan Thaha Jambi Class I Meteorological Station which is the Technical Implementation Unit (UPT) of BMKG in Jambi Province.

Results and Discussion

3000 Feet Wind Analysis

Based on the 3000 ft wind analysis map dated May 7, 2024, in general, in Indonesia, the wind blows from a predominantly southeast to mid-west direction with a speed of 0.5 to 21 knots or ranging from 9 to 38 km/h. In Jambi Province, the wind generally blows from the southeast with a speed of 0.5 to 10 knots or ranging from 9 to 18 km/h. There is a wind turn in the eastern part of Jambi Province, as well as a cyclonic circulation in mainland Malaysia. This can cause the potential for rain cloud growth around the area, including Jambi Province.

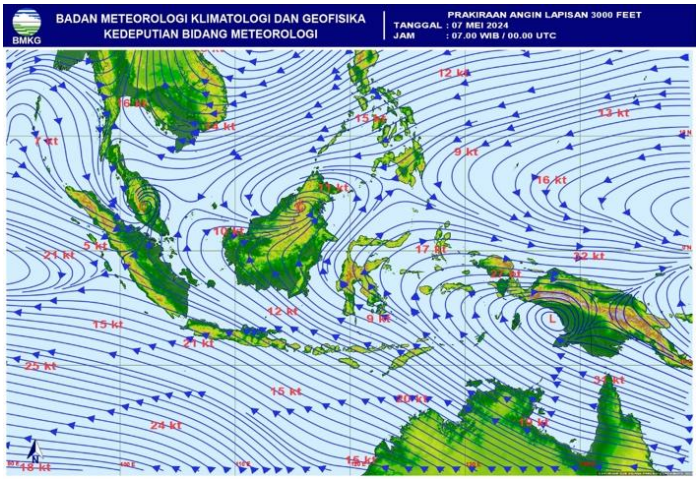

Figure 1. 3000 Feet Wind Forecast

Based on the 3000 ft wind analysis map dated June 21, 2024, in general, in Indonesia, the wind blows from a dominant southeast to west direction with speeds ranging from 10 to 16 knots or ranging from 18 to 29 km/hour. Meanwhile, in Jambi Province itself, it generally blows from the southeast to the west with speeds between 14 to 16 knots or 25 to 29 km/hour. There are wind bends in Jambi Province and cyclonic circulation in the waters west of Sumatra. This can cause the potential for the growth of rain clouds in the Jambi Province area. Based on the 3000 ft wind analysis map dated May 17, 2025, in general, in Indonesia, the wind blows from a dominant direction from the southeast to the south with speeds ranging from 6 to 21 knots or ranging from 11 to 38 km/hour. There are wind bends in the south, east, and west of Jambi Province. There is also a cyclonic circulation in the waters west of Sumatra. This can cause the potential for the growth of rain clouds in the Jambi Province area.

Relative Humidity Data Analysis of the 850 mb Layer

In general, the relative humidity in the 850 mb layer on May 7, 2024, at 15:00 UTC and 18:00 UTC, was 70-90%. This indicates that the air in this layer tends to be humid and triggers the growth of rain clouds in Jambi Province.

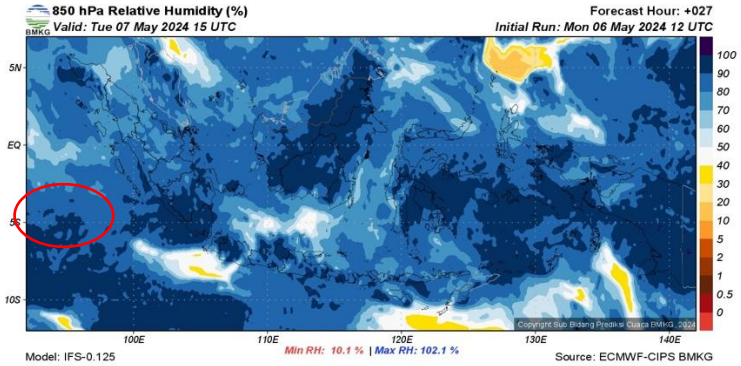

Figure 2. Relative Humidity Data for the 850 mb Layer

In general, the relative humidity of the 850 mb layer on June 21, 2024, at 12:00 UTC and 18:00 UTC was 70-90%. This condition indicates that the air conditions in this layer tend to be humid and trigger the growth of rain clouds in the Jambi Province area. In general, the relative humidity of the 850 mb layer on May 17, 2025, at 12:00 UTC and 18:00 UTC was 70-90%. This condition indicates that the air conditions in this layer tend to be humid and trigger the growth of rain clouds in the Jambi Province area.

Analysis of Relative Data of Humidity Layer 700 mb

In general, the relative humidity in the 700 mb layer on May 7, 2024, at 12, 15, and 18 UTC, was 70-90%. This indicates that the air in this layer tends to be humid and triggers the growth of rain clouds in Jambi Province.

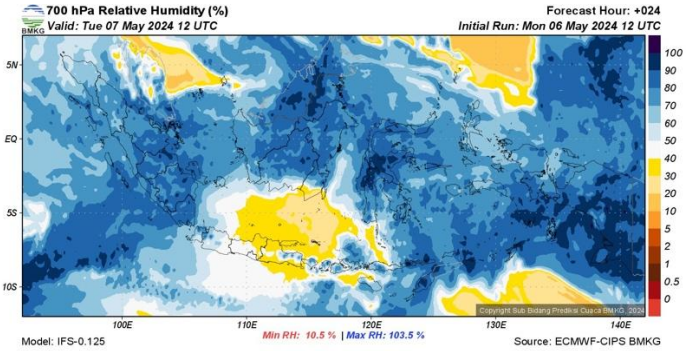

Figure 3. Relative Humidity Data for Layer 700

In general, the relative humidity of the 700 mb layer on June 21, 2024, at 12:00 UTC and 18:00 UTC was 80-90%. This condition indicates that the air conditions in this layer tend to be humid and trigger the growth of rain clouds in the Jambi Province area. In general, the relative humidity of the 700 mb layer on May 17, 2025, at 12:00 UTC and 18:00 UTC was 70-80%. This condition indicates that the air conditions in this layer tend to be humid and trigger the growth of rain clouds in the Jambi Province area.

Relative Humidity Data Analysis of 500 mb Layer

In general, the relative humidity in the 500 mb layer on May 7, 2024, at 15:00 UTC and 18:00 UTC, was 80-90%. This indicates that the air in this layer tends to be humid and triggers the growth of rain clouds in Jambi Province.

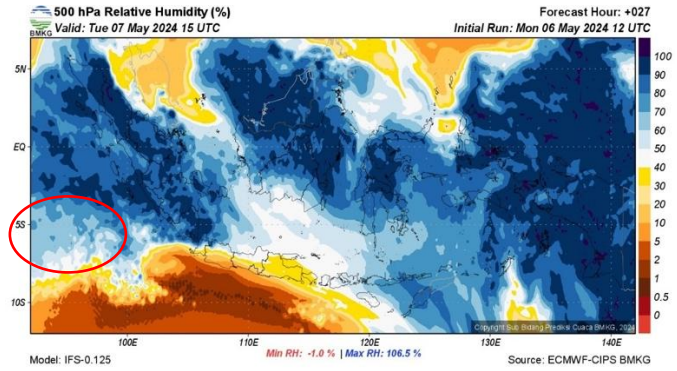

Figure 4. Relative Humidity Data for the 500 mb Layer

In general, the relative humidity of the 500 mb layer on June 21, 2024 at 15 UTC and 18 UTC was 50-80%. This condition indicates that the air conditions in this layer tend to be stable and slightly wet but can trigger the growth of rain clouds in the Jambi Province area. In general, the relative humidity of the 500 mb layer on May 17, 2025 at 12 UTC and 18 UTC was 80-90%. This condition indicates that the air conditions in this layer tend to be wet and trigger the growth of rain clouds in the Jambi Province area.

925 mb Pressure Data Analysis

Sea level air pressure analysis data on May 7, 2024 at 12 UTC shows low pressure in the western part of Sumatra to western Jambi and air pressure in Jambi Province is 1010 mb.

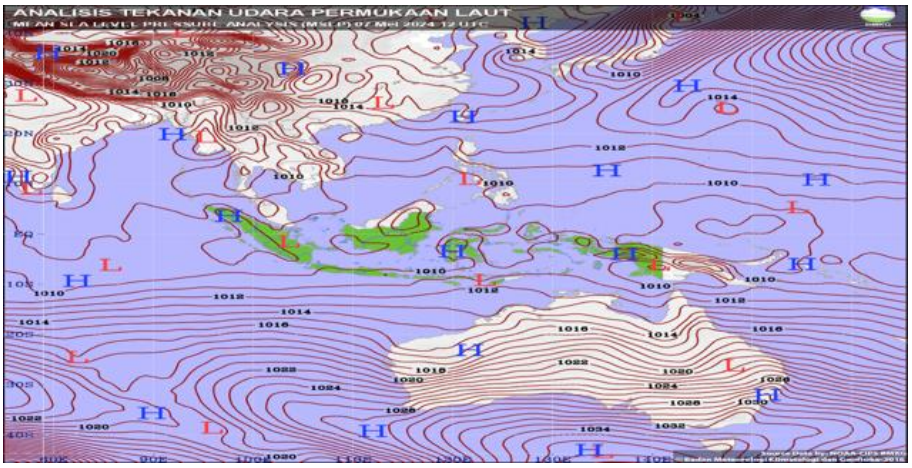

Figure 5. Pressure Data 925 mb

Sea level air pressure analysis data on June 21, 2024 at 12 UTC showed low pressure in the western part of Sumatra to Central Jambi and air pressure in Jambi Province was 1010 mb. Sea level air pressure analysis data on May 17, 2025 at 12 UTC showed low pressure in the western part of Sumatra to western Jambi and air pressure in Jambi Province was 1010 mb.

Weather Radar Data Analysis

According to Wardoyo (2011), reflectivity values are also related to rainfall events. Based on reflectivity values, rainfall is categorized into four categories: light rain, moderate rain, heavy rain, and very heavy rain, as shown in Table 1.

Table 1
Rain Categories

Rain Intensity Category	dBz value	Mm/Hour
Light rain	30 / 38	1 s/d 5
Moderate Rain	38 / 48	5 s/d 10
Heavy rain	48 / 58	10 s/d 20
Very Heavy Rain	>58	>20

The results of the analysis of CMAX product radar images from 20.57 WIB to 01.17 WIB showed the formation process, maturation process to the decay process of the squall line, the formation process began at 20.57 WIB marked by the formation of convective clouds in the areas of Bungo Regency, Kerinci Regency, Merangin Regency, Sarolangun Regency, Tebo Regency, Batanghari Regency and West Tanjung Jabung Regency. Then the maturation process became a squall line starting from 21.47 WIB to 22.07 WIB. The Squall Line forms a straight line starting from the Pekanbaru Province to South Sumatra Province, while in Jambi the Squall Line stretches along West Tanjung Jabung Regency to Batangahari Regency and decays at 22.47 WIB. Based on weather radar data analysis on June 21, 2024, from 9:27 PM WIB to 4:57 AM WIB, it shows the formation, maturation, and decay of a squall line. The formation process began at 9:27 PM WIB, marked by the formation of convective clouds in Bungo Regency, Merangin Regency, and Sarolangun Regency.

Then, the maturation process into a squall line began from 10:27 PM WIB to 12:37 AM WIB. The squall line formed a straight line from Tebo Regency, Batanghari Regency, to Sarolangun Regency, and then decayed starting at 2:27 AM WIB. Based on the analysis

of weather radar data on May 17, 2025 from 21.45 WIB to 00.25 WIB, it shows the formation process, maturation process to the decay process of the squall line, the formation process began at 21.45 WIB marked by the formation of convective clouds in the areas of Tebo Regency, Bungo Regency, Merangin Regency, Sarolangun Regency and Batanghari Regency. Then the maturation process became a squall line starting from 22.25 WIB to 22.45 WIB. The Squall Line formed a straight line starting from the area of Tebo Regency, Batanghari Regency, Merangin Regency to Sarolangun Regency and then decayed starting at 23.45 WIB.

Himawari Satellite Image Data Analysis

Based on the analysis of Himawari satellite imagery data dated May 7, 2024, areas of convective cloud growth were observed in the areas of Bungo Regency, Merangin Regency, Sarolangun Regency, Tebo Regency, Batanghari Regency, West Tanjung Jabung Regency, Muaro Jambi Regency, Jambi City and West Tanjung Jabung Regency from 21.00 WIB to 00.30 WIB. The cloud top temperature reached -80 °C, this indicates the presence of Cumulonimbus convective clouds which have the potential to cause thunderstorms and strong winds. Although the satellite image depicts moderate to heavy rain in the Jambi Province area, the Squall Line pattern is not depicted in the Himawari satellite imagery.

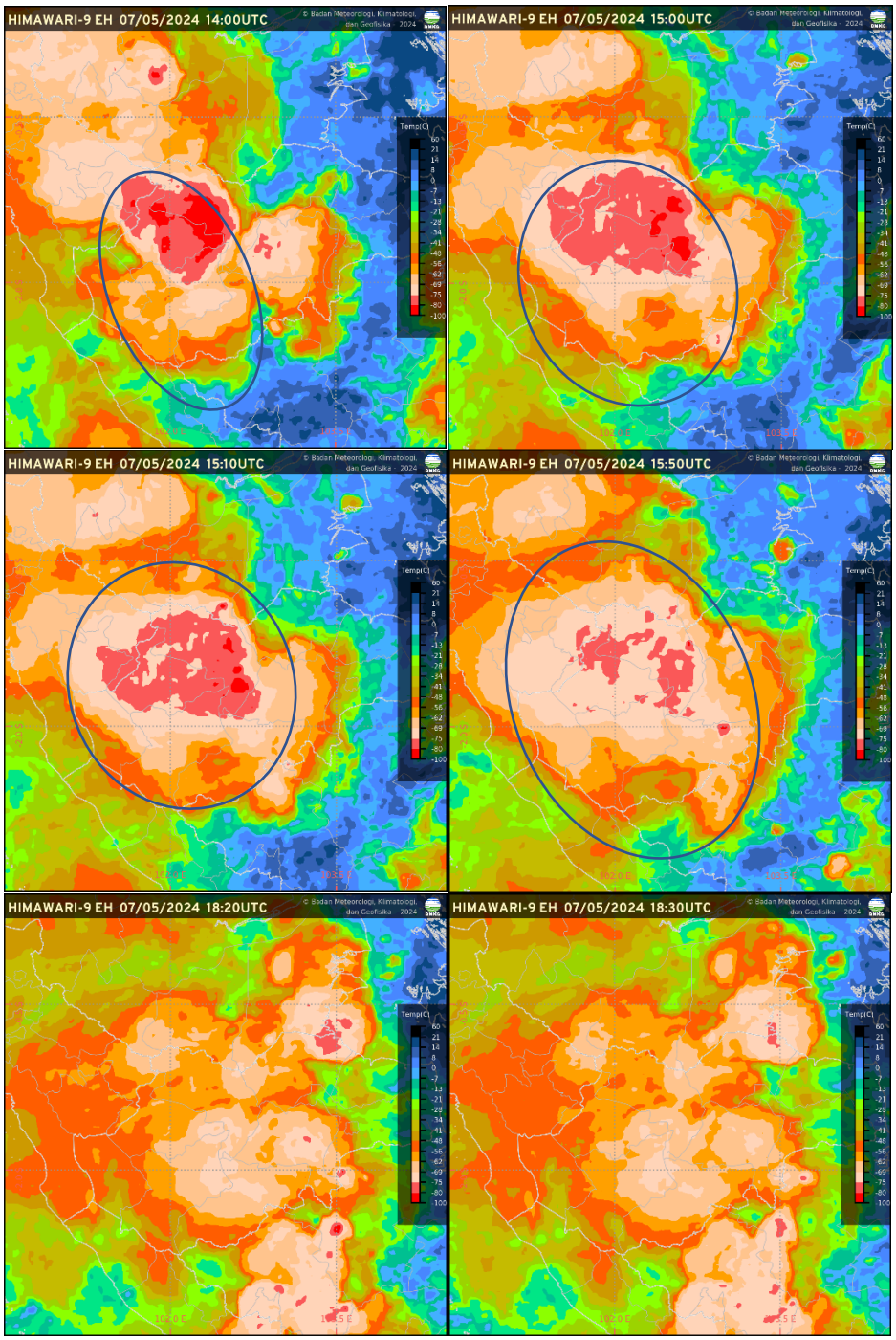

Figure 6. Himawari Satellite Data Analysis

Based on the analysis of Himawari satellite imagery data dated May 7, 2024, areas of convective cloud growth were observed in the areas of Kerinci Regency, Bungo Regency, Merangin Regency, Sarolangun Regency, Tebo Regency, Batanghari Regency, West Tanjung Jabung Regency, Muaro Jambi Regency, Jambi City, West Tanjung Jabung Regency and East Tanjung Jabung Regency. The cloud top temperature reached -80 °C, this indicates the presence of Cumulonimbus convective clouds which have the potential to cause thunderstorms and strong winds. Although the satellite image depicts moderate

to heavy rain in the Jambi Province area, the Squall Line pattern is not depicted in the Himawari satellite imagery.

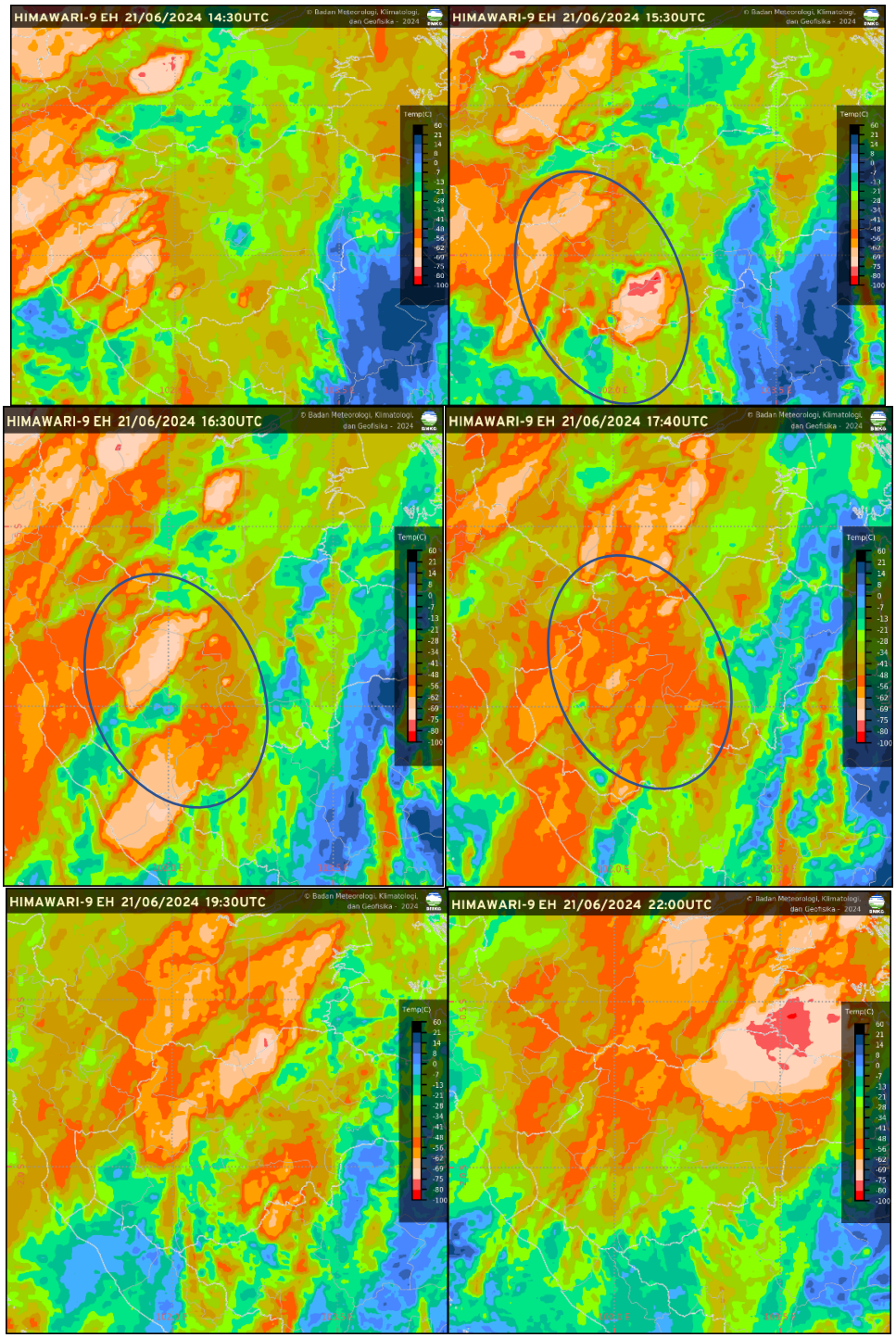

Figure 7. Himawari Satellite Data Analysis

Based on the analysis of Himawari satellite imagery data dated May 17, 2025, areas of convective cloud growth were observed in the Kerinci Regency, Bungo Regency, Merangin Regency, Sarolangun Regency, Tebo Regency and Batanghari Regency. The cloud top temperature reached -80 °C, indicating the presence of Cumulonimbus

convective clouds which have the potential to cause thunderstorms and strong winds. Although the satellite imagery depicts moderate to heavy rain in the Jambi Province area, the Squall Line pattern is not depicted in the Himawari satellite imagery.

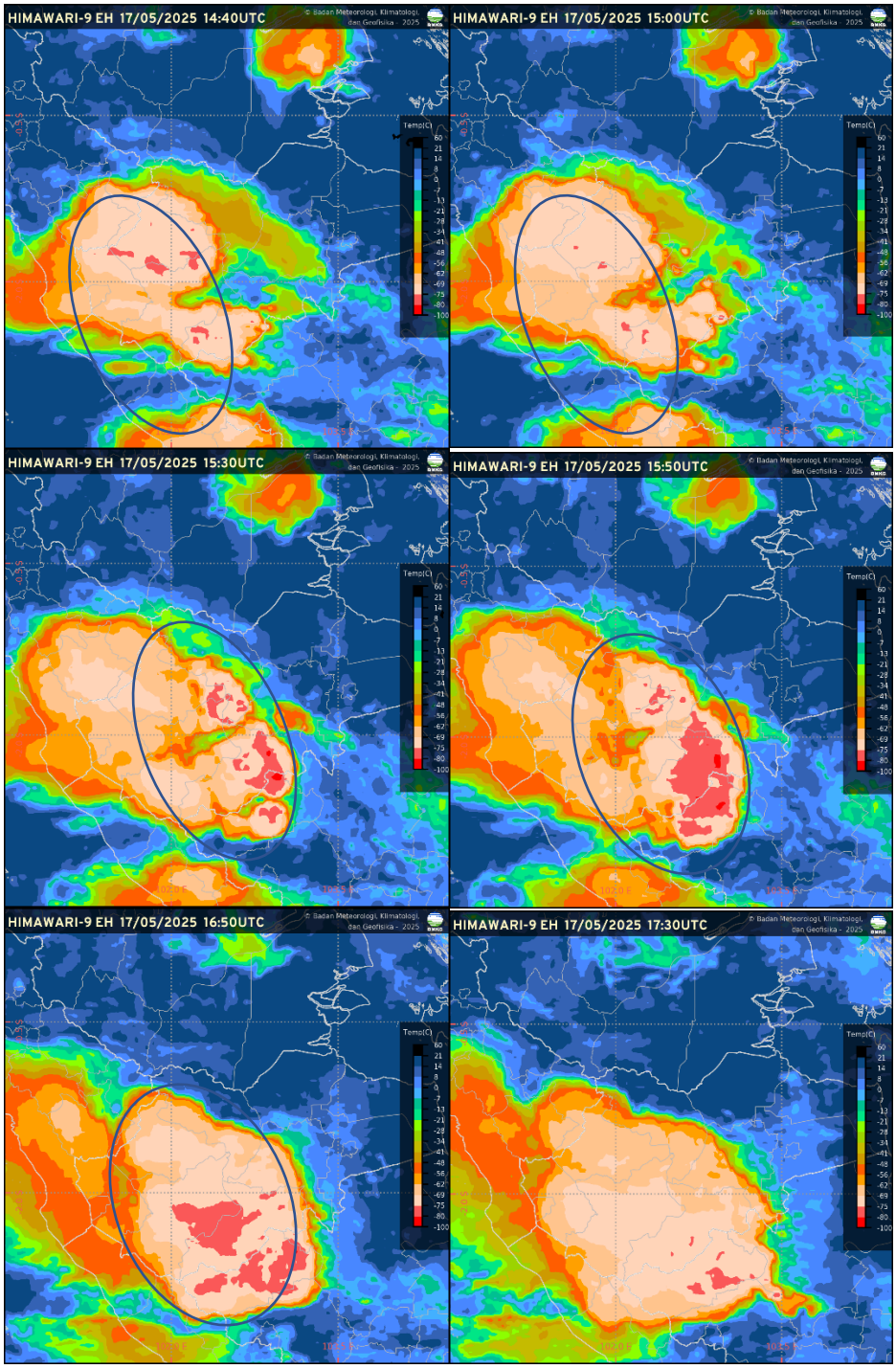

Figure 8. Himawari Satellite Image Data Analysis

Rainfall Data Analysis

Based on daily rainfall data for Jambi Province on May 7, 2024, moderate to heavy rain was recorded in Jambi City, Merangin Regency, Tebo Regency, Muaro Jambi Regency, and West Tanjung Jabung Regency. Meanwhile, light rain was recorded in Kerinci Regency, Bungo Regency, and East Tanjung Jabung Regency. Meanwhile, Batanghari Regency was not recorded due to data errors and incomplete data from two sub-districts in East Tanjung Jabung Regency. Meanwhile, on June 21, 2024, moderate to heavy rain was recorded in most areas of Jambi Province, except for Kerinci, one sub-district in Merangin, one sub-district in Tebo, and one sub-district in East Tanjung Jabung Regency. On May 17, 2025, light rain dominated Jambi Province, except for Jambi City, where it was recorded as moderate rain.

Table 1
Jambi Province Daily Rainfall Data

BMKG

BADAN METEOROLOGI KLIMATOLOGI DAN GEOFISIKA
STASIUN METEOROLOGI KLAS I SULTAN THAHA JAMBI
Jl. Sersan Udara Syawal Paal Merah Baru Jambi Kode Pos 36139 Telp. (0741) 572161 Fax (0741) 573245

DATA HUJAN HARIAN WILAYAH JAMBI RR24

KABUPATEN	KECAMATAN	NAMA ARG/AWS/AAWS	07 MEI 2024	21 JUNI 2024	17 MEI 2025
Kota Jambi	Paal Merah	AWS Digi Stamet Jambi	29.2	33.0	25.6
Kerinci	Kayu Aro	AWS Kayu Aro	7.0	7.4	0
Batanghari	Muara Bulian	ARG Muara Bulian		27.0	1.8
Bungo	Jujuhan Ilir	ARG Jujuhan Ilir	11.6	23.8	0
Bungo	Rimbo Tengah	ARG Muara Bungo	9.6	12.0	3.4
Merangin	Pamenang Barat	ARG Pamenang Barat	26.4	3.4	4.8
Merangin	Sungai Manau	ARG Sungai Manau	14.2	43.0	1.6
Merangin	Bangko	AAWS Bangko	35.8	13.6	8.4
Sarolangun	Pauh	ARG Pauh Sarolangun	2.0	59.4	13.8
Sarolangun	Singkut	ARG Singkut	3.0	12.2	7.4
Sarolangun	Limun	AAWS Muara Limun	1.6		13.4
Tebo	Tebo Ulu	ARG Tebo Ulu	21.6	7.6	0
Tebo	Sumay	ARG Sumay	133.8	79.0	0
Tebo	Tujuh Koto Ilir	AWS Tujuh Koto Ilir	11.4	0	0
Muaro Jambi	Bahar Utara	ARG PTPN VI Muaro Jambi	58.6	73.0	16.0
Muaro Jambi	Kumpeh Ulu	ARG Kumpeh Ulu	25.2	37.8	0.4
Muaro Jambi	Sekernan	ARG Sekernan	9.4	21.8	0
Muaro Jambi	Jambi Luar Kota	AWS Staklim Jambi	71.4	22.4	0.8
Muaro Jambi	Sekernan	AWS Bukit Baling	0		0
Tanjung Jabung Barat	Batang Asam	ARG Batang Asam	19.8	20.6	0
Tanjung Jabung Barat	Merlung	ARG Merlung	3.2	21.6	0.2
Tanjung Jabung Barat	Pengabuan	ARG Pengabuan	0	73.8	0.2
Tanjung Jabung Barat	Tungkal Ulu	AWS Tanjung Jabung Barat	0	30.2	0
Tanjung Jabung Barat	Kuala Tungkal	ARG Tanjung Jabung Barat	47.4	21.8	0
Tanjung Jabung Timur	Nipah Panjang	ARG Nipah Panjang			0
Tanjung Jabung Timur	Rantau Rasau	ARG Rantau Rasau	3.0	7.8	0
Tanjung Jabung Timur	Geragai	AWS Wira Karya Sakti		39.0	0
Tanjung Jabung Timur	Berbak	AAWS Tanjung Jabung Timur	0	22.6	0
Rata2					

Ket :
: Data belum masuk
: Data error

Conclusion

Based on the 3000 ft Wind analysis data on May 7, 2024, June 21, 2024, and May 17, 2025, there are wind bends that can trigger the growth of rain clouds in the Jambi Province area. Meanwhile, the Relative Humidity analysis of the 850, 700, and 500 mb layers shows values of 50 to 90% where these values indicate air conditions tend to be humid to wet and support the growth of rain clouds in the Jambi Province area. The 925 mb air pressure analysis shows the presence of an active low-pressure center along the island of Sumatra, including in the Jambi Province area. From several aspects, it is very supportive of the growth of rain clouds in the Jambi Province area. Based on weather radar image analysis data on May 7, 2024, June 21, 2024, and May 17, 2025, convective clouds were observed in most of Jambi Province. This illustrates the presence of light to moderate rain in the Jambi Province area. The formation, maturation, and decay of the Squall Line are clearly depicted in weather radar imagery. Slightly different from weather radar imagery, satellite imagery shows the growth of convective clouds in most areas of Jambi Province, with cloud top temperatures reaching -80 °C. This condition indicates that the air conditions tend to be humid to wet and have the potential to support the growth of rain clouds in Jambi Province. However, the Himawari satellite imagery does not clearly depict the formation, maturation, and decay of the Squall Line. Rainfall conditions on May 7, 2024, June 21, 2024, and May 17, 2025 show light to moderate rain in the areas crossed by the Squall Line, and this is directly proportional to what is depicted by weather radar and Himawari satellite imagery.

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