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Investigation of the regeneration of precipitating convective cloud in basin topography area

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Abstract. The occurrence of precipitation in basin topography area at Bandung can be generated from repeatedly formed convective clouds in one diurnal cycle, which also is detected as multiple rain peaks during a day. In satellite observations, the formation of a new convective cell after dissipation stage of the predecessor cell around or in the same location indicates a regeneration process. The daily convective activities were analyzed during February–May 2017 to understand the regeneration of precipitating convective clouds in Bandung area. The rainfall events were obtained from cumulative distribution function (CDF) at the highest percentages of daily precipitation. This study proposed regeneration index (RegI) as initial identification for convective cloud regeneration from daily rainfall data with multiple peaks. The cases that obtained through the RegI were then verified by satellite data. Both cases at 27 February and 1 May 2017 show that the regeneration of convective cloud was detected in the study area. The precipitating convective clouds initiate in the north Bandung while regenerate and propagate southward. These cases suggest that the highest percentages of daily rainfall in basin topography area can be generated by multiple convective clouds.

Keywords : precipitation, cumulative distribution function, convective clouds, RegI.

1. Introduction

Indonesia Maritime Continent (IMC) is known to have a strong convective activity, which involved in the formation of precipitating convective cloud [1]. The convective activity in Bandung region has a single diurnal peak related to valley wind circulation and produces local scale convection [2]. The heavy rainfall events in Bandung at daytime may cause flash flood event with 150 minutes duration as stated by Agency of Meteorology, Climatology and Geophysics (BMKG) on local news Tempo.co (available online at: <http://nasional.tempo.co/read/814715/bmkg-ingatkan-banjir-bandung-bisa-terulang>). These events also yield material losses and affect human activities in the study area [3,4]. During diurnal convective cycle, convective clouds regeneration was spotted frequently, which is also indicated on rainfall parameter in other cases at the same region by diurnal observation and numerical simulation [2].

Previous studies detected the formation of regenerative convective clouds that lead to heavy rain in IMC region, associated with external forcing such as monsoon intrusion [5] or intraseasonal oscillation [6]. At extratropical region, regeneration process in convective cloud formation occurs when cold pool



– wind shear interacts with relatively strong intrusion [7]. Meanwhile, in Bandung region the rainfall area that affected by convective cloud has local coverage [3,4,8]. The formation of convective cloud in basin area of Bandung is suspected to occur repeatedly during diurnal active phase due to wind valley circulation [2]. Therefore, this study investigates the evolution of repeated convective cloud formations during diurnal cycle which is used to understand regeneration process and characteristics of precipitating cloud formation events in Bandung region. The regeneration of precipitating convective cloud is analyzed from rainfall data and Himawari 8/9 satellite images during February to May 2017.

2. Data and Method

The precipitating convective cloud life cycle in Bandung region was observed by surface and satellite imagery. Convective cloud activity was monitored by surface observation stations via rainfall parameter. Observation of rainfall data during February-May 2017 was obtained from Weather and Climatology Prediction Laboratory ITB (WCPL ITB) and *Balai Besar Wilayah Sungai Citarum* (BBWS Citarum). The rainfall data in this study were spread across Bandung region as in figure 1 with coordinates of each station listed in table 1. The coordinates of Meteorological station ITB was measured by WCPL ITB and other stations were measured by BBWS Citarum.

The identification of convective cloud regeneration by rainfall was detected from multiple peaks during a day. Prior to the convective cloud identification, the cumulative distribution function (CDF) of daily rainfall in each station was calculated to obtain threshold values at highest 20% (P80), 15% (P85), 10% (P90) and 5% (P95). The rainfall threshold for each cumulative probability was served as initial identification. Rainfall threshold value for all stations was calculated through three methods: mean, median, and single station. Single station method (Meteorological station ITB) was used to determine whether the rainfall data from one station could represent the Bandung region. The cases were identified when daily rainfall in all stations surpasses the threshold value for each method. Daily time series of rainfall from all stations with 5 minutes time step were used to identify the rain peak. This peak was identified when the distance between each peak was above 30 minutes [9] and its value was greater than 0.5 mm from rainfall modes during observation.

The convective cloud regeneration was represented by regeneration index (RegI). This index is proposed to quantify regeneration identification in the study area. The RegI was obtained from array number of observation stations with the multiple rain peaks divided by an array number of observation stations with the single rain peak. This calculation is shown in equation (1).

$$RegI = \frac{[Station_{peaks \geq 2, c=1} \quad Station_{peaks \geq 2, c=2} \quad \dots \quad Station_{peaks \geq 2, c=n}]}{[Station_{peak=1, c=1} \quad Station_{peak=1, c=2} \quad \dots \quad Station_{peak=1, c=n}]} \quad (1)$$

Station_{peaks $\geq$ 2} is total stations that detect multiple rain peaks for a day, Station_{peak=1} is total stations that detect single rain peak for a day, and n is total cases that surpass rainfall threshold during observation period. The RegI has a maximum limit (Station – 1) and minimum limit (Station – 1)⁻¹, with Station is total observation stations in study. This index is used to locate local-scale rain events when similar peak value is detected at 30-70% observation stations or equal to RegI scale at 0.4-2.5 for this study. Calculation of RegI is an approach to find rainfall characteristics based on its coverage and the number of rainfall event detected in one day. However, an analysis of convective cloud regeneration that relies only on rainfall data may have weakness hence verification using satellite data is needed.

The Himawari 8/9 satellite image was used to observe convective cloud growth at the time of the event through black body temperature of IR channel at 10.4 μ m (T_{10.4}) and IR 12.4 μ m (T_{12.4}). Convective cloud activity can be observed from index of black body temperature (I_{TBB}) in Kelvin [10] [11]. I_{TBB} is obtained from:

$$I_{TBB} = 255 - T_{10.4} \quad T_{10.4} < 255 \quad (2)$$

$$I_{TBB} = 0 \quad T_{10.4} \geq 255 \quad (3)$$

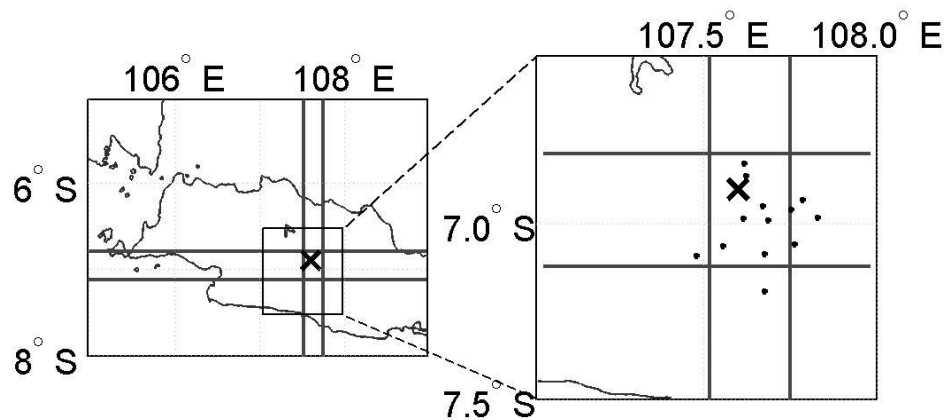


Figure 1. Bandung region as the domain of the study. Black cross depicts the location of meteorological station ITB, while black dot signs are other stations located in Bandung region. The area between vertical (horizontal) lines on map is time-latitude (longitude) cross section.

Table 1. Surface observation stations coordinates in Bandung region.

Location	Coordinates	
	Latitude (°S)	Longitude (°E)
Ancolmekar	7.0853	107.6772
Cicalengka	6.9813	107.8300
Cidurian	6.9490	107.6716
Cisondari-Pasirjambu	7.0903	107.4817
DagoPakar	6.9848	107.6164
Dayeuhkolot	7.0632	107.5559
Hantap	6.9298	107.7871
Jatiroke-Cikuda	7.1919	107.6769
Kertasari	6.8266	107.6177
Meteo-Lembang	6.8618	107.6245
PasehCipaku	7.0566	107.7638
Rancaekek	6.9586	107.7539
Sapan	6.9899	107.6873
Meteorologi ITB	6.9000	107.6000

Identification of convective clouds on IMC uses blackbody temperature threshold at 250 K [10], but in addition, this threshold shows weak correlation with rainfall intensity [12]. This study used threshold value as in equation (2) and (3) to obtain more convective cloud coverage.

The convective cloud identification is performed using an algorithm [13] that relies on data from these channels. Convective cloud detection is obtained from subtraction of IR 10.4 μm and IR 12.4 μm ($T_{10.4-12.4}$). In this study, identification of convective cloud was obtained by trimming convective cloud detection with I_{TBB} 's outer lines. Both I_{TBB} and convective cloud identification was used to analyze convective cloud activity. The analysis of the convective cloud activity of each case was observed through time-longitude variation with latitude averaging at 6.8°S - 7.12°S and time-latitude variation with longitude averaging at 107.52°E - 107.75°E as shown in figure 1.

The convective cloud evolution in each case was reanalyzed to understand precipitating convective cloud regeneration patterns. The I_{TBB} 's time-latitude and longitude variation plot was used to observe convective activity. Convective cloud identification from $T_{10.4-12.4}$ was calculated to find convective core. The core was identified when the result of convective cloud value was less than 2. Rainfall temporal distribution at meteorological station ITB was used along with time-latitude and longitude variation of convective cloud core to ascertain whether the convective cloud core actually produces rain. The time-latitude and longitude variation plot of satellite data was used to observe convective cloud. Based on these data, the convective cloud regeneration was identified and analyzed thoroughly.

3. Results

3.1. Identification of precipitating convective cloud by rainfall data

Daily rainfall data from all observation stations in Bandung region during February-May 2017 were analyzed using cumulative distribution function (CDF) as shown in figure 2. High intensity precipitation is produced by convective cloud [14] therefore the values above threshold represent the highest percentage of daily rainfall data. The rainfall threshold was obtained from CDF of all stations using mean, median and single station (ITB) methods. This threshold value can be seen in table 2.

The case is confirmed when rainfall data exceeds the threshold from the cumulative probabilities at P80, P85, P90, and P95. The threshold for each method has similar value at highest 20% of daily rainfall (P80), whereas the values start to differ when cumulative probability increases up to 5% highest rainfall event (P85-P95). The daily rainfall at highest 5% (P95) has threshold value 33.5-35.7 mm day⁻¹. The cases that meet the criteria were calculated using equation (1) to derive regeneration index (RegI) as shown in table 2. The RegI values in table 2 are between the range of 0.4-2.5 which show that rainfall with high intensity in Bandung region during this period have local coverage with single or multiple peaks.

The regeneration indices from P80 to P90 have varying values. The RegI determined by the mean and median methods give a range values of 1-2.5 that dominated by local rainfall with multiple peaks. Different results are shown by RegI values for single stations method, which is dominated by local rainfall with single peak (0.4-1). However, P95 values for all methods show that rainfall detected at highest 5% of intensity have local character with multiple peaks. The identification of cases conducted with this method gives the same result, which is 27 February 2017. All cases that meet criteria for P95 are shown in figure 3 as composite of hourly rainfall distribution at each station. This composite plot shows the rainfall distribution of each station, variation and diurnal pattern. Some stations on the figure also detect multiple rain peaks for a day.

Heavy rainfall event at 27 February 2017 has the highest rainfall intensity (70 mm day⁻¹) at ITB meteorological station. This event was also detected by most ground stations with intensity 5-56 mm day⁻¹. Figure 4 shows a convective activity for a day. The I_{TBB} values higher than 50 that predominate in figure 4a illustrate a strong convective activity during the day. The convective cloud identification was obtained from $T_{10.4-12.4}$. This result is shown in shading contour in figure 4b and recognized as convective cloud when the calculated value is near to zero.

Table 2. Daily rainfall threshold value and regeneration index (RegI) in Bandung region.

Probability	Rainfall threshold (mm day ⁻¹)			Regeneration index (RegI)		
	Mean	Median	Single station (ITB)	Mean	Median	Single station (ITB)
P ₈₀	10,38	10,80	10,60	1,02	1,23	0,84
P ₈₅	16,04	16,75	15,50	1,39	1,61	0,77
P ₉₀	22,97	21,30	21,60	1,64	1,51	0,71
P ₉₅	34,50	33,50	35,70	2,00	1,03	1,12

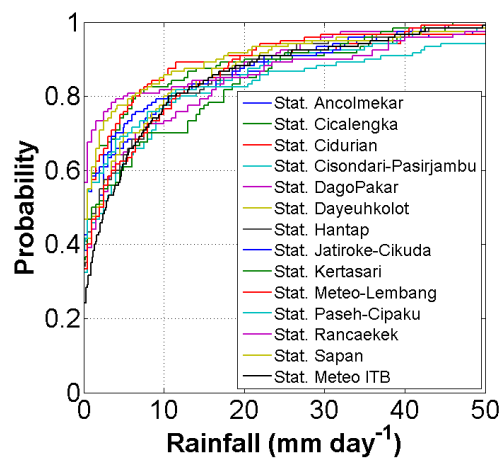


Figure 2. Cumulative distribution function of daily rainfall during period of February-May 2017 at observation stations in Bandung region.

In figure 4 there are two formations of convective clouds detected in northern Bandung after 12.00 local time (LT). Convective cloud formed at 6.8°S was regenerating up to three times while propagating to southern part of Bandung, meanwhile, other convective cloud formed at 6.5°S grew in situ then extended southward. Figure 5 shows a horizontal plot of the convective cloud core in the study area. The convective cloud observed in figure 5a is the first cloud formed on this case; this cloud has reached mature stage at 13.00 LT with a radius of ~10 km. This convective cloud then weakened an hour later as shown in figure 5b. The new convective cloud formed with larger radius (>20km) at southeastern part of predecessor cell was also detected in figure 5b. This cloud formation was also detected in figure 4b as the first regeneration of convective cloud in figure 5a. Meanwhile, the convective cloud at northern part in figure 5b was observed as another initial convective cloud formation at 6.5°S in figure 4b. The rainfall in this case at 15.00 LT was generated from the first regeneration of convective cloud above Bandung region (6.9°S - 7°S) that weakened when intersects with other convective clouds that aroused in the northern part. These cloud formations were also detected in figure 5b. The formation of regenerative convective clouds on the same area was also indicated in [8] where local rainfalls occur in a consecutive manner while propagating southward. This case shows that the weakening of convective cloud activity during regeneration process is related to precipitation that detected on the stations. During active period, convective cells are repeatedly formed until the convective activity decays at night.

3.2. Analysis of regenerative precipitating convective cloud patterns on diurnal scale

The precipitating convective cloud activities in these case study show patterns associated with the initial convection of cloud formation, duration of activities, cloud propagation, and lag time of new convective cell formation. The convective clouds here either have regenerative formation or long duration with strengthening and weakening activities. Another example of cloud regeneration case is shown in figure 5, where the convective cloud activity exhibits multiple peaks in consecutive period. The regeneration pattern of precipitating convective clouds analysis used the cases from the highest 10% of daily rainfall (P90) which yielded 15 events. Analysis of satellite observations combined with surface stations shows that most cases observed also have regenerating convective cloud formation.

One of the cases of regeneration pattern with P90 occurred on 1 May 2017. In this event, ITB meteorological station has detected rainfall with the intensity of 21.9 mm day⁻¹ and other four stations detected 6-24.5 mm day⁻¹. The rainfall on 1 May 2017 was detected by fewer observation stations as opposed to the previous case. However, the convective cloud regeneration pattern is also presented here as shown in figure 5.

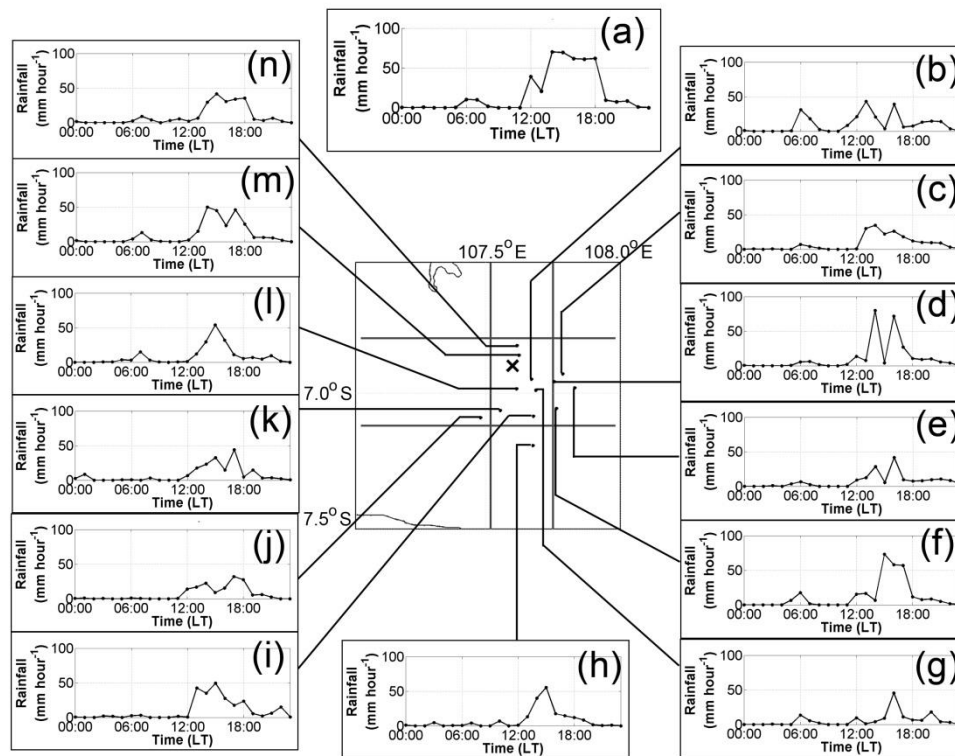


Figure 3. Time series of diurnal rainfall composite for P95 during February-May 2017 at (a) meteorological station ITB, (b) Cidurian, (c) Jatiroke-Cikuda, (d) Rancaekek, (e) Cicalengka, (f) Paseh-Cipaku, (g) Sapan, (h) Kertasari, (i) Ancolmekar, (j) Cisondari-Pasirjambu, (k) Hantap, (l) Dayeuhkolot, (m) Dagopakar and (n) Meteo-Lembang.

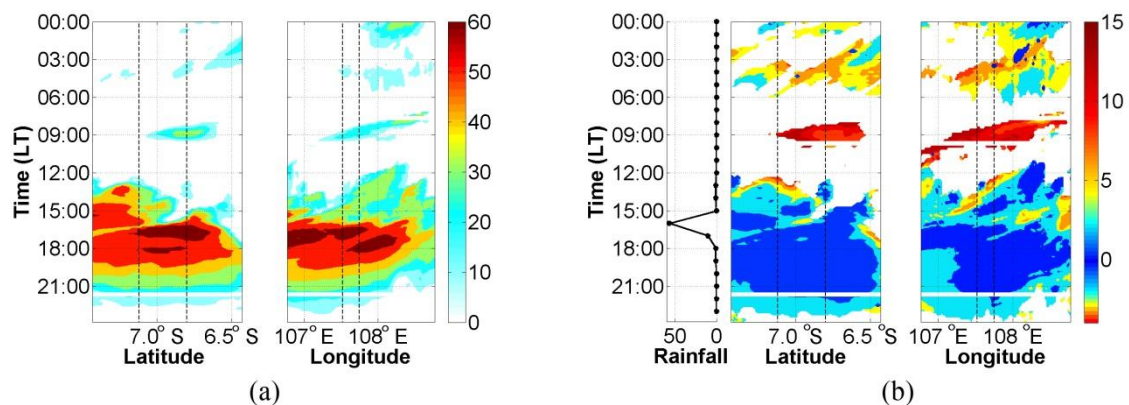


Figure 4. (a) (left) Time-latitude cross sections and (right) time-longitude cross sections of I_{TBB} on 27 February 2017. (b) (left) Time series of precipitation at meteorological station ITB. (middle) Time-latitude cross sections and (right) time-longitude cross sections of convective cloud identification on 27 February 2017. The study area is shown in the region between thick dashed lines in both (a) and (b).

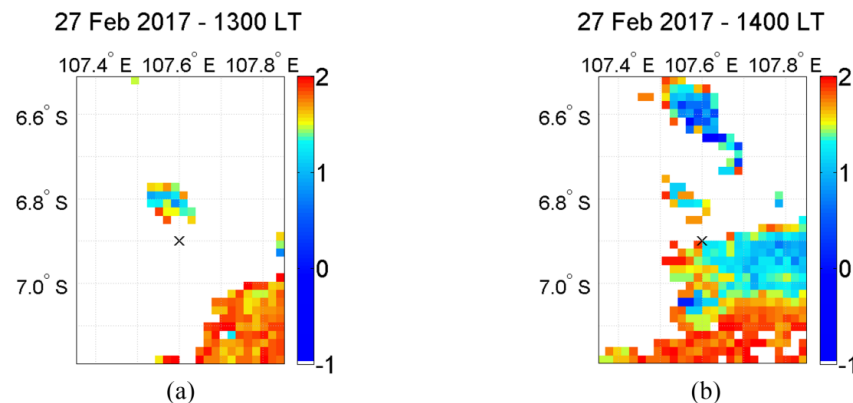


Figure 5. Horizontal distribution of convective cloud core on 27 February 2017, (a) 13.00 LT and (b) 14.00 LT. The cross sign is location of meteorological station ITB.

The convective activity shown in figure 5a exhibits an increase after 13.00 LT then weakened at night. The peak of convective activity around the observed area was detected three times as indicated by increasing I_{TBB} value in figure 5a, which lasted for 1-2 hours and then weakened. The convective cloud cores activity is shown in figure 5b. The contour has higher possibility identified as convective core when the values were close to zero. This figure also shows that the convective cloud cores were mostly detected in northern part of Bandung.

Convective activity started at 13.00 LT in northern and southern part of Bandung as shown in figure 5. The cloud evolution in this case was more prominent in northern part. The first cloud formed in the northern Bandung has been developed in situ for an hour. The precipitation of convective cloud was generated when the first convective cloud activity weakening in the study area, similar to the previous case on 27 February 2017. The precipitating convective cloud was identified by comparing the rainfall time series and the convective core activity in figure 6b. The rapid formation of new convective cloud in figure 5b was detected from the southern part of the preceding cloud and propagated southward with the convective core in the north. The new convective cloud formation on 6.6°S was also detected at 15.00 LT, approximately one hour after the first regeneration was detected. This second regeneration of convective cloud propagated southward then weakened at 17.00 LT. On the same location, a new convective cloud was generated and developed in situ then reached dissipation stage at night.

Convective clouds based on satellite imagery in figure 5 have radius 10-20 km with 1-3 hours lifespan. Similar characteristics of precipitating convective cloud in Bandung region were also shown by radar observations [3,4]. The time duration of new convective cloud needed to form relative to its predecessors varies between 30-120 minutes, but the new convective cloud formed in the south of predecessors have a shorter time lag than the new convective cloud that formed in northern part.

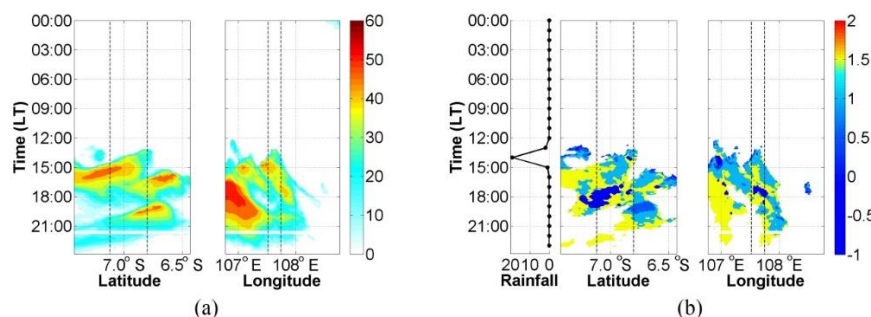


Figure 6. As in figure 4, but for 1 May 2017. (b) (middle) Time-latitude cross sections and (right) time-longitude cross sections of convective cloud core identification on 1 May 2017.

The convective cells that recently formed tend to be at southern part of predecessor cells with a linear regeneration pattern as shown in figure 6. This formation of linear shape at single regeneration of convective cloud can be explained by convective cell life-cycle [15]. The cold air mass from the northern basin meets the wind from southern Bandung producing forced updraft that strengthens positive buoyant force and forms convective cloud cell. Both cold air mass and valley wind are important factors in convective formation in Bandung region based on previous study [2]. Whereas the formation of subsequent convective cells is the result of circulation decay at the front of convective cloud predecessors that raises mixed layer with high potential temperature to the top layer [2].

3.3. Discussion

The formation of precipitating convective cloud in this study mostly started from northern part of Bandung, which corresponds to other studies that showed the location of initiation cloud formation at 6.7°S - 6.9°S . [3,4]. This result is in contrast to the previous studies that concluded a precipitating convective initiation in Bandung began at southern part and propagated northward [2]. The convective clouds that undergo regeneration can propagate southward, or develop in situ then extend southward, although it is possible that the regeneration of convective cloud formed in northern part. This difference of convective initiation may occur since convective cloud activity in this study is restricted to events with heavy rainfall, therefore there is a possibility that the convective activity generated outside criteria yields different result.

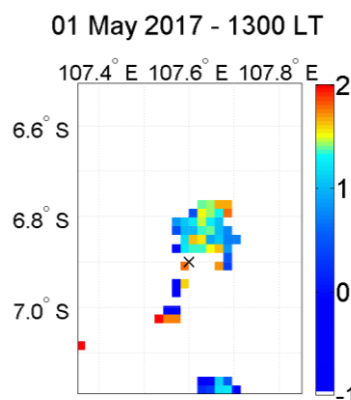


Figure 7. As in figure 5, but for 1 May 2017, 13.00 LT.

The precipitating convective clouds in the study area are not always formed by regeneration, it can also generate by decay-enhance convective activity or stratiform cloud. However, the event that affected by regenerating convective cloud has dominated most events. The rainfall events observed in this study mostly resulted from a decrease in convective cloud activity in diurnal active phase. This result corresponds to previous study [10] that also exhibits the frequency of precipitating cloud in February to March is dominated by deep convective cloud. This cloud type also reaches peak activity faster than other types. Some cases of precipitation that are affected by other clouds such as stratiform type are also detected despite its scarcity.

4. Conclusion

Daily rainfall with high intensity is dominated by multiple rain peaks indicating the presence of precipitating convective clouds. The regeneration of precipitating convective cloud was identified by RegI which proposed in this study. The RegI used high temporal resolution of rainfall data as a proxy to diurnal convective activity. The results of RegI during observation period denote that most of high intensity rainfall has a local coverage with single or multiple peaks. The cases obtained from the RegI were verified with satellite imagery, two sample cases for P95 at 27 February 2017 and P90 at 1 May

2017 were presented on this study. Both cases show the repeated convective cloud formation in the study area, therefore RegI can be used for the initial analysis to identify regeneration of precipitating convective cloud. By using satellite observation, the case on 27 February 2017 was shown to have stronger diurnal convective activity than the other cases. The weakening of convective activity in study area was sometimes accompanied by precipitation. Meanwhile, the daily rainfall observed had a higher maximum value and detected by more stations than the daily rainfall on 1 May 2017.

Both cases show the initial location of convective cloud formation in north Bandung (6.5°S - 6.8°S). The precipitating convective cloud in the study area has a maximum radius of 10-20 km with duration of 1-2 hours. These convective clouds also tend to propagate southward. Convective cloud regeneration is detected in both cases with time lag of new convective cloud formation to its predecessor varies up to 120 minutes. The duration of time lag is also related to location of new convective clouds relative to its predecessor, where new convective cloud in the southern part is formed faster than in the northern part. Heavy rainfall events in Bandung region are dominated by convective clouds that form repeatedly; hence daily rainfall observed is an accumulation of precipitating convective cells.

This study gives different conclusion compared to the previous study that denotes the convective initiation started from southern part of Bandung and propagate northward. This difference may occur since the case observed in this study only restricted to daily rainfall with the highest percentages. This study shows that the convective activity in Bandung region can produce regenerating convective cloud during diurnal active phase. Further analysis for this regeneration pattern is necessary to understand its contributing factors.

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