UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

1st Progress meeting: ISS LIS evaluation using LMA

EUM/CO/18/4600002153/BV

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Outline

0. Introduction

1. Technical description

2. Data selection (sensitivity analysis)

3. Definition of the evaluation

Introduction

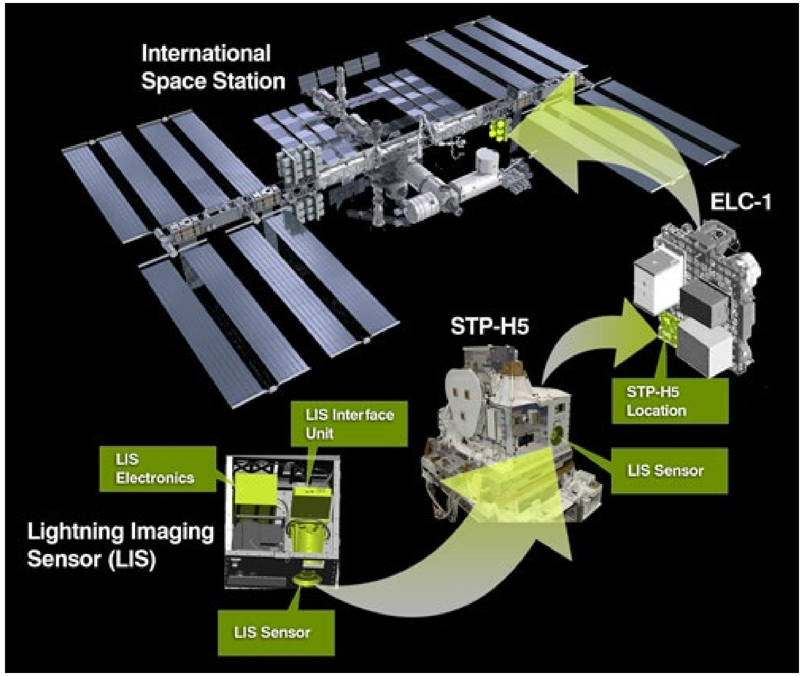
Brief summary: During the period from the kickoff to the present day we have been working preparing the dataset and its properties. We have been focused on the evaluation of the performance of the LMA and the decision of the target area to consider for the evaluation. Finally we have defined (to discuss today) the evaluation.

The work done corresponds to Task 1 to 3 of the project.

The draft report is also submitted.

1. Technical description of the ISS-LIS and LMA

1.1 ISS-LIS



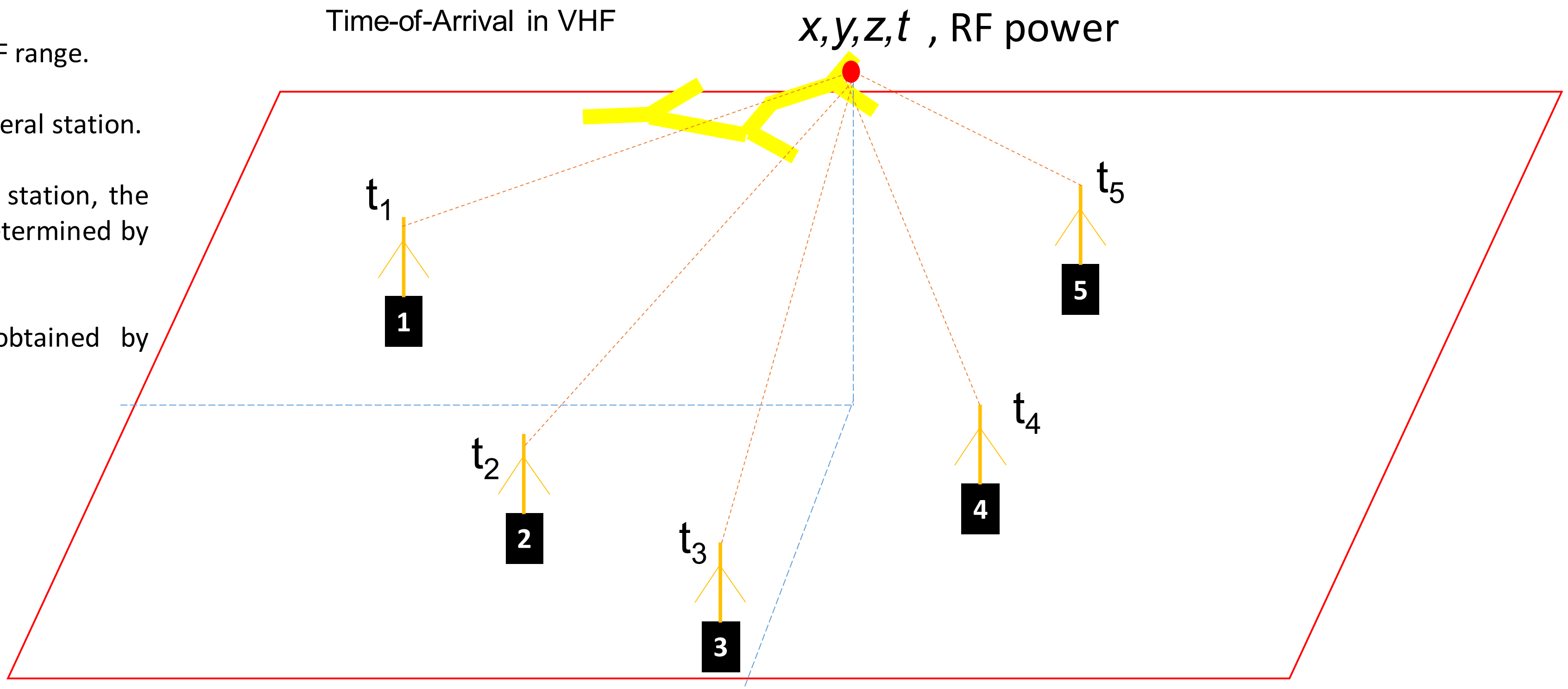
Field-of-View (FOV):	80°x80°
CCD Array Size:	128 x 180 pixels
Dynamic Range:	>100
Pixel IFOV :	4 km (nadir) to 8 km
Interference Filter wavelength:	777.4 nm
Filter bandwidth:	1 nm
Detection threshold:	4.7 $\mu J\ m^{-2}\ sr^{-1}$
Signal to noise ratio:	6
Detection Efficiency (DE)	~90 %
False Event Rate (FER)	<5 %
Measurement accuracy	
Location:	1 pixel
Intensity:	10 %
Time:	tag at frame rate
Frame rate (integration time):	2 ms

Source: hhrc.nsstc.nasa.gov

1. Technical description of the ISS-LIS and LMA

1.2 LMA

- Lightning leaders produce broadband emissions in the VHF range.
- These radio frequency (RF) emissions are measured at several station.
- Knowing the time when the emission is received at the station, the location (X,Y,Z) and t of what is called a **source** can be determined by combining several stations.
- **Source:** a location of a lightning leader emission obtained by combining the detections at individual stations.



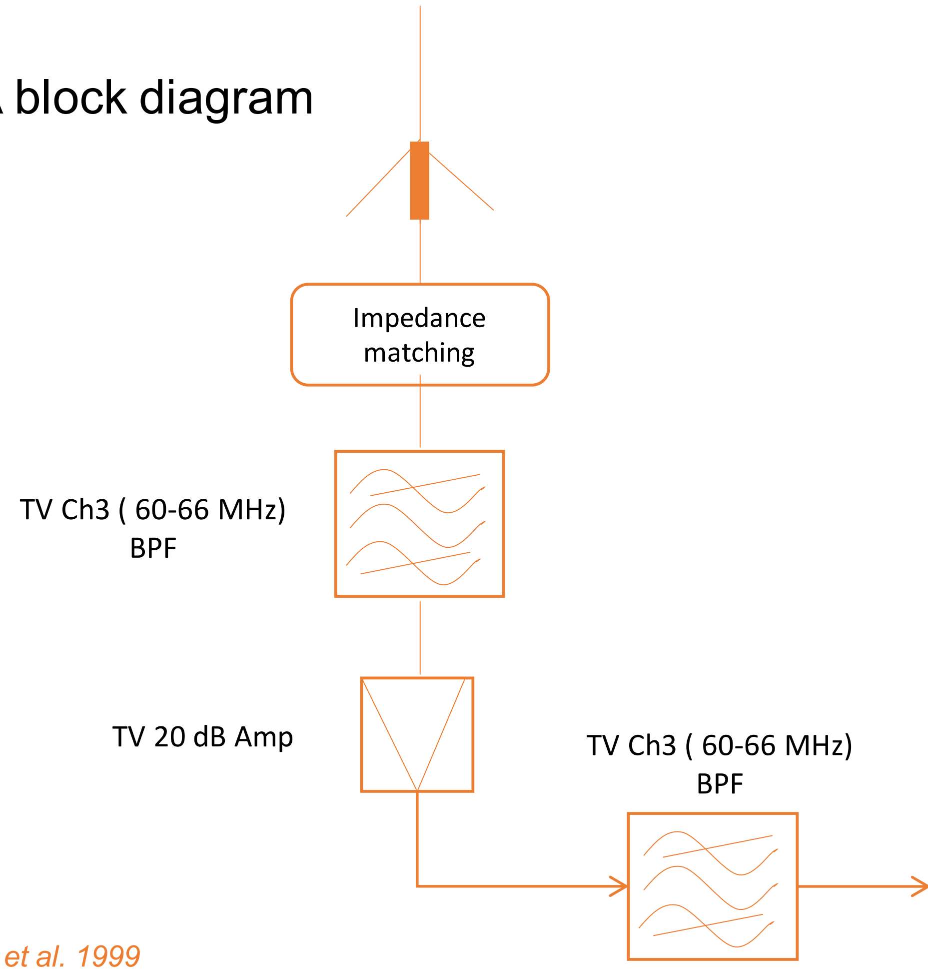
Proctor 1971, 1981, 1991
Proctor et al. 1988
Lennon and Maier 1991

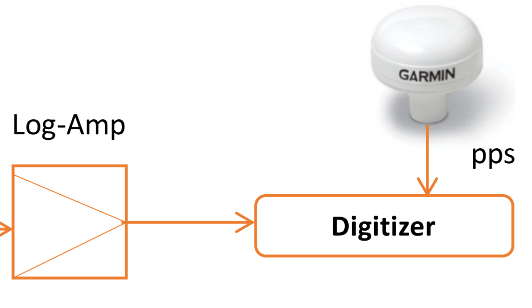
$$t_i = t + \frac{\sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}}{c}$$

1. Technical description of the ISS-LIS and LMA

1.2 LMA

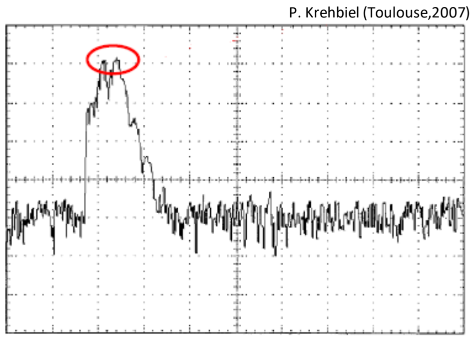
LMA block diagram





Rison et al. 1999
Thomas et al. 2004

Maximum within 80 μs



80 μs

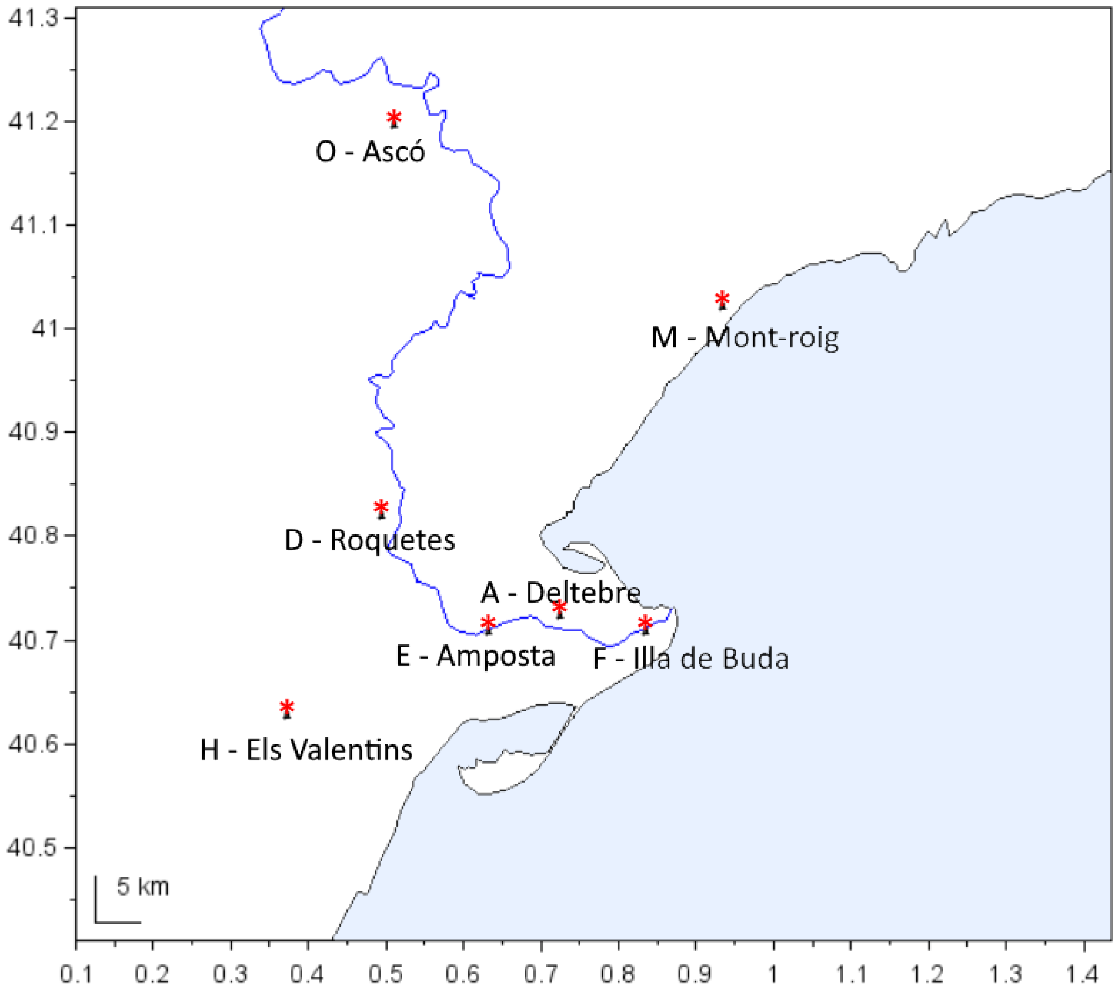
power: +10dB to -90 dB

- Important: LMA measures the RF power in a bandwidth of 6 MHz, not the RF signal. This is why the internal sampling is at 20 MHz and not at more than 130 MHz.
- This measurement is performed in windows of 80 μs. So at intervals of 80 μs the maximum power of the received signals is stored and time stamped with GPS time.
- Then, at best, the LMA can provide sources at rates corresponding each time interval.
- Uncertainties of LMA errors are:
  - Accuracy of the GPS timing (typically not better than 25 ns).
  - Noise level at each station.
  - Cables and electronics needs to be considered at the processing with a parameter delay for each station. We do a tuning of these delays.

1. Technical description of the ISS-LIS and LMA

1.2 LMA

Ebro-LMA (ELMA) 2017-2018



The background noise level at the sites varies usually between -75 dBm to -60 dBm, although higher or lower levels do occur sometimes at some of the stations.

The located sources are mainly coming from negative leaders moving through regions of positively charged cloud particles, but typically weaker sources from positive leader traces inside the negative charge region are often detected as well.

The capability to directly detect sources emitted by positive leaders (e.g., <3 dBW) depends on the distance to the stations and their noise levels. Along positive leaders a retrograde negative breakdown process occurs, called recoil leaders (e.g. Mazur, 2002), which emit stronger sources.

So, the LMA detects breakdown at both negative and positive leader sections, but more efficiently the negative breakdown.

A map of the 7 operational LMA stations in 2018 is shown.

Data from all the stations needs to be collected (over SFTP or by visiting) before source locations can be computed by the time-of-arrival method.

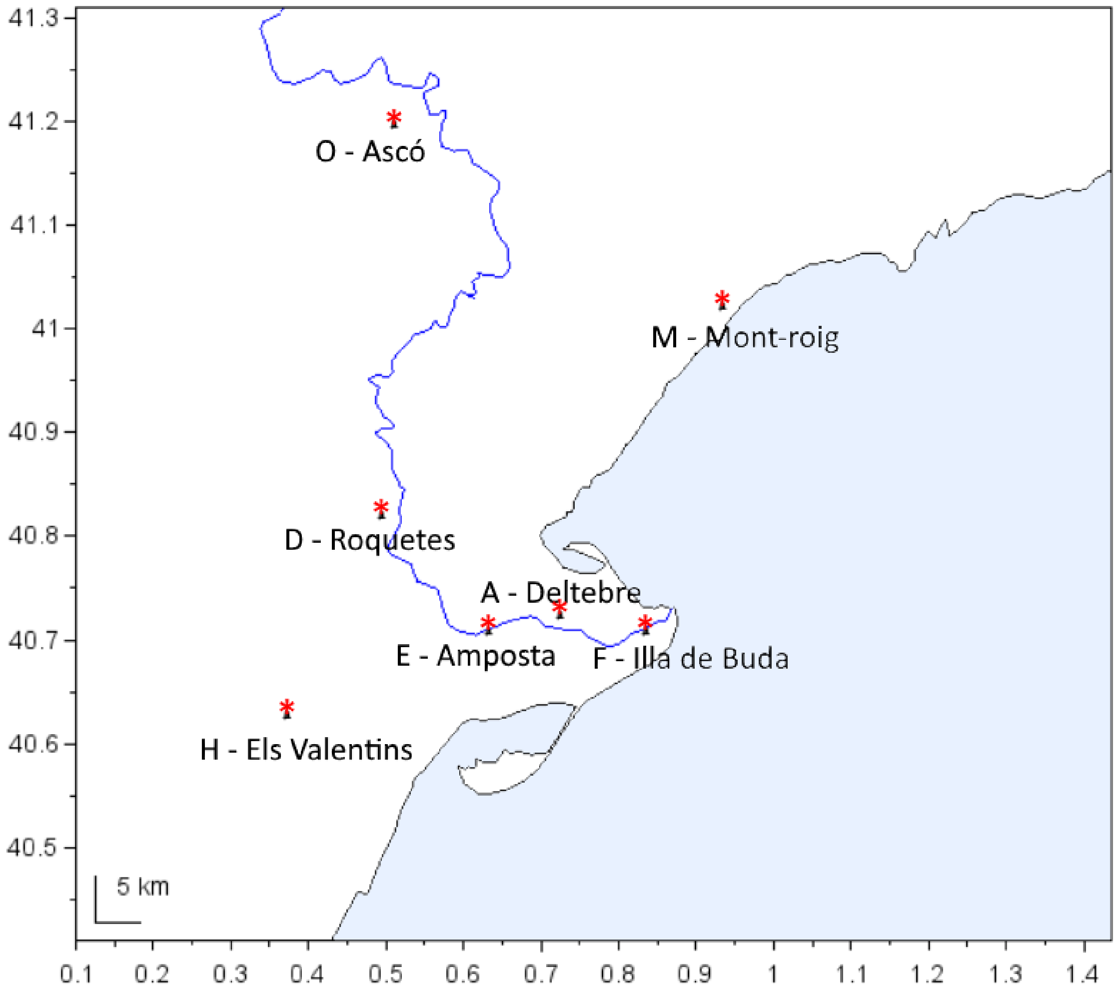
The processing has a few variables that control the output. The main ones are the number of stations used to compute locations, and the Chi-squared.

Our regular processing uses the minimum of 5 stations, but more will be used automatically when available. Chi-squared is defined only for solutions with 6 or more stations. Therefore, it is not used (set at an arbitrary 5.0) for our processing.

1. Technical description of the ISS-LIS and LMA

1.2 LMA

Ebro-LMA (ELMA) 2017-2018



A file with all station locations and delay values (usually up to 300 ns) is also required as input.

This file contains the tuning of delay values, which were found for each station by an iterative tuning process, by varying the value over a range and keeping the one producing the highest number of sources of very low Chi-squared (e.g <0.1) when using at least 6 stations to compute source locations.

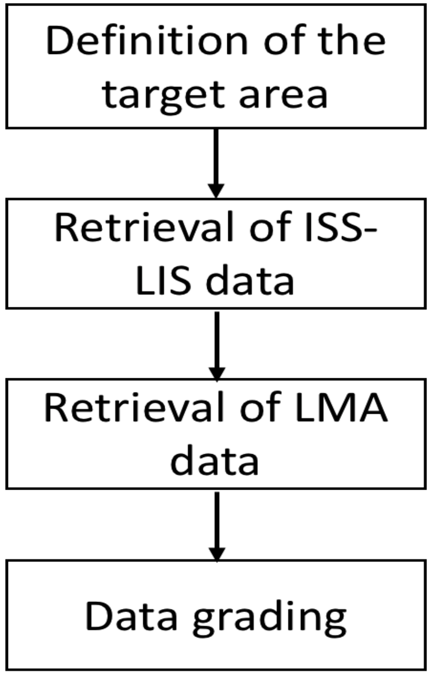
Some days the full network was running, but other days one or two stations may be unavailable. This affects the quality of mapping. Similarly, some stations may experience an increase of background noise. This reduces the number of solutions and can introduce noise which can cause radial artifacts which may appear during flashes. The station availability will be listed for all days of study.

Output files are in ASCII format and include a header with the participating station information, followed by the data:

" 4201.961808533 40.898186 2.325726 15506.6 3.98 15.1 10b1"
time in seconds (UTC), latitude, longitude, altitude (m), chi-sq, power (dBW), stations (hexadecimal)

2. Data selection

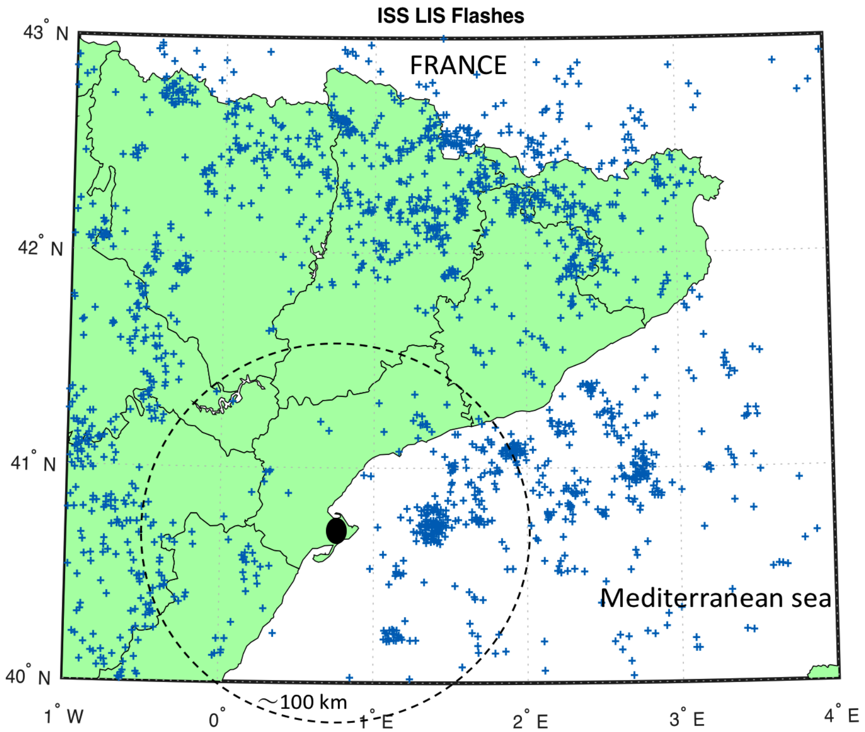
2.1 Methodology



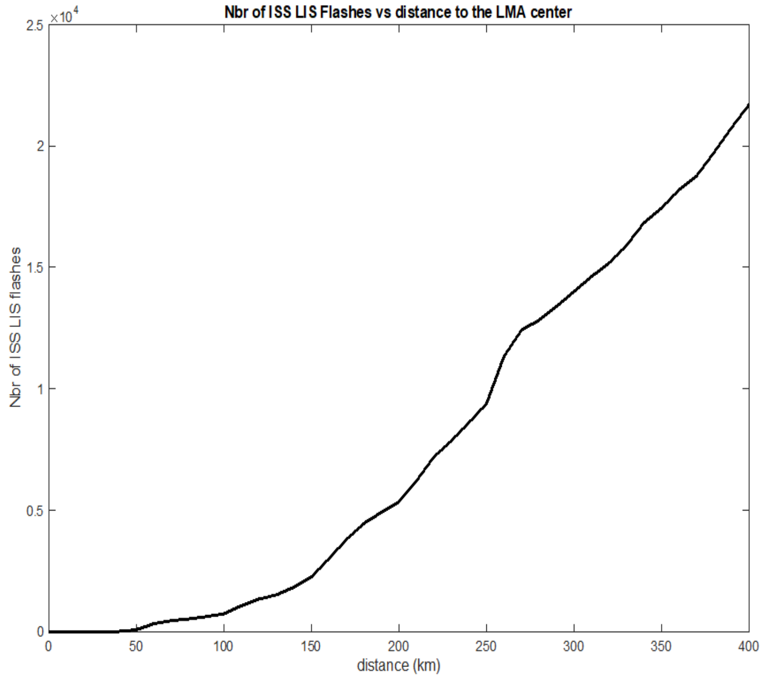
2. Data selection

2.2 Dataset

ISS-LIS flashes
(March 2017 – October 2018)



Number ISS-LIS flashes to the ELMA center
(March 2017 – October 2018)



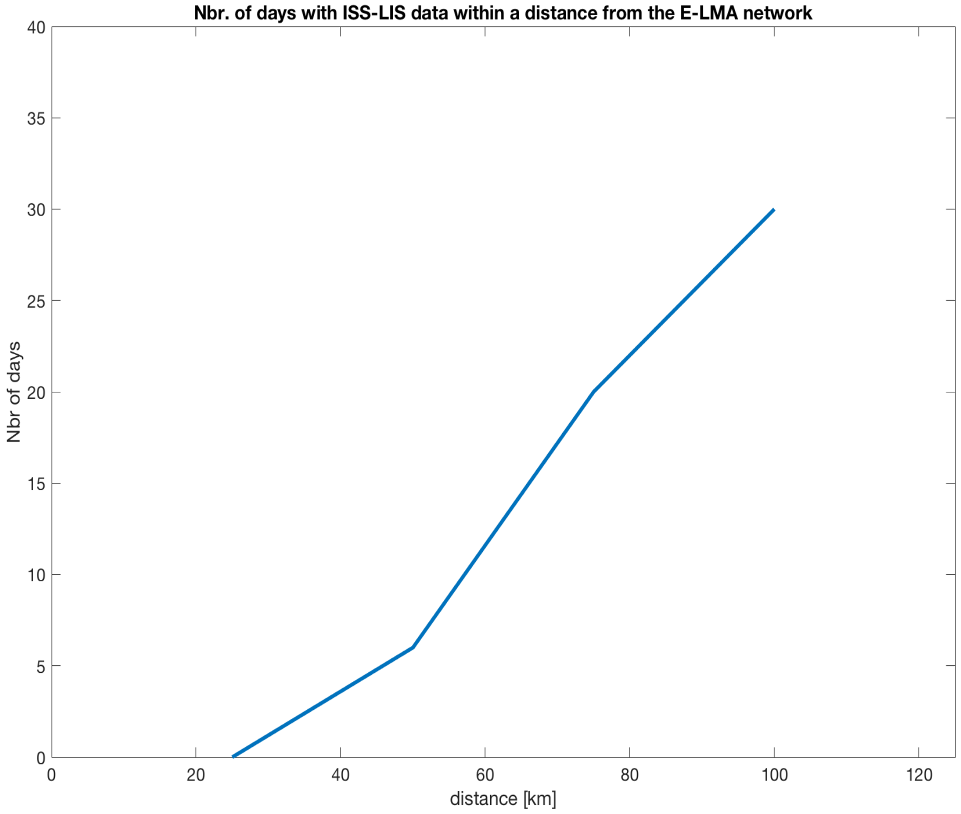
Distance to the center of the ELMA	Number of ISS-LIS flashes
25 km	0
50 km	76
75 km	495
100 km	738
125 km	1396
150 km	2256

2. Data selection

2.2 Dataset

Number of days with ISS-LIS flashes within to the considered range of the ELMA

(March 2017 – October 2018)



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50 km	76
75 km	495
100 km	738
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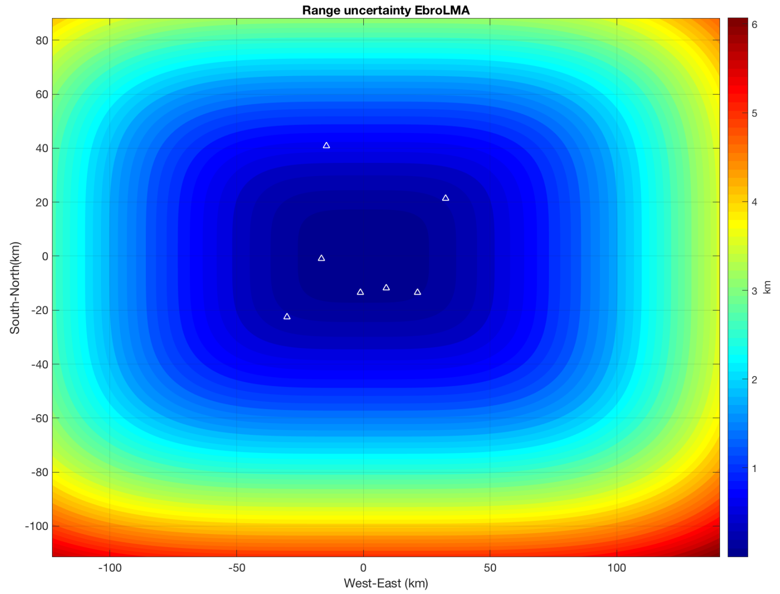
150 km	2256

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

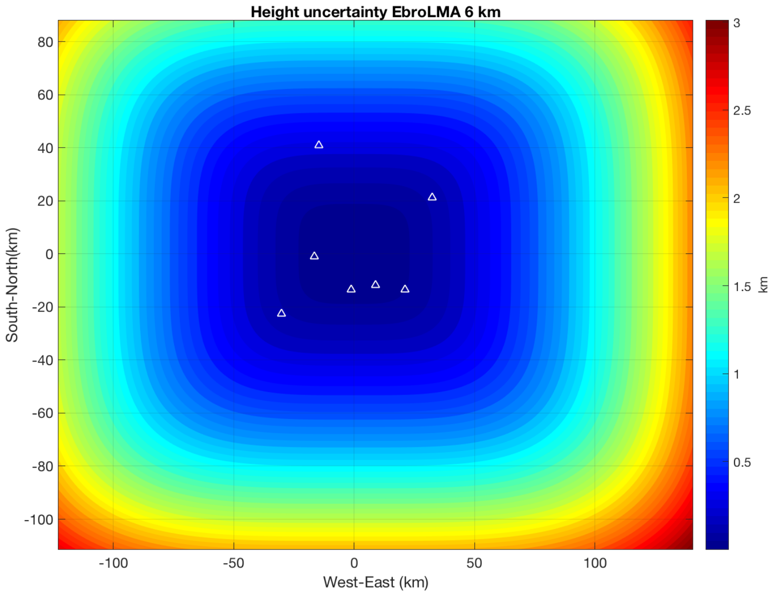
Theoretical location accuracy of the ELMA

X-Y



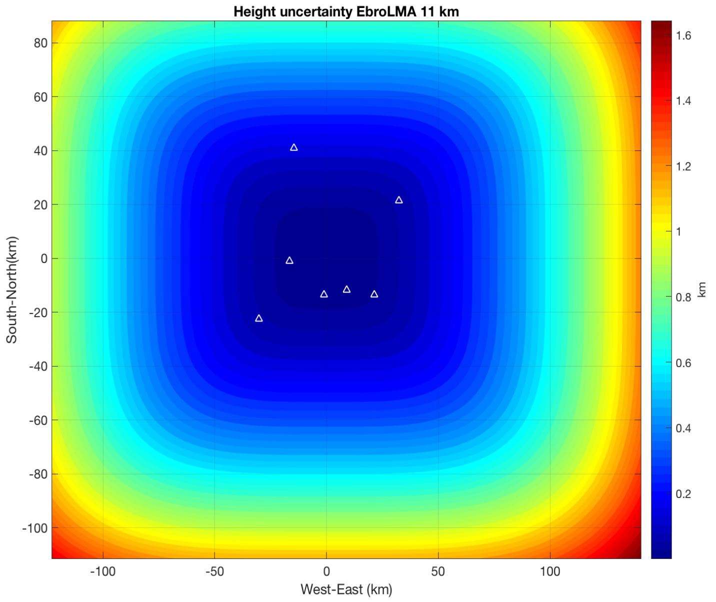
< 2 km within 100 km

Z at 6 km



< ~1 km within 100 km

Z at 11 km

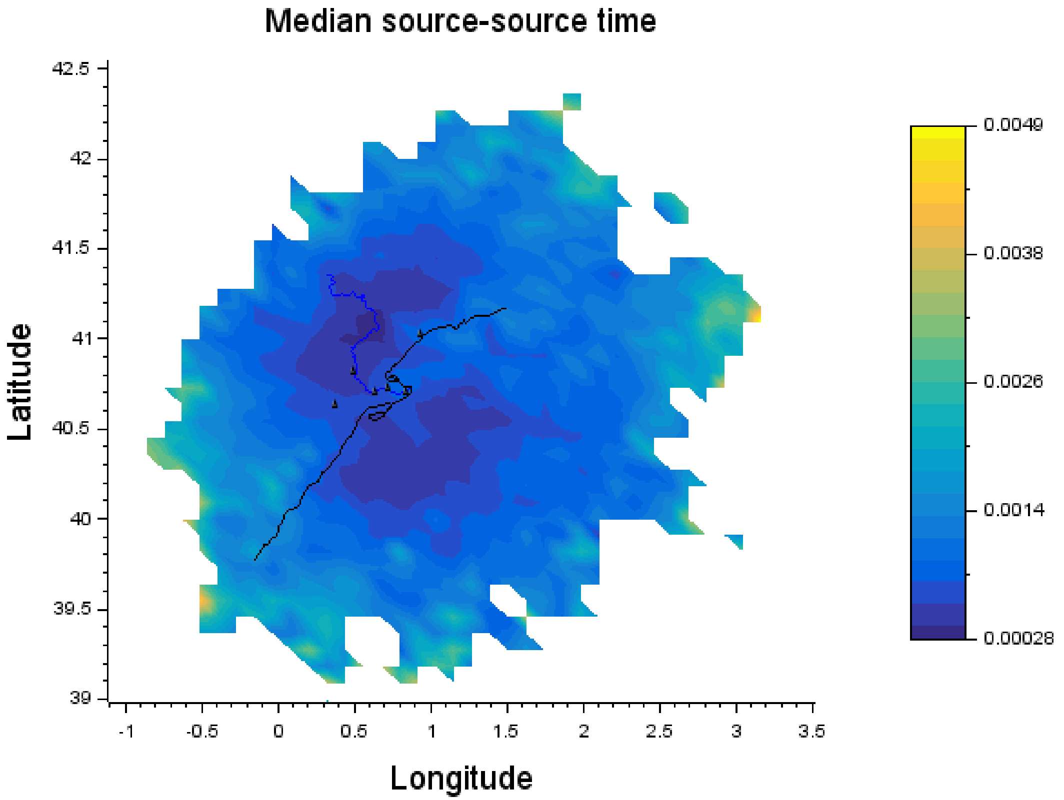


< 1 km within 100 km

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Median time between consecutive sources

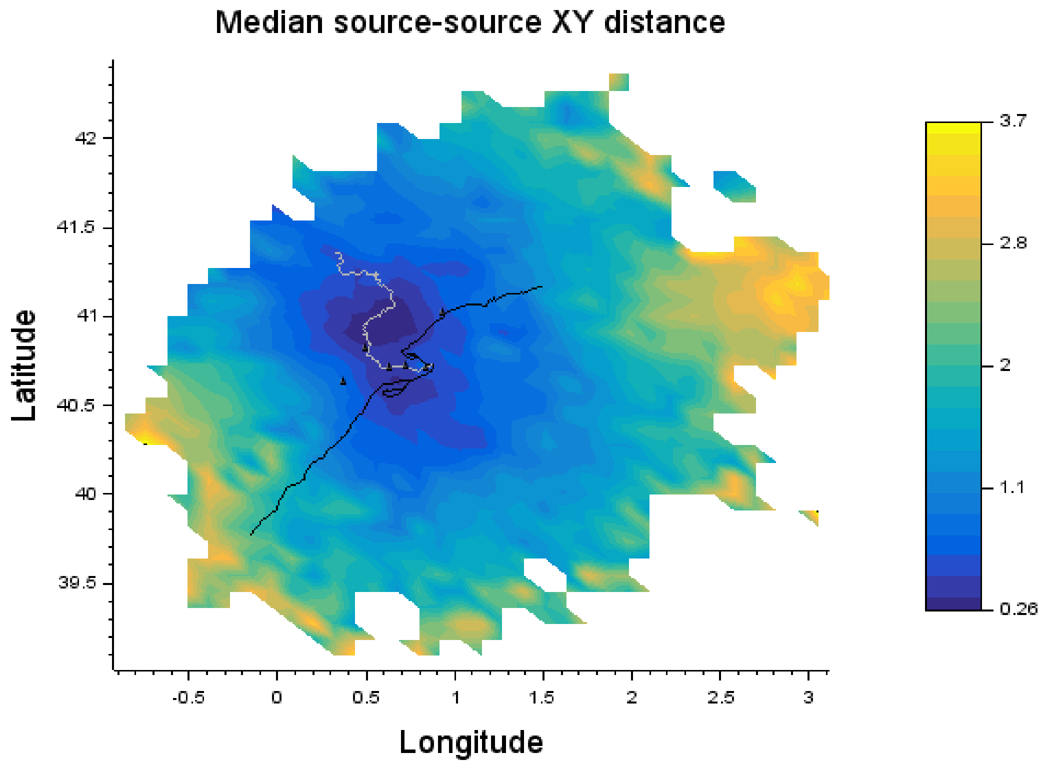


Lower intervals are better, as it represents the more dense mapping in time. It appears that two zones NW and SE of the Ebro Delta show the most favourable values. An axis from WSW to ENE is somewhat less good.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Median distance X-Y between consecutive sources



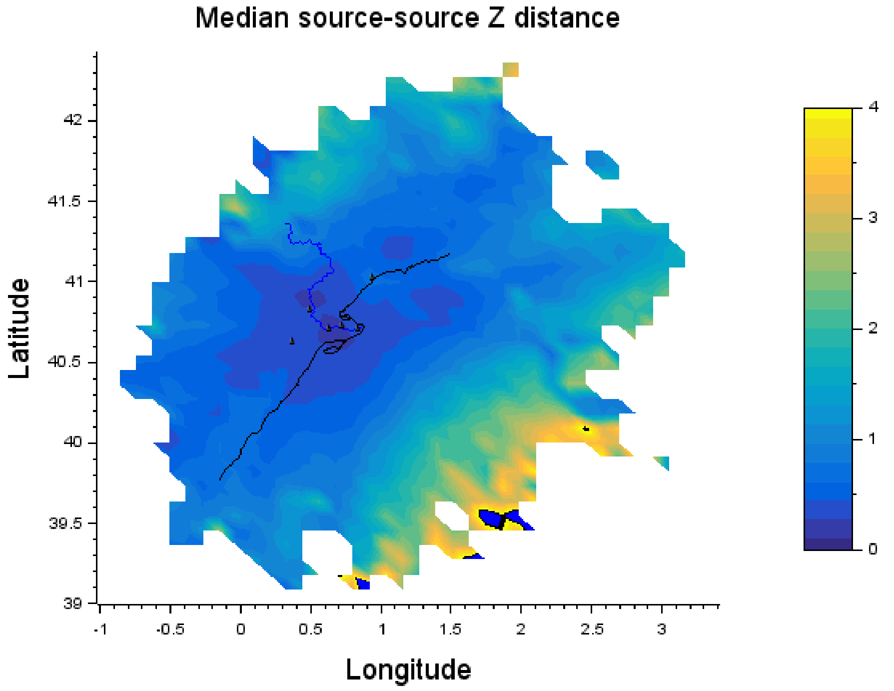
The horizontal scatter in the mapping of channels is minimized in an area from the Ebro Delta to the lower Ebro Valley, which is the region within the perimeter of the LMA stations with less than 500 m horizontal scatter.

But in a wide radius the scatter is less than 1.5 km.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Median vertical distance Z between consecutive sources

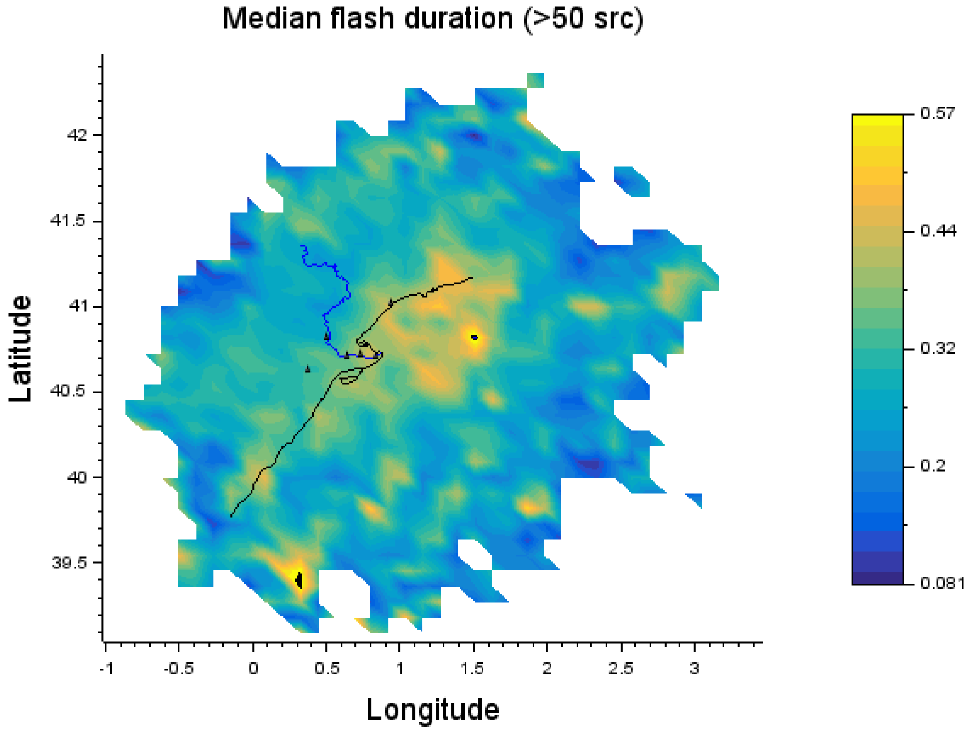


Vertical scatter is best right over the Ebro Delta, where several sensors are clustered. It deteriorates to 1.5-2.0 km scatter over the Mediterranean almost 100 km from the network center, similar to the northwest sector.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Median flash duration

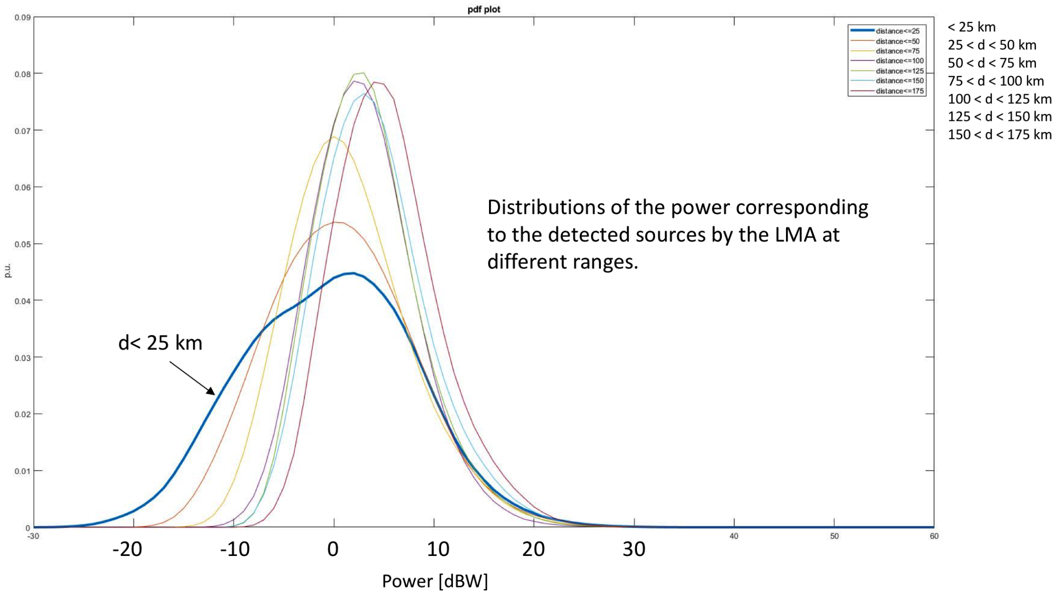


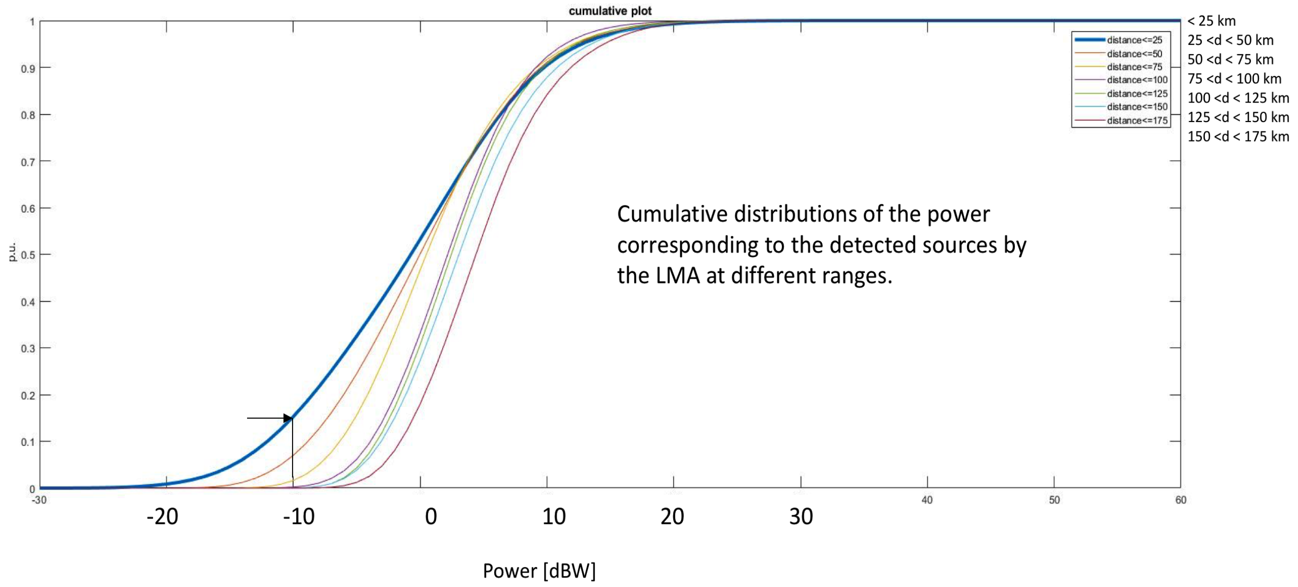
This map is showing more of a characteristic of the lightning flashes themselves, as the duration of a flash is less sensitive to the mapping quality. As result, the median flash duration cannot be used as a metric of the LMA performance.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

RF VHF Power

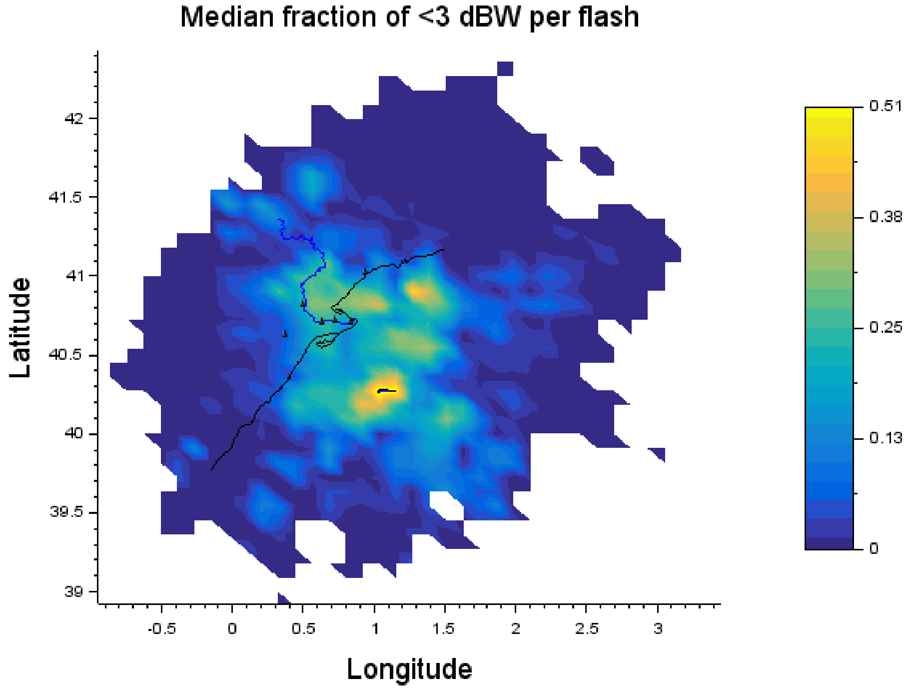


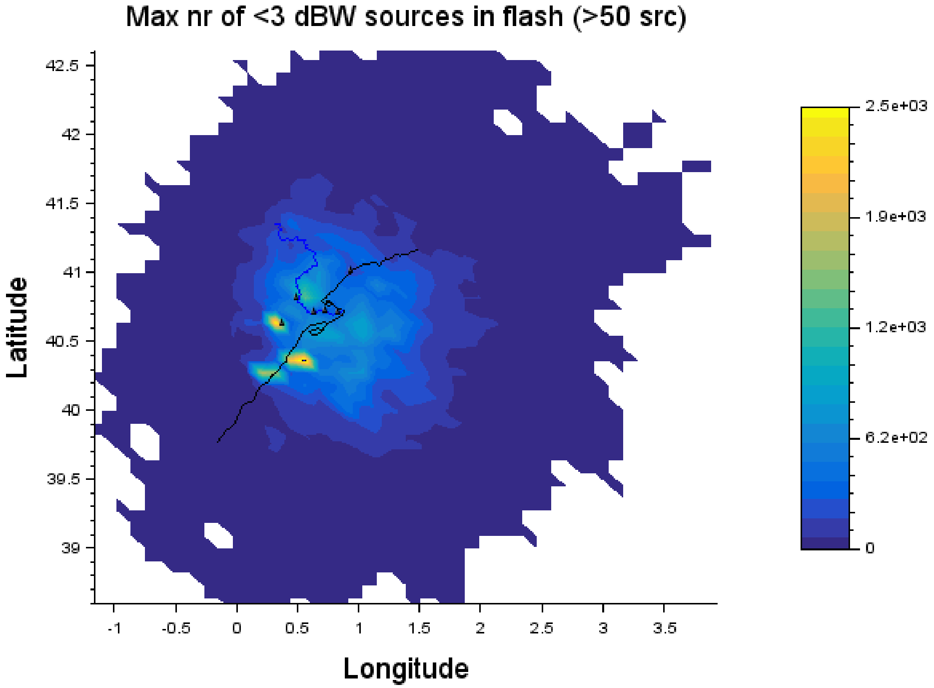


2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Power < 3dBW



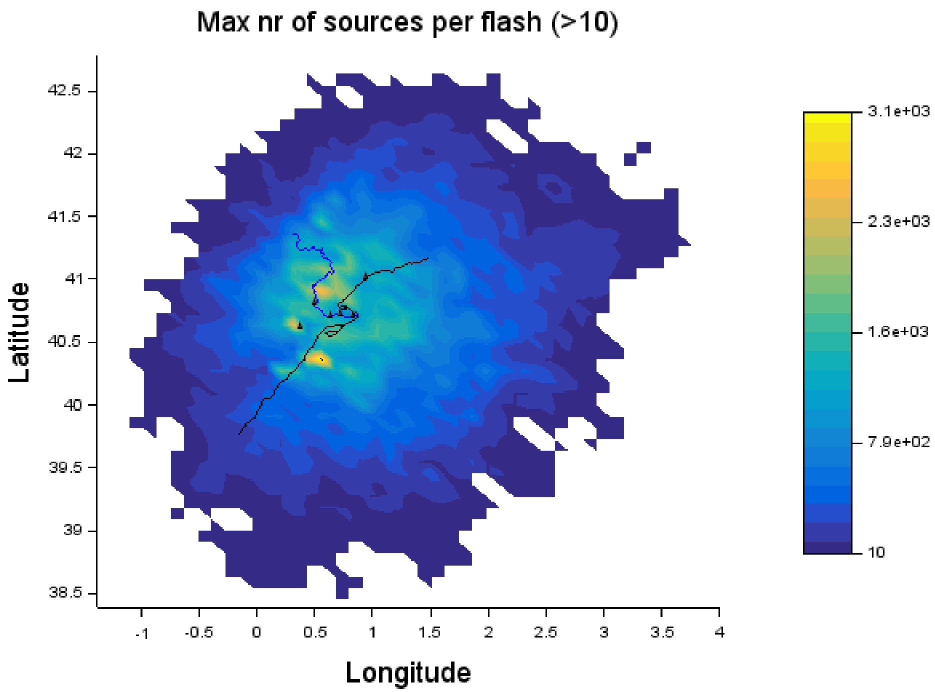


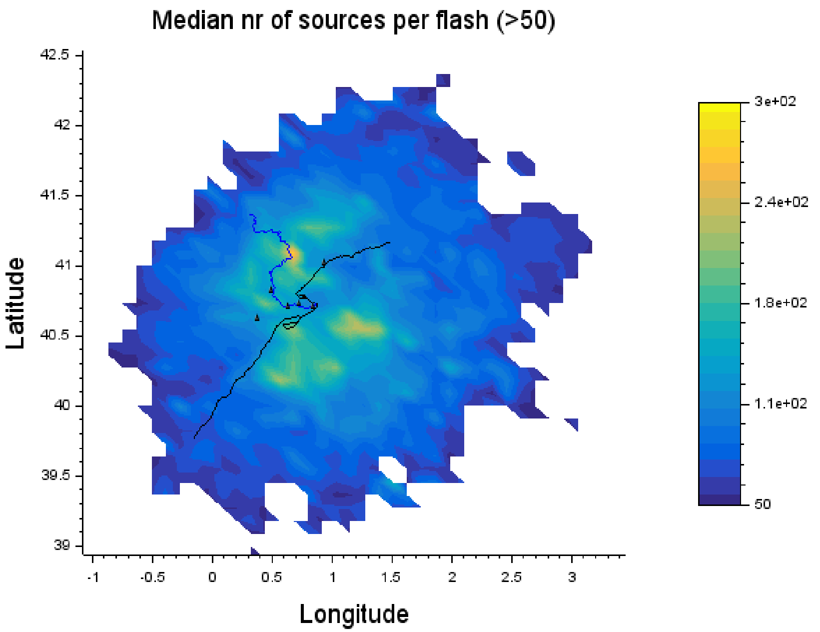
The higher the fraction, the better detected is the contribution of positive leader activity with removes negative charge from the cloud. This can be important for detection efficiency of negative cloud to ground flashes. The quality appears good in the area directly northwest of the network center, as well as the nearby Mediterranean Sea, especially within about 60-80 km radius (but not toward the west). The result may be affected to some extent by the type of thunderstorms that occurred.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Number of sources per flash



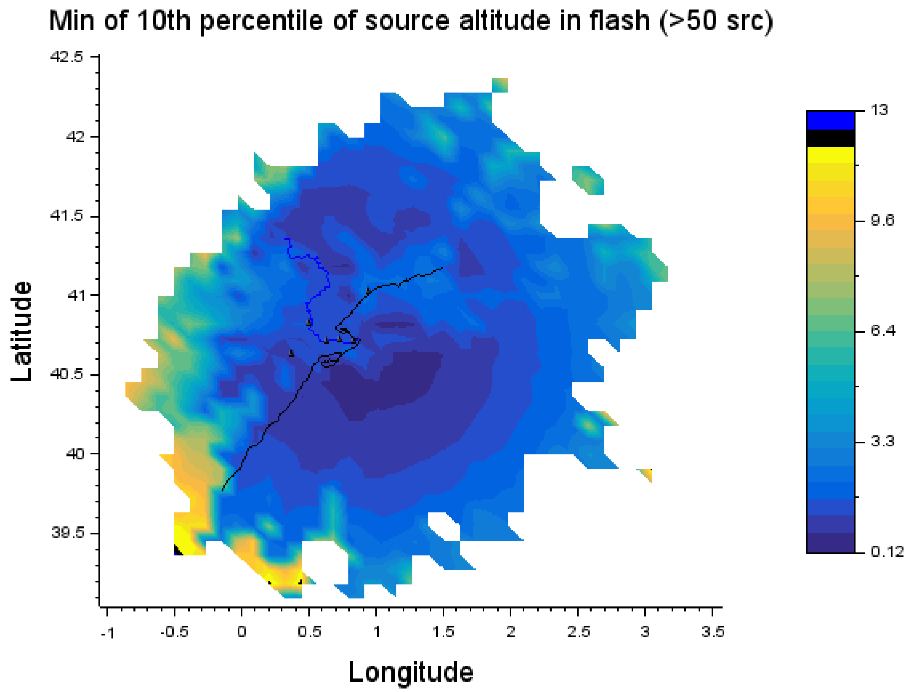


This map shows how many sources (per 10x10 km) can be detected at maximum. The closer the more detail can be provided, with zones of about 60 km radius, then 100 km, and beyond that, never more than a few hundred sources can be detected for a flash.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Minimum source altitude

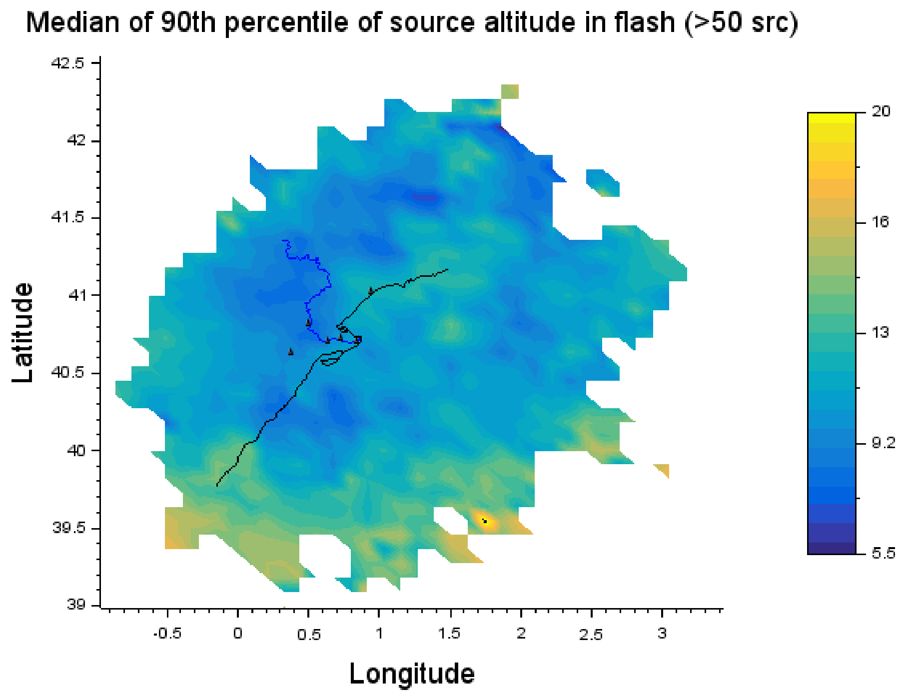


Here we see the absolute lowest source altitudes than can be seen by LMA. The circular part is due to horizon curvature. West and southwest are more blocked by mountains, while also the coast near Tarragona is more blocked for probably the westernmost stations.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

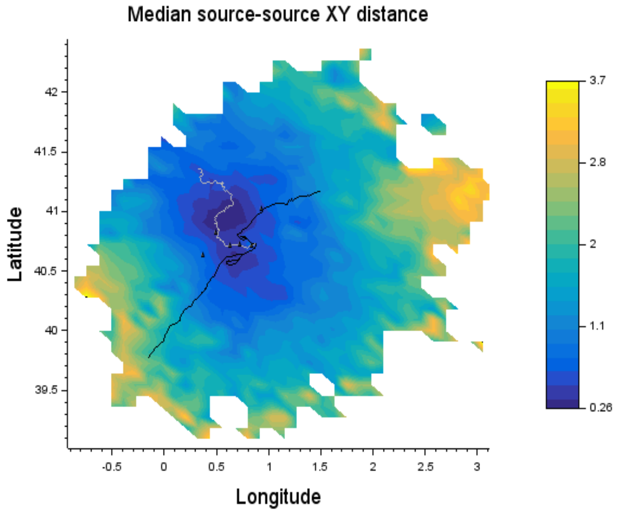
Maximum source altitude

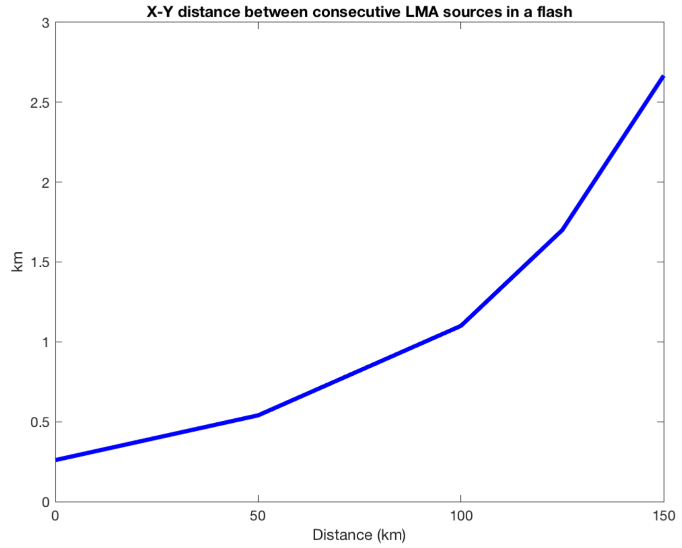


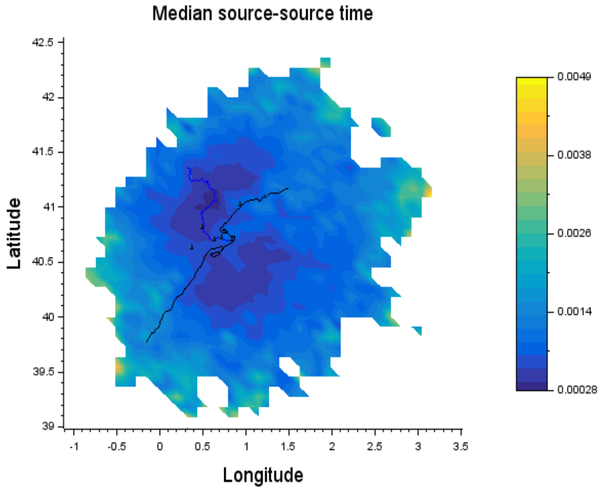
In the ELMA region, most of the sources are typically located below 12 km and, in some cases they reach heights of 14 km. In the figure, we see how the altitude errors increase at distances of more than 100 km (S-E).

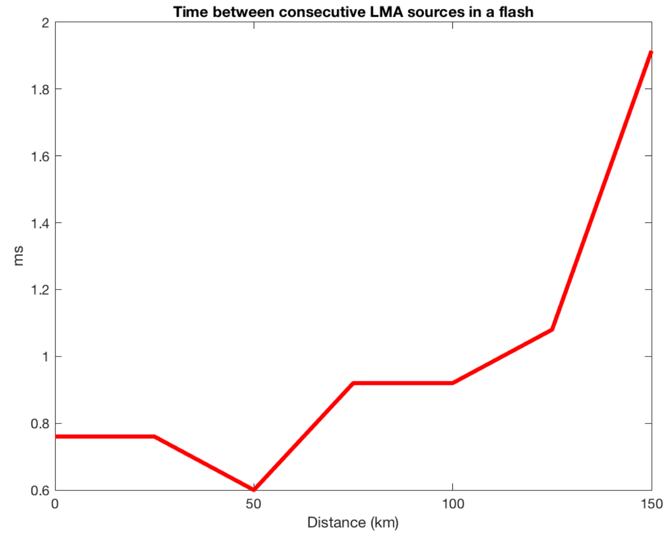
2. Data selection

2.3 Sensitivity analysis: Averaging of the LMA performance





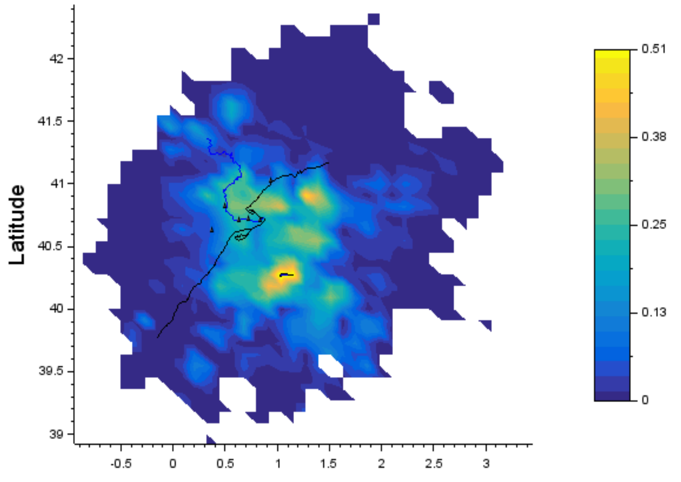


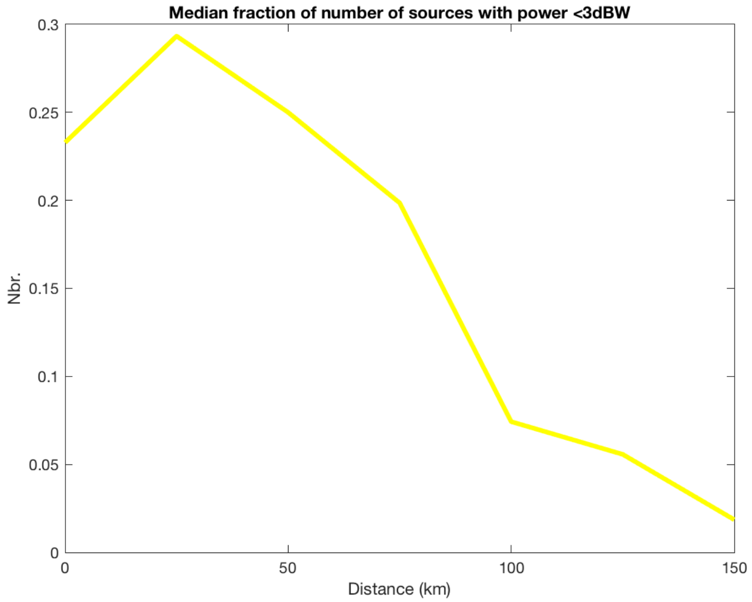


2. Data selection

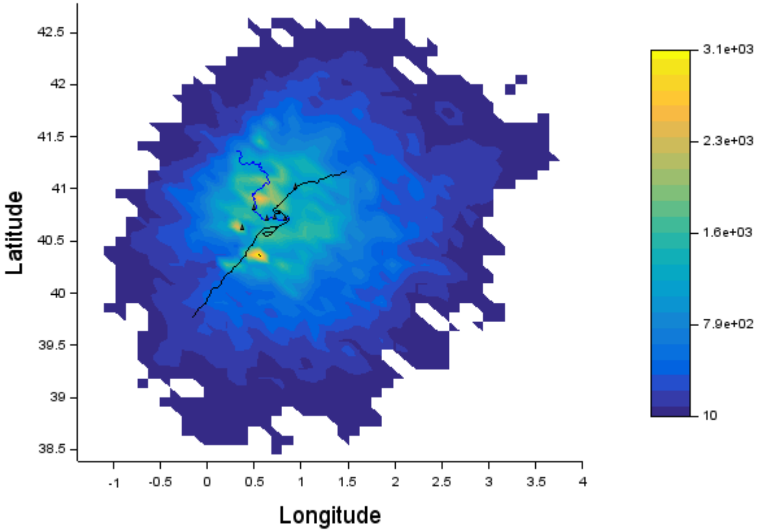
2.3 Sensitivity analysis: Averaging of the LMA performance

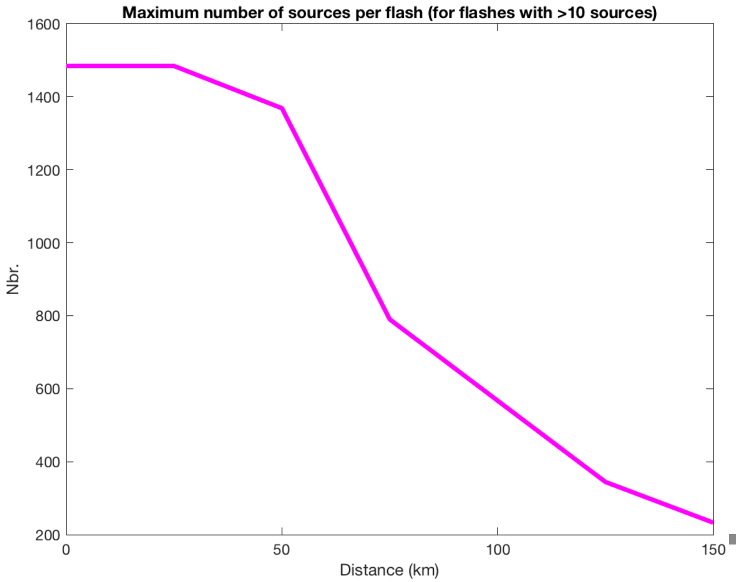
Median fraction of <3 dBW per flash





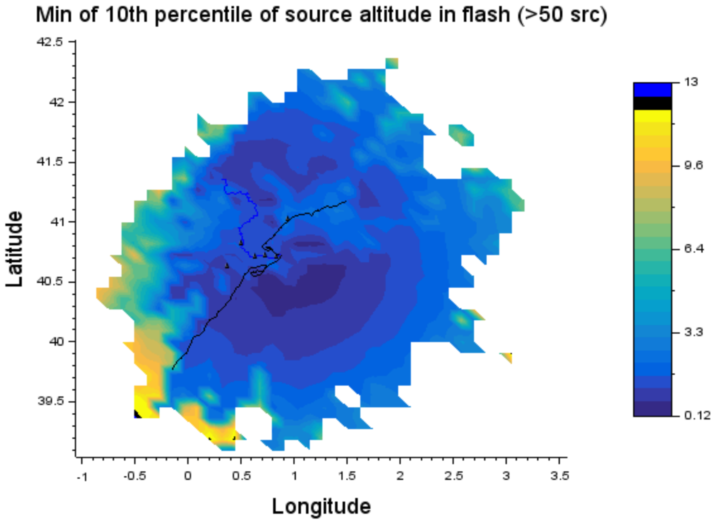
Max nr of sources per flash (>10)

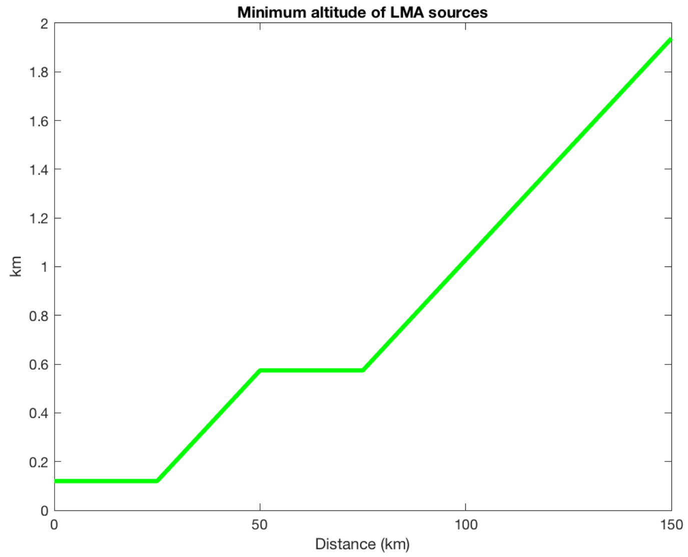


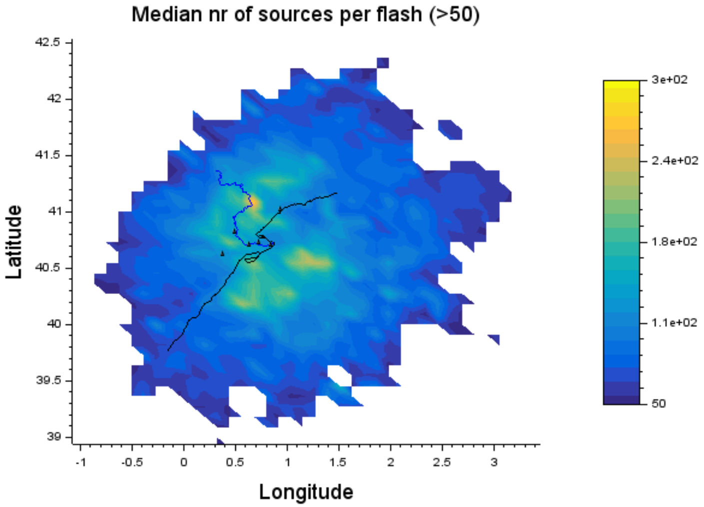


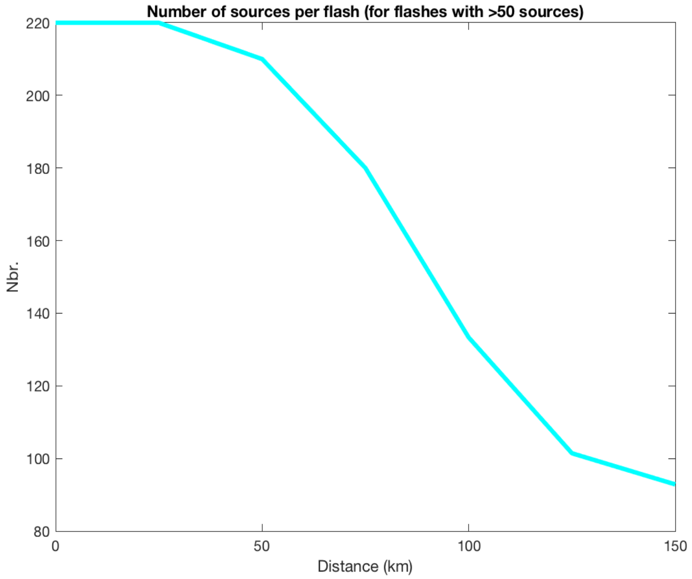
2. Data selection

2.3 Sensitivity analysis: Averaging of the LMA performance









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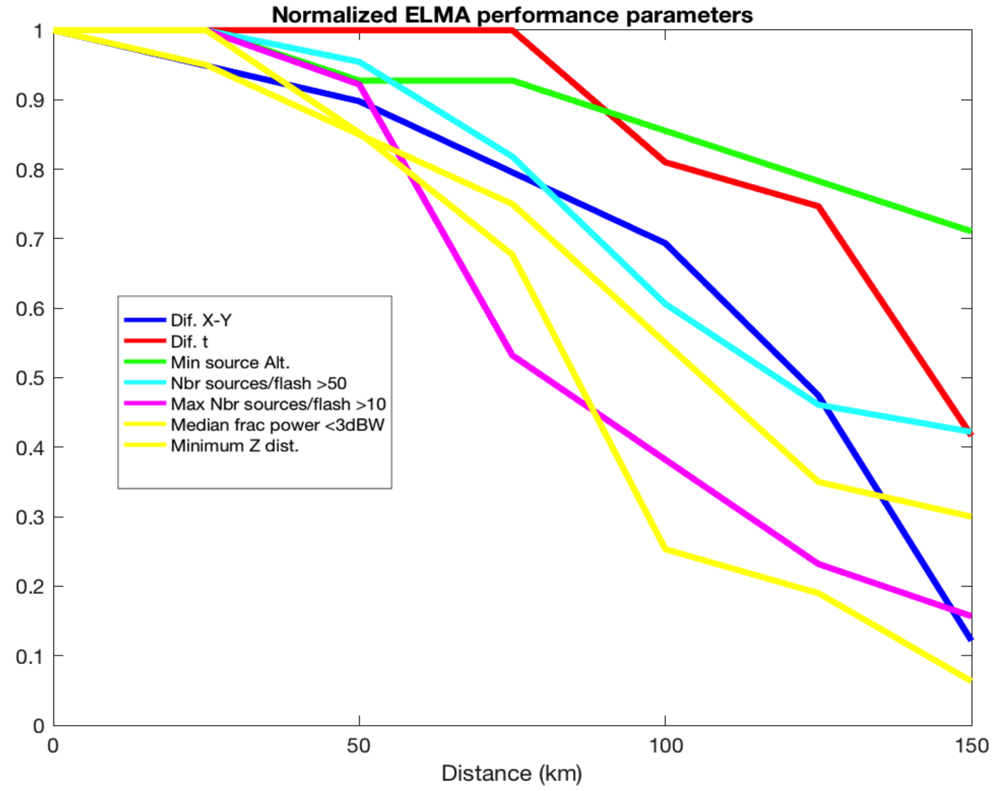
2. Data selection

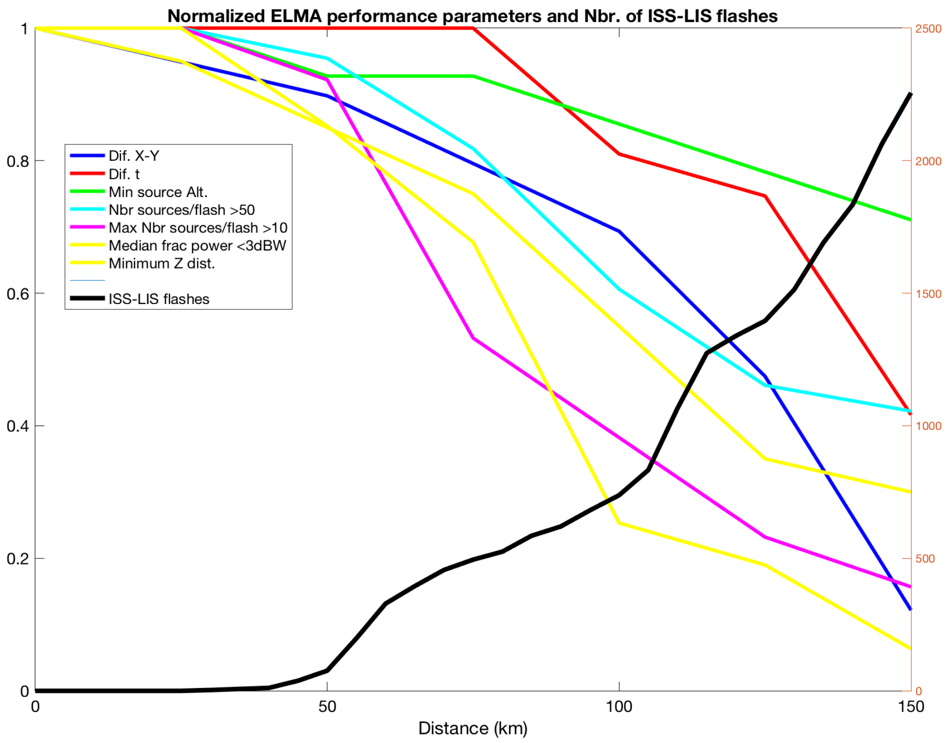
2.3 Sensitivity analysis: Averaging of the LMA performance

Parameter	Value at the ELMA center	Maximum value
X-Y Distance between consecutive sources	0.26 km	3 km
Median Z distance between consecutive sources	0.167 km	3.5 km
Minimum Z altitude of LMA sources	0.120 km	6.4 km
Time difference between consecutive sources	0.001 ms	3 ms
Number of sources per flash	220	228
Maximum number of sources per flash	1484	2067
Median fraction of number of sources with power < 3dBW	0.23	0.51

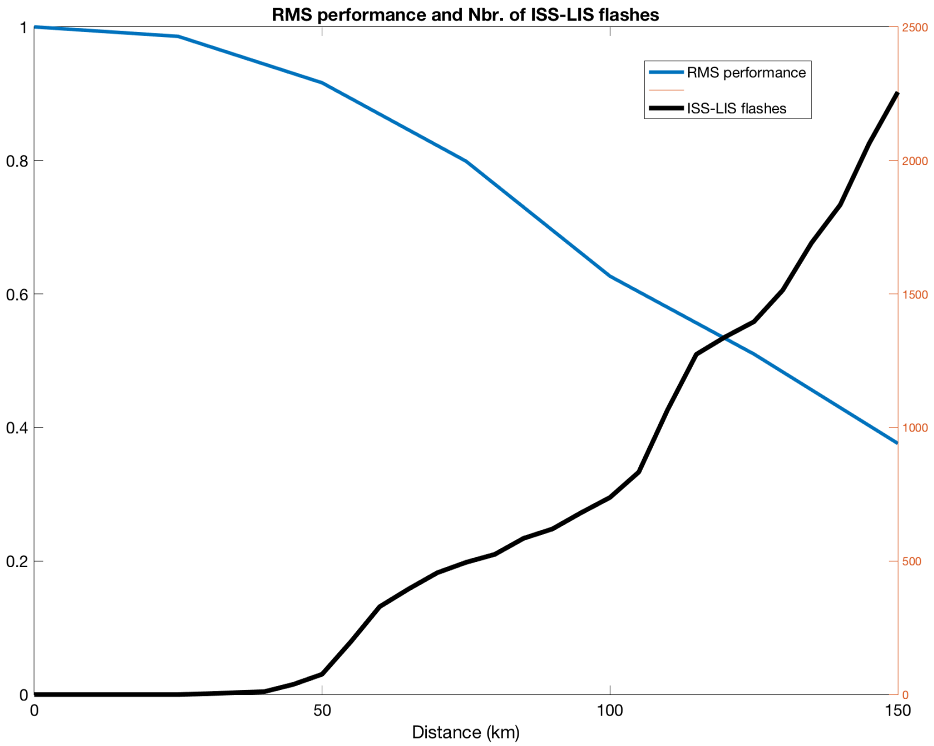


2. Data selection

2.3 Sensitivity analysis: Normalization and analysis

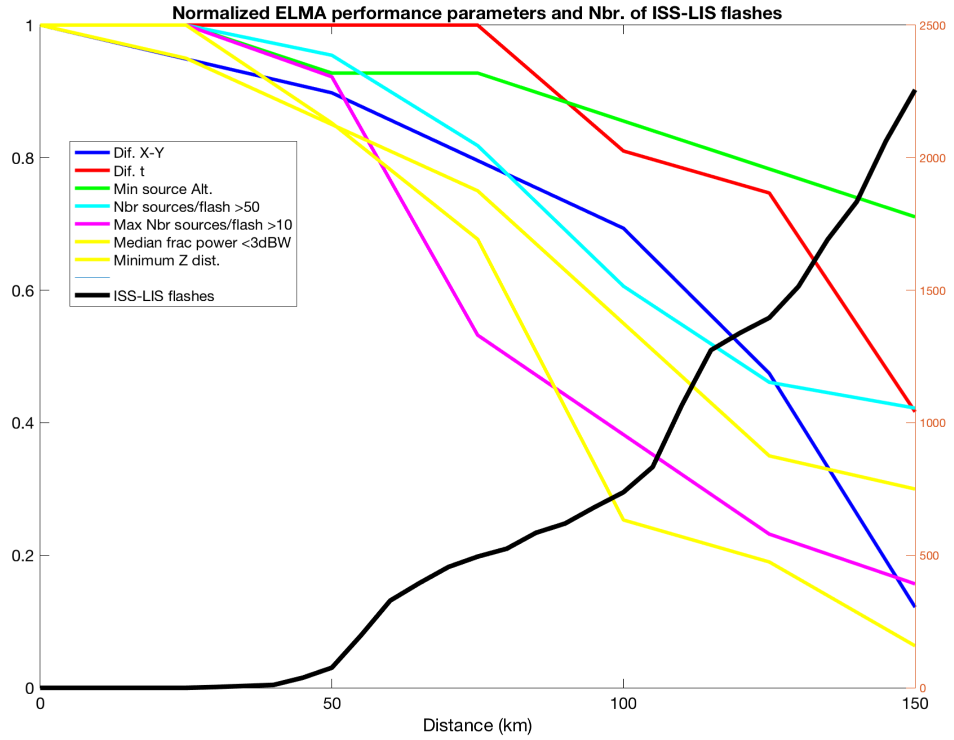


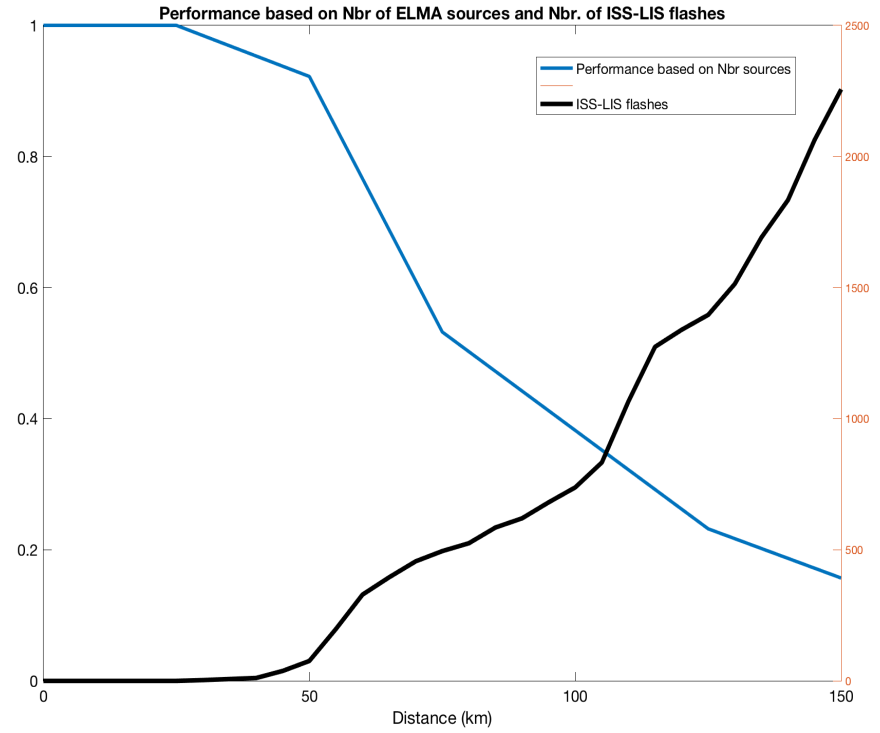
$$RMS = \sqrt{\frac{1}{N}\sum U_j^2}$$



2. Data selection

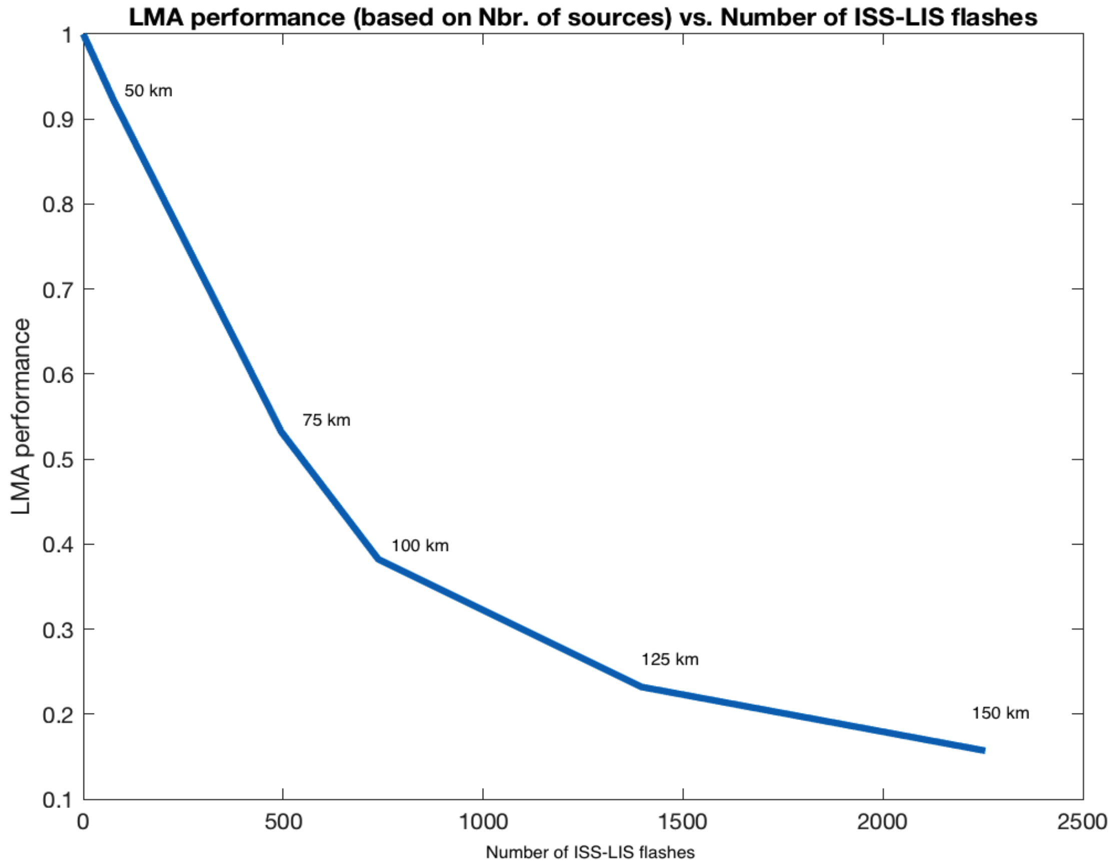
2.3 Sensitivity analysis: Analysis





2.3 Sensitivity analysis: Analysis

Theoretical location accuracy of the ELMA



2. Data selection

2.4 Key properties of the dataset

Range	Number of ISS-LIS flashes	Dates of occurrence	Number of ISS-LIS flashes per date	Availability of ELMA data	Number of expected comparable flashes
<50 km	76	20170424 20171018 20180917 20180918 20181010 20181018	1 15 1 40 2 17	- 20171018 20180917 20180918 - 20181018	74

2. Data selection

2.4 Key properties of the dataset

Range	Number of ISS-LIS flashes	Dates of occurrence	Number of ISS-LIS flashes per date	Availability of ELMA data	Number of expected comparable flashes
< 75 km	495	20170424 20170628 20170708 20170917 20171018 20180427 20180429 20180525 20180605 20180613 20180716 20180809 20180822 20180831 20180917 20180918 20181010 20181014 20181018	1 7 1 4 20 4 2 1 1 1 1 15 2 3 8 322 2 77 23	- - - - 20181018 20180427 20180429 NP 20180525 NP 20180605 20180613 NP - 20180809 20180822 20180831 20180917 20180918 - - 20181018	398 (402 including data to be processed)

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2. Data selection

2.4 Key properties of the dataset

Range	Number of ISS-LIS flashes	Dates of occurrence	Number of ISS-LIS flashes per date	Availability of ELMA data	Number of expected comparable flashes
< 100 km	738	20170424	1	-	578 (593 including data to be processed)
		20170615	5	-	
		20170628	7	-	
		20170708	2	-	
		20170805	3	-	
		20170917	7	-	
		20171018	22	20171018	
		20171129	1	-	
		20180427	8	20180427	
		20180429	2	20180429 NP	
		20180525	2	20180525	
		20180605	2	20180605	
		20180606	2	20180606	
		20180613	1	20180613 NP	
		20180716	3	20180716 NP	
		20180807	5	20180807 NP	
		20180809	78	20180809	
		20180811	4	20180811 NP	
		20180822	2	20180822	
		20180823	2	20180823	
		20180831	68	20180831	
		20180904	4	-	
		20180910	27	-	
		20180917	14	20180917	
		20180918	349	20180918	
		20181008	7	-	
		20181010	2	-	
		20181014	79	-	
		20181018	29	20181018	

2. Data selection

2.4 Key properties of the dataset

Range	Number of ISS-LIS flashes	Dates of occurrence	Number of ISS-LIS flashes per date	Availability of ELMA data	Number of expected comparable flashes
< 125 km	1396	20170424	1	-	1055 (1144 including data to be processed)
		20170529	10	-	
		20170604	220	20170604	
		20170615	23	-	
		20170625	2	-	
		20170628	7	-	
		20170708	2	-	
		20170721	2	-	
		20170805	4	-	
		20170827	30	-	
		20170831	1	-	
		20170917	7	20170921 NP	
		20170921	1	-	
		20171018	47	20171018	
		20171110	4	-	
		20171129	1	-	
		20180427	36	20180427	
		20180429	2	20180429 NP	
		20180509	10	20180509 NP	
		20180525	6	20180525	
		20180530	2	20180530	
		20180604	1	20180604 NP	
		20180605	6	20180605	
		20180606	2	20180606	
		20180609	8	20180609 NP	
		20180613	1	20180613 NP	
		20180623	2	-	
		20180627	6	20180627	
		20180712	5	20180712 NP	
		20180716	3	20180716 NP	
		20180807	12	20180807 NP	
		20180809	82	20180809	
		20180811	4	20180811 NP	
		20180812	3	20180812 NP	
		20180822	2	20180822	
		20180823	2	20180823	
		20180831	252	30180831	
		20180904	5	-	
		20180905	4	20180905	
		20180910	57	-	
		20180915	2	-	
		20180917	15	20180917	
		20180918	373	20180918	
		20181008	14	-	
		20181010	2	-	
		20181014	82	-	
		20181018	33	20181018	

2. Data selection

2.4 Key properties of the dataset

ISS-LIS data

- Event: date, time, location and radiance.
- Group: ID of the group that an event belongs, time, location of the radiance-weighted centroid, radiance
- Flash: date, time, location of the radiance-weighted centroid, radiance.
- Location: View time of 0.5°x 0.5° grid cells. That will be used e.g to verify that an LMA flash not reported by the ISS-LIS actually was in the FOV.
- Illuminated CCD pixels will be considered to determine if a flash might be partially detected

LMA-DATA

- Sources: time, x, y, z, power
- Sources are classified as valid and as noise.
- Flashes will be graded: location, Nbr of stations, noise, number of sources,…..

3. Definition of the evaluation

Parameter	Method	Evaluation
Density	Creation a grid box (4 x 4 km). LMA: number of times in frames of 2 ms that LMA sources occurs within a grid box. ISS-LIS: number of events occurring within a grid box. CG: number of CG strokes within a grid box. Calculation of density. For the analysis, only periods with flashes of the ISS-LIS within the FOV are taken into account. The range to consider will be: 100 km	Comparison of lightning density distributions of ISS-LIS, LMA and CG. Analysis of the differences between densities and their possible reasons (e.g. effects of mountains in the LMA,...)

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3. Definition of the evaluation

Size	Simultaneous plot of LMA and its corresponding ISS-LIS events. Manual tool for lightning length computation for the LMA. Automatic size computation of ISS-LIS flashes (events)	-Statistics of the flash size for ISS-LIS and LMA -Distribution of the size difference between same LMA flash and LIS event.

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3. Definition of the evaluation

Duration	LMA: time difference between the first and the last source (noise sources will be ignored). ISS-LIS: time difference between the first and the last event.	Statistics of flash durations for ISS-LIS and LMA.

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3. Definition of the evaluation

Detection efficiency (DE)	A flash is detected by the ISS-LIS if there is at least one LMA source during the duration of the flash defined by the ISS-LIS. Verification of occurrence in the FOV of LIS. A flash is not detected by ISS-LIS if occurred within the FOV of ISS-LIS. Flashes not detected by LMA. In that case it is necessary to verify of there are CG locations at the ISS-LIS, enable LMA noise, and check data at individual stations. From a plot of ISS-LIS events and LMA for each flash, the detection will be categorized as: ○ Well detected and located. ○ Detected but partially well located (e.g. both partially overlap or are close in a distance < 10 km) ○ Detected but far located (if distance is > 10 km). The range to consider will be: 125 km	Percentage of flashes detected by ISS-LIS from the LMA. Percentage of well detected and located flashes. Percentage of well detected and partially well-located flashes. Percentage of detected but wrong located flashes. Percentage of flashes detected by ISS-LIS but not detected by LMA. Comparison of flash rates.

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3. Definition of the evaluation

Location accuracy (LA)	- For each LMA flash, a convex hull region is created. For each LMA flash, the weighted centroid is calculated. - Computation of the distance between the Flash location (ISS-LIS centroid) and the LMA (centroid) - Plot of individual flashes: ISS-LIS events and LMA. - Computation of the average/median distance between Event locations and LMA locations with time bins of 10 ms. The range to consider will be: 100 km	Statistics of the position offsets between ISS-LIS and LMA: centroids and event-leader distances.

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3. Definition of the evaluation

Distribution of Events in time	- The duration of LMA flash is divided in 10 ms bins. - Distribution of ISS-LIS events in the 10 ms bins of LMA duration. - Normalization. - Statistics of the occurrence: typical occurrence in time of ISS-LIS events. High quality LMA flashes will be selected.	Statistics of the occurrence of ISS-LIS events. Distribution of ISS-LIS events within the LMA flashes (normalized). Results of categorization: - At initiation if ISS-LIS events occur within the first 10 ms. - During the flash. - At the end, if ISS-LIS events occur within the last 10 ms.

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3. Definition of the evaluation

Distribution of Events with height	- The duration of LMA flash is divided in 10 ms bins. - Altitudes of the LMA sources within 10 ms bins at the time of ISS-LIS events. - Statistics of the occurrence: typical LMA source height for ISS-LIS events. - Normalization by LMA tops. - Statistics of the occurrence: typical LMA source normalized height for ISS-LIS events. The range to consider will be: 100 km	Distribution of LMA heights at the time of ISS-LIS event location. Distribution of the normalized LMA heights at the time of ISS-LIS event location. Statistics of the LMA heights at the time of ISS-LIS event location.

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3. Definition of the evaluation

Relation of Events with lightning processes	- LMA, ISS-LIS events and CG are plotted together. - We manually identify the sources to occur according to the following process: ○ Regular negative leader (horizontal leader at <10^5 m/s) ○ Fast negative leader (horizontal leader (<10^5 m/s) ○ Regular positive leader (horizontal leader (10^4 m/s) ○ Recoil leader event. ○ Initial breakdown at the beginning of a flash. ○ Fast upward leader (jump) ○ Fast downward leader (jump) ○ CG. If it is necessary, raw data at a LMA station will be revised. High quality LMA flashes will be selected.	Percentages of events in each categorization.