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# Environmental Study of Tropical Hailstorm and its Relationship with Negative Narrow Bipolar Event and Positive Ground Flashes

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**Abstract**

The thermodynamic conditions in the environmental storms are derived from the Rapid Update Cycle model analysis, where the point nearest to the storm, in the direction of storm motion was used. This paper presented the evolution (5-minute flash rate) of two tropical hailstorms that occurred in Malaysia at two sites namely Bukit Jalil (approximately 112 km from our station) and Sungai Udang (approximately 22 km from our station) with the objective to understand the relationship of the hailstorms with Negative Narrow Bipolar Event (–NBE) and Positive Cloud-to-Ground (+CG) flashes. The hailstorm occurred in Bukit Jalil on June 3$^{rd}$ 2016 started at around 08:20 (UTC) and producing hails around 10:30. Negative NBE rate reaches the maximum at around 10:30 to 10.40 with 17 –NBEs recorded when the hails were reported to hit the ground. Within the same time, 15 +NBEs were detected. 75 minutes before the hails hit the ground, 30 –NBEs and 70 +NBEs were detected. In contrast, only 3 +CG were detected. On the other hand, after 10.40 and up to 14.30 (230 minutes), only 5 –NBE were detected compared to 244 +NBEs and 9 +CGs. The hailstorm occurred in Sungai Udang on September 14$^{th}$ 2016 started at around 17:00 and producing hails around 19:00 to 19:30. Within this 30 minutes duration, 70 +CGs were detected when the hails were reported to hit the ground. 120 minutes before the hails hit the ground, only 4 –NBE were detected compared to 154 +NBEs and 22 +CGs were detected. After 19.30 up to 20.30 (60 minutes duration), 4 +NBEs and 18 +CGs were detected while no –NBE has been recorded. Based on the results of these 2 tropical hailstorms, clearly stronger convection does not related only to higher –NBEs flash rate but also highly correlated to +CGs flash rate.

**Keywords:** negative narrow bipolar event, positive cloud-to-ground flash hailstorm, environmental parameters

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## INTRODUCTION

Severe storms at mid-latitudes have been observed to be related with a special type of electromagnetic pulse known as Narrow Bipolar Event (NBE). A comprehensive study on NBE occurrence in tropical region and higher latitude can be found by Ahmad et al. (2015). Thorough studies on meteorological context of NBEs in Florida (Jacobson and Heavner 2005, Suszcynsky and Heavner 2003) showed a strong correlation between NBE rates and ordinary lightning flash rates. In general, stronger storms have been observed to produce higher percentage NBEs while weaker storms produced less or no NBEs at all. Observation in Great Plains by Wiens et al. (2008) showed that most of NBEs in Great Plains were produced by only a few storms in particular by two severe storms while most of the storms do not produce any NBEs.

Physical scaling argument suggests that total lightning flash rate should increase proportionally to the 5$^{th}$ power of cloud height (Williams and Renno 1993, Çanakçı et al. 2018). In other word, as the cloud top gets higher, ordinary lighting flash rate increases and consequently NBE rate should be increases too. Based on this argument and also evidence of a robust correlation between the strength of convective updraft and the height of cloud top (Wiens et al. 2008) almost

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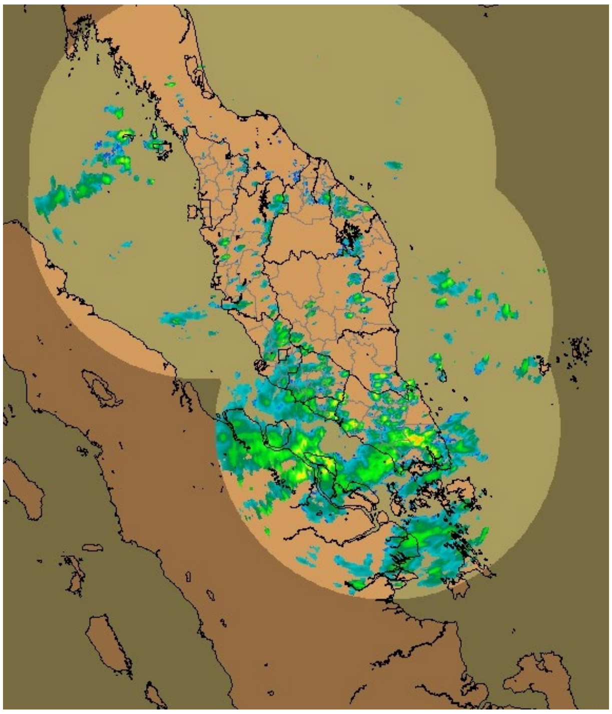

**Fig. 1.** The red circle indicates the observation system [adapted from MMD]

all previous studies mostly based on observations at mid-latitudes have supported the theory that relates NBE rates in particular negative NBEs with the strength of convective updraft which always associated with storm severity. In other word, severe storms should produce the highest rate of NBEs particularly negative NBE rate.

## METHODOLOGY

Observation presented here was from a single observation station (OS) hosting a wideband electric field (E-field) antenna system (decay time constant 13 ms) and a pair of orthogonal wideband magnetic field (B-field) antenna system (additional details can be found in Ahmad et al. (2015)). The OS is located in Universiti Teknikal Malaysia Melaka (UTeM), Malacca, Malaysia (2°18′50.41″N, 102°19′6.9″E; see **Fig. 1**). Radar reflectivity data used here has been obtained from Malaysia Meteorological Department (MMD), Ministry of Science, Technology, and Innovation (MOSTI).

The output of the antennas is digitized at rates of 2 MHz and 80 MHz with a resolution of 12 bits. Data records were 2 s long and event triggered. The timing for each event was provided by a global positioning system (GPS) with accuracy of ±6 ns. The observation presented here from 2 storms formed over Bukit Jalil and Sungai Udang.

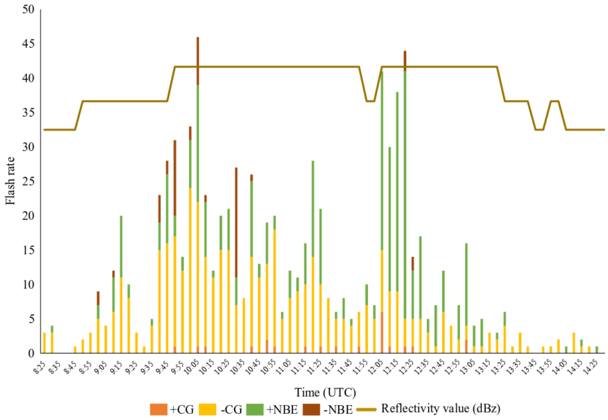


**Fig. 2.** Evolution of the flash rate and radar CAPPI reflectivity values of the storm that producing hails in Bukit Jalil on 3rd June 2016

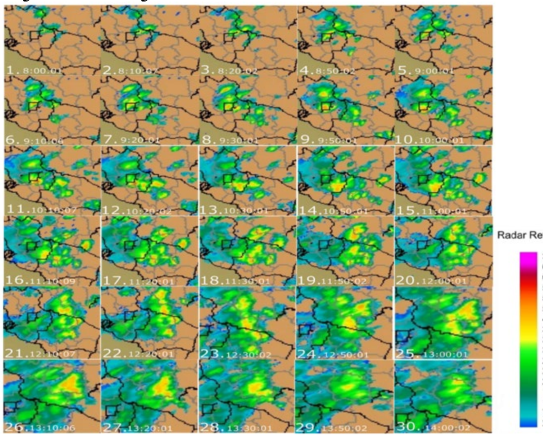

**Fig. 3.** Evolution of radar CAPPI reflectivity values at 2 km altitude for the storm that produce hails between 10:30 and 10:40 in Bukit Jalil

A total of 858 and 1022 flashes were detected from Bukit Jalil and Sungai Udang hailstorm respectively. We categorized the flashes with NBEs and non-NBEs. The NBEs consists of positive and negative NBEs. For the non-NBEs, consists of positive and negative CGs (Ben Salah et al. 2018).

## RESULTS AND ANALYSIS

The first +NBE was detected when the storm reflectivity reached values between 34 and 39 dBz in period between 8:25 and 8:30. The storm was located at the northeast of Kuala Lumpur (see **Fig. 3** block number 3). For the next 25 minutes, the storm seemed to be quiet as no NBEs were detected from the storm. Then, starting at 8.55, the storm started to produce both positive and negative NBEs for a duration of 30 minutes with 18 +NBEs and 3 –NBEs (see **Fig. 2**). Within this period, the reflectivity values were between 39 and 44 dBz (see **Fig. 3** from block 4 to block 7).

Starting 9:30, all flash rates were increased significantly with 17 –NBE, 20 +NBE, 1 +CG and 63 –CG were detected within 25 minutes period. The storm was located over Kuala Lumpur area (see **Fig. 3** between block 8 and block 9). The reflectivity values of the storm have increased from 44 dBz (maxima at 9:30) to 50 dBz (maxima at 9:55). Clearly, the NBE rate for –NBE flash has increased significantly when the reflectivity values of the storm increased from maxima 44 dBz to 50 dBz at 9:50.

Starting 9:55, –NBEs rates were 10 and +NBE rates were 33 within 20 minutes period. Within the same period, 2 +CG flashes were detected. The storm over Kuala Lumpur was moving southeast (see **Fig. 3** from block 9 to block 12). The reflectivity values of the storm were maxima at 50 dBz between 9:50 and 10:10.

Between 10:15 and 11:00, –NBEs were emitted only between 10:30 and 10:45. Interestingly, this period is when the storm produced hails. Within 5 minutes period between 10:30 and 10:35, 16 –NBEs have been detected. In comparison to the previous –NBEs rates (see **Fig. 2**), this rate is the highest. In addition, 4 +NBE and 15 -CG flashes were also detected within 5 minutes period between 10:30 and 10:35. Notice that no +CG were emitted at this period. On the other hand, the reflectivity values in this period remain between 44 dBz and 50 dBz (see **Fig. 3**).

Starting 11:00 to 14:25, only 5 –NBEs and a huge number of +NBEs and –CGs with 222 and 169 flashes were detected respectively within 3 hours and 25 minutes (see **Fig. 2**). In addition, 15 +CG flashes were also detected within this period.

The reflectivity values of the storm were the same between 44 and 50 dBz until 13:15. Starting 13:20 until 14:25, the reflectivity values have dropped with recorded values between 39 and 44 dBz. The storm from southeast Kuala Lumpur was moving to Negeri Sembilan and later diverted to Pahang (see **Fig. 3** from block 15 to block 30).

The total flash rates of –NBEs and +NBEs for a period of 155 minutes (between 8:25 and 11:00) were 47 and 109, respectively. On the other hand, between 11:00 and 14:25 for a period of 205 minutes, the total flash rates of –NBEs and +NBEs were 5 and 222, respectively. Obviously, the production of –NBEs is closely related with reflectivity values of the storm while the production of +NBEs seems to be unrelated with the reflectivity values.

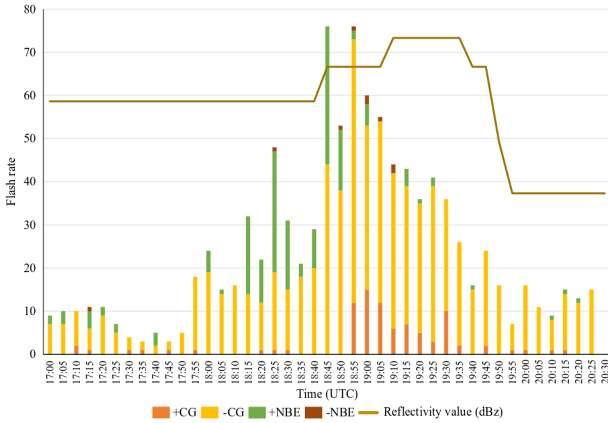


**Fig. 4.** Evolution of the flash rate and radar CAPPI reflectivity values of the storm that producing hails in Sungai Udang on 14th September 2016

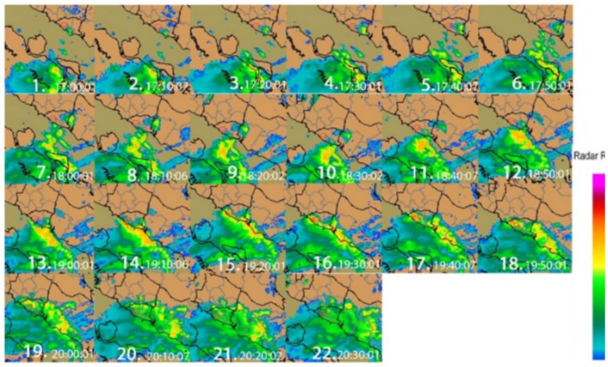

**Fig. 5.** Evolution of radar CAPPI reflectivity values at 2 km altitude for the storm that produce hails in Sungai Udang.

A total of 11 +NBEs, 1 –NBE, 36 –CG and 3 +CGs have been detected when the storm reflectivity reached values between 39 and 44 dBz in period between 17:00 and 17:20 (20 minutes). The storm was located over Sumatra Island in Riau Province (see **Fig. 5** from block 1 to block 4). Between 17:20 and 18:00 (40 minutes), the rate of +NBE flashes is 10 and the rate of +CG flash is 4 (see **Fig. 4**). Within this period of time, not a single –NBE detected. Then, the storm was moved toward Malacca Strait (see **Fig. 5** from block 5 to block 7). Reflectivity values were recorded to be between 39 and 44 dBz.

Starting 18:00 to 18:35 (35 minutes), 76 +NBE, 1 –NBE, 105 –CG and 3 +CG have been detected (see **Fig. 4**). The storm was located over Malacca Straits (see **Fig. 5** from block 7 to block 10). Interestingly, between 18:25 and 18:30, 28 +NBEs have been detected within 5 minutes duration with reflectivity values between 39 and 44 dBz (see **Fig. 5** between block 9 and block 10). This is just before the reflectivity value increased to maxima 50 dBz at 18:45. At 18:45, the number of +NBEs increased to 32 within only 5 minutes period.

12 +CG flashes were detected in 5 minutes period between 18.50 and 18.55 with reflectivity values reached maximum at 50 dBz. The storm was moving closer from Malacca Straits to Sungai Udang (see **Fig. 5** block 11 to block 12). Starting 18:55 until 19:35, 60 +CGs and 264 –CGs flashes were detected when the hails were reported to hit the ground in duration of 40 minutes.

12 +NBEs and 5 –NBEs were detected within the same period. 120 minutes before the hails hit the ground, only 4 –NBE were detected compared to 154 +NBEs and 22 +CGs were detected. When the hails hit the ground, the reflectivity values were recorded to be between 44 and 50 dBz until 19:05 and increased to maximum at 55 dBz until 19:35. Within this period, the flash rate of +CG increases drastically as the reflectivity value increases (see **Fig. 5** block 13 to block 17).

After the hails production was stopped at around 19:35, between 19:35 and 20:30, 4 +NBEs, 6 +CGs and 132 –CGs have been detected while not a single –NBE has been recorded. The reflectivity values were dropped from 55 dBz to 50 dBz in 10 minutes period between 19:35 and 19:45 and the values further dropped to 28 dBz at 19:55 and remain constant until 20:30 (see **Fig. 5** block 18 to block 22).

## CONCLUSION

While the data show an abundance of scatter between CG lightning occurrence and environmental (thermodynamic) parameters, some trends can be established. The –NBE flash mainly has been suggested by Wu et al. (2013) to be used as a tool to monitor severe storm with deepest convection. Due to the nature of NBEs that can emit high Very High Frequency (VHF) radiation that can penetrate through the ionosphere, satellite can be used to monitor the severity of a storm. But for certain cases NBE flash rates are not related with convective strength. More studies need to be done to investigate whether –NBE can be used to monitor severe storm. Also +CG flashes can be suitable candidate to be used as severe storm indicator due to the fact that both –NBE and +CG flashes emitted almost at the same region (close to cloud top between 15 to 21 km height). Based on the convective strength, we can conclude that –NBE flash can be used as an indicator to hailstorm occurrence. In addition, not only –NBE, +CG flashes can be used as an indicator to hailstorm occurrence.

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