Using Lightning Mapping Array to evaluate the lightning detection signatures at different technologies

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ABSTRACT: Ten lightning detection networks measured lightning activity in the São Paulo area during CHUVA-GLM Vale do Paraiba field experiment in the months of December 2011-March 2012. This field experiment gathered different lightning systems from a broad range of electromagnetic frequencies (ELF to VHF and optical), corresponding to a great opportunity for understanding the different lightning detection technologies. Assuming that the Lightning Mapper Array (LMA) can capture the majority of electromagnetic irradiated sources through a lightning discharge (breakdown, step leader, return stroke and dart leaders), it is possible to correlate in space and time what each system is really measuring (i.e., are they measuring sferics, leaders, return strokes, sources or a complete lightning channel?). In a preliminary analysis, the total lightning systems were very comparable in time, i.e., they had coincident time measurements. For the VLF and LF systems that were designed to measure mainly cloud-to-ground discharges, we did find some differences, i.e., sometimes all networks reported lightning, but most of the time just one or two systems had lightning reports. It was observed that often there are temporal coincidences between LIS groups and the ground-based total lightning measurements. Moreover, the probability of LIS groups being detected by LMA increases as the lightning signals are observed at higher heights and it is also dependent on the amount of precipitation overhead of the flash.

INTRODUCTION

CHUVA (**C**loud processes of t**H**e main precipitation systems in Brazil: A contrib**U**tion to cloud resol**V**ing modeling and to the GPM (Glob**A**l Precipitation Measurement)) Project is a series of field experiments to investigate the different precipitation regimes in Brazil. The objective of these field experiments is collect detailed information about the different precipitation regimes found in Brazil and their associated physical processes in support of the GPM program. This information will improve the quality of precipitation estimation and the knowledge of cloud microphysical processes of several different types of convective systems in Brazil, from warm clouds and local thunderstorms to squall lines, frontal and mesoscale convective systems. For more details on the CHUVA experiment see Machado et al. (2012) and http://chuvaproject.cptec.inpe.br/.

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The fourth field experiment was conducted in southeast Brazil, at Vale do Paraiba and São Paulo metropolitan region from November-2011 through March-2012. This particular experiment was called CHUVA-Geostationary Lightning Mapper (GLM) Vale do Paraiba and, in addition to the characterization of precipitating systems and their rainfall, it also collected lightning proxy data for the upcoming geostationary lightning imagers (GOES-R GLM and MTG LI) using 10 lightning locating systems (LLS) (LMA, LINET, TLS200, ENTLN, RINDAT, STARNET, WWLLN, GLN, ATDnet, GLD360), high-speed cameras, and the TRMM-LIS satellite.

CHUVA-GLM has a comprehensive database using different lightning detection technologies, i.e., a) VHF: LMA and Vaisala TLS200; b) VLF: WWLLN, STARNET, Vaisala GLD360 and ATDNet; c) VLF-LF: RINDAT, LINET and Vaisala TLS200; c) ELF-HF: EarthNetworks. As each system uses different frequencies, detection (sky/ground waves or line of sight, electrical and magnetic fields) and methodology for location (TOA, ATD and interferometry) it is expect that each system observes different parts of the lightning flash. Thus taking the opportunity that LMA measures most of the lightning sources associated to all atmospheric discharges, this study concentrate on describing what each technology measures/detects in respect to LMA sources.

DATA AND METHODOLOGY

Of all the ten lightning detection networks of CHUVA-GLM, 4 were deployed specially for this field experiment: LMA, LINET, Vaisala TLS200, and a denser network of EarthNetworks sensors as part of BRASILDAT. Figure 1 shows the location of these sensors around the metropolitan area of Sao Paulo.

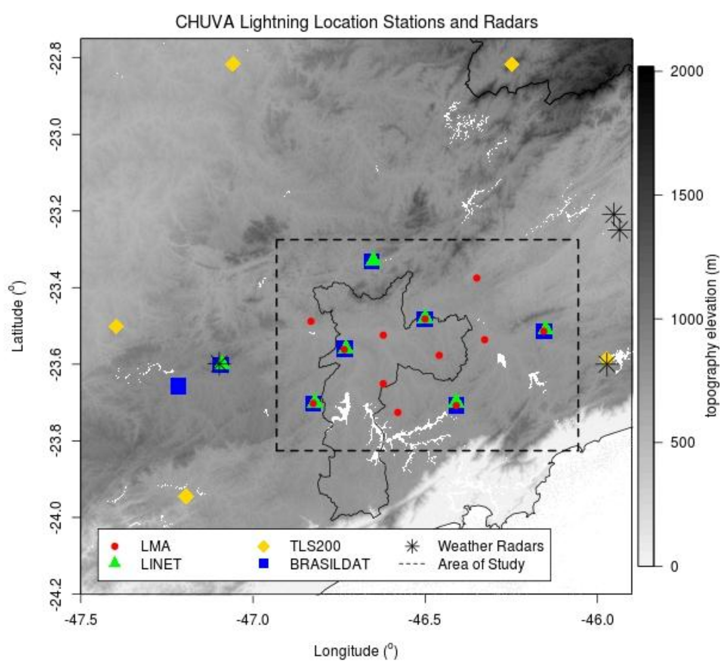

Figure 1 – Sensor location of total lighting location systems deployed during CHUVA-GLM. The shaded background corresponds to local topography. Dashed square shows the area we considered in this of study. Solid contour lines show Sao Paulo city and state of Sao Paulo political boundaries for reference.

Sao Paulo Lightning Mapping Array (SPLMA) was deployed using 12 sensors in a baseline of 15-20km. The LMA was developed by the New Mexico Institute of Mining and Technology (Rison et al. 1999), based on the Lightning Detecting and Ranging (LDAR) system developed to be used at the NASA Kennedy Space Center (Maier et al. 1995). The LMA system locates the peak source of impulsive VHF radio signals from lightning in an unused television channel by measuring the time-of-arrival of the magnetic peak signals at different receiving stations in successive 80 ms intervals. Hundreds of sources per flash can be detected in space and time, allowing a three-dimensional (3-D). In SPLMA we used VHF TV channel 8. During the field experiment it was discovered that channel 8 picked interference from a local TV station on channel 9. To minimize contamination by this local TV station, the noise was removed using a height and distance criteria from the TV antenna and then grouped into flashes by clustering algorithm (Jeffrey Bailey – UAH, personal communication).

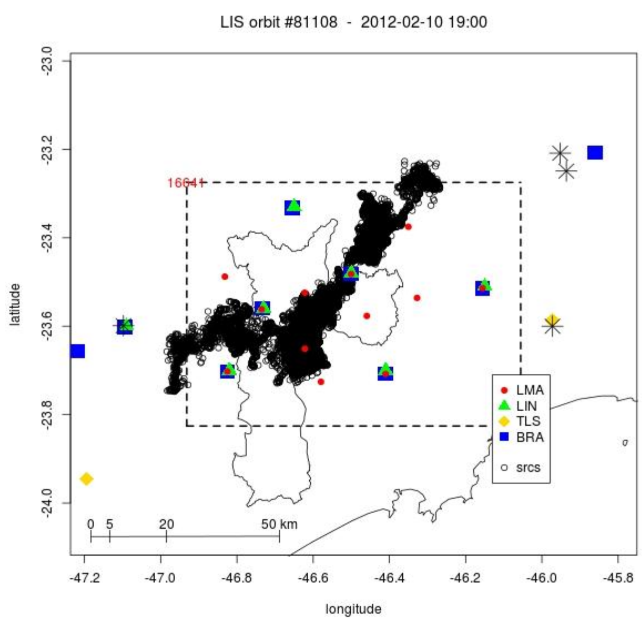

Figure 2 – LMA sources during LIS viewtime (+/-330ms) and within our area of study. Sensors location, Sao Paulo state and city political boundaries are also shown.

Lightning sources, strokes and optical pulses used in this study are those that occurred during TRMM LIS overpasses over CHUV-GLM experiment area. To account for the best LMA detection efficiency and location accuracy, we delimited our area of study as a rectangle around SPLMA with up to 10km of distance from the outermost sensors. This area of study is shown in Figure 1, which should also be within LINET, denser-EarthNetworks and Vaisala TLS200 best coverage in terms of detection efficiency and location accuracy. The actual numbers for detection efficiency and location accuracy of each network are beyond the scope of this study and will not be addressed here. Therefore, we computed LIS view time in 0.10^{o} resolution grid boxes to better determine the time frame of its observations over our area of study. Then we selected all LMA sources that occurred within LIS view time +/-330 ms and within our area of study, but also allowing sources outside this area to complete LMA flashes. An example of LMA sources selected for this study during a LIS overpass on 2012-02-10 19:01:34 (90 seconds of observation) is shown in Figure 2. The remaining LLS measurements where then selected during this same time frame (LIS view time +/-330 ms) and also up to 50 km away from the corner of our are of study. A summary of this selected data is shown in Table1. Only orbits with more than 10 LMA flashes with more than 10 sources each are considered.

Table 1 – Summary of the LMA flashes and other LLS measurements analysed in this study.

LIS orbit	80767	81062	81108	81123	81362	81576	81591	81825
Date and time (UTC)	2012-01-19 23:05:02	2012-02-07 20:10:12	2012-02-10 19:01:34	2012-02-11 18:06:09	2012-02-27 03:15:58	2012-03-11 20:49:10	2012-03-12 19:53:46	2012-03-27 19:03:52
LIS view time (s)	93	89	90	90	111	113	110	80
Number of LMA flashes	12	31	165	11	13	21	78	113
Total LMA sources	2354	3697	16641	3731	7948	5560	5501	8663
LIN strokes (IC / CG)	107 (55 / 52)	126 (95 / 31)	608 (476 / 132)	60 (26 / 34)	130 (101 / 29)	143 (92 / 51)	245 (190 / 55)	867 (622 / 245)
ENT strokes (IC / CG)	41 (35 / 6)	97 (83 / 14)	280 (248 / 32)	65 (50 / 15)	64 (59 / 5)	22 (13 / 9)	122 (104 / 18)	184 (137 / 47)
RIN strokes	7	23	100	37	1	10	9	72
STA strokes	2	8	61	12	1	2	2	11
TLV sources	NA	615	2225	NA	NA	NA	NA	3113
TLL strokes	14	28	120	30	0	25	42	132
WWL strokes	2	0	7	4	3	0	0	14
GLD strokes	2	11	147	19	0	13	10	120
ATD strokes	3	2	1	1	2	0	0	0
LIS flashes	7	15	58	19	24	18	34	77
LIS groups	101	148	329	94	227	214	313	785
LIS events	442	428	1059	412	988	780	909	2958

NA = Not Available. All network names were abreviated: LIN=LINET, ENT = EarthNetworks, RIN=RINDAT, STA=STARNET, TLV=Vaisala TLS200-VHF, TLL=Vaisala TLS200-LF, WWL=WWLLN, GLD= Vaisala GLD360, ATD=ATDnet.

These time (dt=330 ms) and distance (ds=50 km) differences that we added to our selection of data are the same of those used to match LMA flashes with all other LLS strokes and pulses. The value 330ms is the one used by LIS to compose a flash, and 50km is to account for location accuracy of long range

LLS.

RESULTS

Table 1 shows a summary of the LMA flashes and other LLS measurements here analysed. Most of LIS passages occurred during low lightning activity storm cells (<30 flashes in ~90 seconds, ~0.33 flashes per second) except for 3 overpasses when ~100 LMA flashes were detected (~1 flash per second). The men duration of a LMA flash was 0.42 s, with flashes as long as 1.5 s, as illustrated in Figure 3 for a specific orbit. The majority of LMA flashes has less then 100 sources, but a few flashes presented more than 1000 sources.

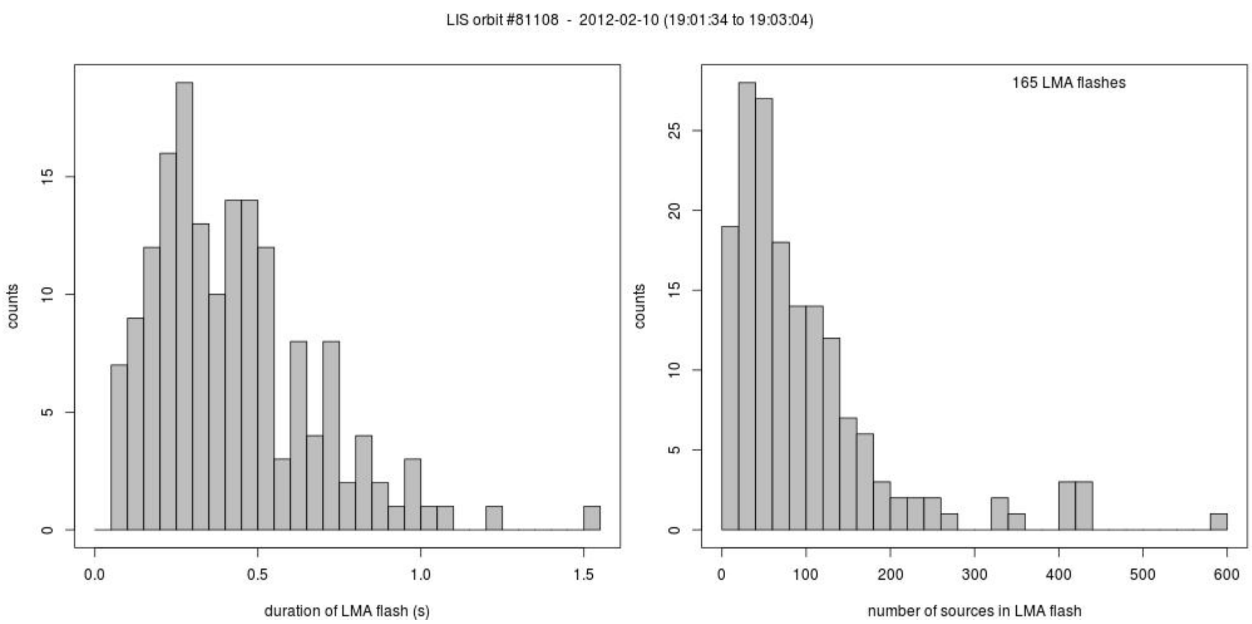

Figure 3 – Frequency distribution of LMA flash duration and number of sources for LIS overpass orbit 81108 on 2012-02-10 (19:01:34 to 19:03:04).

Using a time difference criteria of 330 ms and a distance criteria of 50 km, the LMA flashes were matched to all other LLS measurements. The frequency of distribution of time difference between the networks stroke/source/pulse and the LMA source and the *first source* the LMA flash, and distance between the networks stroke/source/pulse and the LMA source during LIS overpass orbit 81108 on 2012-02-10 (19:01:34 to 19:03:04) is shown in Figure 4. We can see that the difference between LMA sources and the other network measurement have median values between +/- 33ms, and most of the

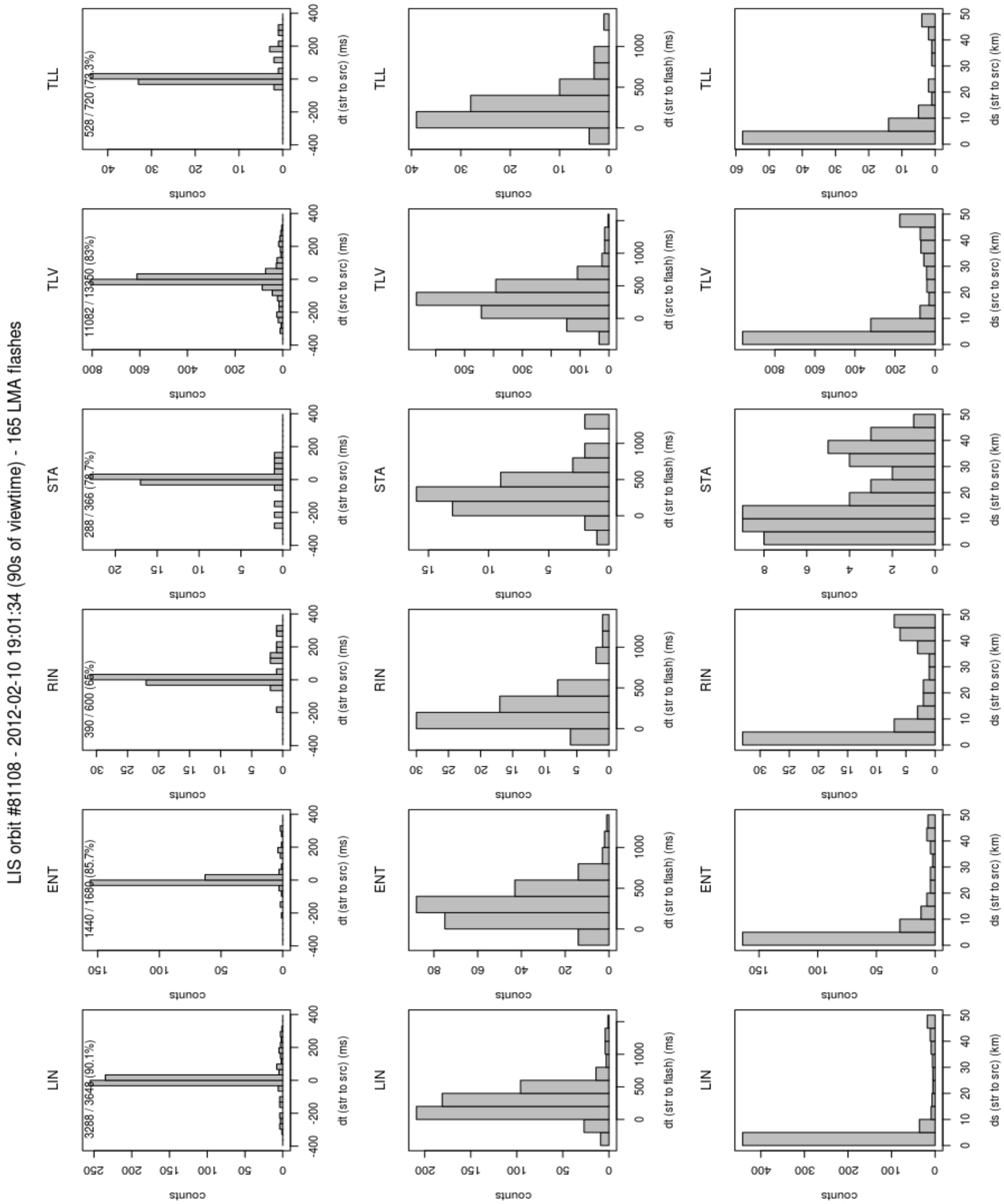

Figure 4 – Frequency distribution of time difference between the network stroke/source/pulse and the LMA source (str to src – left columns) and the first source the LMA flash (stk to flash – middle columns), and distance between the network stroke/source/pulse and the LMA source (strk to src – right columns), during LIS overpass orbit 81108 on 2012-02-10 (19:01:34 to 19:03:04). Numbers on top of left column indicate the number of strokes/sources/pulses matched to LMA.

sources/strokes/pulses of the networks occurred after (dt>0) the first LMA f lash source. This result is consistent with the nature of VHF measurements which measures more "virgin" processes of the breakdown, while LF/VLF measurements come from the return strokes. Note that TLV is also a VHF measurement and, generally, their lightning source detection comes after the first LMA source. This is a reflection of the different location technique used, where TLV uses interferometry while LMA uses time-of-arrival. Interferometers respond best to fast-propagating (10^6-10^7 ms^{-1}) processes which produces fairly continuous VHF emissions for tens of ms (e.g., dart leaders, streamers), and time-of-arrival systems detect preferably breakdown processes with propagating speeds of 10^4-10^5 ms^{-1} [Mazur et al., 1997; Cummins and Murphy, 2009].

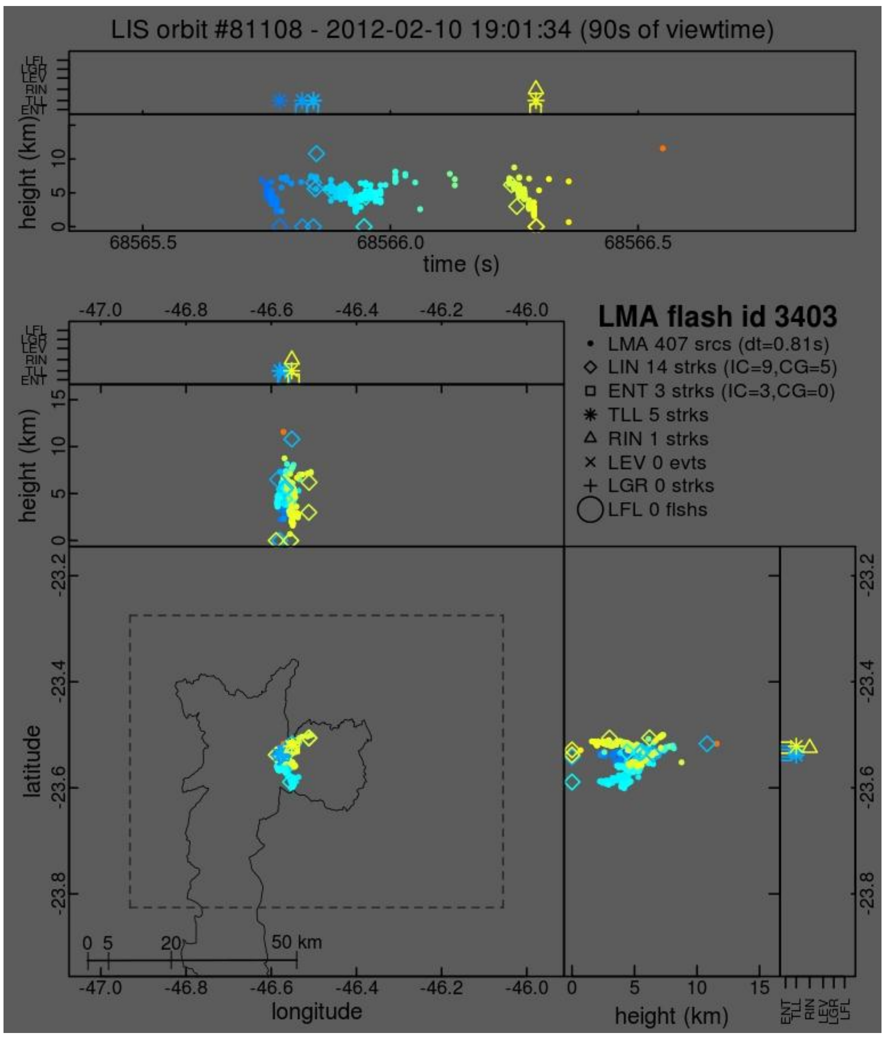

Figura 5 – LMA flash (id = 3404) illustrating the breakdown (detected by VHF - LMA) and return stroke (detected by LF – LIN, ENT, TLL, RIN) processes.

The frequency distribution of distance between the short-baseline systems (LIN, TLV, TLL, ENT) and the LMA sources shown in Figure 4 presents more than 90% of the values lower than 20 km. The long-baseline systems (STA, GLD, WWL, ATD) presents higher distance differences, which is generally associated with lower location accuracy. Most of the networks detected more than 70% of LMA flashes (Figure 4).

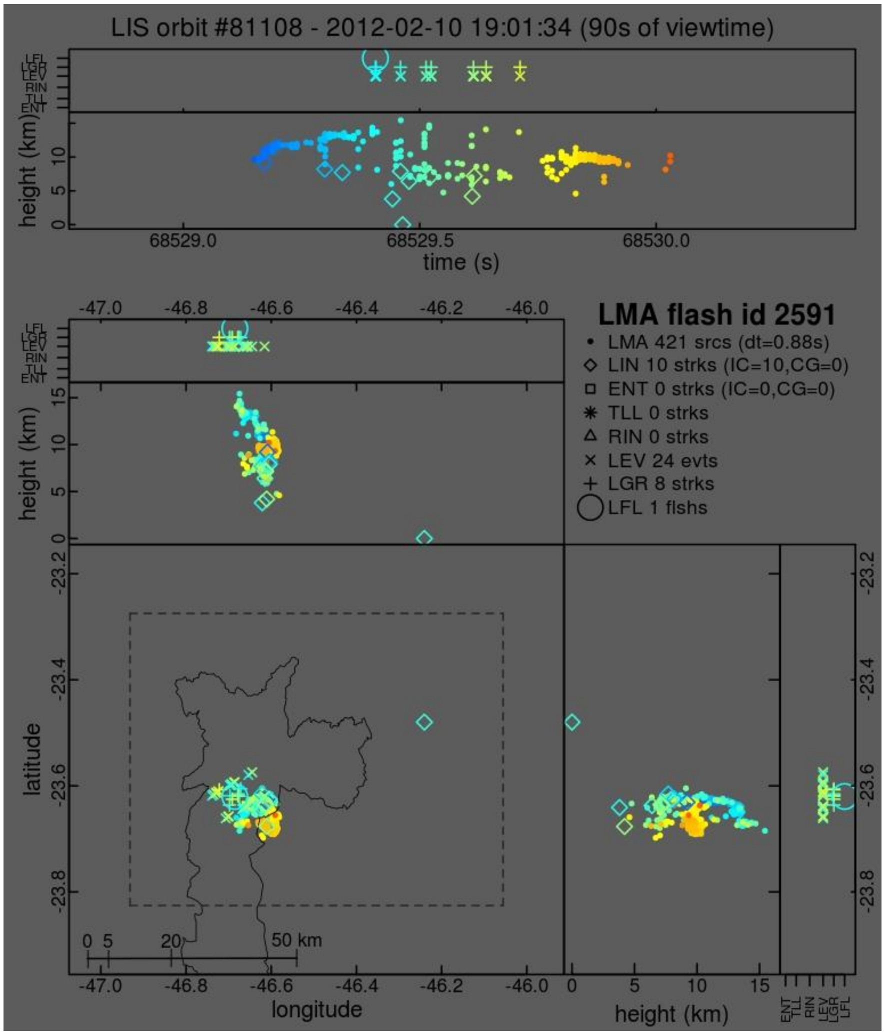

Figura 6 – LMA flash (id = 2591) illustrating the breakdown (detected by VHF – LMA) process and LIS optical rmeasurement.

The VHF and LF characteristics of lightning detection mentioned above are illustrated in Figure 5, which shows the time evolution of a LMA flash breakdown and the return strokes detected by LIN, RIN, TLL, and ENT. In this particular flash there is at least 3 cloud-to-ground return strokes that were also partially detected by LMA, accompanied by IC return strokes. Note that the breakdown occurred at low levels of the cloud (<5km) and no LIS events were detected. The majority of LIS measurements from the flashes analysed in this study were only possible when the breakdown process was extended to upper levels of the cloud (i.e., >9 km), and LIS flash location tends to be positioned at the region with higher altitude sources, as illustrated in Figure 6. This is consistent with the principle of lightning detection space, where lightning is detected by the optical pulses at the top of the cloud.

Finally, Figure 5 shows the number of strokes/sources/pulses per LMA flash. It can be seen that most of LMA flashes have 1 to 5 LF/VLF strokes. LINET tends to show more strokes per LMA flash and is similar to LIS groups distribution, indicating that LIS groups are indeed a representation of cloud strokes.

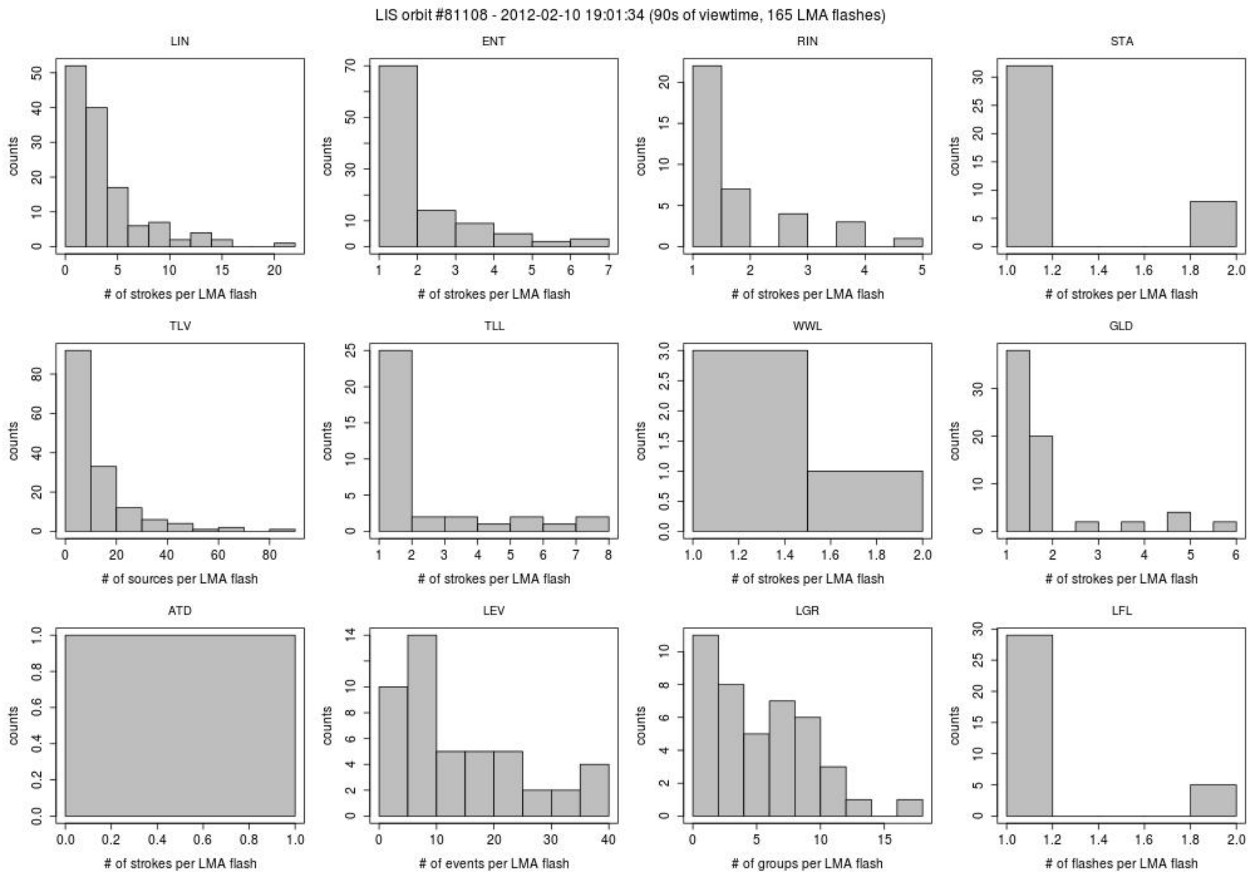

Figure 5 – Frequency distribution of number of strokes/sources/pulses per matched LMA flash, during LIS overpass orbit 81108 on 2012-02-10 (19:01:34 to 19:03:04).

CONCLUSIONS

The comparison of LMA flashes during LIS overpasses were able to show the main characteristics of each network detection technique and which processed of lightning propagation they are measuring. It also indicate the LIS groups are indeed a representation of cloud strokes, but the probability of LIS groups being detected by LMA increases as the lightning signals are observed at higher heights and it is also dependent on the amount of precipitation overhead of the flash. More investigation on this height-precipitation amount dependency should be done to better understand the processes associated to lighting propagation at optical frequencies for the next generation of geostationary lighting imagers (GOES-R GLM and MTG-LI).

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