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Analysis of Heavy Rainfall with Hail using Reflectivity and Radial Velocity Derived from X-Band Radar in Bandung (Study Case: March 17, 2017)

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Abstract. A local heavy rainfall along with hail and strong wind occurred in Bandung basin on March 17th, 2017. This event was documented using an X-band Doppler radar and supported by rain scanner, and C-band radar. Based on three types of radar, it was concluded that this was a local heavy rainfall, started at 10.50 LT. The location of the first reflectivity was detected from 25 km northward (107.6°W, 6.92°S) of X-band Doppler radar location. Reflectivity pattern showed a V-shaped with duration of about 30 minutes and reached its peak at about 11.30 local time (LT). Maximum horizontal wind speeds from Automatic Weather Station (AWS) took place during those periods. Based on vertically integrated liquid (VIL), the potential of hail was located at the right flank of the V-shaped. Three vertical cores with maximum reflectivity were also looked at in the right flank at altitude of 2-6 km with echo top reached up to 9 km above ground surface.

1. Introduction

Severe convective events occur most frequently in location where warm, moist air in the lower troposphere is overlain by cooler, drier air [1]. It is usually accompanied by heavy rain, strong wind, lightning, and hail. This phenomenon has a direct impact on environment, building, and of course, human and their activities. Severe convective storms, in Bandung, occur characteristically in the peak of rainy season and in transition period.

The convective events, like hail storms, have high variability in time and space, so that these events are not always captured accurately by single ground weather station. The occurrence of hail usually occurs only about a few minutes. So that, the use of weather radar is a feasible option because it gives information in spatial and temporal resolution well. Several studies have used reflectivity data and Doppler's velocity based on single polarization radar for observing evolution of an updraft and downdraft cell [2] [3] [4]. The two splitting (formed V-shaped) storms have typical situation where the right member is the dominant one [3]. This echo V-shaped generally indicates a separation process from an object (generally a storm) due to a new updraft formed in the storm [3]. The storm development can be divided into 3 stages, i.e. the initialization stage, the mature stage, and the decaying stage [5].

Bandung is a basin located at ~800 m above sea level (asl) and surrounded by mountains with the peak of northern is higher than the southern. The peak of accumulation of monthly rainfall of Bandung from ground observation data from 1981-2010 occurred in March [6].Water vapour within the bottom of basin during morning and low-level wind convergence induced by valley winds are important factors of convection in Bandung [7]. Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG) gets report from society that on March 17, 2017 heavy rain occurred and it was accompanied by hail from 11.50 until 12.10 LT over Bandung city. The initial condition of this event was recorded by transportable radar operated during campaign. This study wants to investigate the hail event based on reflectivity and radial velocity data on March 17, 2017.

2. Data

The data used in this study were obtained during campaign in Bandung on March 17, 2017. Transportable radar is an x-band Doppler weather radar with single-polarization. It was installed at Rancakasumba Substation (107.6 °E, 6.92 °S) located in Majalaya, south of Bandung city. The area coverage of radar is 100 km radii. Because of power failure, radar was off around 11.32 LT. Even so, the weather radar captured the initial condition of the event. Rain scanner located in Pasteur was used to complement radar data. Rain scanner is a marine radar development by LAPAN to observe rain since 2012. This rain scanner has 44 km radii with temporal resolution 2 minutes. It can detect heavy rainfall well [8] [9] and hail event [10]. The location of transportable radar and rain scanner is shown by A and B in **Figure 1**, respectively.

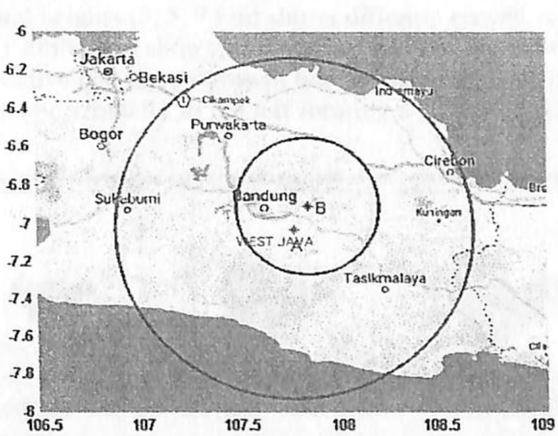


Figure 1. Map of location of the transportable radar (A) and rain scanner (B). The two circles show the area coverage of radar, respectively.

Reflectivity and radial velocity CAPPI product from transportable radar were utilized to analyse the rain. Reflectivity from rain scanner can give the information of the rain overall, from growth until decayed. Radial velocity is in addition to reflectivity data, which is component of movement either toward or away from radar. Doppler velocity can give the information about divergent/convergent signature

To describe the condition of environment during the event in the affected area, the automatic weather station (AWS) data are used. AWS are located in Pasteur (107.59°E, 6.89°S) and Antapani (107.65°E, 6.92°S).

3. Method

The weather radar completes one volume scan in 10 minutes. Each volume scan consists of 20 elevations that can detect cloud rain until 15 km height. The radar products were derived from volume scan.

In this study, we computed the vertically integrated liquid (VIL) from CAPPI product. The VIL is the total amount of concentration of liquid water in a cloud. It can be a useful tool for estimating the severity of a thunderstorm [11]. CAPPI product from 1-15 km height were calculated to get the VIL value using Equation (1):

$$VIL = \sum 3.44\times10^{-6}[Z_i + Z_{i+1}/2]^{4/7}\Delta h \quad (1)$$

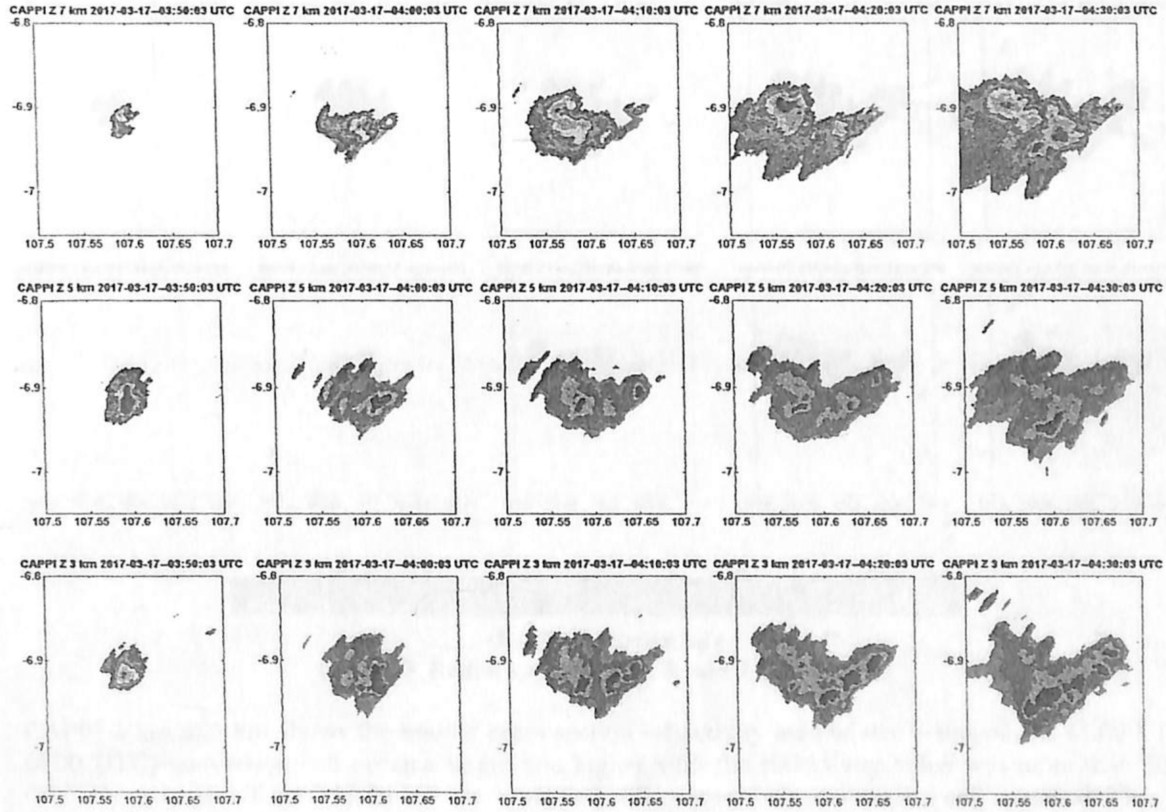
where VIL has unit of kg m^{-2}, Z_i and Z_{i+1} are bottom and top of the sample layer of reflectivity value in mm^6 m^{-3}, respectively and Δh is the layer thickness in m unit.
Amburn and Wolf (1994) show that VIL density (VILD) is a useful method for assessing hail potential in thunderstorms. The VILD can be used to identify the convective storms with high reflectivity relative to their height. The VILD was computed by using Equation 2:

$$VILD = \frac{VIL}{ET}\times10^3 \quad (2)$$

where VILD is in g m^{-3} and ET is echo top in m. As VILD value increased, the hail core should become deeper and more intense, and increase the hail size [12].

4. Case study

Figure 2 shows the reflectivity distribution in case study on March 17, 2017. The **Figure** describes the pixel echo shown in the 25 km at northwest (300°) from radar location with no contribution from other echo around it. This echo started to develop at 3.50 UTC and grown rapidly in vertical in the next 1 hour. CAPPI in several heights (3, 5, 7 km) shows different growth in every level of height with different echo top. CAPPI 1 km height shows near surface level of the convective activity. From 3.50 LT until 4.00 LT, the convective cell shows growth but no major changes in shape. After that in 4.10 LT the cell started to expand horizontally to the left forming a V-shaped with an angle of around 80° lookalike until 4.30 LT.



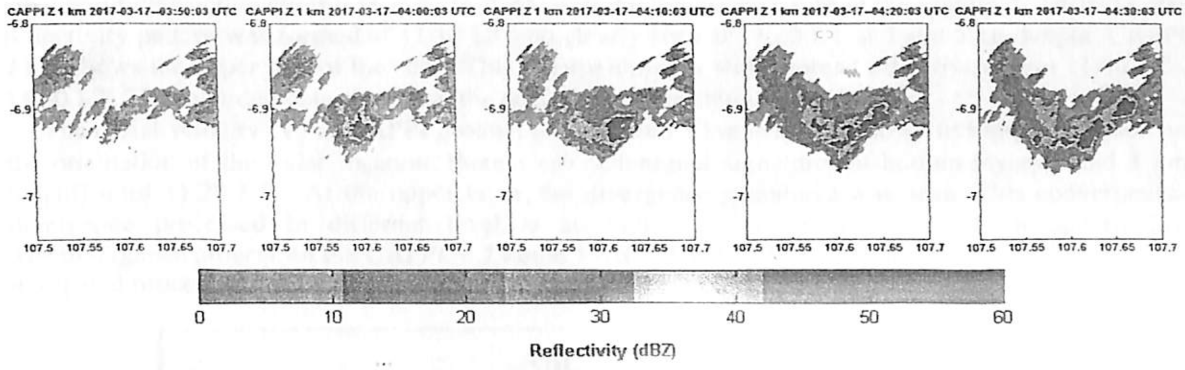


Figure 2. Spatial distribution of CAPPI product at 3, 5, and 7 km height.

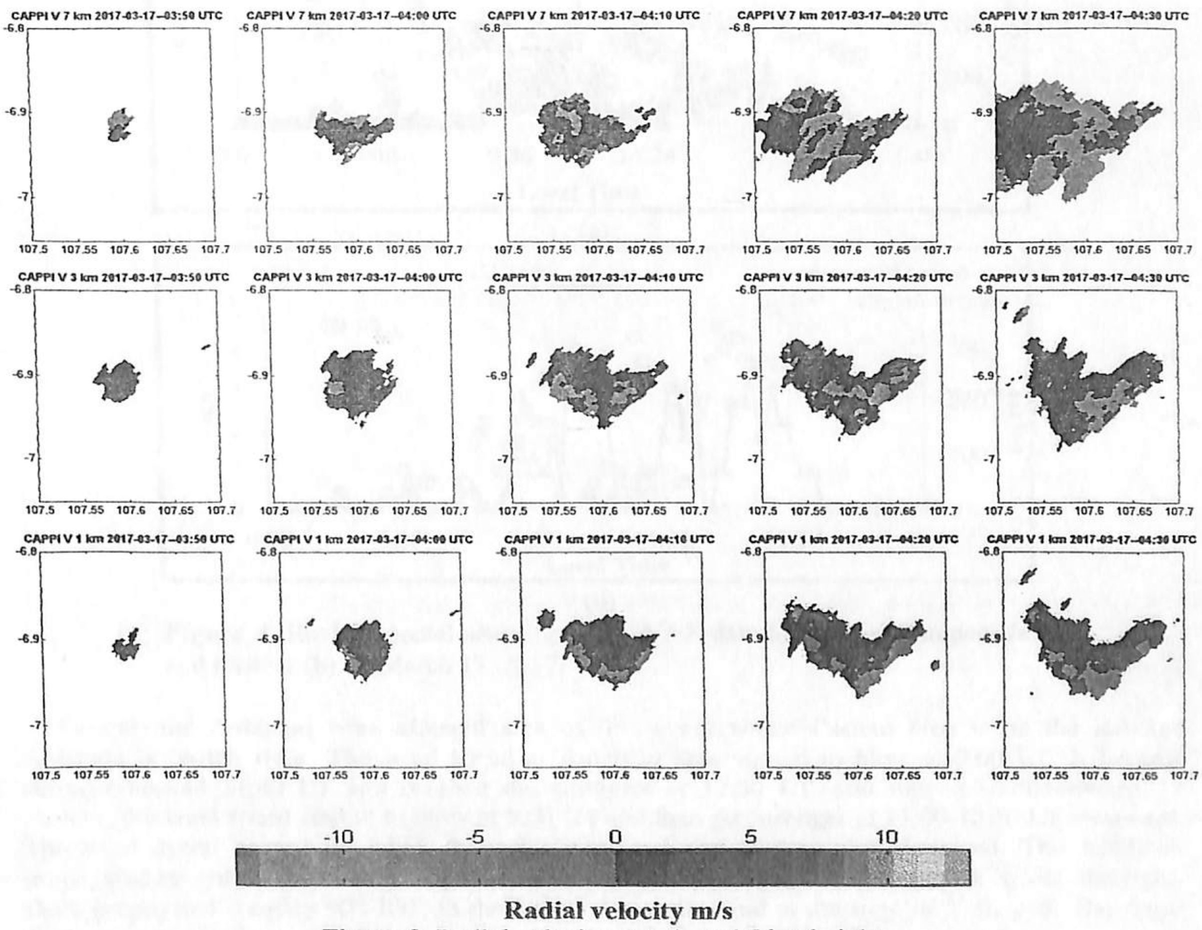


Figure 3. Radial velocity at 1, 3, and 7 km height.

CAPPI 1 km to 5 km shows the middle cross section reflectivity area of the V-shaped. At 11.00 LT (4.00 UTC) convection cell became larger and higher with the reflectivity value was more than 50 dBZ. From 11.10 LT until 11.20 LT, the V-shaped still existed with two distinct cell appeared. Then, at 11.30 LT, the left flank was started to dissipate while the right flank still increased rapidly. The

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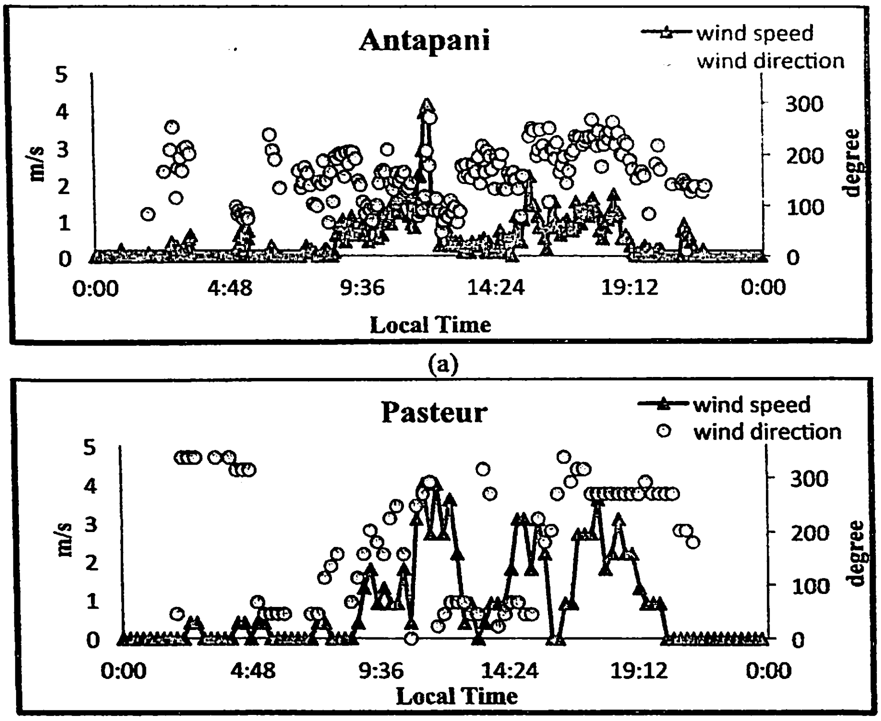
position of convective cores was at right-flank with the largest core was in the middle. V-shaped radar reflectivity pattern was formed at 11.10 LT and clearly seen at 11.20 LT at 3 and 5 km height. CAPPI 7 km shows the upper part of the echo. This **Figure** shows a wider spread reflectivity from 11.00 LT - 11.30 LT. The recorded data show that the echo top still existed in 9 km.

The radial velocity (V) of CAPPI product for 1, 3, and 7 km height is shown in **Figure 3**. Based on the orientation of the radar location, there were convergent signatures at bottom layer (1 and 3 km height) until 11.20 LT. At the upper layer, the divergence signatures was seen. This convergence-divergence processed in different level is an indication of the presence of an updraft [3]. The divergence process on the CAPPI V 7 km at 11.20 LT until 11.30 LT was also an indication of the dissipated process of the left flank of the V-shaped.



(b)

Figure 4. Environmental situation from AWS data located in Antapani (a) and Pasteur (b) on March 17, 2017.

Pasteur and Antapani were affected area of this event where Pasteur area is on the left and Antapani is on the right. The wind speed at Antapani area started to blow at 9.00 LT. It became stronger around 11.40 LT and reached the strongest at 12.00 LT, and moved southeastward. In Pasteur, the wind speed started to blow at 9.00 LT and then got stronger at 11.00-12.30 LT westward. The wind speed soared up when the echo increased and formed the V-shaped. The left-flank propagated roughly 40°-50° to the right of the mean wind at the time of -V-shaped. While, the right-flank propagated roughly 90°-100° to the left of the mean wind at the time of V-shaped. The right-flank moved away to the southeast.

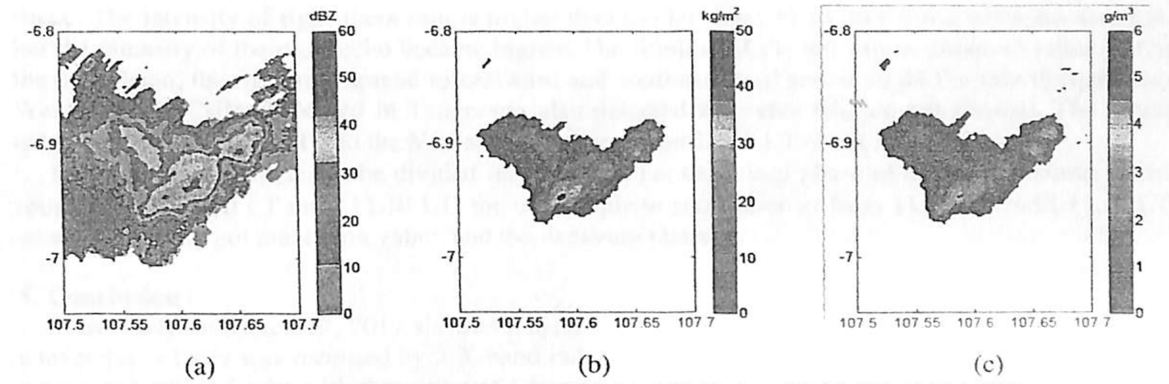


Figure 5. Composite reflectivity a), VIL b), VILD c) at 11.30 LT (4.30 UTC).

The maximum composite reflectivity distribution (**Figure 5a**) at 11.30 LT revealed the maximum value of reflectivity inside the V-shaped area. The right-flank had larger reflectivity (reached >50 dBZ) than left-flank. **Figure 5b** shows that there is a large VIL value > 30 kg m^{-2} at the right-flank. The VIL increased as the rain cloud extended more vertically. Based on the echo top at this level, the VIL value indicates that there is still strong energy of updraft to maintain reflectivity value in upper level [13]. Spatial distribution of VILD is presented in **Figure 5c**. The VILD shows value >3.5 g m^{-3}. Amburn and Wolf (1994) reported that VILD increased above 3.5 g m-3 in a thunderstorm would potentially produce severe hail. The VILD increased due to the increase in target size. If VILD increases, the hail cores tend to be deeper and more intense, and hail size tends to be larger [12]. This VILD value was also used to show the hail core location compared to VIL. VILD value shows that the hail event occurred at the right-flank, with the largest hail even in the middle of V-shaped.

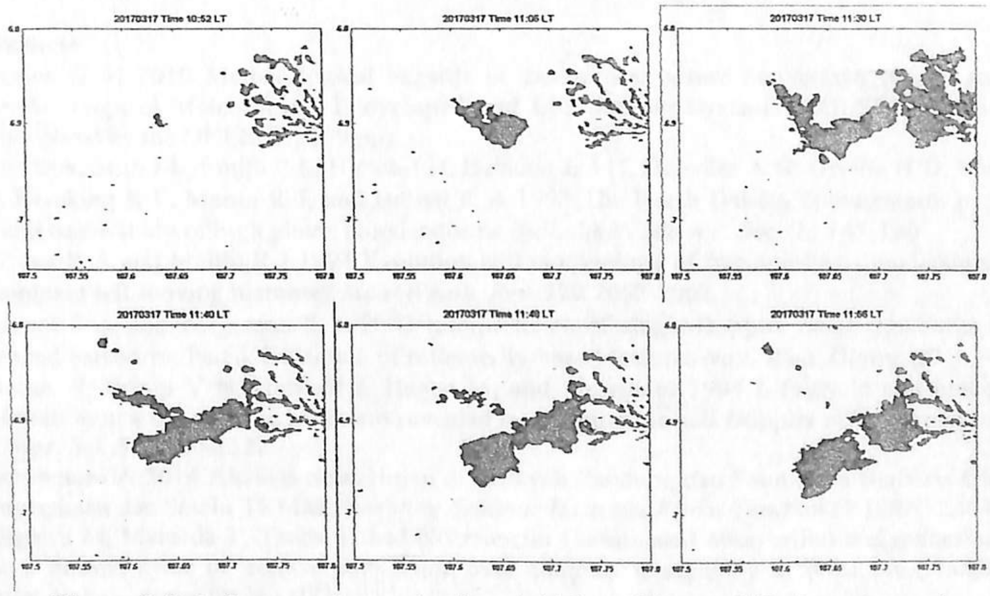


Figure 6. Rain Scanner observation from initial condition until V-shape decayed.

SANTANU rain scanner was used to observe the lost data from transportable radar. **Figure 6** describes the event from rain scanner observation. There is suitability between transportable radar and rain scanner results. The rain started at 10.52 LT and then the rain spread into 2 regions at 11.06 LT, the left region elongates northwestward and the right rain expand northeastward and formed the V-shape. The intensity of right-flank rain is higher than the left-one. At 11.30 LT the left-echo decayed, but the intensity of the right-echo became higher. The lifetime of the left-rain is about 45 minutes. On the other hand, the right rain spread to eastward and southeastward and at 12.48 the rain disappeared. Weather radar C-Band located in Tangerang also detected the event (Figure not shown). The initial echo was seen at 11.02 LT and the V-shaped was seen from 11.18 LT -until 11.34 LT.

From all those data, it can be divided into 3 stages i.e. the initial phase of convective storm lasted roughly from 10.50 LT until 11.10 LT, the mature phase took place at from 11.20 LT until 11.40 LT when reflectivity got maximum value, and the decaying phase.

5. Conclusion

Case study on March 17, 2017 showed a local convective activity in the Bandung area. This local convective activity was recorded by 2 X-band radars. From CAPPI products in certain height showed a distinct V-shaped echo with the region of 1 km until 5 km while the upper part of echo showed wider spread area. The V-shaped possesses two flanks and the right-flank of V-shape has more convective activity than the left-flank. The V-shaped possesses high updraft activity indicated from the convergence and divergence of the radial velocity in the lower and upper level. VIL and VILD show there is a strong potential of hail occurred in the right flank of the v shape. The echo was then gradually dissipated from the left flank after one and a half hour and moved towards southeast that influenced by the dominant wind.

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