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The Use of Lightning Data for Convective Rainfall Estimation

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Abstract

The objective of this study is to analyse electrification processes in the convective clouds. The intensity of lightning could characterized by three stages of thunderstorm's life i.e. cumulus, mature and dissipation. First analysis focused on the relationships between lightning and rainfall. To accomplish this goal, a Storm Tracker Lightning Detector was used in the study area for detecting cloud-to-ground lightning (CG). The lag-time between the peak of CG lightning and the peak of rainfall are also being our focus. The results show that surface rainfall tends to follow the lightning (positive lag-time) ±15 minutes after the peak of CG lightning. The index of lightning (L-Index) created to analyse the possibility of heavy rainfall/extreme (>50 mm/day) in 15 minutes ahead, by considering the rainfall categories and normalization of data (from 0 to 1). L-Index of 0 - 0.5 indicating potentially occurs of slight rainfall to moderate rainfall with the intensity of 5-10 mm/hours; and L-Index >0.5 potentially occurs heavy rainfall to extreme rainfall with the intensity > 10 mm/hours.

Keywords: CG lightning, lag-time, L-Index, rainfall.

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1. Introduction

For many years, researchers have documented their research on the relationships between lightning and rainfall. Moreover, it has been obtained some significant results of the relationships between lightning and rainfall [1,2,3,4,5,6,7] .

In addition, other specific results between lightning and convective rainfall as well as shown by [8,9]. Those results indicated a very tight relationship between lightning and rainfall. However, some previous investigators i.e [10,11] indicated no lightning activity during the heavy rainfall.

Cumulonimbus (Cb) is the primary source of lightning as mentioned by [12]. He also showed that maximum electric fields typically measured in thunderclouds are 1-2 x 105 V/m (the highest measured value is 4 x 105 V/m). This study supports what was mentioned by [9] i.e. heavy rainfall corresponds to the strong atmospheric electrical activity in the convective weather system, not in strati-form clouds.

As mentioned by [13], many investigators agreed that the electrics processes in the cloud and produce lightning depend on the complex interactions involving cloud microphysics and dynamics [14,15,16,17,18,19,20,21,22, 23,24,25,26].

Indonesia is a tropical regions and characterized by the activity of the massive convective cloud formation. As a result of these conditions, the potential for the formation of Cumulonimbus (Cb) that can produce heavy rainfall (rain with high intensity) or even extreme, almost always there [27]. As mentioned by [28], rainfall and lightning are related and while CG lightning are easy to be counted, in contrast with convective rainfall i.e. cannot be measured directly, since the rain gauge do not distinguish between "strati-form" and "convective" rainfall.

Table 1 summarizes some studies of relationships between lightning and rainfall by using ground-based lightning sensors. Therefore, the objective of this study is to analyse the potential of CG lightning for use in estimating convective rainfall. This study was carried out in the Bandung, west of Java, Indonesia, which is a complex region because of the mountains effect and convection thermally (see Figure 1) below.

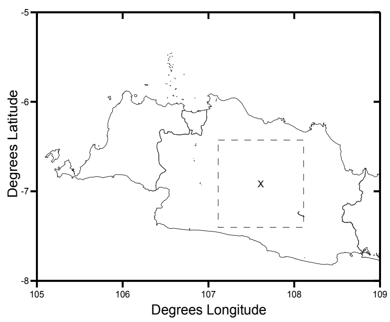

Fig. 1. Domain of study, site location labelled as "x".

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Table 1.
Rainfall and Lightning characteristics reported by investigators

No.	Author (s)	Location	Lightning type	Lag time (min)	Corr. (*r*)	Eq. estimation
1.	Gungle and Krider [13]	East Coast ,Florida	CG	5	0.83	-
2.	Zhou et al. [9]	Pingliang, Cina	CG	-	0.86	$R = 1.67\ln(L) - 0.27$ R is the ave. Precipitation L is the number of lightning
3.	Soriano et al. [8]	Iberian, Peninsula	CG	-	0.67-0.85	-
4.	Soula and Chauzy [6]	Paris, France	CG and IC	10	-	-
5.	Tapia and Smith [29]	Melbourne, Florida	CG	-	-	$R(t,x) = C\sum_{i=1}^{N_i} Zf(t,T_i)g(x,X_i)$ Ni is the Number of flash, Ti is the time of *i*th flash, Xi is the spatial location, Z is the RLR for the storm, and C is the units conversion factor
6.	Kane [30]	Northern Virginia	CG	5-15	-	-
7.	Williams et al. [25]	Huntsville, Alabama	CG and IC	5-10	-	-
8.	Piepgrass et al. [5]	KSC, Florida	CG and IC	4-10	-	-

2. Data and Method

The domain of this study is an area covered by the Storm Tracker lightning detector that is installed at the Indonesia Agency for Meteorology, Climatology and Geophysics (BMKG) located in Bandung (6˚ 54' 51.90" S and 107˚ 36' 33.50" E) of Indonesia (see Figure 1). Lightning Detector (LD) is ground based lightning sensor with a Magnetic Direction Finding (MDF) and consists of a loop antenna for lightning location. Rainfall tries to estimate by using near real time (15-minutes) CG lightning data for the year 2009. Rainfall derived by near real time (10-minutes) semi-automatically in situ instrument (Hellman gauge) and also installed at BMKG of Bandung. For the convective rainfall analysis, rainfall >50 mm/day will be selected.
Rainfall analysis using lightning data reveals opportunities to detect the possibility of heavy rainfall / extreme by making the Lightning Index (L-Index). Hence, it requires a temporal resolution of lightning data with a minimum interval, Δt = 15 minutes. During the year 2009 will be reviewed four heavy rainfall events (>50 mm/day). As shown in Fig. 2, the distribution of CG lightning at time intervals are constant, where: $t_i = 0$, $t_{i+1} = \Delta t$ and $t_{i+2} = 2\Delta t$. Thus, the value of a CG function at time t_i , t_{i+1} and t_{i+2} respectively, are : $CG(t_i) = CG_i$, $CG(t_{i+1}) = CG_{i+1}$ and $CG(t_{i+2}) = CG_{i+2}$. First, by making the data normalized, being 0 to 1, with the number of data n=96 which is indicated number of data normalization for one day (24 hours) at 15-minute intervals (i = 1: n). Thus, the normalization of data can be written as :

$$CG_{norm} = \frac{CG_i}{\max(CG_{1:n})} \quad (1)$$

then the L-Index can be defined as :

$$L - Index_i = CG_{i+1} - CG_i \quad (2)$$

Where CG as Cloud-to-Ground lightning; L-Index as index of lightning 0 to 1 (see Table 2 for the detail).

For the detection of extreme rainfall using CG lightning data, normalization of lightning data using the threshold = 50 so it will get L-Index from 0 to 1. L-Index was tested using four samples of heavy rainfall with the amount of rainfall >50 mm/day.

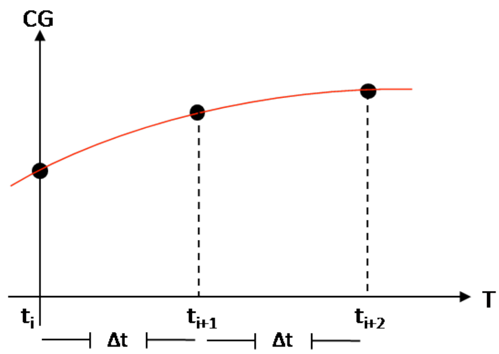

Fig. 2. Illustration of L-Index calculation for the detection of extreme rainfall based on CG lightning data.

Table 2.
Rainfall category based on L-Index

L-Index	Rainfall category	Rainfall intensity
0 – 0,5	light – moderate	5 – 10 mm/hr
> 0,5	Moderate - heavy	> 10 mm/hr

Based on L-Index as well on Table 2 above, if the L-Index value between 0-0.5, the potential of rainfall occurs ± 15 minutes ahead are 5-10 mm/hr. Furthermore, if the L-Index value >0.5, the potential of rainfall occurs ±15 minutes ahead are >10 mm/hr.

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For the detail, there are four heavy rainfall events (>50 mm/day) during the year 2009 to be reviewed.

3. Results and Discussion

3.1. The rainfall event on March 11, 2009

Cumulatively between rainfall and lightning shows a lag-time 15 minutes, where rainfall events preceded by the lightning as seen in Figure 3a, with a correlation r=0.92. Lightning activity (blue line) started at 14.00 LT, 15 minutes earlier than rainfall (red line), both of lines increases sharply that is indicating a mature stage of clouds. In this case, mature stage ended at 15.00 LT.

Based on Figure 3b, comprehensively using L-Index, it shows a positive curve exceeds above the threshold value (L-Index >0.5) and indicate the potential for rainfall >10 mm to 15 minutes ahead (see Table 2). In fact, there has been rain (see Figure 3b, "yellow dashed line" indicate as rainfall) for the next 15 minutes with an intensity of rainfall of 26.9 mm (total intensity of the average rainfall i.e. 30.7 mm/hr of 1.7 hour duration).

As well as in Figure 4a, the distribution of CG lightning at 14.00-15.00 LT localized at radius 0.5° around Bandung, similarly if compared to the IR1 MTSAT satellite (see figure 5a) which is indicates accumulation of clouds above Bandung area, besides that the temperature top of cloud reaches -54 to -90 °C, that is the mechanism of collision and coalescence become more intense to produce cloud electrification.

Some classical studies suggested that collisions between ice crystals and riming grapple pellets being primary of charging mechanism within thunderstorms [31,32,33, 34,35]. Thus, increasing of lightning is expected because the cloud electrification increases with ice mass [36,37].

3.2. The rainfall event on May 18, 2009

In the second example, on May 18, 2009, there are 30 minutes of lag-time between rainfall and lightning as in Figure 3c, with a correlation r=0.40. Lightning activity started at 14.15 LT, lead 30 minutes than rainfall. Both of rainfall and lightning does not show an increase sharply. Thus, mature stage of clouds also unclearly visible as in the previous event (March 11, 2009).

By using L-Index (see Figure 3d), it shows a negative of the curve (L-Index <0.5) 15 minutes before the rainfall or a positive of the curve (L-Index <0.5) 30 minutes before the rainfall. These not significant of value based on Table 2 and indicates the potential of rainfall 5-10 mm (light to moderate). In reality, there has been rainfall for the next 15 minutes (from negative curve) with an intensity of the rainfall of 0.7 mm (total intensity of the average rainfall of 23.2 mm/hr of 1.7 hour duration).

There was no lightning distribution due to 0.5° of radius at 14.00-15.00 LT around Bandung (see Figure 4b). If compared to the IR1 MTSAT satellite (see Figure 5b), clouds are not distributed at around Bandung but spread to almost the entire of Java. The temperature of the top cloud at around Bandung is -27 to -47 °C.

Therefore, charging mechanism in the cloud is not too strong. This also impacted to the relationship between rainfall and lightning (weak).

3.3. The rainfall event on October 12, 2009

There are no lag-time between rainfall and lightning at October 12, 2009 with a correlation r=0.72. Both of lightning and rainfall activities started at 13.30 LT but stopped at 14.00 LT and then increases again at 16.15 LT (see Figure 3e).

As well as on Figure 3f, there are three positive of curves were not significant referring to the value (L-Index <0.5) and indicates the potential of rainfall 5-10 mm (see Table 2). In fact, there has been rainfall during the peak of curves with an intensity of the rainfall of 4.1 mm (total intensity of the average rainfall i.e. 16.7 mm/hr of 3 hour duration).

As in Figure 4c, there was CG lightning distribution due to 0.5° of radius at 14.00-15.00 LT around Bandung. However, clouds are not distributed well at around Bandung but spread to almost the entire of Java if compared to the IR1 MTSAT satellite (see Figure 5c). Top cloud of temperature at around Bandung are -21 to -40 °C. This situation still unclear and to be questioned, if compared to the event on May 18, 2009. The relationship between rainfall and lightning is not expected strong.

3.4. The rainfall event on November 26, 2009

For the last examples, i.e. November 26, 2009 there are 60 minutes lag-time between rainfall and CG lightning with a correlation r=0.45 as seen in Figure 3g. Lightning activity started at 14.00 LT, 60 minutes earlier than rainfall. Both of rainfall and lightning does not show an increase sharply. Therefore, mature stage of clouds also unclearly visible, similarly with the event on May 18, 2009.

Comprehensively by using L-Index (see Figure 3h), it shows two positive of curves, but not significant of value based on Table 2 (L-Index <0.5) before the rainfall (5-10 mm). In fact, there has been rainfall for the next 15 minutes with an intensity of rainfall only 0.2 mm (total intensity of the average rainfall i.e. 18.9 mm/hr of 3 hour duration).

As in the Figure 4d, the distribution of CG lightning at 14.00-15.00 LT localized at radius 0.5° around Bandung. It is similarly if compared to the IR1 MTSAT satellite (see figure 5d) which is indicates accumulation of clouds above the Bandung area.

The top cloud temperature (-54 to -90 °C) is also indicating the mechanism of collision and coalescence become more intense to produce cloud electrification as well as event on March 11, 2009. This situation also questioned when compared the weak of lightning and rainfall correlation that is resulted. However, the long duration of rainfall as the characteristics of cumuliform cloud type resulting a weak relationship between lightning and rainfall.

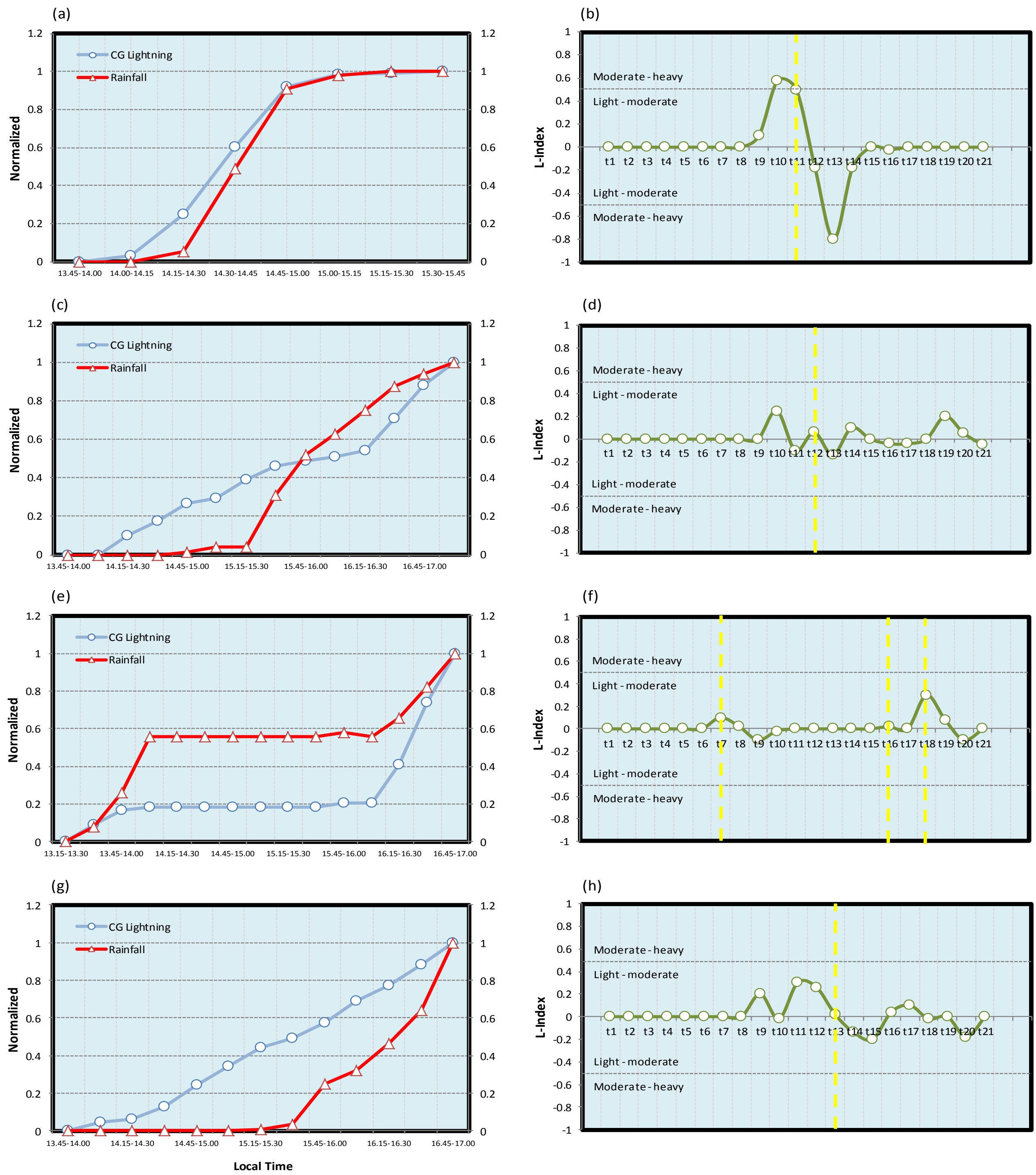

Fig. 3. Cumulative of CG lightning and rainfall (left side) and L-Index (right side) where : a) Cumulative of CG lightning and rainfall on March 11, 2009; b) L-Index based on CG lightning on March 11, 2009 (rainfall marked as "yellow dashed line"); c) Cumulative of CG lightning and rainfall on May 18, 2009; d) L-Index based on CG lightning on May 18, 2009 (rainfall marked as "yellow dashed line"); e) Cumulative of CG lightning and rainfall on October 12, 2009; f) L-Index based on CG lightning on October 12, 2009 (rainfall marked as "yellow dashed line"); g) Cumulative of CG lightning and rainfall on November 26, 2009; h) L-Index based on CG lightning on November 26, 2009 (rainfall marked as "yellow dashed line").

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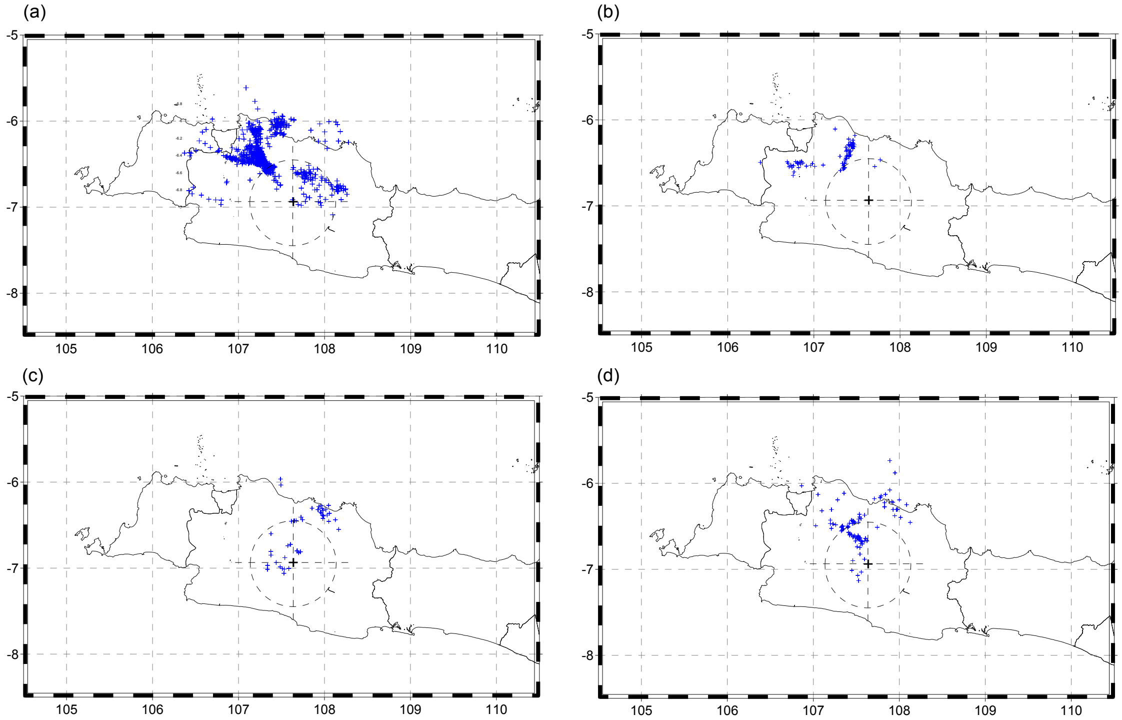

Fig. 4. CG Lightning distribution (blue dot) detected using lightning sensor of Bandung, which is a) March 11, 2009 at 14.00-15.00 LT; b) May 18, 2009 at 14.00-15.00 LT; c) October 12, 2009 at 14.00-15.00 LT; and d) November 26, 2009 at 14.00-15.00 LT.

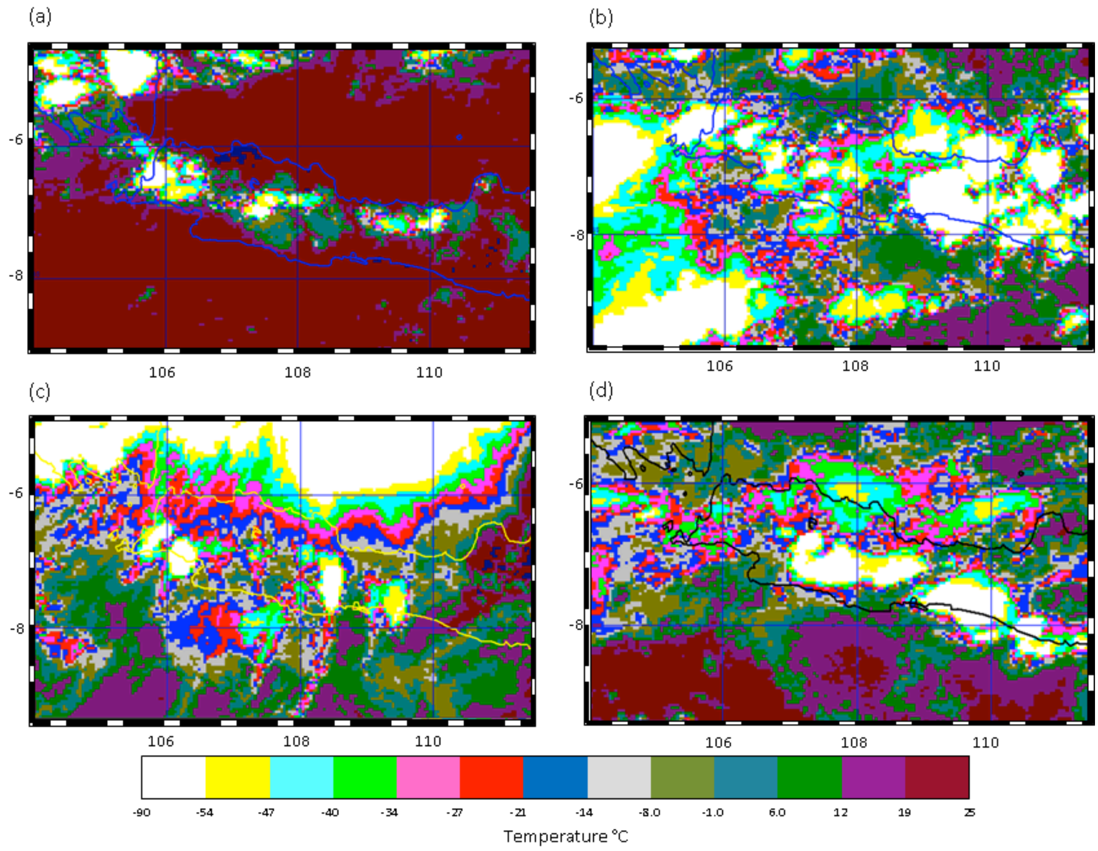

Fig 5. Temperature of the top clouds derived by IR1 MTSAT satellite, which is a) March 11, 2009 at 14.00-15.00 LT; b) May 18, 2009 at 14.00-15.00 LT; c) October 12, 2009 at 14.00-15.00 LT; and d) November 26, 2009 at 14.00-15.00 LT.

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4. Conclusion

We have examined four examples of rainfall events (>50 mm/day) during the year 2009 at Bandung i.e. March 11, May 18, October 12 and November 26. The objective of this study was to analyse the relationship between CG lightning and rainfall. We have found that there is a linear relationship between the lightning and rainfall. The highest correlation r=0.92 of lightning and rainfall are on March 11, 2009. This event shows the physical conditions were very supportive of lightning and rainfall relationship. Mature stage of clouds started after optimum incoming solar radiation (above 12.00 noon). Significant of L-Index (>0.5) also supported by real condition of rainfall that is occurs 15 minutes after the lightning. Lightning distribution also described positively resulting when compared to the top cloud of temperature (-54 to -90 °C). Rainfall tends to follow the lightning (positive lag) where the rainfall preceded the lightning by 15 minutes, and had non-significant lags at October 12, 2009. Although, some questioned results about the physical processes of clouds that seems contrasting to the previous events, lightning analysis still promising to rainfall estimating. Since lightning and rainfall could well be different in other seasons and location, we believe such relationship merit for further study.

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