URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Total Lightning Distribution and Heavy Rainfall Characteristics Associated With Multicellular Thunderstorms

Debrupa Mondal[(1)], Yasuhide Hobara[(1,2)], Hiroshi Kikuchi[(2)], Jeff Lapierre[(3)]
(1) University of Electro-Communications, Tokyo, Japan; e-mail: debrupamondaljam@gmail.com; hobara@ee.uec.ac.jp
(2) Center for Space Science and Radio Engineering, University of Electro-Communications, Tokyo, Japan; e-mail: hkikuchi@uec.ac.jp
(3) Earth Networks, Germantown, MD 20874, USA; e-mail: jlapierre@easrthnetworks.com

Abstract

Recently, detailed spatio-temporal analysis, using X-band multi-parameter radar-derived 3D volume scan and total lightning data in Japan, have shown the peak IC (In-Cloud lightning) occurs 5-10 mins prior to maximum ground precipitation for individual cells of a thunderstorm during heavy rainfall events, which can be useful for monitoring and short-time prediction of ground precipitation. But we found merging and/ or splitting between the cells with total lightning distribution, is a common phenomenon of multicellular TSs (ThunderStorms) which needs to be taken into account for more accurately predicting the storm evolution. In this paper, we have analyzed the preliminary observation results of two isolated, multicellular TS events with heavy precipitation (~100 mm) that showed merging and splitting between cells in their life cycle. The abrupt decrease or increase of IC lightning and precipitation volume at the time steps of splitting and merging respectively, were normalized with consideration of cell area ratio (before and after merging or separation), which resulted in a reasonable and similar trend for time series plot of IC vs ground precipitation. We also obtained a time lag between the peak IC and ground PV after applying the correction criteria. Thus, the proposed method will be promising for prediction and nowcasting the heavy ground precipitation using lightning data for multicellular TSs.

1 Introduction

With the rising intensity and severity of short-term heavy rainfall events, the need for accurate earlier prediction of occurrence as well as the quantitative parameter such as amount of rainfall is becoming obvious. Investigating the correlation and spatio-temporal dependencies of precipitation along with total lightning studies have shown that total lightning data can be used as a precursor of heavy precipitation [1-3]. There are studies which examined the relationship between total lightning behavior and radar reflectivity data to examine the signature of thunderstorm intensity for mesoscale convective events such as squll lines (line of thunderstorms), supercells [4, 5] as well as precipitation characteristics for convective multicell thunderstorms [6]. Multicellular thunderstorms possess cells in different stages of their life cycle (developing stage, mature stage, dissipation stage) at a time. During a preliminary study for isolated thunderstorms, we observed that merging between cells and splitting of a cell during the thunderstorm's life cycle is a common phenomenon. Since these merging and splitting lead to a sudden change in the considered cell area, while using the spatial and temporal distribution of total lightning data for prediction, there is a high chance of false forecasting. This study attempts a methodology for the more accurate evaluation of temporal dependence of total lightning (mainly IC) and ground rainfall.

2 Observational Data

2.1 eXtended RAdar Information Network (XRAIN)

In this study we have collected precipitation data from the Ministry of Land, Infrastructure, Transport, and Tourism's eXtended RAdar Information Network which cover most parts of Japan around 14 major cities. The network is composed of 26 C-band radars and 39 X-band multiparameter (X-MP) radars. The X-MP radars produce 3D volume scan data ranging from 0° to 20° by scanning twelve elevation angles.
X-band and C-band radar-derived high resolution (temporal resolution=1min, spatial resolution=250m) composite ground rainfall intensity data (mm/h) is also collected from XRAIN.

2.2 Japanese Total Lightning Network (JTLN)

Total lightning data associated with the events were collected from JTLN which consists of 16 Earth Networks Total Lightning Sensors over Japan (Figure 1 showing 11 sensors, data set in 2017) deployed by the University of Electro-Communications and jointly operated with Earth Network.
These ground-based sensors can detect lightning pulses over a very wide frequency range, from 1 Hz to 12 MHz i.e., from ELF to HF series with 500 m spatial resolution. We have collected total lightning (TL) parameters such as types of lightning (IC (In-Cloud) and CG (Cloud to Ground)), time of occurrence (UT), location (latitude-longitude) for each lightning discharge.

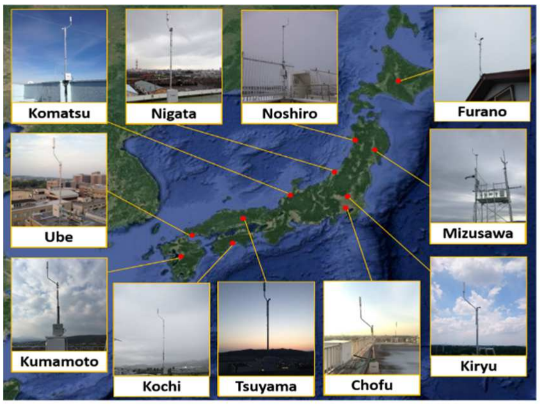

Figure 1. JTLN sensor distribution over Japan

3 Results

We have analyzed high-resolution precipitation data and total lightning activity during the life cycle of two multicellular thunderstorm events with heavy ground rainfall (max ~100mm/h) that occurred on June 2, 2022 in Gunma prefecture (event 1) and August 22, 2020 in Gifu prefecture (event 2) in Japan.

3.1 Event 1 Analysis: Consideration of Splitting

For the detailed analysis of this thunderstorm, we took every 5-min full volume scan data of Yattajima radar (36.2647 E, 139.1972 N) and produced Constant Altitude Plan Position Indicator (CAPPI) plots. To visualize the evolution of the precipitation core, maximum radar reflectivity projection on the horizontal plane (NS-EW) with the spatial distribution of total lightning activity was produced.

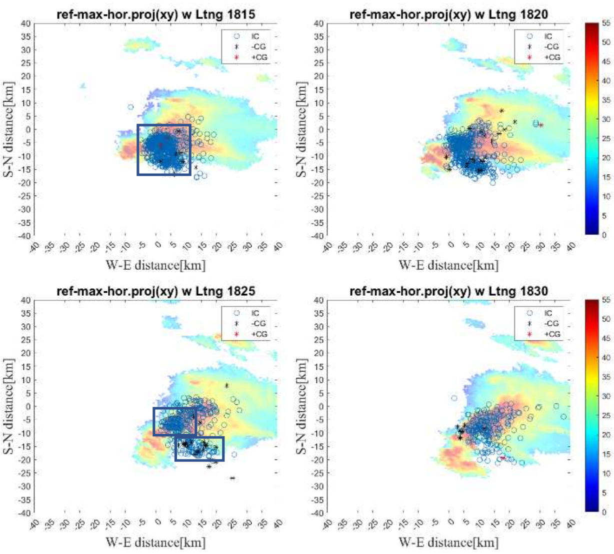

Figure 2. Maximum radar reflectivity projections on the horizontal plane along with the lightning distributions

The panels of Figure 2 show the projection of maximum radar reflectivity on the horizontal plane with the spatial distribution of IC (blue circle), +CG (red asterisk), -CG (black asterisk) for the time steps before, during and after splitting of the cell. The horizontal axis represents the W-E distance (km) from the radar location and the vertical axis represents the N-S distance (km) from the radar (the radar is located at (0,0)).

During the TS, IC lightning started occurring at around 17:30, near the northwest of the radar location (20 km W, 10 km N) which gradually moved south-eastward and the number of IC lightning also increased gradually. Around 18:15 a compact IC lightning core is observed. Around 18:20 the IC lightning flashes start concentrating in two adjacent separate cores and at 18:25 two separate cores are observed. The southward core diminishes in the next 5mins whereas the northward core is sustained till 18:45 and IC lightning gradually decreases.

Next, we have analyzed the temporal evolution of ground precipitation volume (PV) with the TL, IC, and CG rates. Figure 3(a) shows the time series of ground PV (solid blue line) and IC pulse rates (black dashed line) per 5 min for the analyzed cell. The peak of IC (around 703 pulses/5 min) occurred around 18:15 and then a sudden drop in flash rate was observed at 18:20 which resulted from the splitting of cells (blue dashed vertical line shows the time of splitting). To resolve this, during tracking a precipitation cell that is separated into two cells at time t, we have considered the following area correction process. If at the time step (*t*-5 min), the cell area is a_1 and in the next time step i.e. at *t*, the main cell area becomes a_2 after splitting, and the precipitation volume drops from PV_1 at (*t*-5) to PV_2 at *t*, then corrected PV (PV_2') will be

$$PV_2' = \frac{PV_2 a_1}{a_2} \tag{1}$$

The IC flash rate is also corrected similarly by multiplying with the same area ratio.

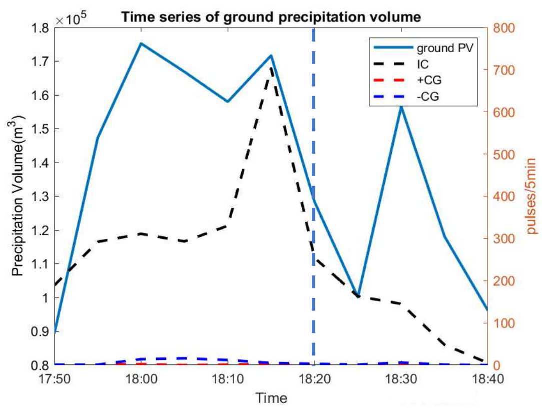

Figure 3(a) Temporal evolution of ground PV and IC pulse rate

Figure 3(b) shows the temporal evolution of ground PV and IC lightning same as Figure 3(a) but considering area correction after splitting. The shaded portion represents the values that are not the real values. This correction resulted in a similar temporal dependence trend as well as a time lag of 5 min between IC peak and ground precipitation peak.

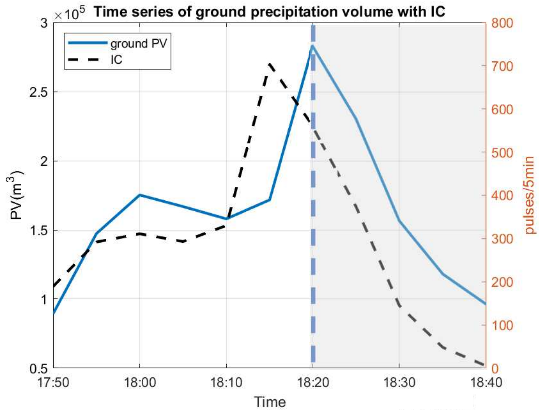

Figure 3(b) Temporal evolution of ground PV and IC pulse rate considering area correction

3.2 Event 2 Analysis: Consideration of Merging

For the detailed analysis using the 5-min full volume scan data we considered Bisai radar (35.2994 E, 136.7344 N) data for this thunderstorm.

During this multicellular TS, IC lightning started occurring around 16:30 at two cell locations, one in northeast direction of radar (35-40 km N, 10 km E) and the other one in northwest (10 km W, 35 km N) of radar location. Around 16:50 both the cores became well developed with concentrated IC distribution. The left cell starts shifting slightly north-eastward from 16:45 and around 16:55 as the IC pulses tend to shift westward for the right cell also, both the cells start merging. At 17:00 JST both the cells are completely merged. Figure 4 shows the maximum radar reflectivity projections on horizontal plane along with the lightning distribution same as Figure 2 for the time steps before, during and after merging of the cells.

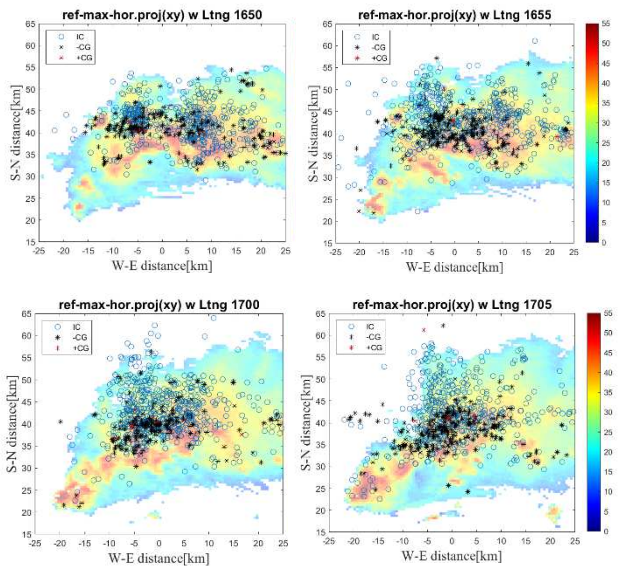

Figure 4. Maximum radar reflectivity projections on horizontal plane along with the lightning distributions

We have analyzed the temporal evolution of ground precipitation volume (PV) with the TL, IC, and CG rates for both the cells of this thunderstorm. Figure 5(a) and Figure 6(a) show the time series of ground PV with IC and CG flash rates per 5 min for the leftward cell and right one respectively. For the left one, with an IC lightning jump, observed at 16:50 (a rapid increase from nearly 187 pulses to 487 pulses in the next 5 min), the ground PV also increased very rapidly within this 5 min. For the rightward cell, both IC and ground PV start increasing gradually with time and similarly at 16:50 a sharp increase in IC pulse rate and PV are observed. Though for both the cells ground precipitation peak comes 10 min later than the peak IC, the spatial distribution shows that these lightning jumps may be the result of merging between the cells around 16:55 (blue dashed vertical line shows the time of merging).

To verify this, we have carried out the similar area correction process mentioned for splitting. Figures 5(b) and 6(b) show the temporal evolution of corrected ground PV, IC and CG flash rates for the two cells analyzed here.

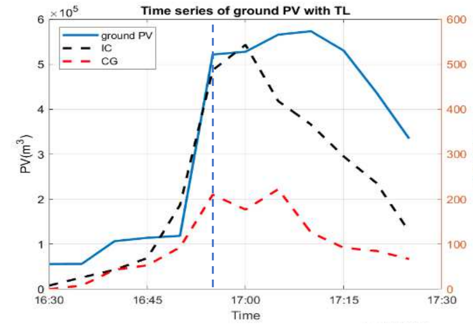

Figure 5(a) Temporal evolution of ground PV, IC and CG flash rates of left cell

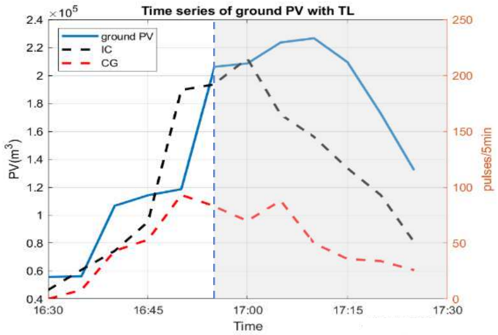

Figure 5(b) Temporal evolution of corrected ground PV, IC and CG flash rates

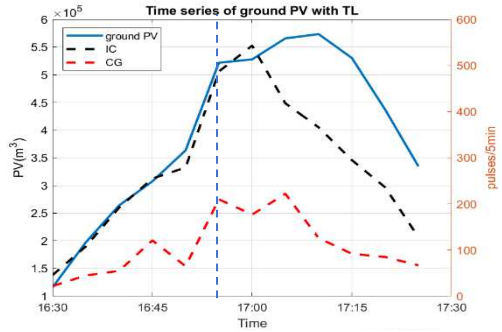

Figure 6(a) Temporal evolution of ground PV, IC and CG flash rates of right cell

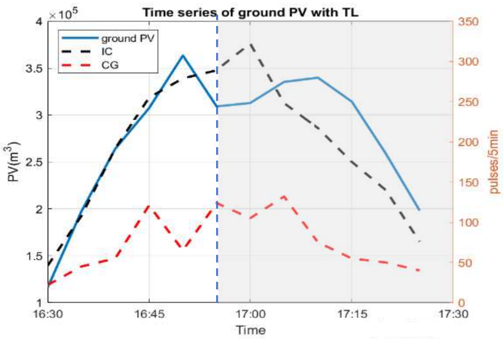

Figure 6(b) Temporal evolution of corrected ground PV, IC and CG flash rates

In Figure 5(b) and Figure 6(b) the values of ground PV, IC and CG flash rates are real values from 16:30 to 16:50, the shaded area represents the values of these parameters that are corrected from the time of merging (16:55 JST). We found that for the left cell, the lightning jump after 16:50 may be a false one. The IC lightning increased only from 187 flashes to around 192 flashes (not real value) in the next 5 min. The peak IC lightning and peak ground PV observed at 17:00 JST and 17:10 JST respectively. The occurrence of peaks remained the same whereas the peak precipitation volume became sufficiently low, from 5.73×10^5 m^3 (real value) to around 2.26×10^5 m^3.

For the rightward cell also, instead of nearly 200 flash increase in 5min, we found the flash rate increase may be only 279 pulses/5 min to 289 pulses/5 min after 16:50. Though after correction, the peak of PV (16:50) comes earlier than the peak IC (17:00), a continuous high rainfall trend is observed until 17:10. For this cell from spatial distribution we observe a compact core around 16:50, and the IC flashes start decreasing and shifting a bit westward afterward. If we consider this time step (16:50) as the mature stage of the cell, in the next time steps i.e. in the dissipation stage the cell area may decrease. Since for correction, we are considering the area of the cell in the previous time step of merging (here, the area of the mature stage), it may result in a higher than actual IC flash rate.

4 Discussion

Liu *et al* [3] showed continuous monitoring of total lightning data, in particular IC lightning makes it possible to track and predict the various properties of high-impact weather events. Earlier for the isolated thunderstorm events analysis, we found that consideration of a smaller spatial scale (individual cell) rather than the storm scale, resulted in a peak of IC (or, IC lightning jump) occurrence nearly 5~10 min earlier than peak ground PV which may be used as a precursory parameter for short-term prediction of maximum ground rainfall. But for the multicellular thunderstorms having merging between cells and/or splitting of a cell in their life cycle, tracking of total lightning data may give false lightning jump or a sudden drop in lightning. So, for the short-term prediction of heavy precipitation using TL, it is very important to analyze such events for a more accurate prediction of ground rainfall. In this current study, we demonstrate that, PV multiplication by area ratio normalizes these abrupt changes to some extent and successfully obtain the precursory signature of heavy rainfall for multicellular thunderstorms. Therefore, our proposed methodology will be promising to improve the prediction and nowcasting of heavy rainfall using lightning data.

Acknowledgements

We acknowledge the support from the Ministry of Education, Culture, Sports, Science, and Technology (AiQuSci Scholarship). The authors are grateful to the Ministry of Land, Infrastructure, Transport and Tourism for providing XRAIN data and also to the KDDI foundation for supporting partially this research project. The authors also thank P. Le Floch and E. DiGangi of EN, Tada Farm, Noshiro City Children's Center, Niigata Science Museum, NAOJ Mizusawa, JAIST, Gunma Univ., Rissho Univ., ISEE (Nagoya Univ.), NIT Tsuyama College, Kochi Univ., Ama town, Yamaguchi Univ., Tokai Univ. for their help JTLN observations in Japan.

References

[1] B. Gungle, E. P. Krider, "Cloud-to-ground Lightning and Surface Rainfall in Warmseason Florida Thunderstorms," Journal of Geophysical Research: Atmospheres, **111**, 2006.

[2] T. Ogawa, Y. Hobara, H. Iwasaki, S. Heckman, M. Stock, "Statistical Study of The Relationship Between Total Lightning and Heavy Rainfall," 16th International Conference on Atmospheric Electricity, Nara, Japan, 2018

[3] C. Liu, C. Sloop, S. Heckman, "Application of Lightning in Predicting High Impact Weather," OBS/IMO/TECO-2014.

[4] S. M. Steiger, R.E. Orville, L.D. Carey, "Total lightning signatures of thunderstorm intensity over North Texas, Part II: Mesoscale convective systems," Mon. Weather Rev. 2007, **135**, 3303–3324.

[5] L. D. Carey, M. J. Murphy, T. L. McCormick, N. W. S. Demetriades, "Lightning location relative to storm structure in a leading-line, trailing-stratiform mesoscale convective system," JGR Atmospheres, **110**, Isssue D3, 2005.

[6] J. Sun, J. Chai, L. Leng, G. Xu, "Analysis of Lightning and Precipitation Activities in Three Severe Convective Events Based on Doppler Radar and Microwave Radiometer over the Central China Region," Atmosphere, 2019, 10(6), 298.