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Application of Himawari-9 and Radiosonde Data in Analyzing Extreme Rainfall Events (Case Study: Malang, November 25, 2023)

Rini Arista[1], Muhammad Alvin Faiz[1]
[1]Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

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ABSTRACT

This study uses Himawari-9 meteorological satellite data and radiosonde data to examine the severe rain event that happened in Malang on November 25, 2023. The Japan Meteorological Agency's (JMA) Himawari-9 satellite collects high-frequency atmospheric data, and radiosonde data provide vertical atmospheric information. This study determines the distribution of major convective clouds and meteorological characteristics that suggest the possibility of severe weather by analyzing satellite photos using the RGB technique and radiosonde data. Convective clouds identified by satellite images at 07:40 UTC started to blanket the Malang City area and spread until they filled the entire East Java region at 09:00 UTC, according to the analysis's findings. Weather metrics including the Showalter Index (SI), Lifted Index (LI), and Convective Available Potential Energy (CAPE) are displayed in radiosonde data to support the possibility of heavy rain. There is a significant chance that flooding in Malang will result from heavy rains due to these unstable atmospheric conditions.

Corresponden Author:

Rini Arista,
Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)
Tangerang City, Banten, Indonesia
Email: riniarista1308@gmail.com

1. INTRODUCTION

Indonesia is among the world's biggest archipelagic nations. Due to its geographical location between two continents (Asia and Australia) and two major oceans (the Indian and Pacific), Indonesia has a very complex and dynamic climate system that is impacted by numerous global atmospheric and oceanic cycles [1]. Indonesia experiences two distinct seasons throughout the year, namely the rainy season and the dry season [2]. The country's climate and weather patterns are heavily influenced by the change between these two seasons. The Indonesian archipelago experiences the most intense convective activity, resulting in frequent occurrences of heavy rainfall [3]. Strong updrafts and the upward movement of heat and moisture in the atmosphere cause convective clouds to form. Extreme rainfall events may result from the heavy and localized precipitation that these clouds, especially cumulonimbus, can produce in a brief period of time.

In general, rainfall in Indonesia can be divided into three types: equatorial rainfall, which occurs in regions such as Sumatra, Kalimantan, Sulawesi, Maluku, and Papua; monsoon rainfall, which covers Java, Bali, and Nusa Tenggara; and reverse monsoon rainfall, which is found in limited areas of Sulawesi and Maluku[2]. Understanding extreme precipitation, which is a key contributor to hydro-meteorological hazards, is vital for society as it can result in prolonged disasters, including flooding, landslides, and soil erosion during intense wet periods, as well as droughts and forest fires during extended dry periods [4]. The Indonesian archipelago experiences intense convective activity, leading to frequent occurrences of heavy rainfall [3]. The rising intensity of rainfall has contributed to an increase in the frequency of flood disasters from year to year [5].

Intense convective activity can produce heavy rainfall, which can cause catastrophic flooding in a number of Indonesian locations. When a lot of rain falls quickly, the current drainage systems frequently can't handle the volume of water, especially in cities with plenty of impervious surfaces like concrete and asphalt. Additionally, waterlogging is more likely to occur in regions close to rivers or with low-lying topography. The likelihood of flooding is enhanced when severe rainfall occurs more frequently due to extreme weather events since the amount of water is more than what the land can absorb or the rivers can hold [6]. In addition to the risk of infrastructure damage, places that experience heavy rainfall are also vulnerable to interruptions in social and economic activities.

On November 25, 2023, around 07.40 UTC or 14.40 WIB, flooding occurred in Malang city as a result of heavy rains. Several parts of Malang, East Java, experienced flooding due to the day's heavy rainfall. These events can be analyzed in more depth by utilizing remote sensing data from Himawari-9 satellite imagery, along with radiosonde data that provides vertical atmospheric information. Researchers can learn how distinct atmospheric layers can encourage the creation of heavy rainfall by using radiosonde, which measures temperature, humidity, and air pressure at different atmospheric heights [7]. The Himawari-9 satellite, which is the next generation of Himawari-8 and operated by the Japan Meteorological Agency (JMA), is equipped with advanced technology for atmospheric monitoring [8]. The data advantage of the Himawari-9 satellite lies in the high frequency of data acquisition, which is every 10 minutes for full coverage and 2.5 minutes for areas around Japan [9]. The satellite is equipped with an advanced sensor called the Advanced Himawari Imager (AHI), which has a total of 16 bands, including visible (VIS, 3 bands), near infrared (NIR, 3 bands), and infrared (IR, 10 bands) [10]. Both satellite and ground-based measures can be used to gather rainfall data [11]. Rainfall variability has a significant impact on many facets of the lives of those who reside in the area, making rainfall research crucial. Rainfall variability is an important topic for scientific investigation since it impacts many aspects of the lives of the millions of people who live in the region. Furthermore, Indonesia's most frequent natural disasters, such as floods and landslides, are mostly caused by periods of intense rainfall. In order to improve the precision and comprehension of weather and climate forecasts and to develop Decision Support Systems (DSS) that lessen the probability of disaster impact, research on rainfall in this region is necessary. As a result, accurate rainfall measurements are critically needed, particularly better methods for estimating rainfall from remotely sensed devices [12].

In this research, the Red Green Blue (RGB) method is used, which is processed through the SATAID application. This application, developed by the Japan Meteorological Agency (JMA), is widely used by researchers and professionals in the field of weather and climate to interpret satellite data and make better decisions related to weather and the environment [13][14]. By using the RGB method, we can identify the clouds that cause rain leading to flooding in Malang City, as well as uncover certain factors that contribute to the formation of these clouds [15][16].

2. RESEARCH METHOD

The method applied in this study is through a literature review, which involves collecting and reviewing various relevant reading sources. These sources consist of books, academic journals, research reports, articles, and other documents related to the issue under study. These sources were then used as references for the design of the Radiosonde System for Air Quality Monitoring in Tangerang City.

In addition, this method also includes a critical assessment of the existing literature to find gaps in the research, as well as summarising previous results to strengthen a more in-depth analysis. This approach aims to gain in-depth insight into the topic of study and create a strong theoretical foundation to support the research results.

2.1 Location and Time of Research

Malang City is located in East Java Province, with coordinates between 112.06° - 112.07° East Longitude and 7.06° - 8.02° South Latitude. The city is bordered to the north by the Singosari and Karangploso sub-districts of Malang Regency; to the south by the Tajinan and Pakisaji sub-districts of Malang Regency; to the west by the Wagir and Dau sub-districts of Malang Regency; and to the east by the Pakis and Tumpang sub-districts of Malang Regency. The research location map was sourced from the Malang City Administration data [17]. The heavy rain event occurred from 07:30 UTC (14:30 WIB) to 09:00 UTC (16:00 WIB) on November 25, 2023.

2.2 Research Procedure

The Meteorological, Climatological, and Geophysical Agency (BMKG) provided the Himawari-9 satellite imagery data. The following channels or bands are used for processing: Band 3 (0.6 µm), Band 5 (1.6 µm), Band 7 (3.7 µm), Band 8 (6.2 µm), Band 10 (7.3 µm), Band 11 (8.6 µm), Band 12 (9.6 µm), and Band 13 (10.4 µm). The Red Green Blue (RGB) technique is used in this study, and the SATAID application is used to process the data [18]. Researchers and experts in the domains of weather and climate utilize this program, which was created by the Japan Meteorological Agency (JMA), extensively to analyze satellite data and make better weather and environmental decisions. The SATAID system's primary purpose is to show binary satellite data as pictures.

The SATAID system's primary purpose is to show binary satellite data as pictures [19]. Using the RGB approach, we can determine which clouds produced the rain that resulted in floods in Malang City as well as some of the contributing causes to their creation. The meteorological conditions over Malang City during periods of intense precipitation are examined using upper air observation data (Radiosonde) from the Wyoming Sounding website https://weather.uwyo.edu/ in order to support the RGB technique [20][21].

3. RESULT AND DISCUSSION

3.1 Himawari-9 Satellite (RGB)

Based on Himawari-9 satellite image data processed using the Day Convective Storm method, observations are produced in the form of convective cloud distribution. Using satellite image data, the Day Convective Storm technique analyzes convective clouds during the day. By concentrating on the hue and features of the clouds that suggest the presence of dense clouds and strong updrafts, this technique finds convective clouds. Bright yellow clouds are a sign of severe weather, which can bring storms and a lot of rain [22][23]. Strong updrafts and thick clouds that portend terrible weather or clouds containing ice particles are indicated by vivid yellow clouds. Bright yellow convective clouds were observed to have started to envelop the Malang City region at 07.40 UTC. Then, at 9:00 UTC, the convective cloud dispersion blanketed nearly the whole East Java region.

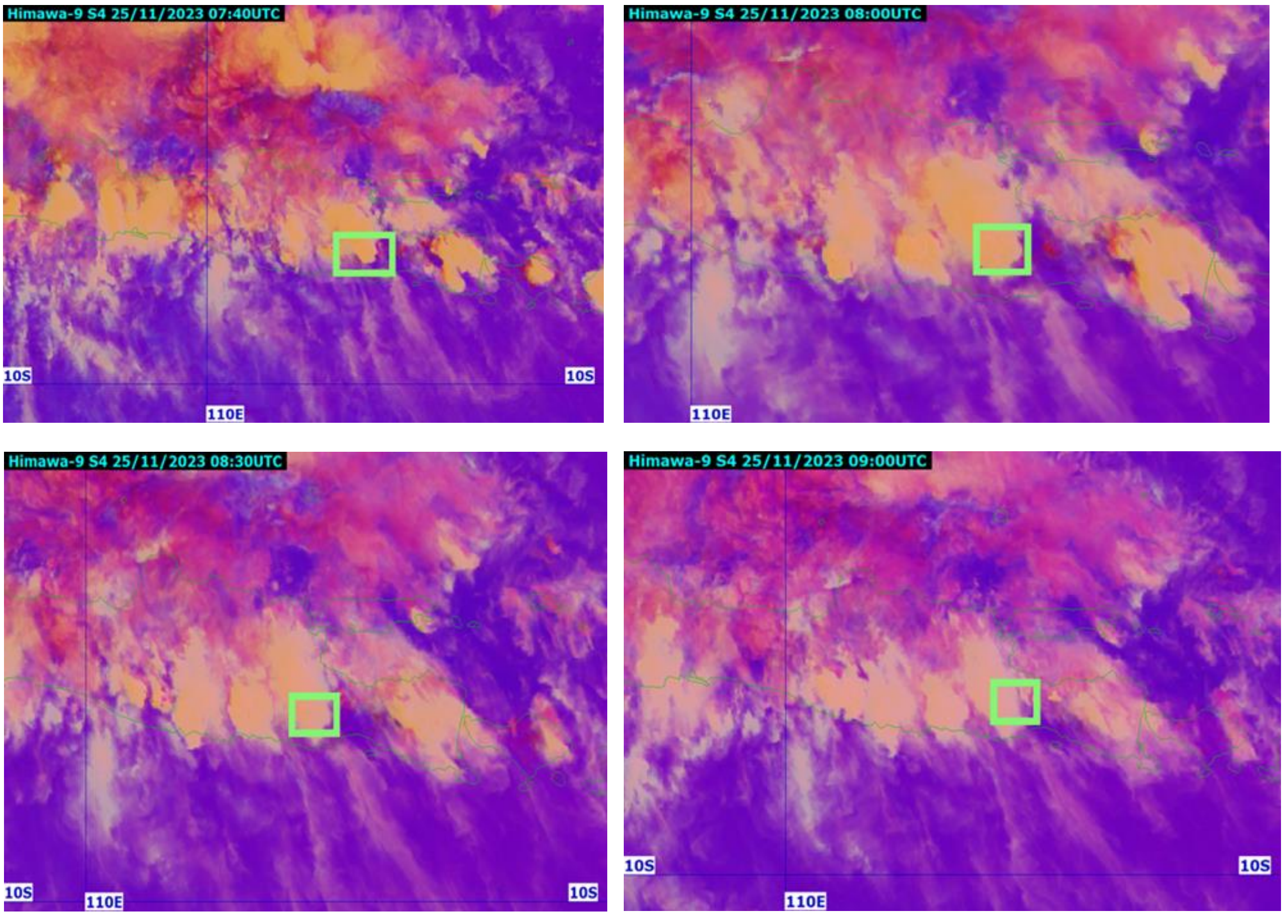

Fig. 1. Himawari-9 RGB *Day Convective Storm* image on 25 November 2023 at 07:40 – 09:00 UTC.

Cloud observations in the Malang City area indicate the existence of clouds, which are represented by the color white, according to the Airmass method processed using Himawari-9 satellite picture data. The cloud's white hue suggests that it is a thick convective cloud that was created by a warm air mass. Using satellite data, the Airmass technique is a great way to identify the kinds of clouds and air mass structures that are present in a given area. This method allows us to examine the impact of warm air masses on the development of dense convective clouds. Since warm air masses allow the air to rise quickly, creating clouds that might result in intense rainfall, these thick convective clouds are typically linked to extreme weather conditions like heavy rainfall. Thus, it is crucial to make observations using the Airmass approach in order to comprehend the possibility of severe weather events, such as storms or heavy rain, which could impact a region, including Malang City. Strong updrafts and high cloud thickness are indicated by the white representation of thick convective clouds in satellite photos [24]. Then, there is a slight dark green color that indicates the clouds are slightly thick and contain warm air masses. These warm air masses cause water vapor from the Java Sea region to be carried into the area. The development of Airmass clouds covering the Malang City area can be observed from 07:40 UTC to 08:00 UTC. This process shows that these slightly thicker clouds could contribute to the potential formation of more intense rainfall due to the interaction between the warm air mass and the high humidity carried from the Java Sea. In other words, the change in color and the development of these clouds serve as an important indicator in predicting weather conditions that may lead to adverse weather in the area.

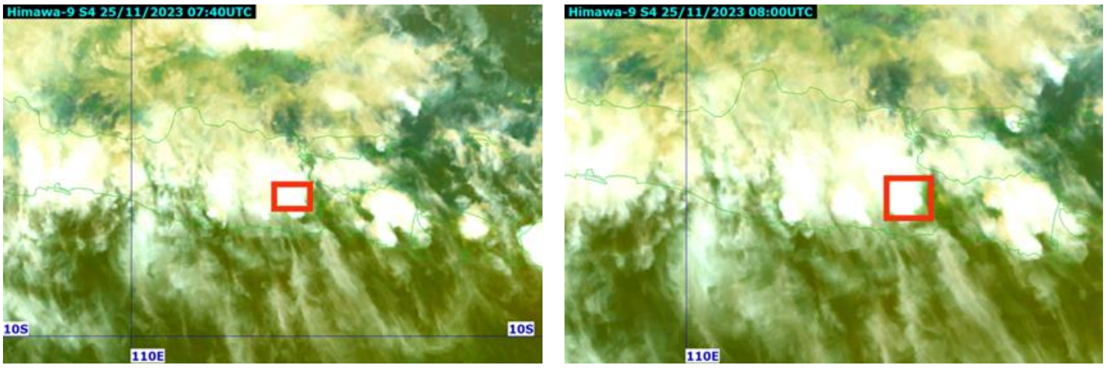

Fig. 2. Himawari-9 RGB *Airmass* image on 25 November 2023 at 07:40 – 09:00 UTC.

This data provides insights into the temperature of the cloud tops, which is derived from radiation observations at a wavelength of 10.4 micrometers. This particular parameter is essential in satellite-based weather observation as it helps in identifying cloud formation and assessing its potential severity, which is crucial for understanding weather patterns. The temperature of the cloud tops is then categorized using a color scheme to make it easier to interpret. For example, black or blue colors indicate areas with minimal cloud formation, where the clouds appear bright and thin. On the other hand, as the temperature of the cloud tops decreases, the color shifts towards orange and red. This color change suggests that the clouds are growing significantly in height, which is a strong indicator of developing storms. When cloud tops show such cooler temperatures, it often signals the formation of Cumulonimbus clouds, which are known for their association with severe weather conditions. These clouds can bring extreme weather events, including intense rainfall, thunderstorms, and even the possibility of flooding. At 07.30 UTC, the cloud top temperature in the Malang City area was observed to show a red color, indicating the potential development of Cumulonimbus clouds. This provides a clear indication that significant weather disturbances were possible in the area at that time.

3.2 Himawari-9 EH Products

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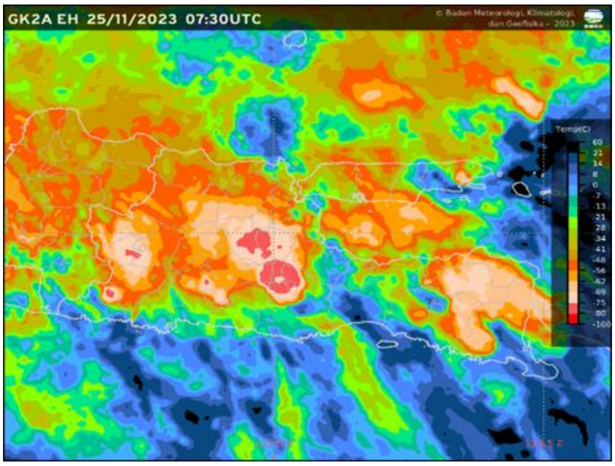

Fig. 3. EH temperature image on 25 November 2023 at 07:30 UTC.

3.3 Wyouming Sounding (Radiosonde)

Based on data obtained from the Wyoming weather website at 00 UTC, several key parameters were calculated to assess the potential for thunderstorms in the Malang City area. The Showalter Index (SI) yields a value of -0.05, indicating a tendency for thunderstorm development. The Lifted Index (LI) shows a value of -2.09, signaling an unstable atmosphere and the possibility of lightning. Additionally, the K Index (KI) gives a value of 25.7, which suggests a potential for thunderstorms in the region. The SWEAT (Severe Weather Threat) parameter results in 231.59, further confirming a high likelihood of thunderstorms. The Convective Inhibition (CIN) value of -22.33 suggests that there is a significant potential for severe weather events. Moreover, the Convective Available Potential Energy (CAPE) parameter is recorded at 1186.67, indicating a high possibility of strong thunderstorms developing. With these parameters pointing towards unstable and conducive conditions for severe weather, it is expected that the Malang City area could experience heavy rainfall at 00 UTC.

4. CONCLUSION

On November 25, 2023, Malang City had significant rain that caused flooding in various regions. Different methods that integrate satellite data and other meteorological measurements are used to detect different types of clouds. The RGB approach, which enables more detailed monitoring of the distribution of convective clouds, is one of the techniques employed. Data from upper-air observations (Radiosonde) that suggested the possibility of heavy rain in Malang at the time was supported by the low cloud-top temperatures derived from Himawari 9-EH products, which showed rather intensive cloud formation.

The meteorological conditions at the time were extremely conducive to extreme weather, as evidenced by upper air observations, satellite data measurements of atmospheric factors, and cloud observations. Based on temperature and humidity, the air masses in the atmosphere can be analyzed and categorized using the Airmass method. This technique aids in determining the kinds of clouds and air mass features that are present in an area when using satellite pictures. Thick convective clouds, which can result in extreme weather conditions like intense rainfall, are typically linked to warm air masses. Strong updrafts and high cloud thickness are indicated by the white representation of thick convective clouds in satellite photos.

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