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Identifying Hail Events Using Weather Radar and Satellite Data (Study Case in East Java on 23 December 2021)

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ABSTRACT

Hail is an extreme weather phenomenon that rarely occurs in tropical regions such as Indonesia. However, if convective clouds are strong enough to develop higher, a hail event is likely to occur. Interestingly, on 23 December 2021, hail events occurred in four different nearby locations. Weather Radar data from the Juanda Meteorological Station and Himawari-8 Satellite data were used to analyse this hail phenomenon. The Radar measured reflectivity values, cloud top height, water vapour content, and the derivative product of the probability of hail occurrence. The Himawari-8 data were utilised to observe cloud top temperatures. From the results, it is known that the reflectivity value of hail is in the range of 45 dBZ to 55 dBZ, with a probability of hail above 80%, and the temperature at the top of the Cumulonimbus cloud is between -67.5°C to -82.5°C. These thresholds may be used in monitoring hail events, especially in the East Java region. be able to stand alone.

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1. INTRODUCTION

A simple definition of hail is any form of ice falling from thunderstorm clouds, with a diameter exceeding 5 mm (Punge and Kunz, 2016; Allen et al., 2019). Hail originates from either single-layered or multi-layered cumulonimbus clouds near the Earth's surface. These clouds can be either single-layered cumulonimbus clouds or multi-cell cumulonimbus clouds with an extent of approximately 3-5 km. They grow vertically, reaching heights of 30,000 feet or more (Fadholi, 2012). Indonesia, located in the equatorial region with hot temperatures throughout the year, might seem an unlikely place for hail phenomena. However, although quite rare, hail events regularly occur in different parts of the country. Not only do they occur in mountainous regions with low temperatures, but hail phenomena have also been spotted in urban areas. Hail is considered extreme weather because it can damage properties and threaten human lives (Chatterjee et al., 2008; Sari et al., 2018).

Radar and satellite are two main remote sensing tools for observing and analysing the atmosphere. Weather Radar (Radio Detection and Ranging), as its name implies, has a general principle of detecting targets/objects through the transmission of radio waves into the atmosphere. It then processes the received wave signals to determine the distance, position, and type of object (Meischner, 2000). Weather radar, in its daily usage, is employed in meteorology and has the capability to quantitatively detect meteorological phenomena. This includes measuring the intensity of rainfall, providing warnings for severe weather conditions, detecting and analysing wind speed, determining the base and top heights of clouds, tracking the speed and movement of rain clouds, profiling vertical and horizontal wind, and identifying the phases of rain cloud growth. Weather radar is also highly valuable for delivering early warnings of extreme weather events (Wardoyo, 2015).

The Himawari-8 satellite represents the latest generation, succeeding the MTSAT (Multifunctional Transport Satellites). It is equipped with the Advanced Himawari Imager (AHI) sensor, featuring 16 spectral bands comprising 3 visible bands, 3 near-infrared (NIR) bands, and 10 thermal or infrared (IR) bands (Choi and Suh, 2018). The satellite has a temporal resolution of 10 minutes. Infrared bands exhibit varied responses to the temperature of cloud tops, water vapour, land, and sea surfaces, aiding in mapping the classification of rain clouds (Kushardono, 2012). The infrared bands, especially at the freezing level, can serve as indicators for detecting the potential occurrence of hail. In Indonesia, hail can only occur from cumulonimbus clouds, where their tops surpass the freezing level with an air temperature of 0°C or approximately 16,000 feet (Karmini, 2000).

By utilising radar and satellite data, this study seeks to analyse hail phenomena in four neighbouring locations in East Java (Porong, Blitar, Malang, and Jember). Interestingly, these hail events occurred on the same day, namely 23 December 2021. The analysis of radar and satellite threshold values aims to establish a foundation for predicting future hail events.

2. LITERATURE REVIEW

2.1 *Hail*

Hail is precipitation in the form of ice pellets with a minimum diameter of 5 mm or more, originating from cumulonimbus clouds (Tjasyono, 2004). Hailstones are ice rocks that fall during hailstorms. Hail can only form in cumulonimbus clouds (Cb) whose tops exceed the freezing level (Blyth et al., 2015; Purba et al., 2023).

Almost all hailstorm events originate from thunderstorms, but it can also occur in extreme rain without lightning and thunder, although this is relatively rare (Dotzek and Price, 2009). Additionally, many thunderstorms can produce thunder but not necessarily hail. Hail formation can occur at altitudes of 5 to 10 km Cb clouds containing supercooled droplets with temperatures < 0^0C (Browning and Foote, 1976). A strong updraft is required to sustain the rise of parcels in the primary ice-forming layer (Nelson, 1983). Hailstorms that frequently occur from cumulonimbus clouds are often accompanied by strong gusts of wind and can also be accompanied by tornadoes with brief durations. Hail growth can occur in both single-cell and multicell cumulonimbus clouds whose bases are close to the Earth's surface. Hail growing from multicell cumulonimbus clouds can cover an area of 3-5 km with a short duration, ranging from 3-5 minutes (Deni, 2016).

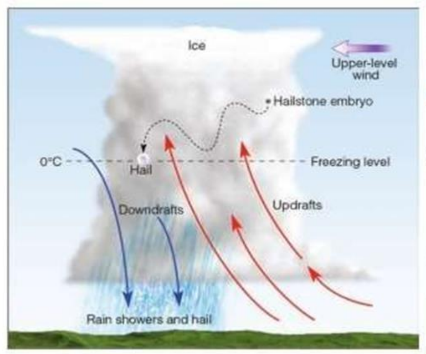

Figure 1. The process of hail formation within cumulonimbus clouds (Ahrens, 2014)

2.2 *Hailstorm analysis*

Research on hail has been conducted in Central Java using radar imagery (Giyarto, 2016). The data used are from the weather radar station Ahmad Yani Semarang, consisting of reflectivity and velocity products. The results of this study indicate an increase in colour gradation from low decibel units to high decibel units (60.2 dBz), indicating the formation of cumulonimbus clouds during rapid growth with very rapid changes in rain in dry and hot environmental conditions. These clouds grow vertically with a cloud base height generally less than 1000 m and can reach a peak height of 15 km.

Another study focused on case studies that occurred in Pondok Indah on 29 October 2013, Tomang on 22 April 2014, Yasmin on 30 November 2015, and Bandung and Sukabumi on 26 March 2016 (Gosima, 2016). This research used a descriptive method to analyse radar products to identify and understand the characteristics of hail. The radar products used in this study include CMAX (Column Maximum), VCUT (Vertical Cut), indicating a maximum reflectivity value >50 dBz. The vertical integrated liquid (VIL) product showed values >25 kg/m2, except for the Tomang area, which had a VIL value of 19 kg/m2.

The phenomenon of hail was also studied using weather radar explaining the relationship between the three-body scattering pattern and the size of hail particles (Zrnic et al., 2010). Three-body scattering is the reflectivity seen on weather radar located behind storm cells caused by scattering between water particles and the ground. The results of this study showed that the three-body scattering pattern could be caused by hail particles with sizes between 10 mm and 20 mm.

The hail phenomenon in Ruteng was investigated using satellite data to determine atmospheric instability conditions, convective activity, and cloud top temperature during the hail period (Maharani, 2015). The results of the study indicated that hail was influenced by convective activity, convergence patterns, wind shear in the lower atmosphere, and high humidity in the upper atmosphere supporting the formation of cumulonimbus clouds.

3. METHODS

The type of research used is descriptive and case study. The location of this research is the area experiencing hail phenomena in Porong, Blitar, Malang, and Jember, which fall within the coverage of the Surabaya radar. The Surabaya radar is a Doppler-type radar located at 7.41028° S latitude and 112.76056° E longitude.

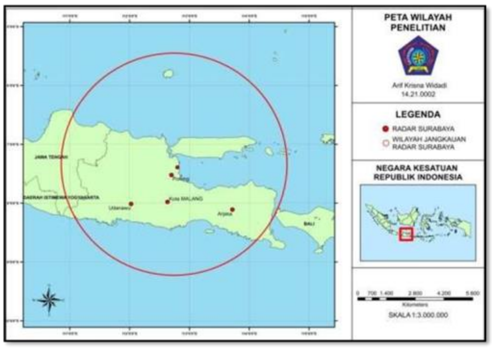

Figure 2. Focus area of study

3.1 Hail Event Data

Hail event data is obtained through online media, reports from the Regional Disaster Management Agency (BPBD), and information from social media during the hailstorm on 23 December 2021. From this information, four hail events were identified in a single day in East Java.

3.2 Weather Radar Data

Raw volumetric weather radar data from Surabaya during the hailstorm on 23 December 2021, is used. The Surabaya weather radar operates in Volume Coverage Pattern (VCP) 21 mode, with elevations ranging from 0.50 to 45.0 degrees. Radar data on the date of the hail event is processed, and radar products such as CMAX (maximum reflectivity in each scanning column), VCUT, EHT, and ZHail are generated to observe the characteristics of convective clouds based on radar image displays (Anggoro dan Pramujo, 2018; Rinanto et al., 2023).

3.3 Weather Satellite Data

Himawari-8 Satellite data is obtained from the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG). The satellite weather data will be processed using the SATAID application to obtain the profile of the top temperature of cumulonimbus clouds in the infrared and water vapour channels (Dewita et al., 2016).

4. RESULTS AND DISCUSSION

From the analysis of the Surabaya Radar Image during the hailstorm incidents in Porong, Malang, Blitar, and Jember on 23 December 2021, it can be observed that the hailstorm occurrences in these locations occurred between 13:00 and 15:50 local time (UTC+07:00). The reflectivity values at these four locations were not the same. The minimum reflectivity threshold that can be used as a consideration for the occurrence of hailstorm is 50 dBZ (Kunz and Puskeiler, 2010).

Example of Hail Analysis in Porong

The Porong area is located in the Sidoarjo Regency of East Java, with an elevation of 4 metres above sea level. The hail incident in the Porong Sub District of Sidoarjo Regency, based on information from electronic media, the community, and the BPBD report, occurred at 15:50 local time. According to observations from the Surabaya Radar CMax product (Figure 3), the growth of convective clouds, specifically Cumulonimbus, was already noticeable from 15:31 to the east and south of the Porong Subdistrict. By 15:43, the Cumulonimbus cloud was directly above Porong, and at the time of the hail incident at 15:49, the Cumulonimbus cloud with a reflectivity value of 55 dBZ was observed.

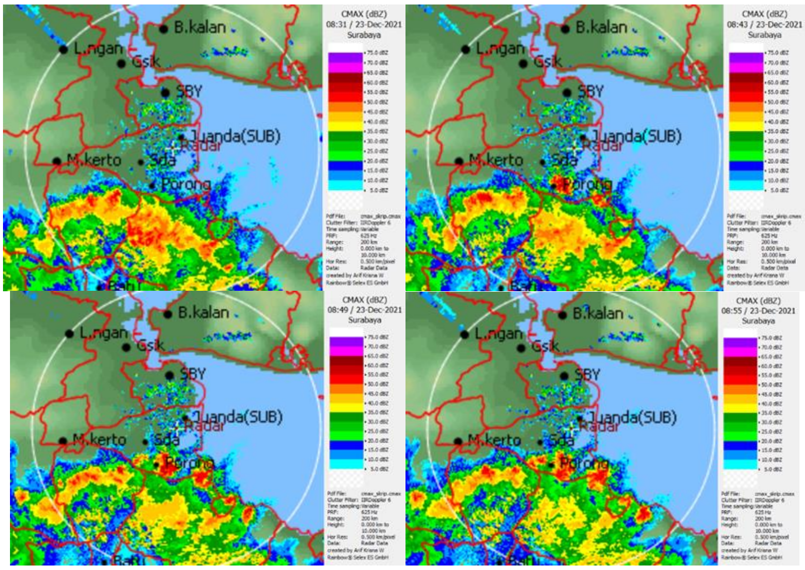

Figure 3. The CMAX product from the Surabaya Radar image during the hail incident in Porong

In the analysis of the VCUT product, it is observed that the reflectivity display of the hail in Porong is 55 dBZ (Figure 4) with a cloud base height below 1 km. This indicates that the base height of the Cumulonimbus clouds in Porong and its vicinity is very low.

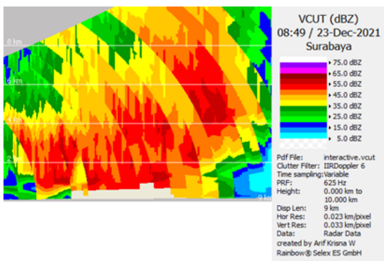

Figure 4. The VCUT product during the hail in Porong

To analyse the height of Cumulonimbus cloud tops from the Radar

Image, one can use the EHT (Echo Height Top) product as shown in Figure 5 below. The heights of Cumulonimbus cloud tops during the hail incident at 15:49 can reach 12 km.

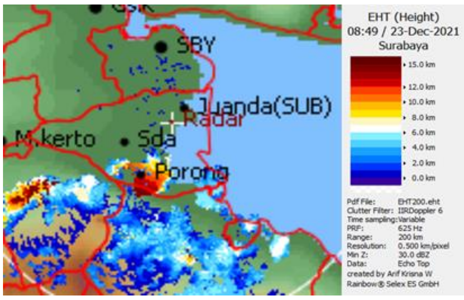

Figure 5. The EHT (echo top) product during the hail in Porong

The cloud base height obtained from the Echo Base layer shows that the base height of Cumulonimbus clouds is below 1 km as shown in Figure 6.

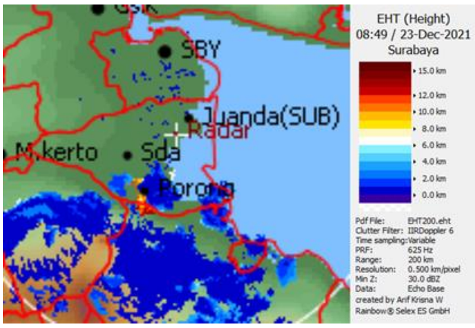

Figure 6. The EHT (echo base) product during the hail in Porong

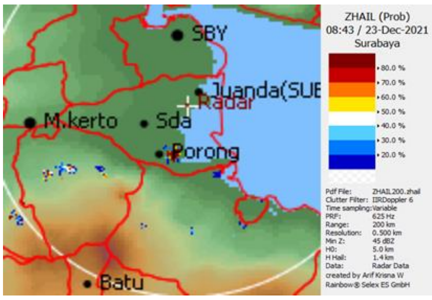

Figure 7. ZHail product during the hail in Porong

The ZHail Radar Image product is also utilised, which is used to forecast the probability of hail occurrence. In Figure 7, it can be observed that the probability of hail in the Porong area at 15:43 (minutes before hail occurence) is very high, reaching 80%.

From the analysis of the water vapour content values in the Vertically Integrated Liquid (VIL) display of the Surabaya Radar product, it is evident that the water vapour content value just before the hail occurrence (15:43) in the Porong area is 30.71 mm (Figure 8). During the hail incident (15:49), the water vapour content values tend to decrease.

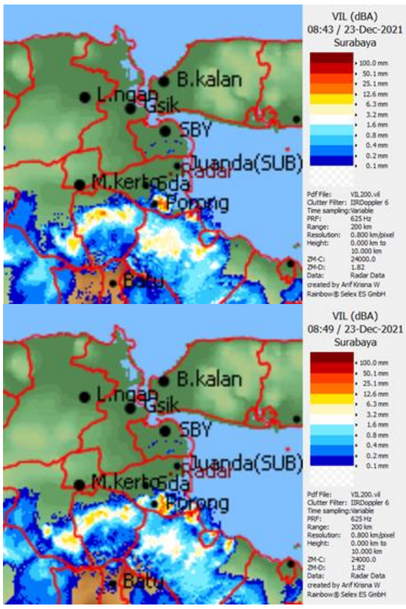

Figure 8. The VIL product during the hail in Porong

The hail incident in Porong is discernible from the image below, illustrating the swift temperature changes at the summit of Cumulonimbus clouds as the hailstorm unfolded from 12:00 to 16:00 local time. A rapid decrease in temperature was observed, corresponding to the proliferation of Cumulonimbus clouds in the Porong area. According to Himawari 8 satellite data processed using Sataid software, the temperature at the apex of Cumulonimbus clouds during the hail incident in Porong was recorded at -67.5^{0}C at 15:50 local time (Figure 9). The satellite image reveals that Cumulonimbus clouds in the Porong and southern Porong areas exhibited a multicell type, with CB clouds observed above the Porong region and south of Porong (Figure 10).

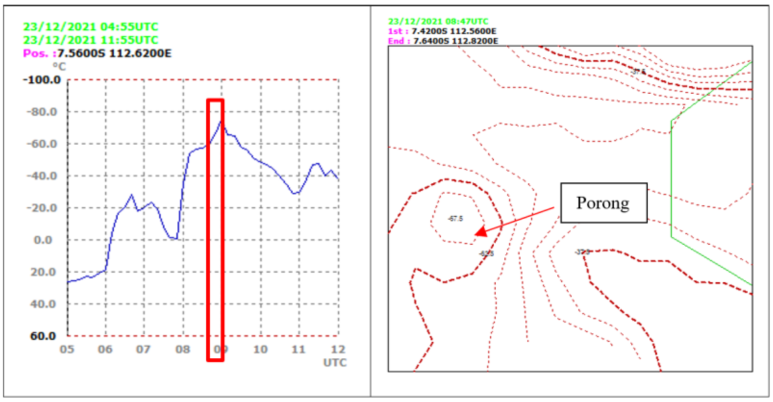

Figure 9. Graph depicting the temperature changes at the summit of clouds and the temperature at the cloud's peak during the hailstorm in Porong.

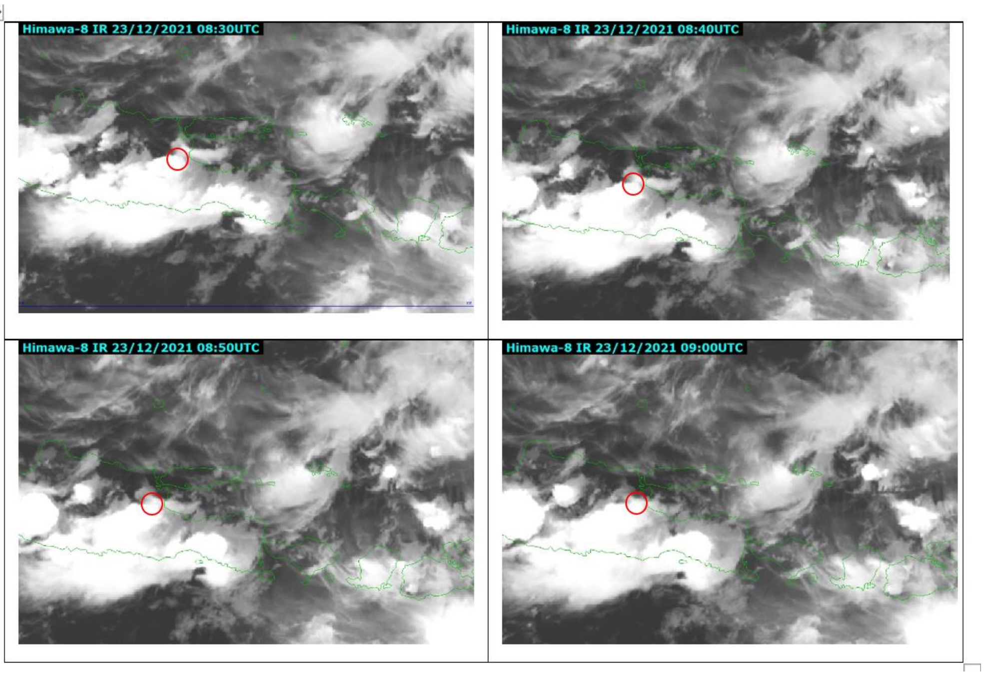

Figure 10. Himawari 8 Satellite Image, IR Channel, depicting hail in Porong

Hailstorms in other locations, such as Malang, Blitar, and Jember, are being analysed using a similar approach as the one employed for the Porong hail analysis. The summary of parameter values obtained from radar and satellite products is presented in Table 1 below.

Table 1. Summary of Parameter Values During Hailstorm

Location	Weather Radar Parameters								Satellite
	Elev (m)	Dist (km)	CMax (dBz)	VCut (dBz)	E Top (km)	E Base (km)	ZHail (%)	VIL (mm)	Cloud top temp (°C)
Porong	1	13,8	55	55	12	< 1	80	30,7-6,8	-67,5
Malang	445	61,6	60	60	11	< 1	> 80	27,1-5,0	-72,5
Blitar	122	104,6	55	55	10	< 1	> 80	3,3	-72,5
Jember	203	133,2	45	45	15	< 2	80	0,53	-82,5

5. CONCLUSION

Based on the research findings from the hailstorm events in four locations in East Java on 23 December 2021, several conclusions were drawn:

1. The maximum reflectivity values during hailstorms in each studied area varied between 45 dBZ to 60 dBZ. The differences in reflectivity values during the hailstorm events in these four locations can be attributed to the varying radar locations, different topographies influencing the electromagnetic wave propagation emitted from the radar.
2. This finding supports the previous theory of cumulonimbus clouds as the source of hailstorms, as indicated by the high reflectivity value, low cloud base value (<1 km), and high cloud top (>10 km).
3. The ZHail product can be utilised for nowcasting hail events, given its high probability of hail (>80%) before the hail occurrence.
4. From satellite data, the cloud top temperature indicative of hailstorm events in this study ranged from -67.5^{0}C to -82.5^{0}C.
5. Due to the numerous hail occurrences simultaneously and in nearby areas, further research is needed to understand the larger atmospheric systems contributing to these hailstorms.

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