# Supporting Information for "Analysis of blue corona discharges at the top of tropical thunderstorm clouds in different phases of convection"

Krystallia Dimitriadou[1], Olivier Chanrion[1], Torsten Neubert[1], Alain Protat[2],

Valentin Louf[2], Matthias Heumesser[1], Lasse Husbjerg[1], Christoph Köhn[1],

Nikolai Østgaard[3], and Victor Reglero[4]

[1]National Space Institute, Technical University of Denmark (DTU Space), Kgs. Lyngby, Denmark

[2]Australian Bureau of Meteorology, Science and Innovation Group, Radar Science and Nowcasting Team, Melbourne, Australia

[3]University of Bergen, Birkeland Centre for Space Science, Bergen, Norway

[4]University of Valencia, Image Processing Laboratory, Valencia, Spain

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Corresponding author: K. Dimitriadou, DTU Space, Technical University of Denmark, Elektrovej, Building 327, 2800 Kgs. Lyngby, Denmark. (krstd@space.dtu.dk)

**Introduction** This supplementary information contains plots adding more details to the observations described in the main manuscript. The calculation of the rise times of the blue corona discharges is described thoroughly. For the blue corona discharges accompanied by an elve, we expain in detail what a single and what a double UV pulse mean. Furthermore, we provide information about the atmospheric sounding that characterized the thunderstorm environment where blue corona discharges were facilitated from. Last, we describe all the possible errors induced by projection offsets, different spatial resolutions of the instruments/detectors involved.

## 1. Rise time calculation

In order to calculate the rise times of the BEDs we implemented an algorithm which processes the whole sequence of ASIM observations in the storm and work as follows:

1. [Find all blue peaks]. It finds all the peaks in the blue photometer that increase by more than 5 $\mu W/m^2$ in 5 samples. The rise time is calculated by counting the number of samples it takes for the BED event to increase from 10% of the full amplitude to 90% of the full amplitude

2. [Disregard peaks close to each other] If several peaks occur within 500 samples, it disregards all except the biggest peak.

3. [Disregard delta peaks (cosmic rays)] It sums the blue photometer data together, 100 samples before and after the peak, and take the ratio as (after)/(before). If this ratio is below 2.97, it disregards the blue peak. Note that a lower ratio here suggests highly narrow peaks like cosmic rays.

4. [Disregard peaks where the red photometer is large] It sums blue and red photometer data up 50 samples before the peak and 150 samples after the peak and take their ratio, i.e. sum(phot3[i-50:i+150])/sum(phot1[i-50:i+150]) where i is the peak index. If this ratio is below 0.15 it considers the peak a BED.

In general, the step 1 results in hundreds of peaks, which then are reduced to tens of peaks in step 2, down to single or no peaks in step 3 and 4. All the values in the algorithm are found empirically.

## 2. Single and double UV signals

10 out of the 14 blue pulses are associated with a UV signal in the 180-230 nm (VUV) ASIM photometer. Those signals are characterised as either single or double pulses depending on how many peaks are identified. 4 out of 10 of UV signals are double, indicating that the VUV photometer has recorded signals from both the blue discharge and the accompanying elve. In the remaining 6 signals, characterized as single pulses, the VUV photometer records only the signal from the blue discharges emanating from the cloud top.

## 3. The atmospheric sounding

Figure S1 displays a Skew-T log-P diagram, commonly known as an atmospheric/ balloon sounding or radiosonde. Such diagrams are important both for weather forecasting models and assessing the atmospheric conditions in a give time and place. They provide information regarding the stability or instability of the atmosphere, pinpoint weather elements (temperature, dew point, wind speed and direction etc.) in all layers of the atmosphere as well as important atmospheric indices (CAPE, CIN, K index etc.), important for the categorization of convection environments.

The basic lines that constitute such diagram are the isobars on the vertical axis, solid lines of equal pressure that run horizontally and with the space between the pressure levels to change, thus the log-P. Pressure is mostly given every 100 hPa but the presented sounding indicates more levels in between. In each pressure level the corresponding altitude is give next to it in metres. Pressure height is preferred instead of the actual typical height, since pressure is not constant in the upper atmosphere (low and high pressure systems). On the horizontal axis, there are the valus of the isotherms, solid lines of equal temperature than run vertically. There are three additional types of lines, the saturation mixing ratio lines, the dry adiabatic lapse rates line and the moist adiabatic lapse rate lines which are out of the scope of this study, therefore will not be discusses. Last, on the right of the diagram, the wind barbs are plotted which indicate the wind speed and direction for a given atmospheric layer. A wind bar points to the direction from which the winds are coming. The lines and triangle perpendicular to the wind bars indicate the speed of the wind. Half line is 5 knots, a full line is 10 knots and the triangle is 50 knots. Wind speed is calculated from the summation of all the lines and triangles.

In the diagram, two intense and one faint black lines are plotted. From left to the right, the first line is the dewpoint plot. Dewpoint is related to the quantity of moisture in the air. The second line is the temperature measured in the atmosphere (or environmental sounding) and it is always to the right of the dew point line. The faint black curved line is the parcel lapse rate and indicates the path an air parcel will take if raised from the Planetary Boundary Layer (100 m - 2 km). This line is used for the calculation of thermodynamic indices such us CAPE (Convection Available Potential Energy), CIN (Convective INhibition), LI (Lifted Index) etc. CAPE, an index commonly used for characterising convection in storms, is the integration of positive area on a sounding. Positive area is defined the region where the the parcel temperature (curved thin black line) is warmer than the actual temperature (second line from the left). Depending on how close are the dewpoint and the temperature line we extract information about the humidity and the saturation of air. In the presented sounding of Figure S1, the two lines are really close indicating a highly humid and saturated atmosphere in the given station.

## 4. Data uncertainties and induced errors

In Figure 1 of the manuscript, for displaying purposes, blue corona discharges are projected in 17 km altitude instead of the 16 km projection altitude in the ASIM cameras. This does not affect the physical meaning of the presented cases and is only preferred in order for the events to be clearly visible in the 3D plot. ASIM geolocation errors in the ground are up to 10 km. This might slightly affect the position of the blue events, as indicated on the cloud top altitudes (Figure 1) and on the radar data (Figure 4). The induced uncertainties in the position are not significant for the physical meaning of the data. Furthermore, one can note that the values of Cloud Top Temperature (CTT) and Cloud Top Height (CTH) refer to a spatial resolution of 2 km, which is the resolution of Himawari satellite.

In Figure 4b and c, the step feature (light blue peaks) is a result of the gridding technique of the radar data. When there is a gap between those areas, there are no observations from the discrete elevations the radar uses to sample the atmosphere and it is not certain if there is a cloud as high as either sides of those gaps.

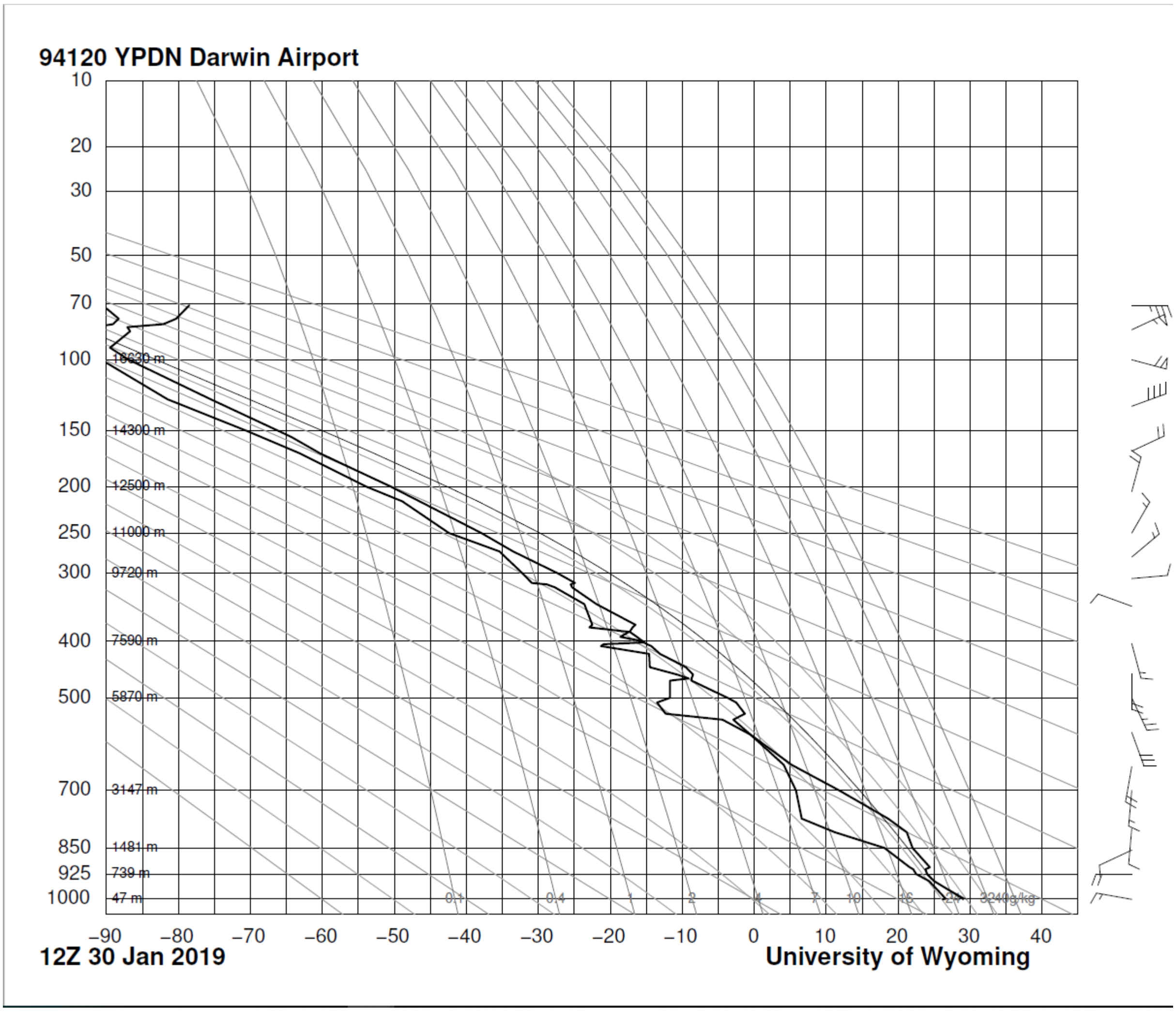



**Figure S1.** Atmospheric Sounding (SkewT-logP) from Darwin Aiport at 12 UTC on January 30, 2019.

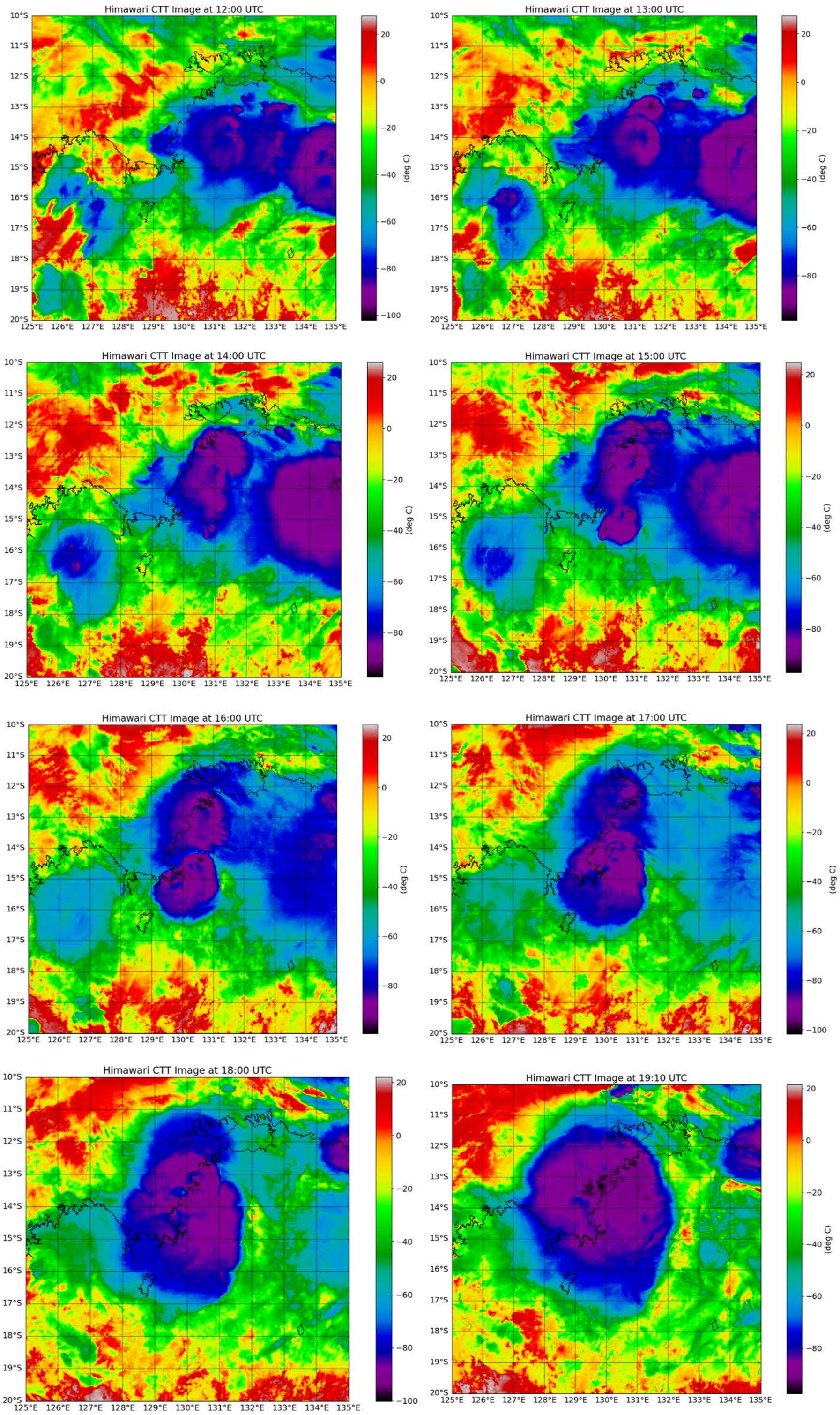



**Figure S2.** Storm evolution every 1 hour, from 12 UTC to 19 UTC detected by the 10.4 IR channel (Brightness Temperature) of Himawari geostationary satellite.

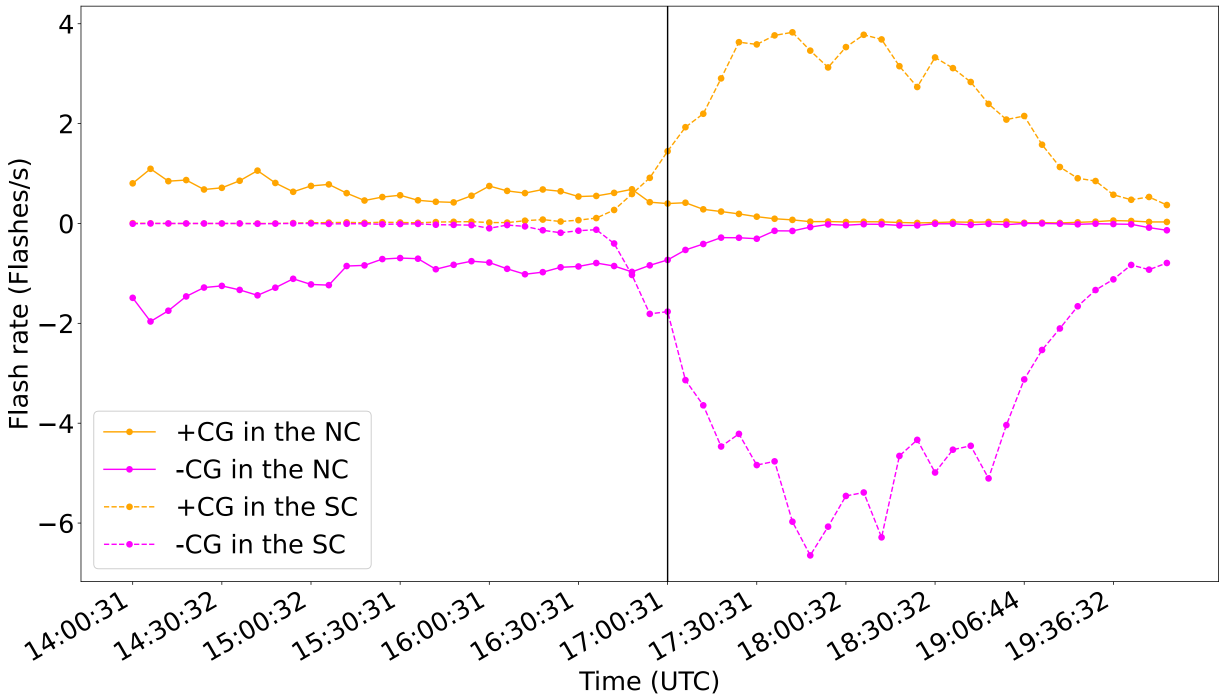



**Figure S3.** Flash rates of positive (orange) and negative (magenta) CGs in northern (straight line) and southern (dashed line) cells. The negative y-axis refer to the flash rates of all the negative strokes. Each point represents a radar scanning cycle (6 min) and the calculated flash rate is the average flash rate per cycle.

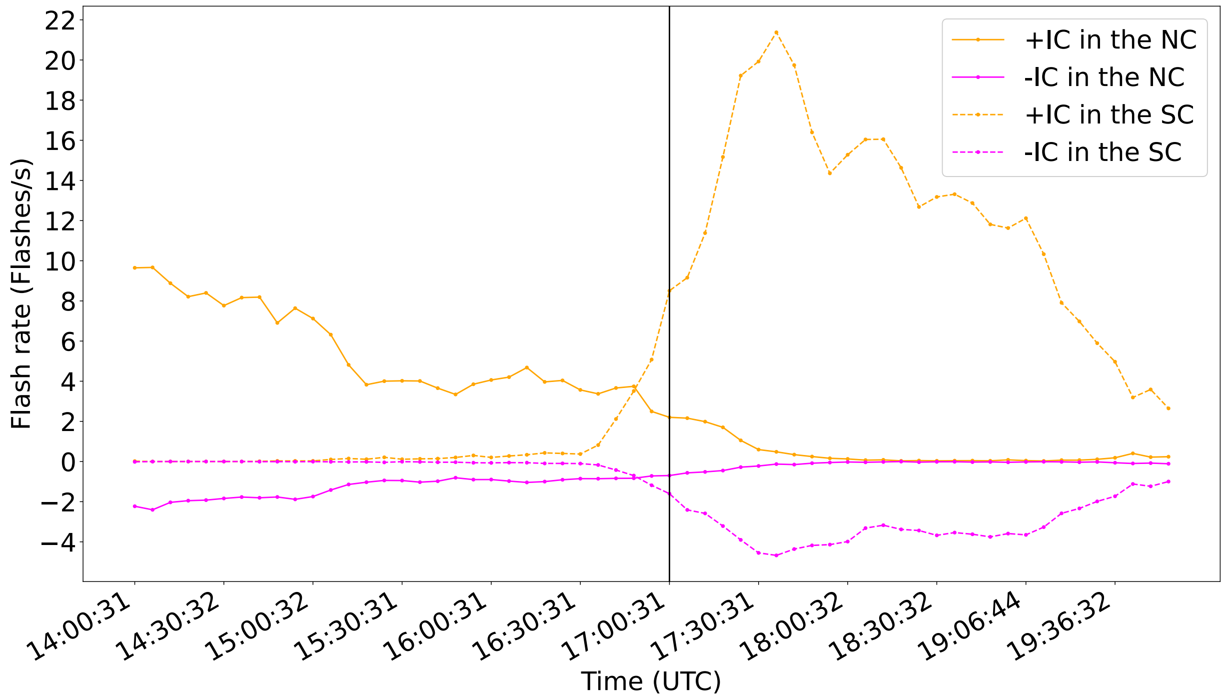



**Figure S4.** Flash rates of positive (orange) and negative (magenta) ICs in northern (straight line) and southern (dashed line) cells. The negative y-axis refer to the flash rates of all the negative strokes. Each point represents a radar scanning cycle (6 min) and the calculated flash rate is the average flash rate per cycle.

**Table S1.** Blue corona discharge electrical and meteorological properties

| Blue flash time[a] (UTC) | Blue flash rise time (μs) | Accomp. UV pulse | UV pulse rise time (μs) | GLD or EN current (kA) | CG or IC[e] | Group of cells | CTT (°C) | CTH (± 0.5) (km) | Reflectivity (dBZ km) |
|---|---|---|---|---|---|---|---|---|---|
| 17:02:22.645 | 20 | - | - | -9 | IC | NC | -87 | 16.6 | 40 |
| 17:02:32.397 | 10 | single | 10-20 | -50 | CG | SC | -81 | 15.9 | 36 |
| 17:02:34.731 | 20 | - | - | -9 | IC | NC | -84 | 16.3 | 25 |
| 17:02:47.708 | 20 | single | 20-30 | -54 | CG | SC | -90 | 17+ | 43 |
| 17:02:48.829[b] | 10 | double | 20-30<br>100 | 102 | CG | SC | -88 | 16.7 | 38 |
| 17:02:50.855[c] | 20 | single | 20-30 | -32 | CG | NC<br>SC | -89<br>-83 | 17<br>16.2 | 38<br>49 |
| 17:02:54.327 | 10 | - | - | -12 | IC | SC | -90 | 17+ | - |
| 17:02:59.141 | 20 | single | 10 | -144[d] | CG | SC | -91 | 17+ | 46 |
| 17:03:01.899[b] | 20 | double | 10-20<br>100 | 64 | CG | SC | -86 | 16.5 | 30 |
| 17:03:04.016 | 10 | - | - | -19 | CG | SC | -85 | 16.4 | 49 |
| 17:03:20.002[b] | 20 | double | 20-30<br>60-70 | -75 | CG | SC | -88 | 16.8 | 34 |
| 17:03:21.392[b] | 20 | double | 30<br>80 | -79 | CG | SC | -86 | 16.5 | 50 |
| 17:03:26.741 | 20 | single | 10-20 | -54 | CG | SC | -84 | 16.3 | 28 |
| 17:03:34.235 | 20 | single | 30-40 | -72 | CG | SC | -89 | 16.9 | 42 |

Abbreviations: NC=Northern group of cells, SC=Southern group of cells, CTT= Cloud Top Temperature, CTH=Cloud Top Height

[a]The time refers to the filtered photometer pulses.

[b]Blue flashes accompanied by double UV signals.

[c]Blue flash referring to two spots of activity within the same ASIM frame.

[d]Only observation with current reported by Earth Networks.

[e] Classification provided by GLD and Earth Networks.

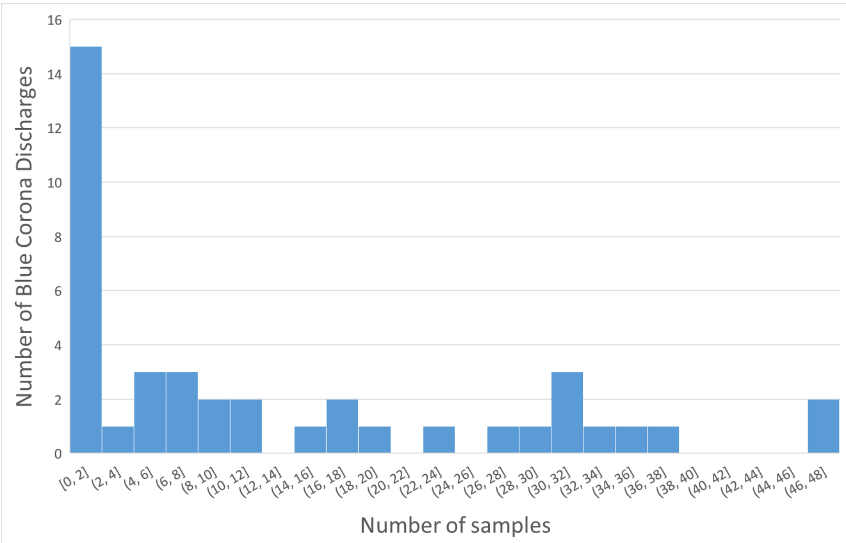



**Figure S5.** Rise time distribution of Blue Corona Discharge emissions for the whole storm.

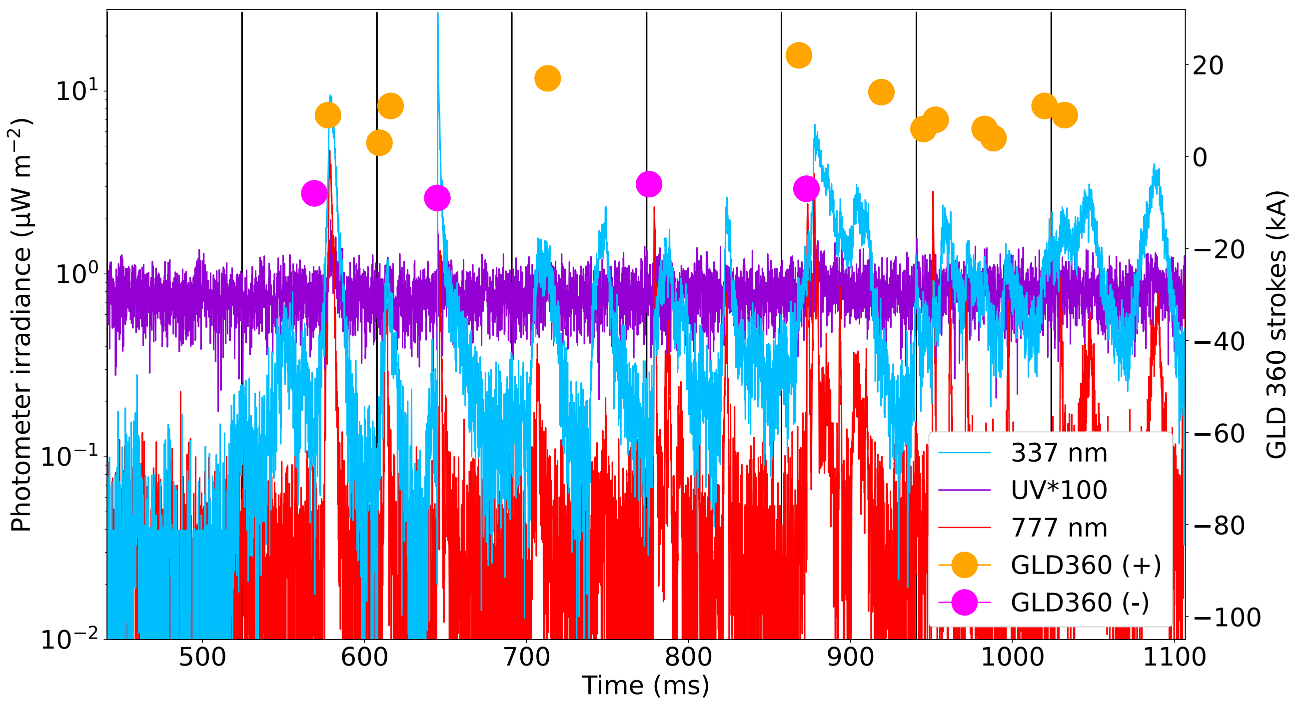



**Figure S6.** Blue Corona Discharge in a dissipating cell: Photometer signals of the whole MMIA event and GLD360 detections. Vertical lines mark the camera image exposure periods (∼83.3 ms). The frame of interest is Frame 3.

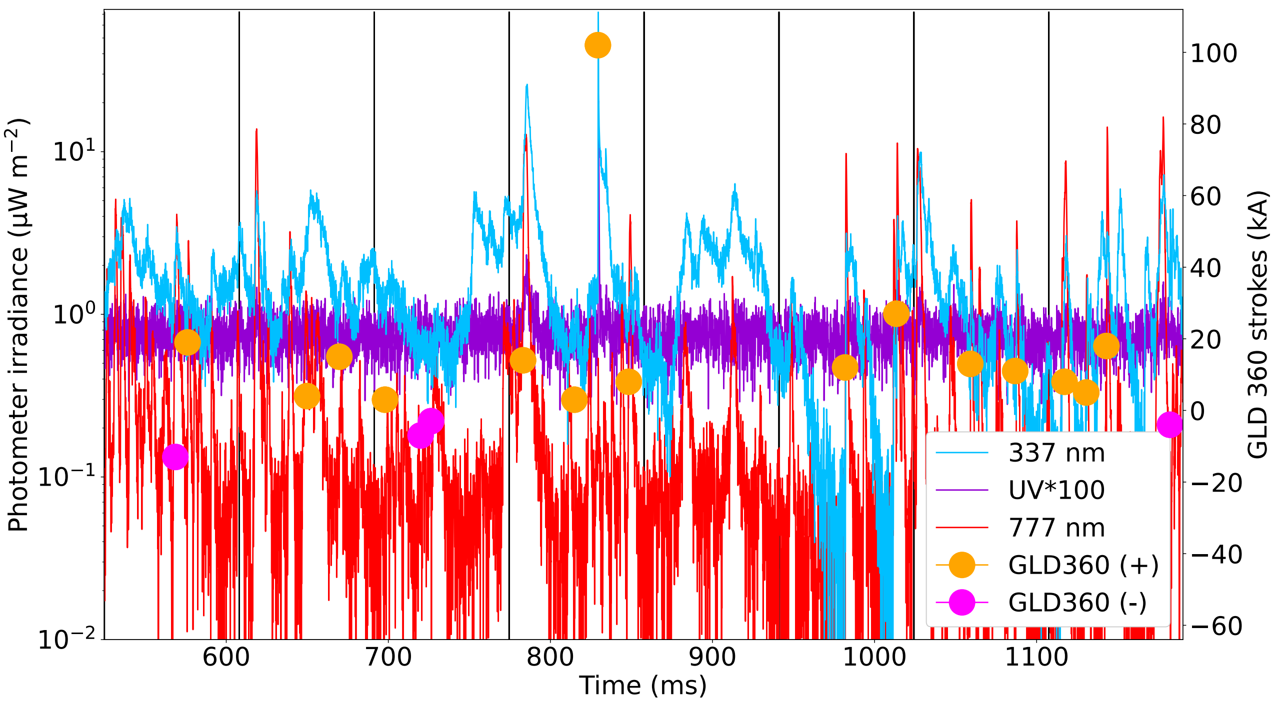
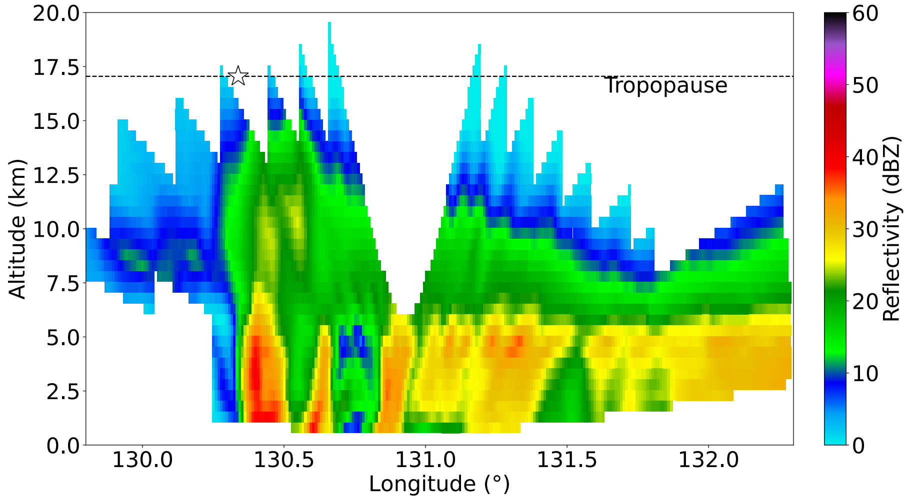
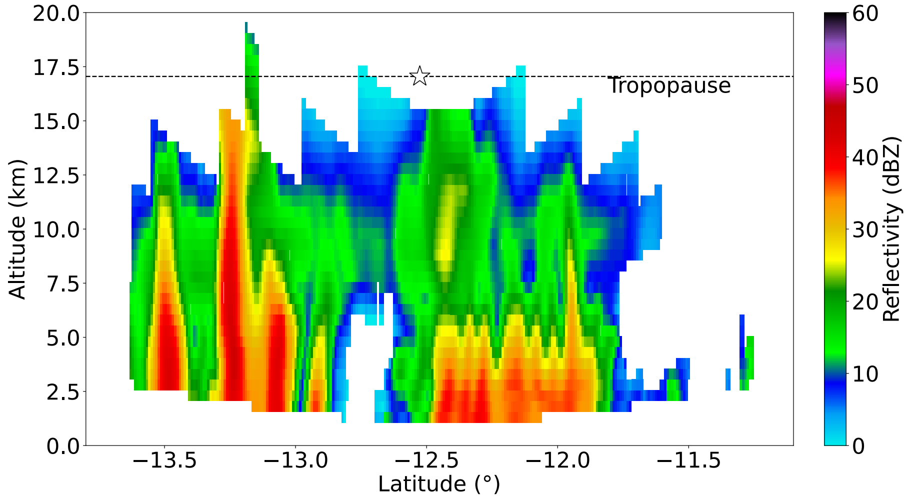



**Figure S7.** Blue Corona Discharges in a developing cell: Photometer signals of the whole MMIA event and GLD360 detections. Vertical lines mark the camera image exposure periods(∼83.3 ms). The frame of interest is Frame 4.

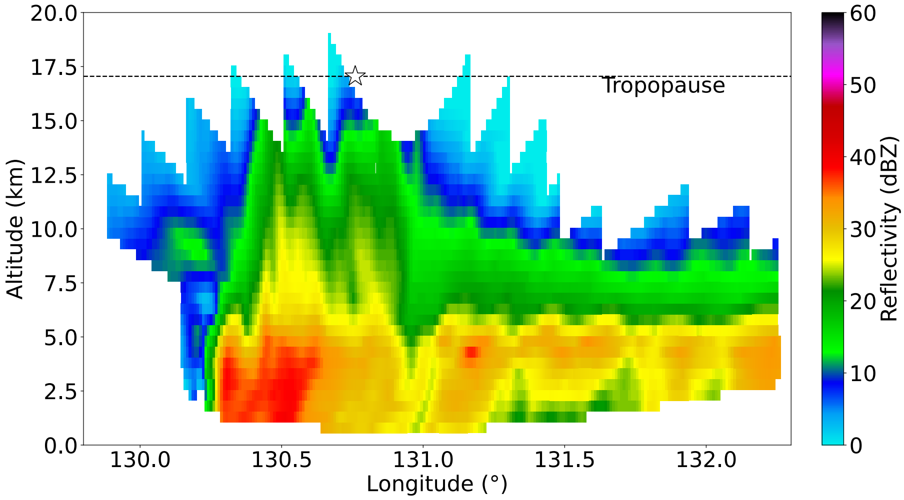



a)

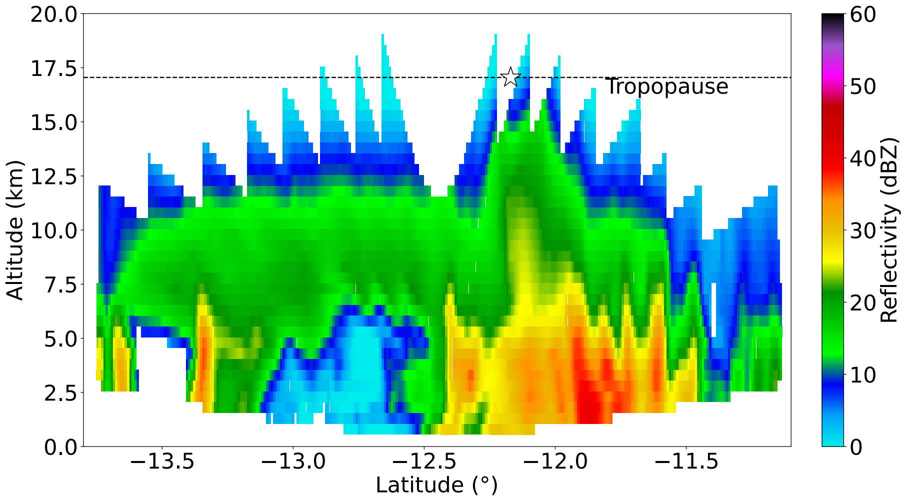



b)

**Figure S8.** Additional cross sections in the Blue Corona Discharges of dissipating clouds: a) The vertical cross section along -12.53° latitude (BED latitude indicated by a '*'). b) The vertical cross section along 130.34° longitude (BED longitude indicated by a '*')




a)




b)

**Figure S9.** Additional cross sections in the Blue Corona Discharges of dissipating clouds a) The vertical cross section along -12.17° latitude (BED latitude indicated by a '*'). b) The vertical cross section along 130.76° longitude (BED longitude indicated by '*')