HAIL IDENTIFICATION BASED ON WEATHER FACTOR ANALYSIS AND HIMAWARI 8 SATELLITE IMAGERY (CASE STUDY OF HAIL ON 2ND MARCH 2021 IN MALANG INDONESIA)

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Abstract. A hail phenomenon occurred in Malang, Sumbermanjing Wetan District (8°6'S and 112°24'E) on March 2, 2021. According to the Regional National Disaster Management Agency, it was accompanied by heavy rain and strong winds, which caused several trees to fall, resulting in damage to people's houses (BNPBD, 2021). Hail is precipitation in the form of ice, usually an irregular round shape produced by cumulonimbus convective clouds (AMS, 2019). The research was conducted by examining global, regional, and local weather factors and analysing the cloud characteristics from satellite image data during hail events. Based on the analysis, it was found that ENSO, sea surface temperature anomalies, and MJO had no effect on the incidence of the hail. The streamline map showed the presence of shearlines and tropical cyclones around the Malang area, and the temperature significantly decrease from 07.00 UTC to 08.00 UTC of 4.4°C and from 08.00 UTC to 09.00 UTC of 3.6°C with significant increase in humidity from 07.00 UTC to 08.00 UTC of 10%. The cloud top temperature was analysed to be at the ripe stage at 07.40 UTC and 8.40 UTC, at -68.2°C.

Keywords: *hail, cumulonimbus, Himawari-8*

1 INTRODUCTION

Astronomically, Malang Regency, East Java, Indonesia is located at 7°42'S–8°24'S and 112°18'E–112°54'E and geographically it is bordered by the South Coast, Kediri Regency, Lumajang Regency, and Pasuruan Regency. This area is situated in the equatorial region so receives solar radiation with relatively high temperatures. The regency is an area with a tropical climate and has a monsoon rainfall pattern. The high radiation in Malang is one of the factors that supports the growth of convective clouds, such as cumulonimbus. In addition, its location is close to the ocean, which provides water vapor reserves for the formation of convective clouds. If the atmospheric conditions of an area are wet, this will support the formation of clouds (Wirjohamidjojo, Soerjadi, & Swarinoto, 2013).

The weather factors that affect cloud growth can be divided into three types, global, regional and local. Local ones include a relatively narrow area and a relatively short time, such as air temperature, humidity, and wind. Air temperature refers hot or cold air that occurs due to the movement of air molecules that affect kinetic energy. Air humidity is the amount of water vapour in a volume of air, while wind is air that flows from areas of high pressure to low pressure. Based on Pertiwi's (2018) research, cumulonimbus clouds range from 4 to 5 octas and the cloud-covered part of the sky of around 6 to 8 octaves is formed when the air temperature ranges from 24.20C to 320C and relative

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humidity ranges from 57% to 93%. Regional-scale weather factor analysis has been conducted on phenomena that have a coverage of between 20 km to 2000 km (Aiqiu et al., 2017). Regional scale analysis includes streamlined map analysis and Madden Julian Oscillation. Analysis of the streamline is made by considering potential areas of weather disturbance, such as low pressure areas (L), the area of a shearline, ITCZ (convergence), the area of an eddy, and divergent and other circulations (Zakir, 2010). Madden Julian Oscillation (MJO) is a propagation phenomenon of oscillating waves that move eastward, with a recurrence duration of 30–90 days. This oscillation is very strong and is felt at low latitudes and near the equator, and first occurs in the Indian Ocean and moves eastward between 10°N and 10°S (Yanai et al., 1973). Global scale weather factors are weather phenomena that are formed due to weather disturbances in the form of waves that have a propagation area of more than 5000 km, with a time scale of events ranging from several days to weeks or longer (Aiqiu et al., 2017). Global scale analysis includes the El Niño Southern Oscillation (ENSO) and sea surface temperatures. The ocean component of ENSO is El Niño and La Niña, while the atmospheric component is the Southern Oscillation (Trenberth, 1997). The center of ENSO activity is in the Pacific Ocean close to the equator (Trenberth, 1997; Trenberth & Caron, 2000). The identification of ENSO is based on several measurements, such as the Southern Oscillation Index (SOI) and the Niño index. Positive to very positive SOI values indicate events from La Niña, while negative to very negative SOI values indicate El Niñoo events (Kirono, cited in Prabowo, 2002). Based on the research of Dewi and Marzuki (2020), the index that has the strongest correlation with the territory of Indonesia is the Niño 3.4 index.

Himawari-8 is a satellite launched in 2015 with a temporal resolution of 10 minutes and has 16 channels as an updated generation of MTSAT-2 (Multi Transpose Satellite-2) which makes observations of convective cloud growth with satellites more detailed (JMA, 2015). Some of the channels provided by Himawari 8 satellite image data include infrared (IR), visible (VIS), and water vapor (WV) images. Ardiyanto (2010) explains that the characteristics of VIS images show the intensity of sunlight reflected by clouds and/or the Earth's surface. Areas with high reflectance are visualised as bright, while low reflectance areas are seen as dark. The IR image depicts the temperature distribution of the cloud tops. Areas of the IR image that have low temperature are visualised as bright while those high temperatures are seen as dark. The WV image depicts the temperature distribution used to determine the middle and upper levels of humidity. Lower temperature areas are depicted as lighter, while the higher temperature ones appear darker.

A hail phenomenon occurred in Malang, Sumbermanjing Wetan District (8°6'S and 112°24'E) on March 2, 2021. According to the Regional Disaster Management Agency, it was accompanied by heavy rain and strong winds, which caused several trees to fall, damaging people's houses (BPBD, 2021). Hail is precipitation in the form of ice, usually an irregular round shape produced by cumulonimbus convective clouds (AMS, 2019). Unlike rain, hail can be dangerous on a large scale, and can cause damage to roofs, agriculture and even aviation (Hidayati, 2015). The growth of towering convective clouds, such as cumulonimbus, indicates a strong updraft in a region. Generally, clouds will only form in the troposphere and stop growing in the stratosphere, but there are clouds with strong storm cells that can penetrate the stratosphere, called overshooting clouds. If the cloud top is higher, this can allow cloud particles to pass the freezing level or freezing point. When the cloud has passed this level, the supercooled water particles freeze into ice particles. These fall due to downdraft and the effects of gravity (Paski et al., 2017). Increasing the height of the 0 °C isotherm can change the melting point level (Xie et al., 2008) and increase the potential for coalescence-collision events, which play an important role in the formation of rain in warm clouds (Lin et al., 2005). Currently, one of the greatest uncertainties in the field lies in evaluating changes in hail frequency, as storm cloud development generally occurs on small spatial and temporal scales (Kunz, 2007). The scarcity and poor standardisation of hail detection and monitoring systems are important issues in identifying hail events. Based on research by Hidayat et al., (2017), the cloud top temperature during the hail incident in Bandung on April 19, 2017, was -74 °C and on April 23, 2017, it was -60 °C.

Identification of the hail phenomenon is needed to assist mitigation efforts. The purpose of this study is therefore to determine the characteristics of the clouds that were analysed through Himawari 8 satellite imagery data and to determine the weather conditions, both globally, regionally, and locally, during hail events in Malang. Himawari 8 satellite image data processing using SATAID (Satellite Animation and Interactive Diagnosis) software, which was developed by the Japan Meteorology Agency (JMA) and serves to retrieve meteorological parameter data from satellite images. This software processes binary data from satellites and converts them into images.

2 MATERIALS AND METHODOLOGY

The research was conducted in Sumbermanjing Wetan District (8°6'S and 112°24'E) Malang Regency on March 2, 2021. Data on global, regional and local scale weather factors, together with satellite image data from Himawari 8 were employed. The global scale weather factors analysed were El Niño Southern Oscillation (ENSO) data include a graph of the Niño 3.4 index and a graph of Southern Oscillation. Index (SOI), accessed from http://www.bom.gov.au/climate/enso/indices.shtml and sea surface temperature (SST) data accessed from https://ncics.org/portfolio/monitor/mjo/. For the analysis of regional weather effects, Madden Julian Oscillation (MJO) data were employed, obtained from http://www.bom.gov.au/climate/mjo/,and streamlined maps obtained from http://www.bom.gov.au/australia/charts/archives/. Analysis of the influence of local scale weather was made using synoptic observation data from Geophysical Station Class III Karangkrates Malang, East Java (8°9'S and 112°27'E), which included pressure, temperature, humidity, wind direction and speed. In addition, analysis of atmospheric conditions was conducted using IR, VIS, and WV channels Himawari 8 satellite image data, with the extension -.z, which was then processed using the SATAID application.

The descriptive statistical method was used to analysed the data. Descriptive statistics are methods related to the collection and presentation of data in order to provide useful information (Walpole, 1995). Descriptive statistics function to describe or provide an overview of the object under study through sample or population data

(Sugiyono, 2007). The stages of data analysis are:

a. Analysis of global, regional, and local weather factors when hail occurs, in the case on March 2, 2021.
b. Analysis of the stages of cloud development, from the growth stage, to maturity, and dissipation, taken from satellite image data related to cloud top temperatures and cloud development time series. Based on this analysis, the times of the growth, maturation, and convective cloud dissipation stages were obtained.
c. Analysis of cloud types when they are at the mature stage through satellite image data of in the infrared, visible, and water vapor channels.

3 RESULTS AND DISCUSSION

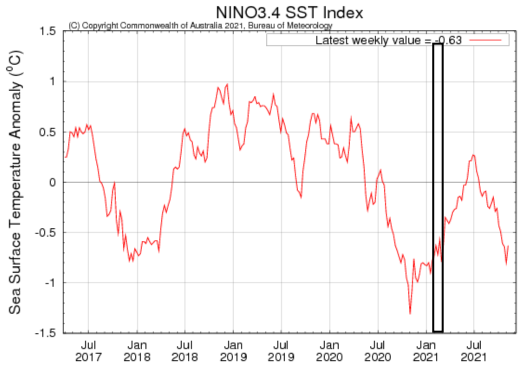
3.1 Global Scale Weather Effect Analysis

3.1.1 El Niño Southern Oscillation (ENSO)

In Figure 3-1, it can be seen that the ENSO graph for the variability of the Niño 3.4 index shows a negative value, indicating the occurrence of La Niña. This value is in the range of -1 to -0.5, which indicates the intensity of La Niña is in the weak category. On the other hand, the value of the Southern Oscillation Index (SOI) in March 2021, which ranged from 0 to 6, was generally in the normal category. Therefore, it can be said that hail in Malang was not influenced by the ENSO phenomenon.

3.1.2 Sea Surface Temperature (SST) Analysis

Figure 3-2 shows the overall sea surface temperatures for a period of 7 days. The temperature in Indonesia as a whole is higher than areas at higher latitudes. This is because Indonesia is located at the equator, so it receives high solar radiation every year. High sea surface temperature conditions will increase the possibility of evaporation which can provide a source of water vapor in the air which can condense to form clouds and cause rain.



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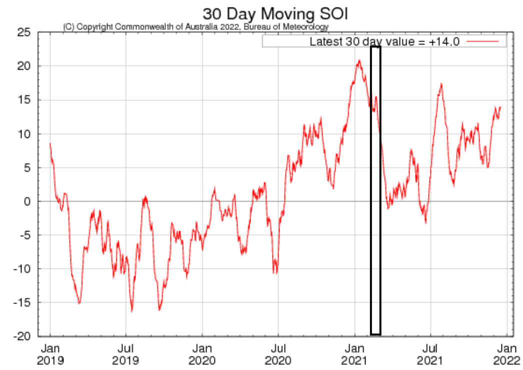


(b)

Figure 3-1: Graph of the Niño 3.4 Index and SOI. (a) Variability of the Niño 3.4 Index in January 2017 to November 2021, and (b) Variability of the SOI Index in October 2011 to November 2021 (Source: http://www.bom.gov.au/climate/enso/indices.shtml)

Figure 3-3 shows sea surface temperature anomalies for three months, namely December, January and February (DJF), January, February and March (JFM), February, March and April (FMA), and March, April and May (MAM). In the JFM and FMA periods, the sea surface temperature anomaly ranges from 0.2 °C to 0.6 °C. This range indicates that the SST factor does not support an evaporation rate which would trigger the formation of convective clouds in the Malang area.

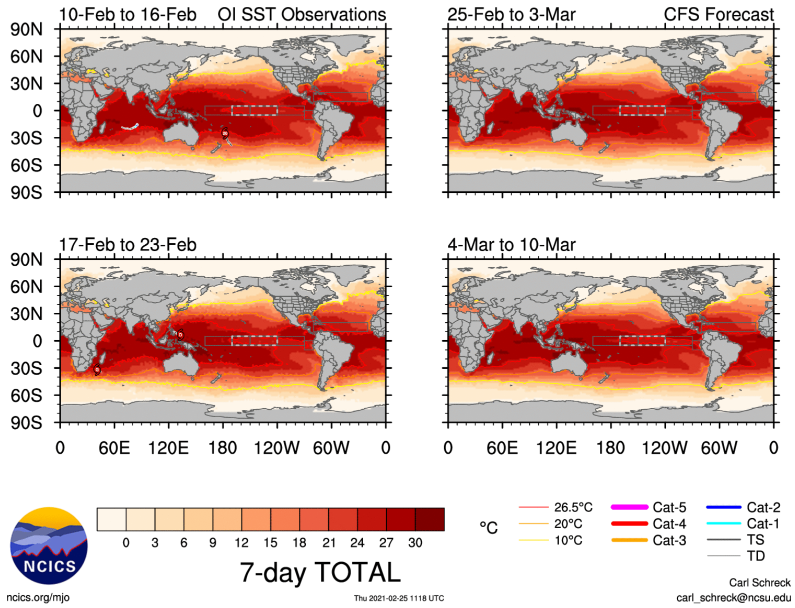


Figure 3-2: Total Sea Surface Temperatures for the 7 days from 10 February to 10 March. (Source: https://ncics.org/portfolio/monitor/mjo/)

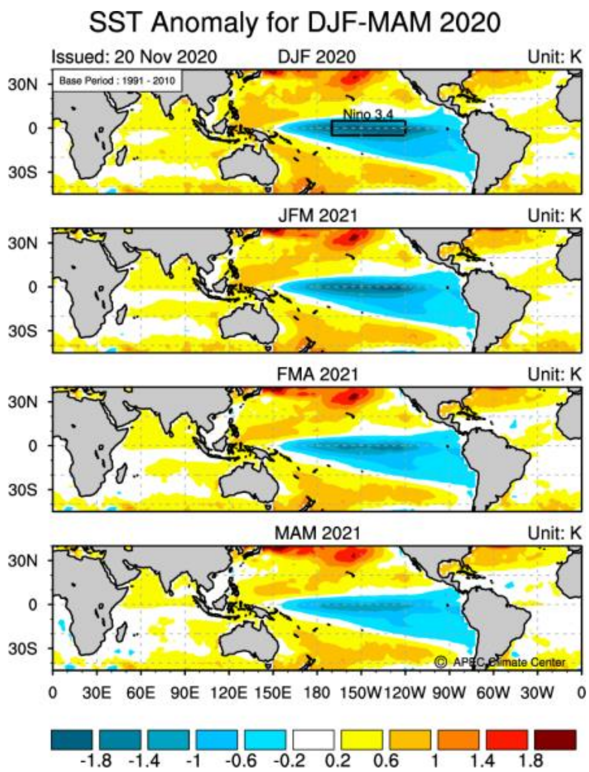


Figure 3.3: Sea Surface Temperature Anomaly (Source: https://apcc21.org/)

3.2 Regional Scale Weather Effect Analysis

3.2.1 Madden Julian Oscillation (MJO) Analysis

The MJO phase diagram in Figure 3-4 shows the movement of the MJO. From 27 to 31 January, the MJO was in phase 6 in the Western Pacific region. Then during February, it was in phase 7 which was active in the Western Pacific region. Furthermore, between 1 to 7 of March, the index value was in the middle circle, so the MJO in March 2021 was categorised as weak/inactive in the territory of Indonesia. In other words, the MJO did not affect the weather patterns around Indonesia.

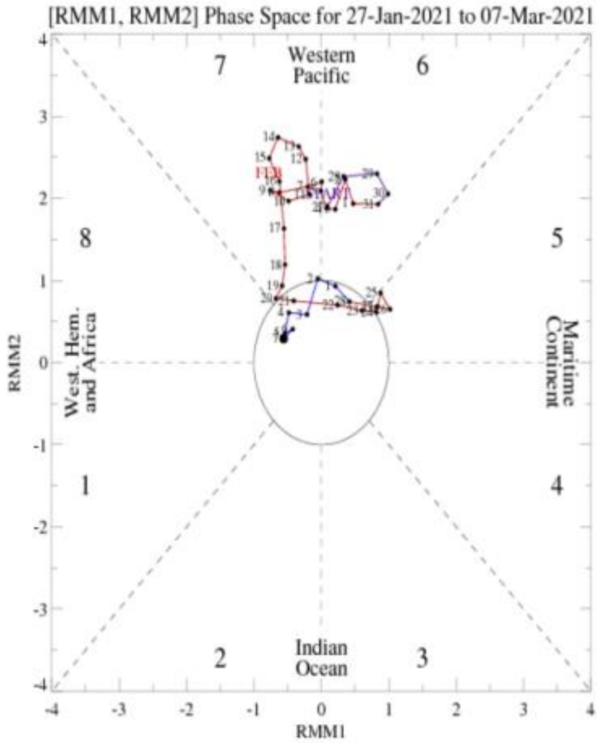


Figure 3-4: MJO Phase Diagram for the Time Period 27 January 2021 to 7 March 2021 (Source: https://www.cpc.ncep.noaa.gov/)

3.2.2 Streamline Map Analysis

The streamline map shown in Figure 3-5 indicates the presence of shearlines around the Malang area. Shearline caused change in wind direction suddenly and whose speed tends to decrease, causing a buildup of air masses that cause extreme weather. Deep layer shear (high density shearlines), of 39% supports the formation of hail. Shearlines that cause heavy rain have a lower speed than those that cause hail (Tuovinen et al., 2015). The streamline map identifies the tropical cyclones Marian and Niran in the Indian Ocean. The location of the cyclones is relatively close to Malang, which can be a trigger for extreme weather, such as hail. The presence of a low pressure centre in the cyclone will cause a buildup of air masses around it. This can encourage the growth of convective clouds such as cumulonimbus allowing them to grow taller and exceed the freezing level, causing water vapour to cool into ice crystals. In the process that occurs in cold clouds, hail can occur.

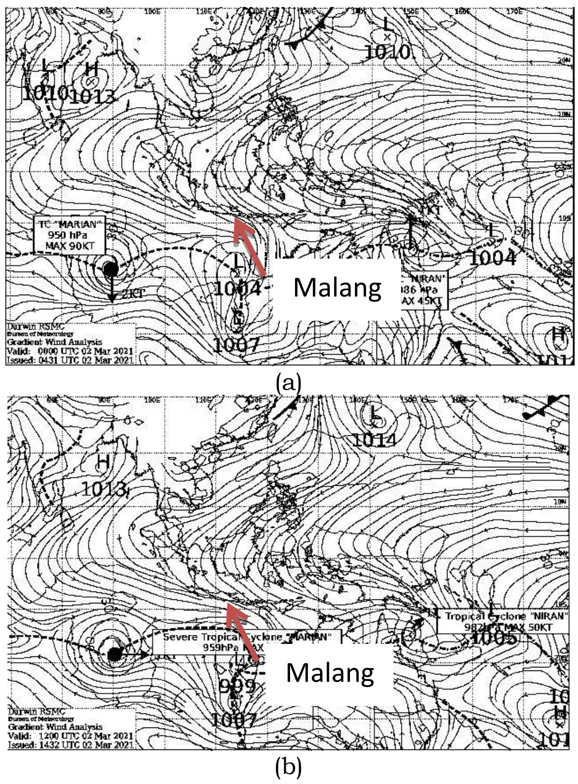


Figure 3-5: Streamline Map March 2, 2021. (a) 00.00 UTC (b) 12.00 UTC (Source: http://www.bom.gov.au/australia/charts/index.shtml/)

3.3 Local Scale Weather Effect Analysis

Data on surface weather elements were obtained from the Karangkrates Geophysics Station in Malang, with coordinates 8°9'S and 112°27'E, while hail occurs at coordinates 8°6'S and 112°24'E. Although hail does not occur at Karangkrates Geophysics Station, the proximity of the incident location to the Karangkrates Geophysics Station is an extension of the BMKG Malang area. Therefore, an approach was taken based on the results of the synoptic observations at 00.00 UTC to 15.00 UTC, which were used as material for analysis, as shown in Table 3-1.

Table 3-1: Results of Synoptic Observations on March 2, 2021 at the Karangkrates Geophysics Station, Malang

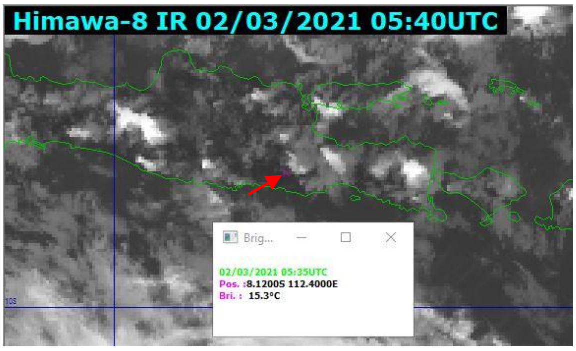
Time (UTC)	Tempe-rature (C)	Relative Humi-dity (%)	Wind Direc-tion	Wind Speed (knot)
04.00	31.2	66	Calm	0
05.00	31.2	68	South-east	4
06.00	32	61	South-west	2
07.00	32.6	61	North-west	2
08.00	28.2	71	West	6
09.00	24.6	81	Calm	0
10.00	23.4	86	East	1
11.00	22.8	89	East	2
12.00	22.6	90	East	2

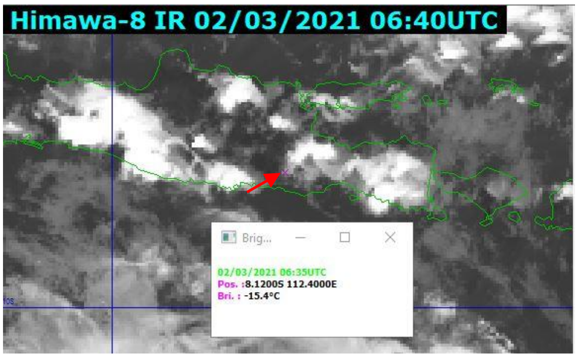
On March 2, 2021, from 04.00 UTC to 07.00 UTC, there was an insignificant increase in air temperature. Then at 07.00 UTC to 08.00 UTC there was a significant fall in temperature of 4.4°C. A further significant fall of 3.6°C also occurred between 08.00 UTC to 09.00 UTC. Such falls can occur because the latent heat released during the formation of hail is reabsorbed, so the hail temperature will be several degrees higher than that temperature of the surrounding cloud (Hidayati, 2015). Furthermore, the temperature continued to drop, but not significantly, between 09.00 UTC and 12.00 UTC. Air humidity between 04.00 UTC and 07.00 UTC was also observed to fall, but then increased between 07.00 UTC and 12.00 UTC this increase was quite fairly significant between 07.00 UTC and 08.00 UTC, at 10%. Another study also showed a fall in temperature accompanied by a significant increase in air humidity at H-2 hours before hail occurred on October 22, 2011 in Bandung (Hidayati, 2015). The direction and speed of the wind on March 2, 2021 were quite varied, dominated by an easterly, but with insignificant wind speeds.

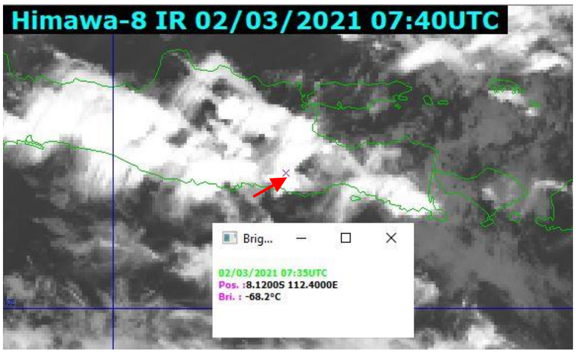
3.4 Himawari-8 Satellite Image Data Analysis

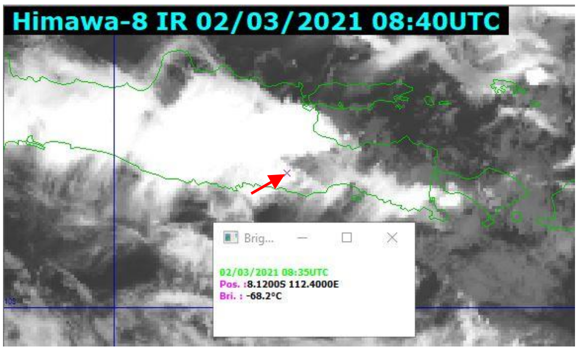
3.4.1 Analysis of Cloud Peak Temperature and Cloud Growth

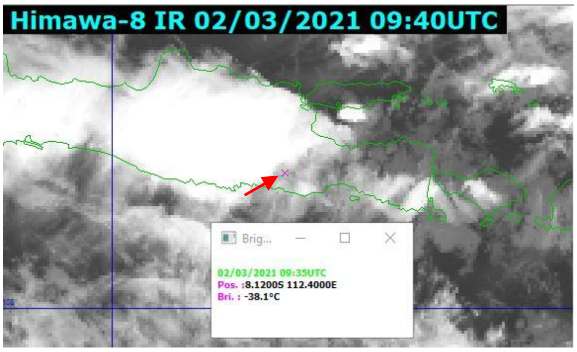
Based on the analysis of satellite imagery from March 2, 2021, as shown in Figure 3-6, with regard to cloud development from 05.40 UTC to 10.40 UTC, the highest cloud top temperature occurred at 07.40 and 08.40 UTC, at -68.2 °C. That time identified as the mature stage of the cloud which was the cause of hail in Malang. At 05.40 UTC and 06.40 UTC, the cloud top temperature continued to fall from +15.3 °C to -15.4 °C. That time was identified as the stage of cloud growth. Then at 09.40 UTC and 10.40 UTC the cloud top temperature increased, identified as the dissipation stage. Identification of the cumulonimbus clouds was made by observing the cloud cover area with very low cloud top temperatures, which can fall to lower than -50°C. Meanwhile, ordinary tall clouds such as cirrus, which are located at the same altitude as the convective cloud tops, usually have low temperatures, but are generally not as cold as the cumulonimbus cloud tops. The brightness of the very bright top of the cumulonimbus cloud indicates that the cloud has reached a very high altitude and can be ascertained to be in the solid phase (Karmini, 2000). At 07.40 UTC and 08.40 UTC it occurs during the day in Malang. This is in line with Tjasyono's (2006) research, in which most rain fall after maximum convection. Convective rain is from convective clouds and occurs after maximum insolation or after 12.00 local time. Convective clouds can cause precipitation in the form of heavy rain or, hail, accompanied by lightning.











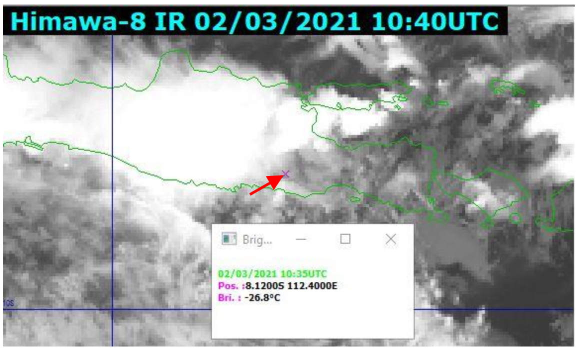


Figure 3-6: Convective Cloud Development March 2, 2021 05:40 UTC to 10:40 UTC

In Figure 3-7, the cloud growth stage is indicated by the red box, the mature stage is indicated by the yellow box, and the dissipation stage is indicated by the green box. This is based on the cloud top temperature. The lower the temperature, the greater the number of convective clouds identified. The lowest temperature peak was identified as the mature stage of convective clouds, while the increase in temperature was identified as a convective cloud dissipation stage. The growth stage occurred from 06.00 UTC to 07.00 UTC. Mature stage from 07.00 UTC to 09.00 UTC, and the dissipation stage from 09.00 UTC to 10.00 UTC.

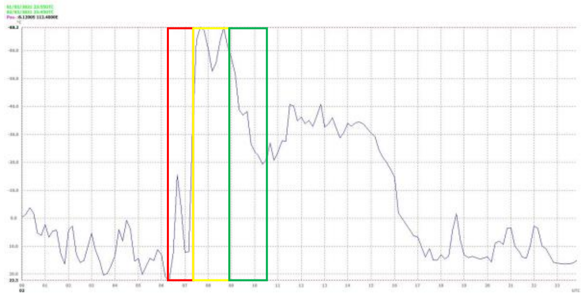


Figure 3-7: Time series Development of Convective Clouds March 2, 2021

Analysis was also made of the temperature contours of the cloud tops around the Malang area as shown in Figure 3-8. Based on the cloud top temperature contour map dated March 2, 2021, the location of the hail incident experienced a lower temperature than the surrounding area shown by the red arrow, which is -67.5 °C, as shown by red arrow. When compared with the contours of the surrounding temperature, the difference is great where there is an area with a temperature of +12.5 °C which is indicated by the green arrow. This means that there is the phenomenon at the location of a very low cloud top temperature. This is identified as the location of the occurrence of hail.

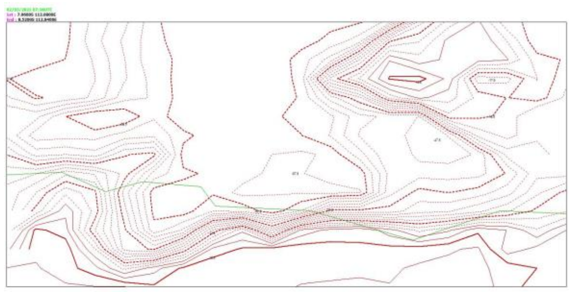
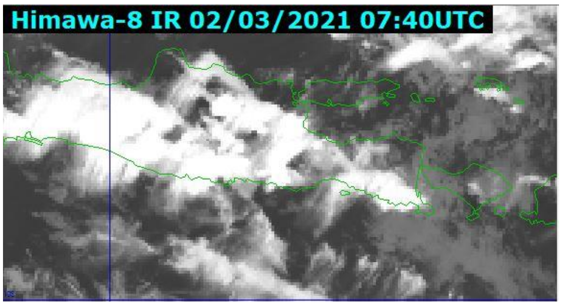


Figure 3-8: Cloud Peak Temperature Contour on March 2, 2021

3.4.2 Identification of Cloud Types

Figure 3-9, shows that the cloud type is cumulonimbus, as in the infrared, visible, and water vapour channels the color is bright which indicates that the reflection of energy is high (can occur due to the high water vapour content), the cloud top temperature is low, and the combination of both, which is indicated by the water vapour channel where the water vapor contained is also high.



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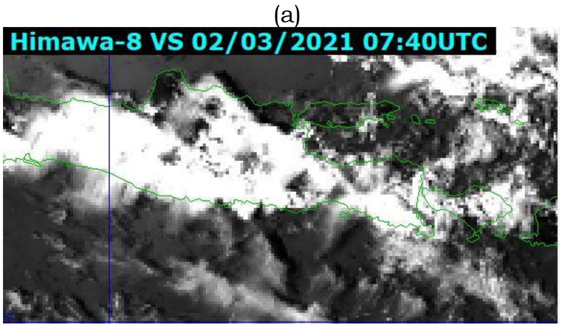

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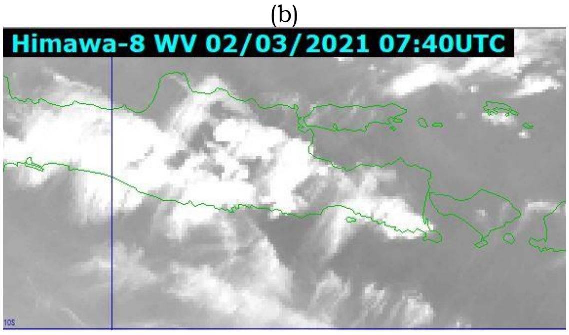

(c)

Figure 3-9: Satellite Image Data (a) infrared (b) visible (c) water vapor

4 CONCLUSION

Based on the explanations given in the paper, it can be concluded that:

a. In relation to global weather factors, the ENSO phenomenon and sea surface temperature anomaly have no effect on the occurrence of hail.

b. Regarding regional weather factors, the MJO phenomenon does not affect hail events, and the streamline map shows the presence of shearlines and tropical cyclones around the Malang area, which analysed could affect the incidence of hail.
c. Regarding local weather factors, there was a significant decrease in temperature from from 07.00 UTC to 08.00 UTC of 4.4°C and from 08.00 UTC to 09.00 UTC of 3.6°C and an increase in air humidity from 07.00 UTC to 08.00 UTC of 10%
d. Based on the cloud top temperature, the growth stage occurred between 06.00 UTC and 07.00 UTC, mature stage between 07.00 UTC and 09.00 UTC, and dissipation stage between 09.00 UTC and 10.00 UTC. The cloud top temperature at 07.40 UTC and 8.40 UTC was -68.2 °C
e. Based on the infrared, visible, and water vapour images, the type of cloud was identified as cumulonimbus.

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AUTHOR CONTRIBUTIONS

Marinda Nur Auliya; writing, methodology, data processing, and analysis Aditya Mulya.: validation, review, and editing.

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