# The Influence of Hail on Severe Storms Electrification

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**ABSTRACT:** Two hailstorms that occurred in March 2017 and November 2017 were analyzed using weather radar measurements from FCTH, lightning occurrence from BrasilDAT and a hailpad network deployed during SOS-CHUVA Project in the Metropolitan Region of Campinas. The most intense case according to radar and hailpads occurred in 2017-11-15, but showed low electrical activity during its life cycle, while the 2017-03-14 case showed higher lightning rates with less intensified reflectivity cores. Two relationships could be determined: an increase in lightning rate before hailfall, compatible with severe storms observations, and an increase in lightning rate after hailfall. These findings should be further investigated with an improved storm tracking and radars with better resolution and strategy.

## INTRODUCTION

Hailstorms are defined as storms that produce hail that touch the ground. These storms can be severe considering the damages they can cause to tree leaves, plantations and even vehicles, constructions and animals (American Meteorological Society, 2018). This motivates several studies about frequency and distributions of hailstorms around the world (Baldi et al. 2014; Berthet et al. 2013; Jean Dessens and Fraile 1994; Eccel et al. 2012; Jin et al. 2017; Martins et al. 2017).

The structure and life cycle of a hailstorm are different that an ordinary thunderstorm: intense updrafts are necessary for hail formation, combined with shear for growth of large hail (Knight and Knight 2001), features rarely found in ordinary storms, since it implies in a longer life cycle and multicellular configuration; depth of the mixed-phase region – low in ordinary thunderstorms – determines the concentration of supercooled water, that must be high to favor hail formation; aerosols as cloud condensation nuclei affect the cloud microphysics, specially in the mixed-phase region, increasing thunderstorm intensity (Albrecht et al. 2011; Loftus and Cotton 2014; Stolz et al. 2015).

Inside a hailstorm, ice particles such as graupel and hail play an important role in the electrification of the storm. Studies show that the charges acquired by these larger hydrometeors when they collide with ice crystals depends on how they grow: hail in wet growth and hail/graupel in dry growth by deposition become positively charged, while hail/graupel in dry growth by sublimation become negatively charged (Takahashi 1978; Williams et al. 1991). This behavior can justify the difference between ordinary and severe thunderstorms main charge regions and consequently the polarity of the electrical discharges generated by these clouds (Carey and Buffalo 2007; MacGorman and Burgess 1994).

The state of São Paulo is affected by severe thunderstorms during the whole year, with a preference for occurrence in summer (Albrecht et al. 2012; Held et al. 2004). There are no studies about hailstorms as

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well as its relation to electrical activity in this region because of the lack of a uniform database with records of these events. To address this problem, hailstorms were analyzed using remote sensing and a hail detection network deployed during the SOS-CHUVA Project (FAPESP 2015/14497-0). This project aims to develop research in thunderstorm nowcasting specifically in the Metropolitan Region of Campinas during the summers of 2016-2017 and 2017-2018, integrating several meteorological databases including weather radars, meteorological stations, lightning detection networks and a hail detection network.

## DATA AND METHODS

Two cases that occurred during SOS-CHUVA project were analyzed. Table 1 describes the selected cases.

Table 1: Cases selected for analysis. Source:
https://topicssoschuva.blogspot.com.br/2017/03/summary-of-case-studies.html.

| Date of the Event | Description | Affected regions | Features |
|---|---|---|---|
| 2017-03-14 | Heavy rains and hailfall in the division between Campinas and Indaiatuba and in Jacareí | Campinas, Indaiatuba, Jacareí | Hail |
| 2017-11-15 | Favorable thermodynamical conditions led to the formation of convective systems concentrated in the center of São Paulo state | Indaiatuba, Bebedouro | Hail |

### *Hail Detection Network*

Within the SOS-CHUVA Project, a hail detection network was deployed in the Metropolitan Region of Campinas. The hailpads used are made of a isolation styrofoam covered by a aluminum sheet and fixed in a iron support. Figure 1 shows the current state of the network and a hailpad installed in Indaiatuba.

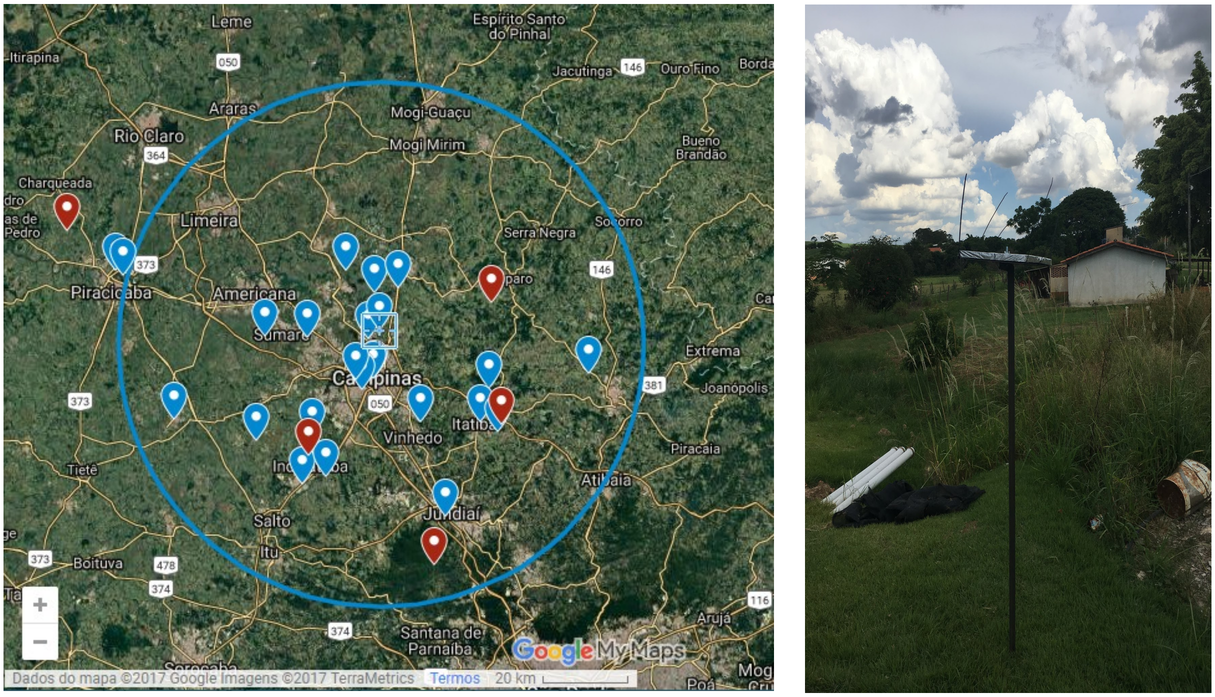


Figure 1: Hailpad network (blue dots – installed; red dots – to install) (left) and one of the installed points, located in Indaiatuba (right).

Three hailpads were collected for the two cases analyzed in this work – Table 2 describe these plates. The hail diameter distribution were measured several times by the Department of Atmospheric Sciences of IAG-USP using a pachymeter and correcting with a calibration curve of the type of styrofoam. From this distribution, the kinetic energy of the hailpad (several plates would be necessary to calculated the kinetic energy of hail itself) was calculated using Mezeix et al. (1981).

Table 2: Description of the hailpads collected for each case.

| **Date of the Event** | **Collected Hailpad Code** | **Location** | **Measured by** |
|---|---|---|---|
| 2017-03-14 | C001 | Cosmópolis | IAG |
| | R002 | Indaiatuba | IAG |
| 2017-11-15 | R004 | Indaiatuba | IAG |

To define the intensity of the hailstorm, two scales were used. The TORRO Hailfall Intensity Scale (http://www.torro.org.uk/hscale.php) (Webb et al. 1986) was develop in Great Britain and compares hail typical diameter with kinetic energy, indicating possible damages that this event can cause; the scale varies from H0 (no damage) to H10 (extensive structural damages). The ANELFA Scale (J. Dessens et al. 2007) was developed in France using a 16-year hailpad climatology and compares hail maximum diameter with kinetic energy, indicating possible damages specially to plantations; the index varies from A0 (damage to tree leaves) to A5 (extremely dangerous event).

### *Lightning Detection Network*

The BrasilDAT – Brazilian System of Electrical Discharges Detection (Naccarato et al. 2014) was used in this work. This network operates between LF (low frequency) and HF (high frequency) bands, detecting electromagnetic pulses (called strokes) and differentiating between return discharges of cloud-to-ground (CG) lightning and pulses of intra-cloud (IC) lightning, as well as estimate cloud-to-ground lightning polarity. The position of electrical discharges are estimated using the arrival time difference technique (Lewis et al. 1960). This database was provided by the Atmospheric Electricity Group (ELAT-INPE).

### *Weather Radar*

The polarimetric weather radar S-Band Doppler operated by Fundação Centro Tecnológico de Hidráulica (FCTH) in Biritiba Mirim (23°36’S, 45°58’20’’W, 916 m height) does a volumetric scan every 5 minutes in a 250 km cover – Figure 1 shows its location and cover. Horizontal profiles of PPI (Plan Position Indicator) in the lowest elevation (1°) and vertical cross sections in specific azimuthal angles were analyzed. The data were processed using the Py-ART package (Helmus and Collis 2016) developed in Python programming language. The storms that produced hailfall measured in situ were selected using the 1° PPI scans; a manual tracking of theses systems were made using the same data.

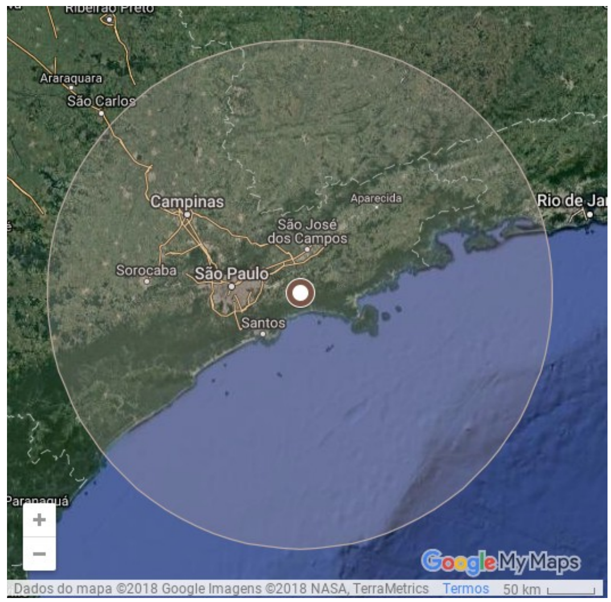


Figure 2: Location and cover of the FCTH radar.

### *Hydrometeor Classification*

To define more accurately hail occurrence in radar measurements, a fuzzy logic hydrometeor classification was applied using the package CSU_RadarTools (Lang et al. 2017) also developed in Python. This method is consistent with summer storms and distinguish 10 hydrometeor types: drizzle, rain, ice crystals, aggregates, wet snow, vertical ice, low-density graupel, high-density graupel, hail and big drops (Liu and Chandrasekar 2000). To accomplish this, reflectivity, correlation coefficient and differential reflectivity fields, as well as a temperature profile from a sounding, are necessary. The soundings were collected in Campo de Marte (São Paulo city) station in dates closer to the events and are available in http://weather.uwyo.edu/upperair/sounding.html. The CSU_RadarTools package also calculates liquid and ice water mass using reflectivity and differential reflectivity (Cifelli et al. 2002).

## RESULTS

Figure 3 shows the hailstorm intensity classification according to TORRO and ANELFA scales. The

2017-03-14 case were less intense that the 2017-11-15 case in both scales. Only one point (hailpad) fitted in one index – 2017-11-15 in ANELFA A2 (serious damages to vegetables and trees); the rest of the points, specially in the 2017-03-14 case, showed diameters much larger than the kinetic energy for the H0 (no damage) and A0 (damage to tree leaves) indexes.

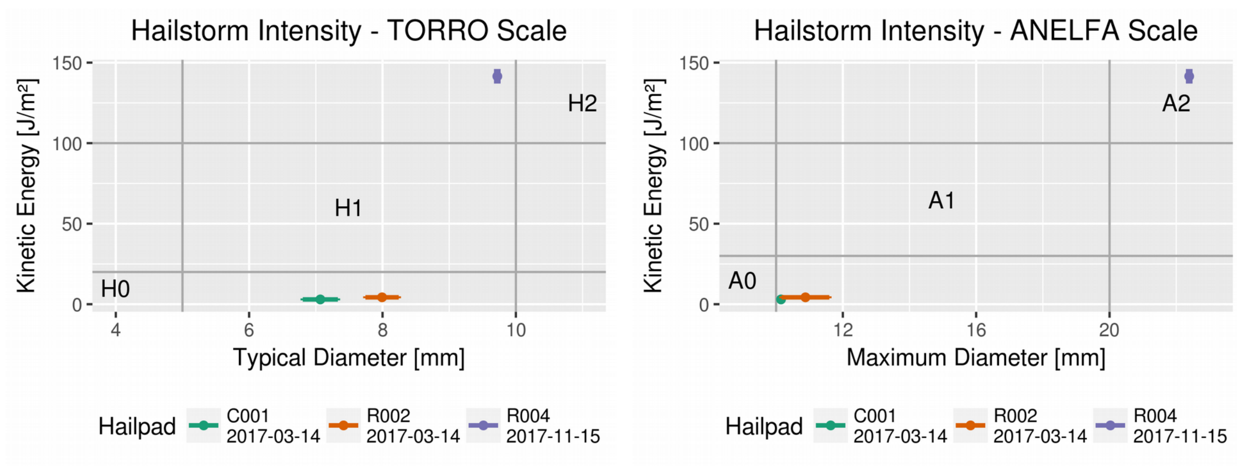


Figure 3: Hailstorms intensity according to TORRO (left) and ANELFA (right) scales.

Figure 4 shows the electrical activity during the life cycle of the hailstorms measured by BrasilDAT. The 2017-03-14 case was more electrically active than the 2017-11-15, affecting a larger area. More intra-cloud strokes were detected than cloud-to-ground during the whole life cycle. Two different relations between electrical activity and hailfall are noticed: an increase in IC lightning activity after (about 20 minutes) the hailfall (2017-03-14, in Cosmópolis); an increase in both IC and CG lightning activity before (about 10 minutes) the hailfall (2017-03-14 in Indaiatuba and 2017-11-15) – compatible with the lightning jump hypothesis for severe thunderstorms (Williams et al. 1999).

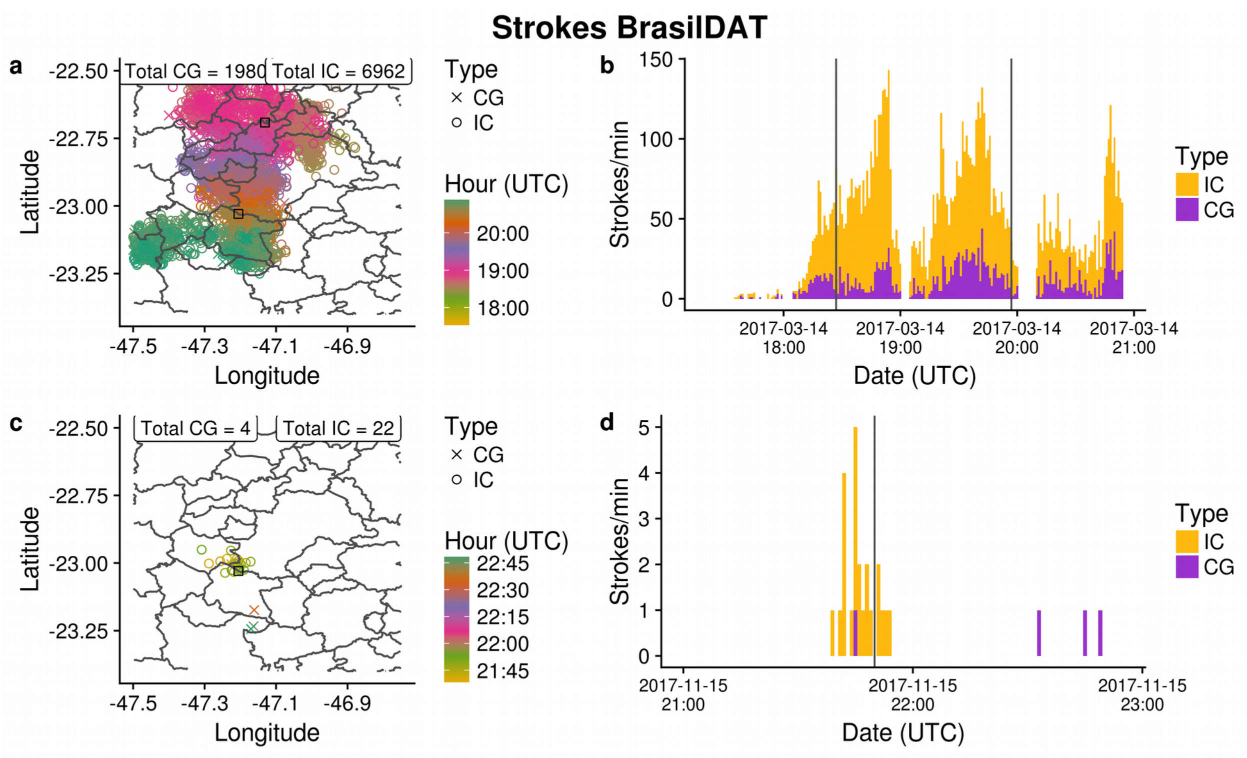


Figure 4: Intra-cloud (IC) and cloud-to-ground (CG) strokes positions (left) and rates (right) measured by BrasilDAT network for the 2017-03-14 (a and b) and 2017-11-15 (c and d) cases. The black squares on the left figures represent hailpads positions, while the gray lines on the right show when the hailfalls occurred.

Since the CG lightning activity in the 2017-11-15 case were practically null, the positive and negative CG lightning activity were analyzed only for the 2017-03-14 case (Figure 5). Almost 10 times more CG- lightning were detected than CG+. These negative discharges showed the same behavior of the IC lightning, with an increase of electrical activity after the first hailfall and before the last hailfall.

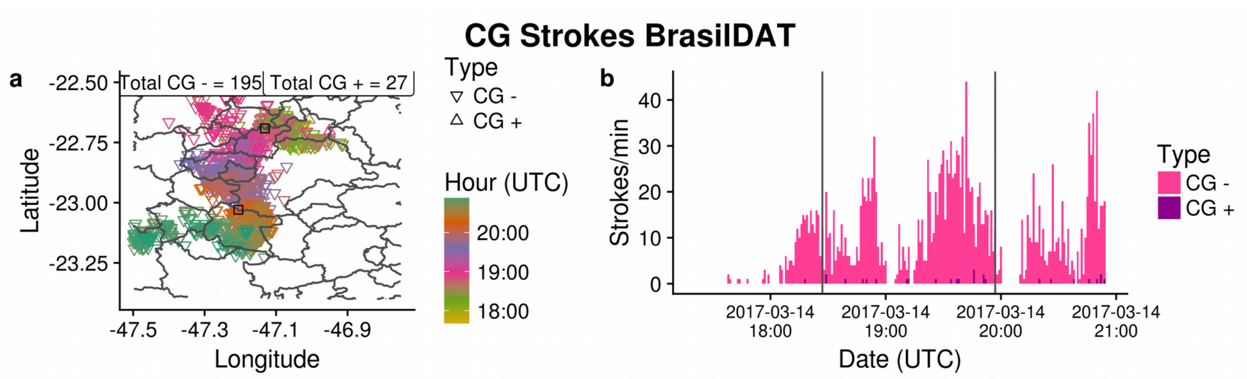


Figure 5: Positive (CG+) and negative (CG-) cloud-to-ground strokes positions (a) and rates (b) measured by BrasilDAT network for the 2017-03-14 case. The black squares on (a) represent hailpads positions, while the gray lines in (b) show when the hailfalls occurred.

To confirm the hailstorm intensity observed by the hailpad network, Figures 6, 7 and 8 show cross sections of radar variables at the time of maximum intensity of the system.

In the 2017-03-14 case, when the system passed by Cosmópolis (Figure 6), the vertical extent shows two intense cores of reflectivity closer to the hailpad location. The classification shows hail extending from the cloud base to 12 km height, as well as hard-density graupel near the location of the hailpad. Liquid and ice water mass were present near the hailpad, with two times more ice than liquid water. When the system passed by Indaiatuba (Figure 7), the two cores of high reflectivity were less intense than in Cosmópolis, with hail extending to 10 km height mixed with graupel and large drops. Less ice water mass was present near the hailpad.

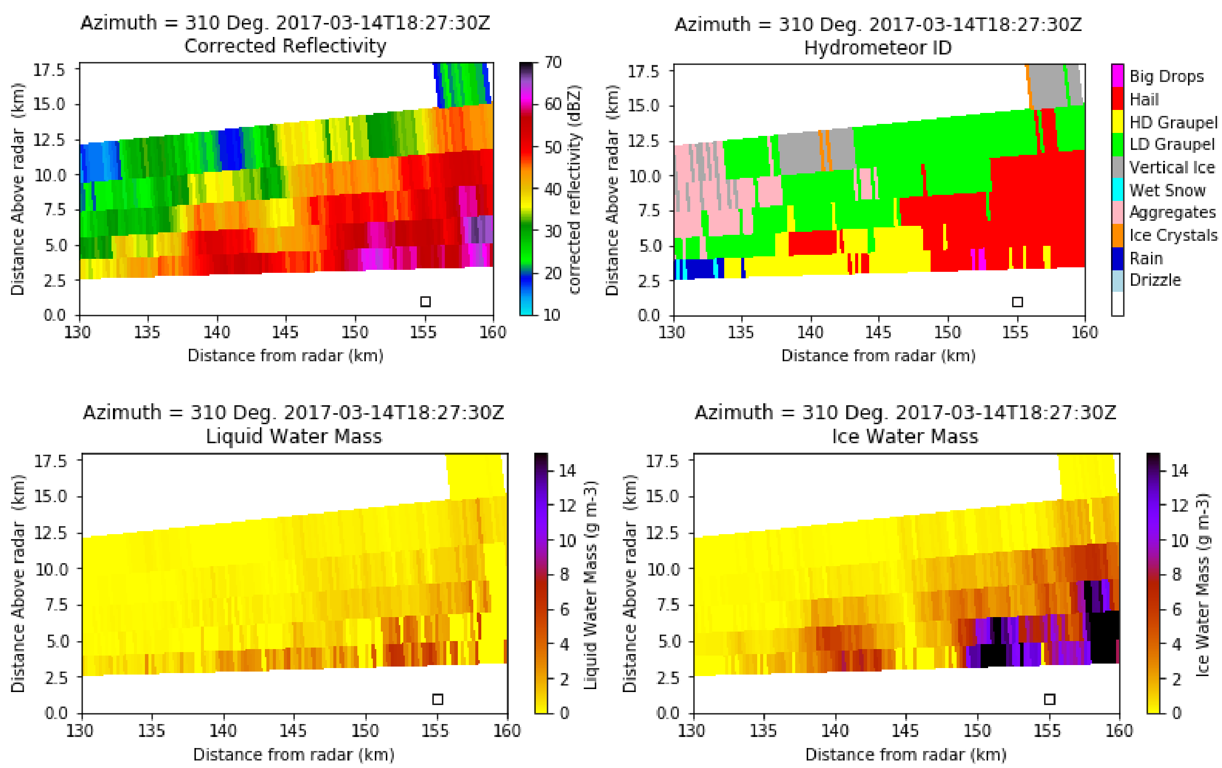


Figure 6: Cross section of reflectivity (upper left), hydrometeor classification (upper right), liquid water mass (lower left) and ice water mass (lower right) for the 2017-03-14 case, when the system passed by Cosmópolis. The squares represent the location of the hailpad.

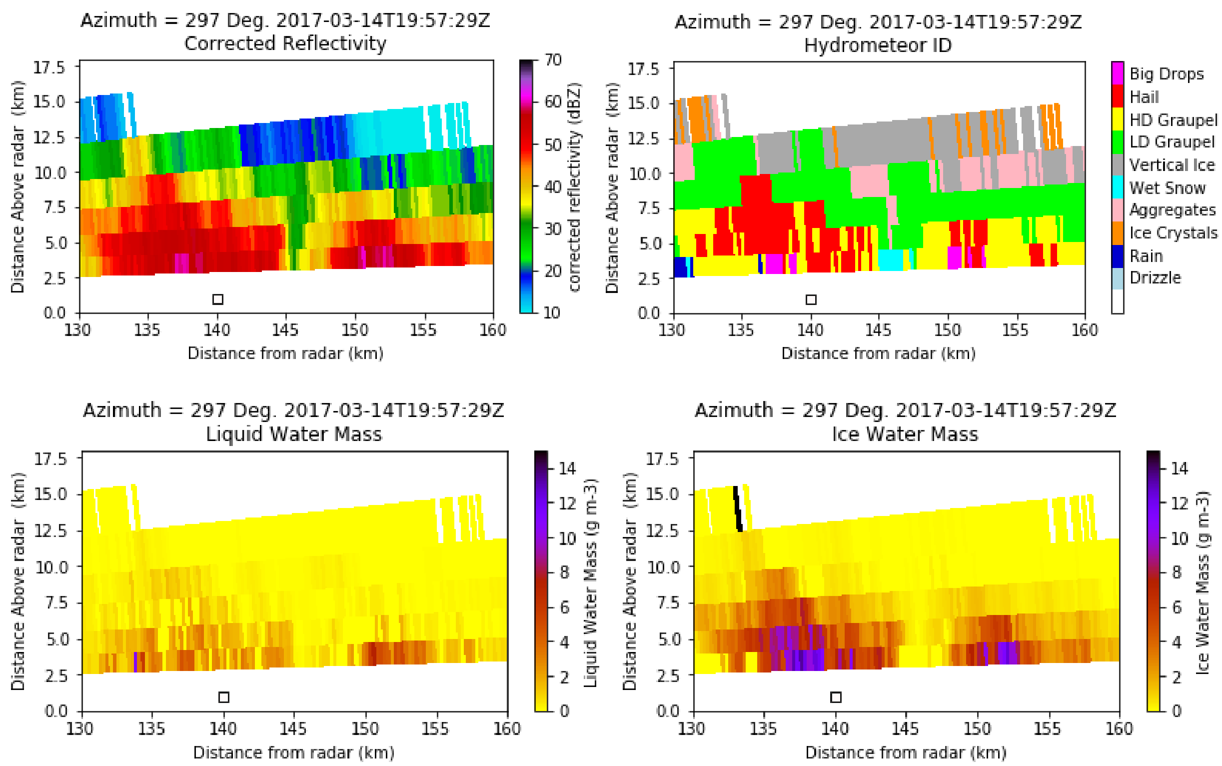


Figure 7: Cross section of reflectivity (upper left), hydrometeor classification (upper right), liquid water mass (lower left) and ice water mass (lower right) for the 2017-03-14 case, when the system passed by Indaiatuba. The squares represent the location of the hailpad.

For the 2017-11-15 case (Figure 8), a well-defined high reflectivity core can be observed above the hailpad, with values closer to 70 dBZ and hail classified in the whole central core, extending to 12 km height. There is a greater amount of liquid water mass closer to cloud base than in the previous case, as well as ice water mass, above 15 g/m³ in the same region.

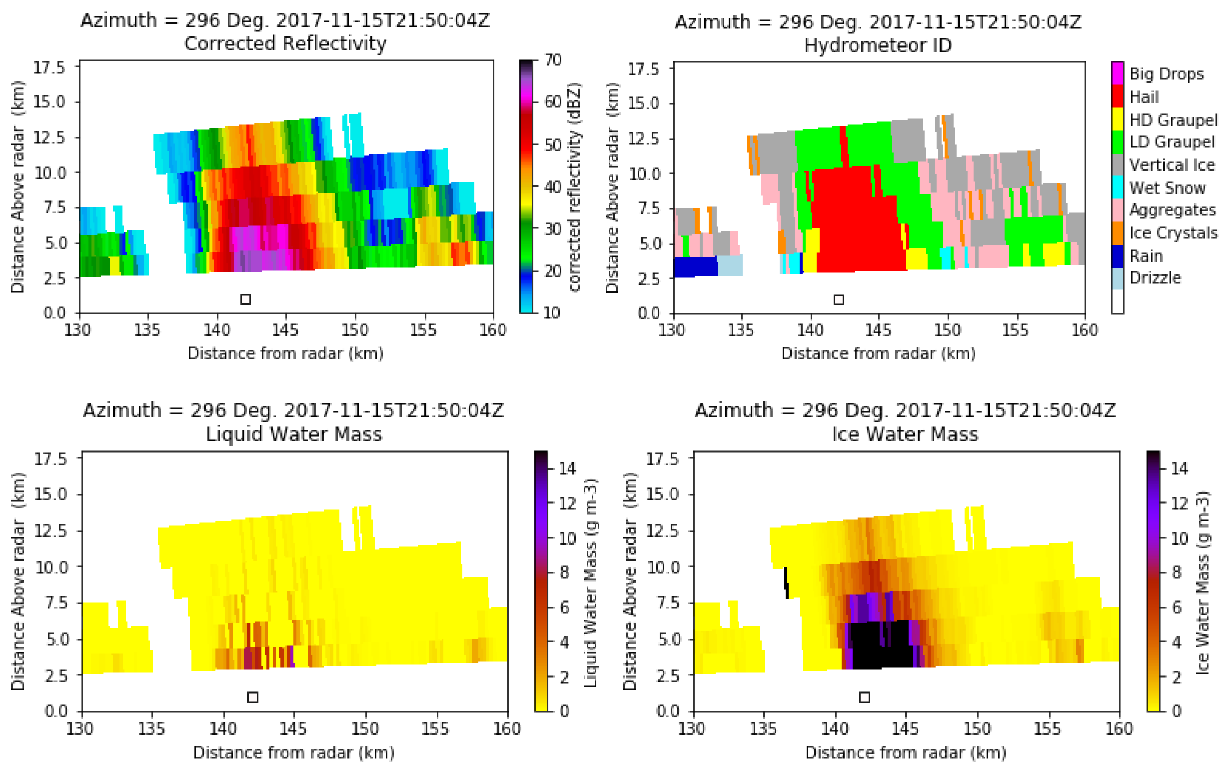


Figure 8: Cross section of reflectivity (upper left), hydrometeor classification (upper right), liquid water mass (lower left) and ice water mass (lower right) for the 2017-11-15 case. The squares represent the location of the hailpad.

## CONCLUSIONS

This work analyzed two hailstorms that occurred in the Metropolitan Region of Campinas during SOS-CHUVA Project in order to establish a connection between hailstorm intensity and hailfall occurrence with electrical activity. A weather radar, a lightning detection network and a hail detection network were used.

The most intense case according to the hailpads and the weather radar, occurred in 2017-11-15, showed low lightning rates during its life cycle, with an increase in lightning rate before hailfall. The 2017-03-14 case had a longer duration, intense electrical activity and several reflectivity cores; the increase in lightning rate, both intra-cloud and cloud-to-ground, occurred after the hailfall in Cosmópolis and before the hailfall in Indaiatuba – which had the less intense cores of the cases analyzed.

Several limitations should be taken into account with the findings of this work: the manual tracking of the systems could have limited the life cycles of lightning rates specially in the 2017-11-15 case; the FCTH radar strategy did not permit a visualization of features below the cloud base, as well as the resolution was deprecated because of the distance between the radar location and the study area. These results will be improved by using other weather radar for storms tracking and other lightning detection networks to confirm the relationships found.

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