1st Progress meeting: ISS LIS evaluation using LMA

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Outline

Introduction

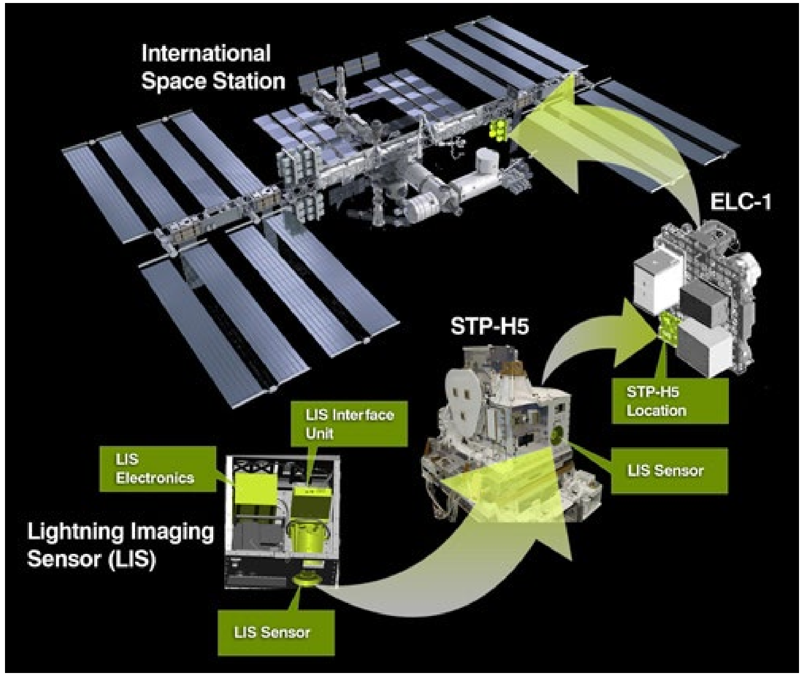
Brief summary: During the period from the kickoff to the present day we have been working preparing the dataset and its properties. We have been focused on the evaluation of the performance of the LMA and the decision of the target area to consider for the evaluation. Finally we have defined (to discuss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



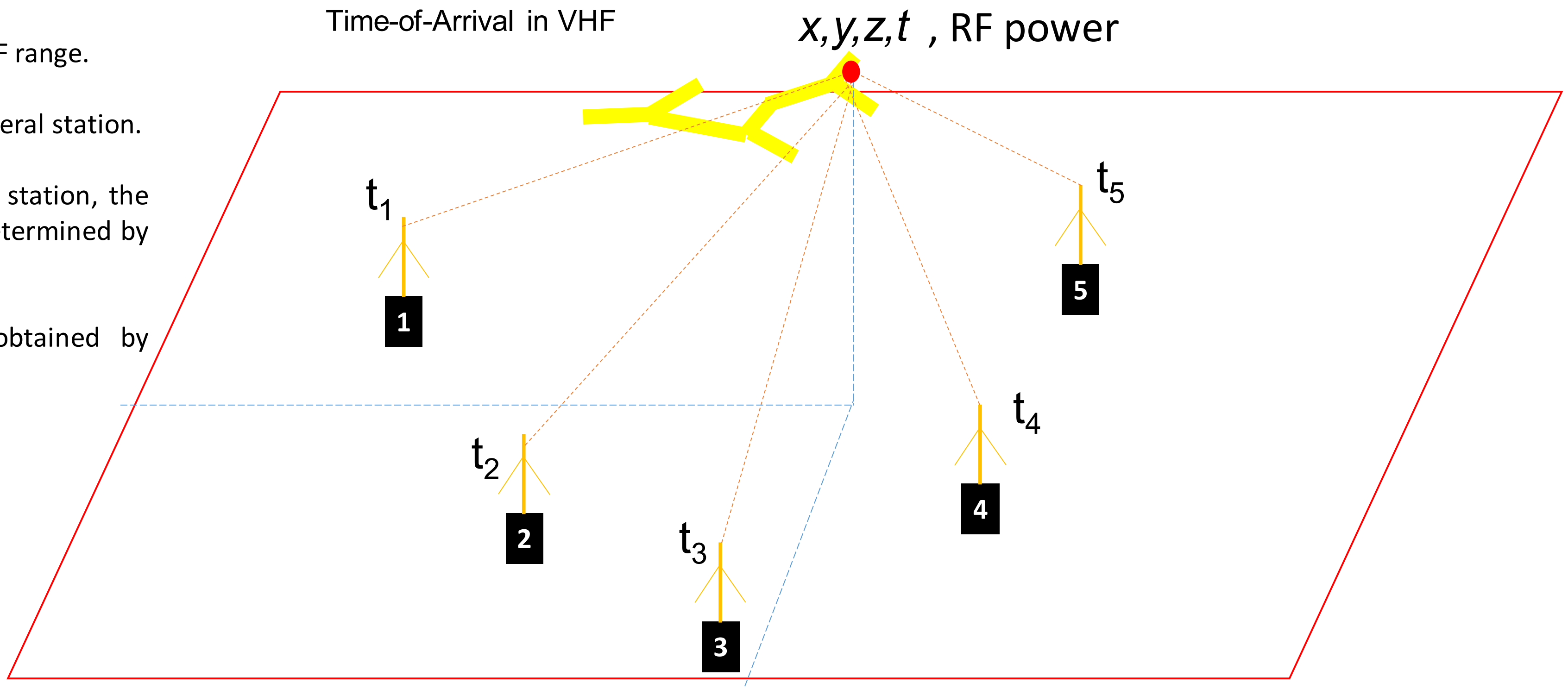
Field-of-View (FOV):	80°x80°
CCD Array Size:	128 x 180 pixels
Dynamic Range:	>100
Pixel IFOV :	4 km (nadir) to 8 km
Interference Filter wavelength:	777.4 nm
Filter bandwidth:	1 nm
Detection threshold:	4.7 $\mu J\ m^{-2}\ sr^{-1}$
Signal to noise ratio:	6
Detection Efficiency (DE)	~90 %
False Event Rate (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.



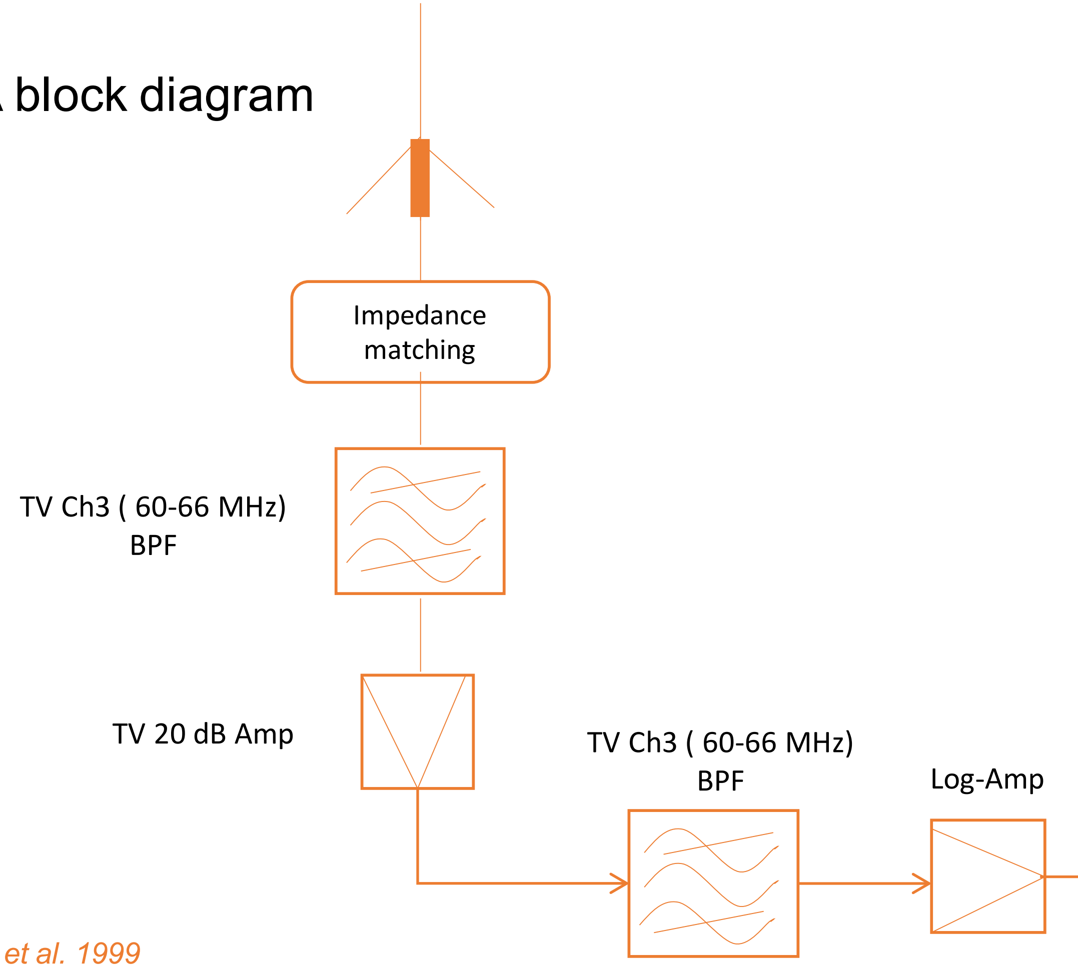
Proctor 1971, 1981, 1991
Proctor et al. 1988
Lennon and Maier 1991

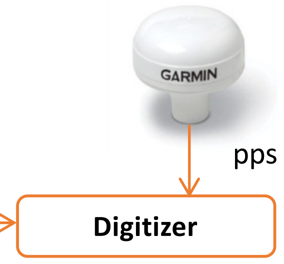
$$t_i = t + \frac{\sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2}}{c}$$

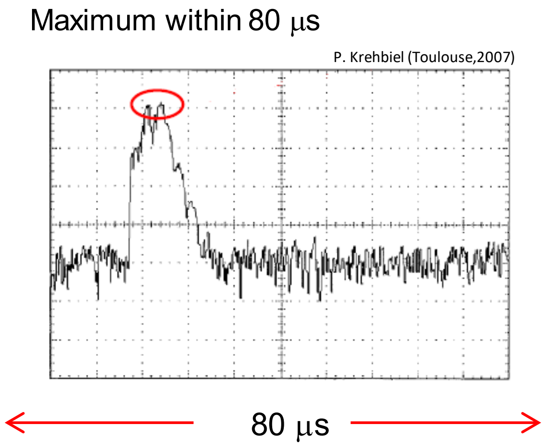
1. Technical description of the ISS-LIS and LMA

1.2 LMA

LMA block diagram







power: +10dB to -90 dB

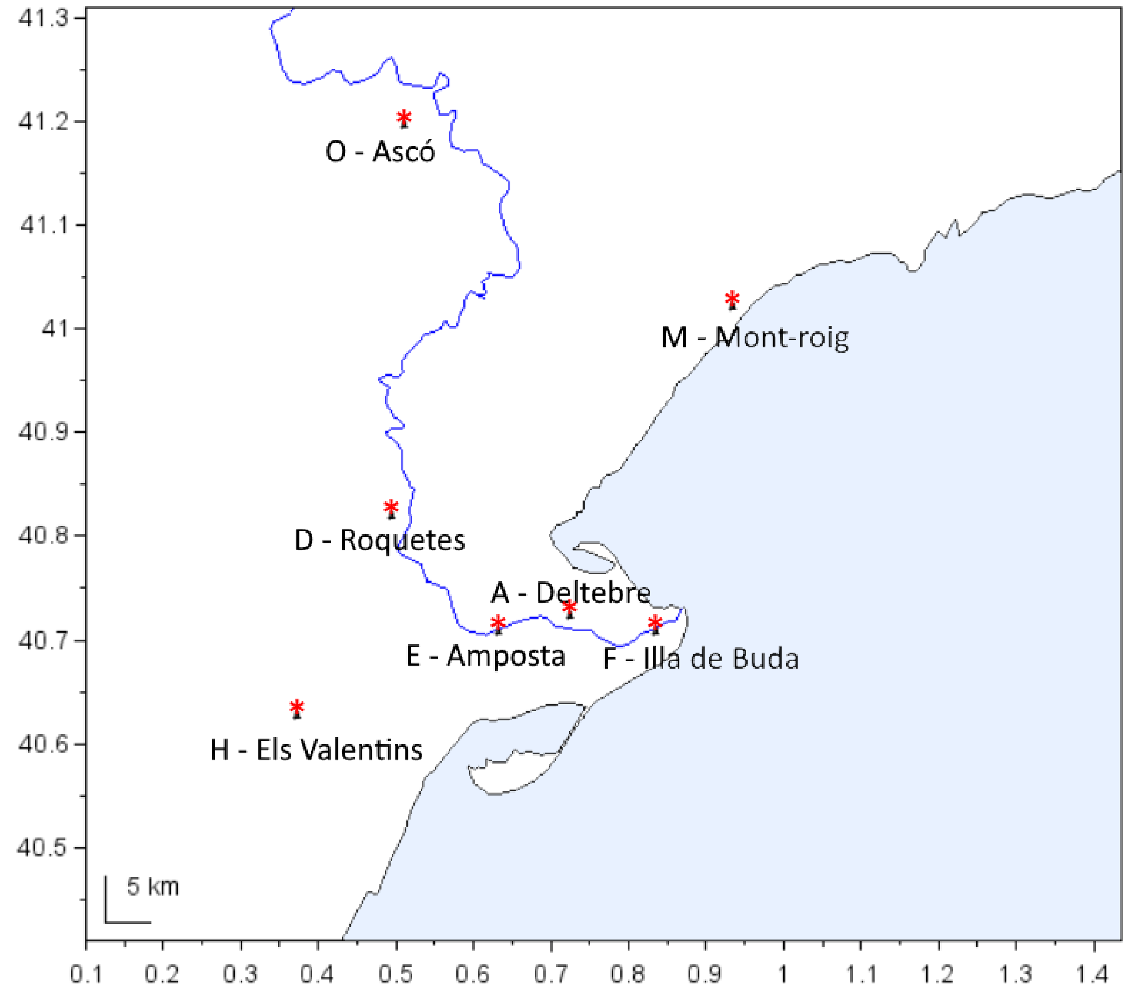
Rison et al. 1999
Thomas et al. 2004

- 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.

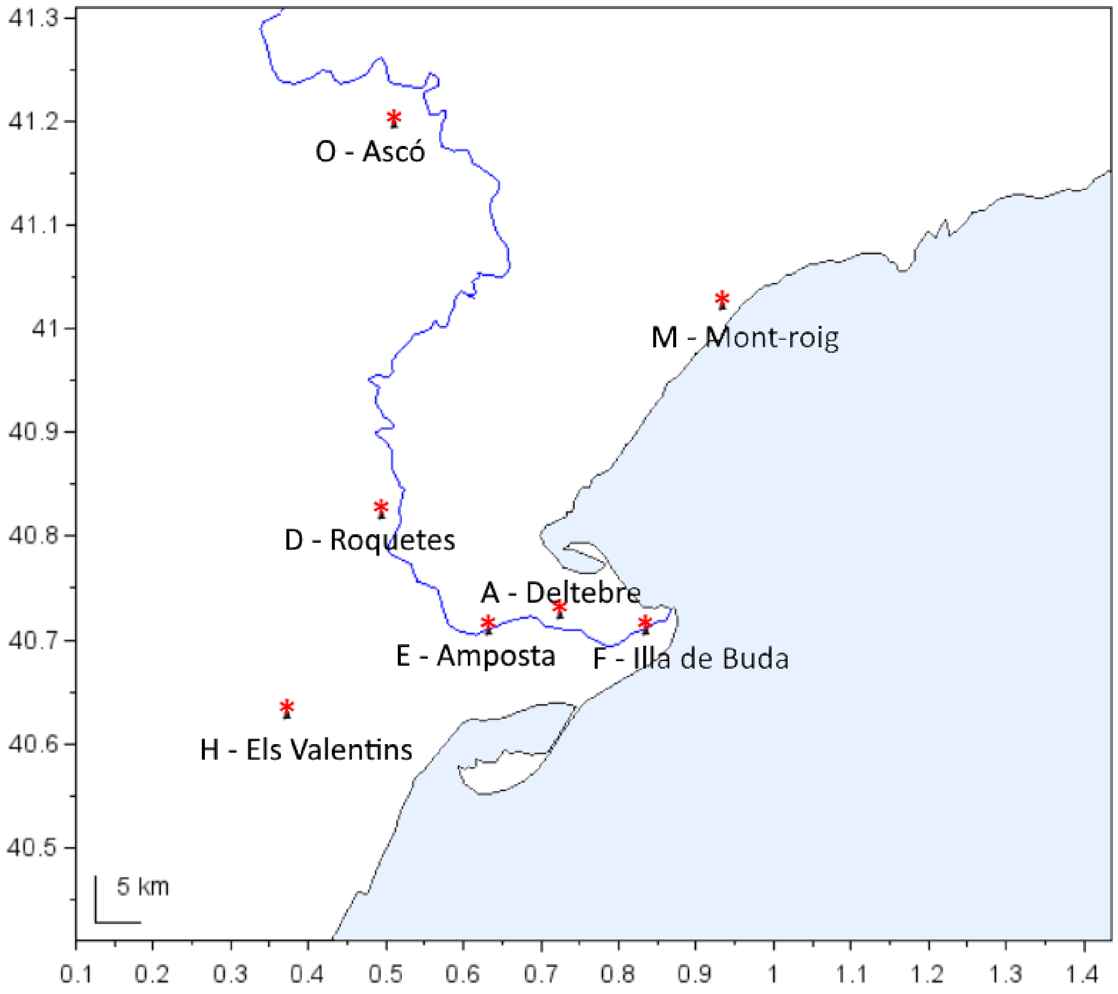
The processing has a few variables that control the output. The main ones are the number of stations used to compute locations, and the Chi-squared.

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.

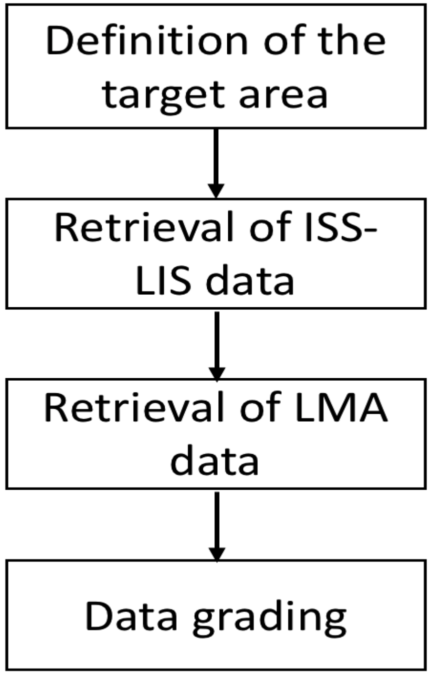
Some days the full network was running, but other days one or two stations may be unavailable. This affects the quality of mapping. Similarly, some stations may experience an increase of background noise. This reduces the number of solutions and can introduce noise which can cause radial artifacts which 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

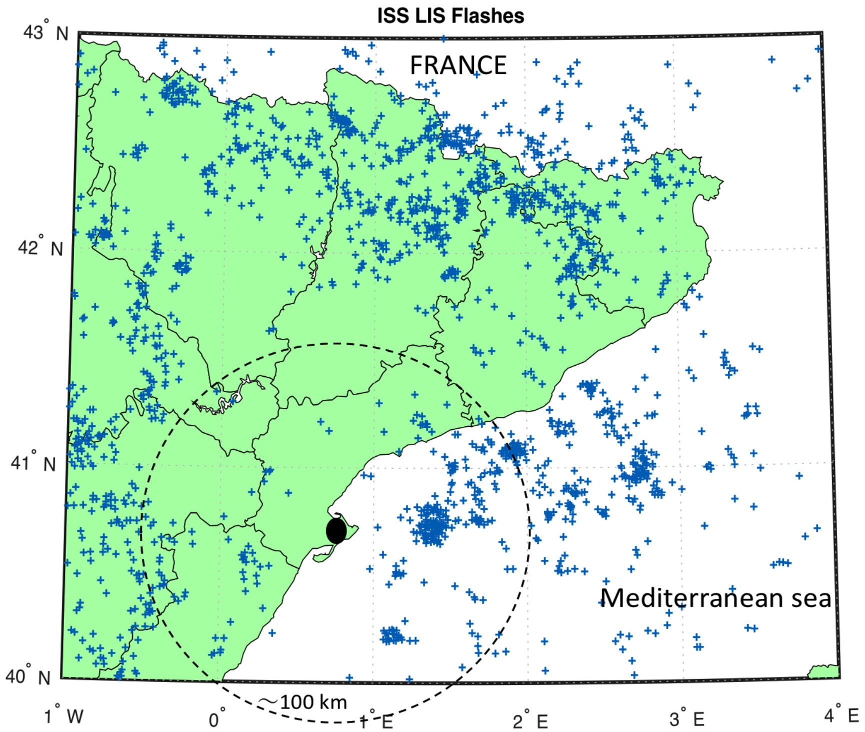
2.1 Methodology



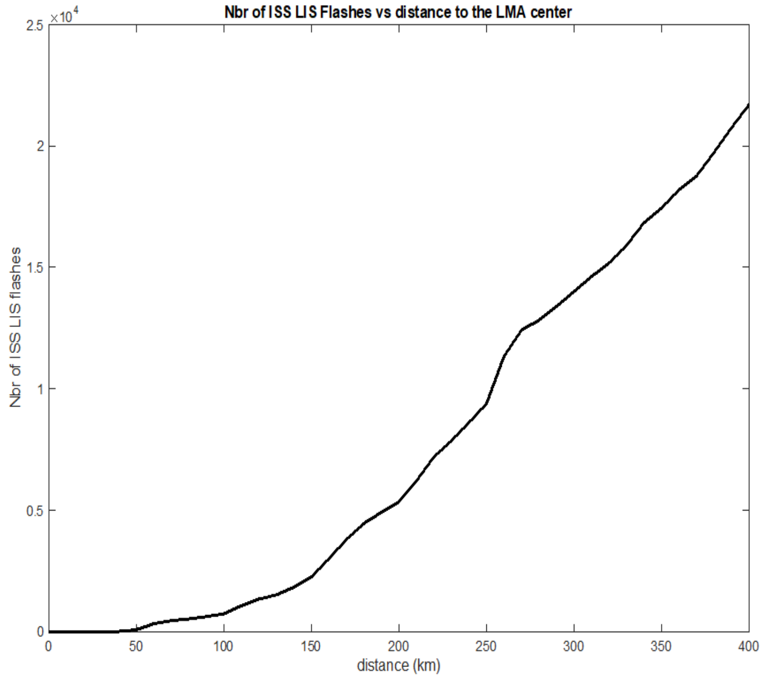
2. Data selection

2.2 Dataset

ISS-LIS flashes
(March 2017 – October 2018)



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

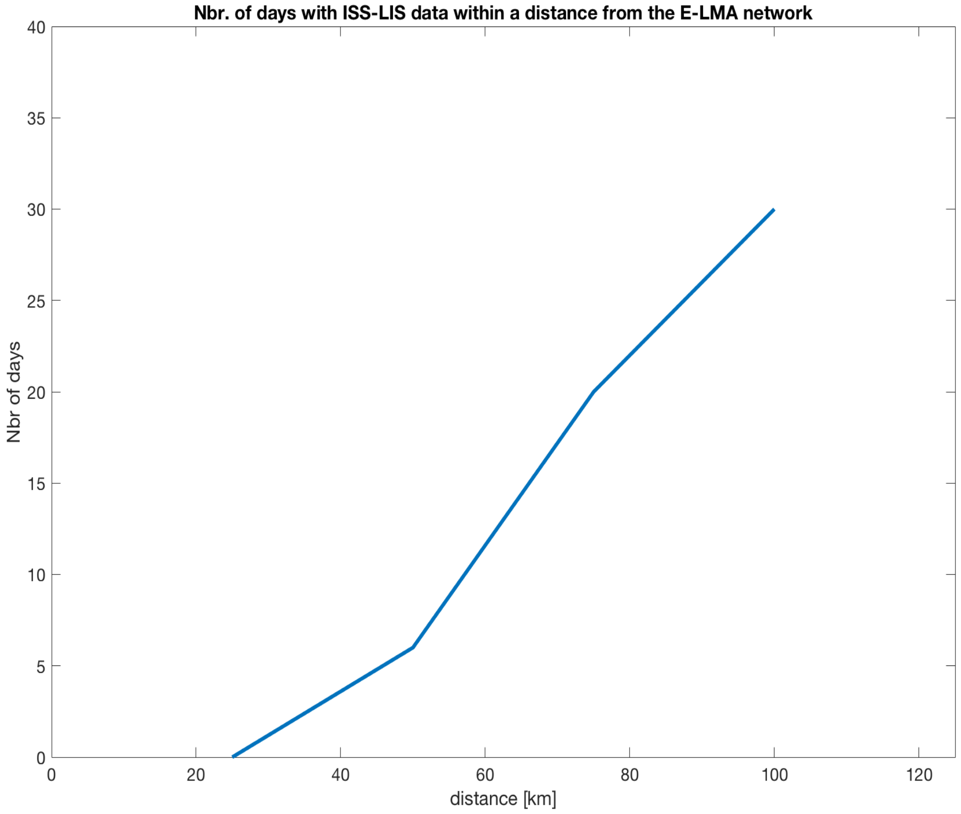


Distance to the center of the ELMA	Number of ISS-LIS flashes
25 km	0
50 km	76
75 km	495
100 km	738
125 km	1396
150 km	2256

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)



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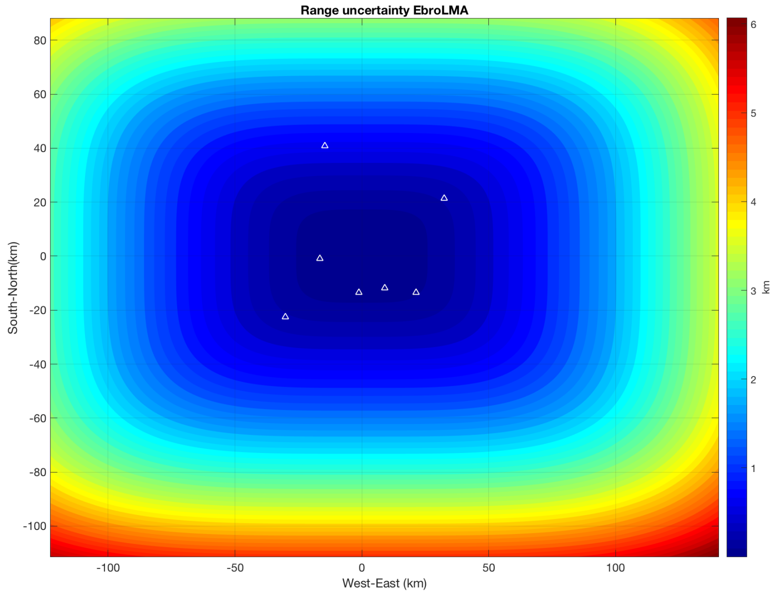
150 km	2256

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

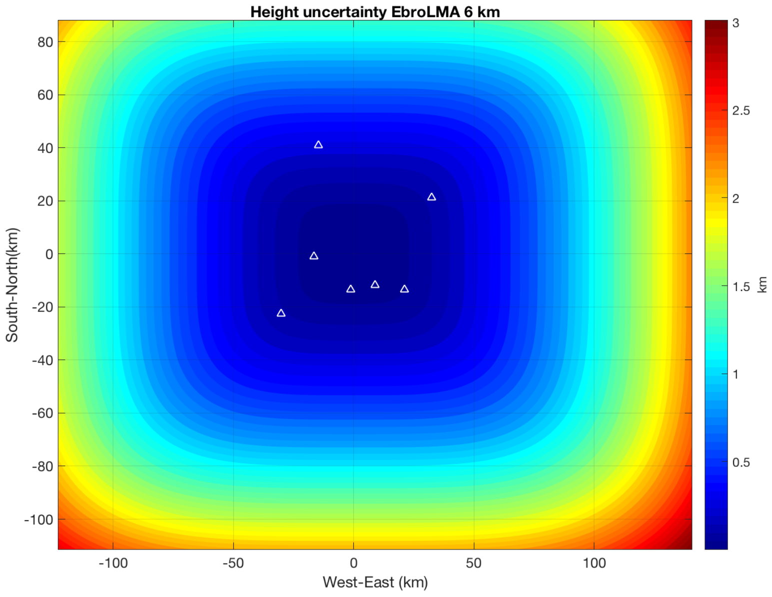
Theoretical location accuracy of the ELMA

X-Y



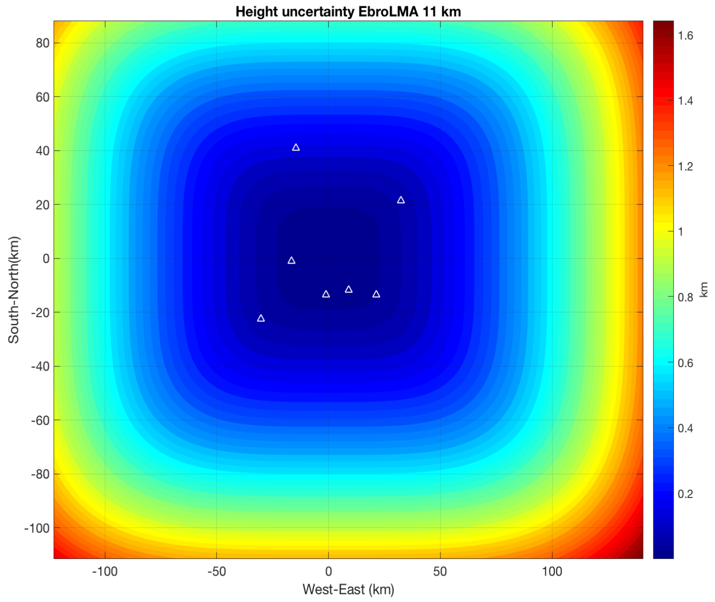
< 2 km within 100 km

Z at 6 km



< ~1 km within 100 km

Z at 11 km

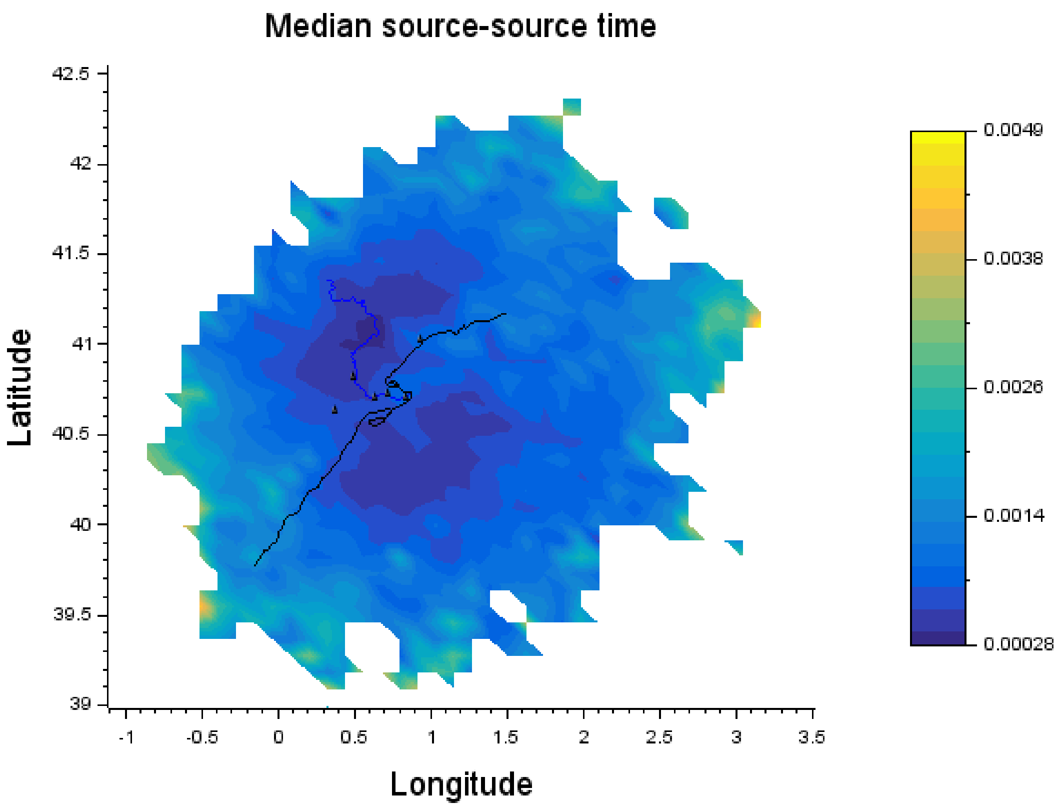


< 1 km within 100 km

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Median time between consecutive sources

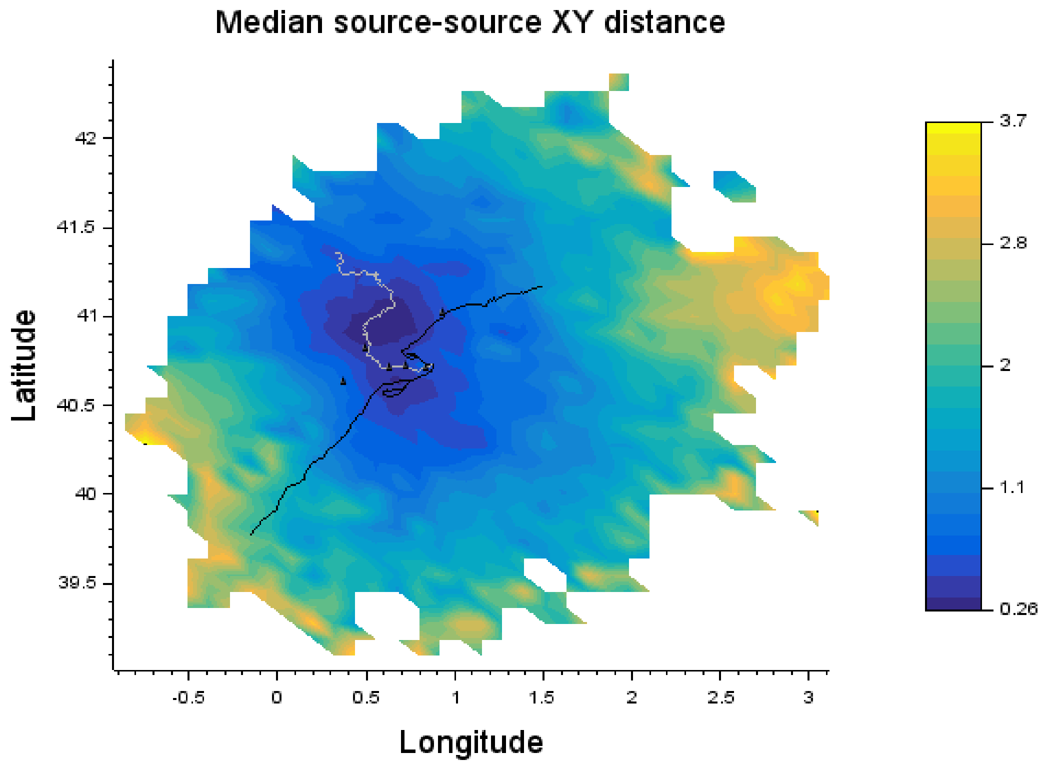


Lower intervals are better, as it represents the more dense mapping in time. It appears that two zones NW and SE of the Ebro Delta show the most favourable values. An axis from WSW to ENE is somewhat less good.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Median distance X-Y between consecutive sources



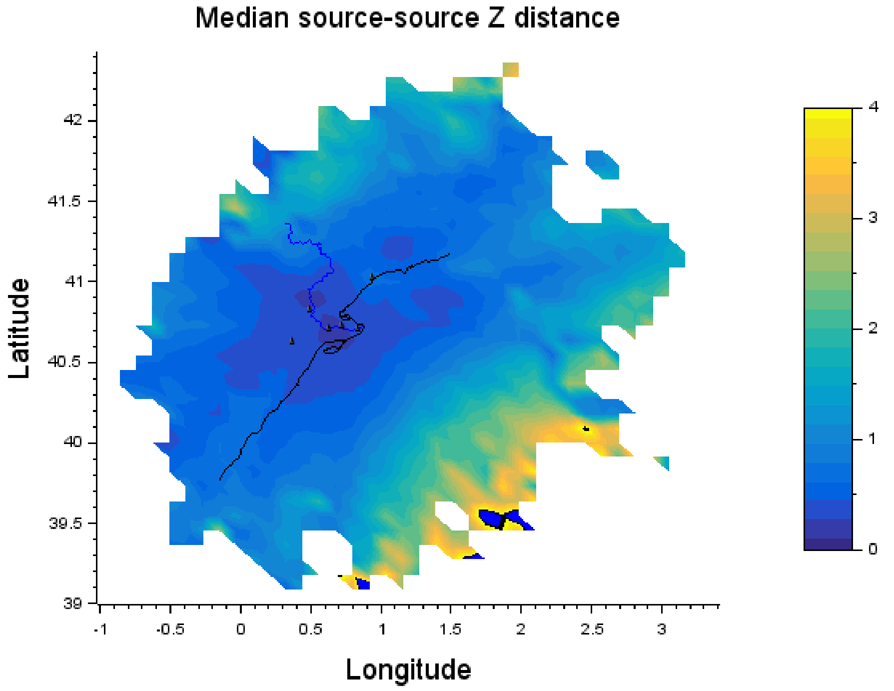
The horizontal scatter in the mapping of channels is minimized in an area from the Ebro Delta to the lower Ebro Valley, which is the region within the perimeter of the LMA stations with less than 500 m horizontal scatter.

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

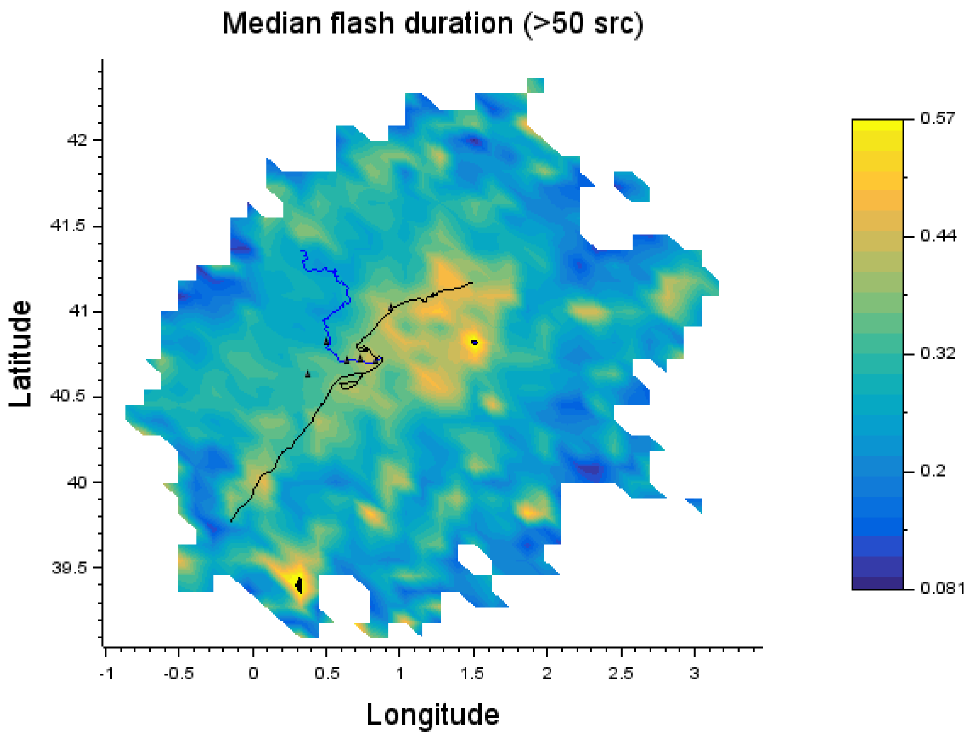


Vertical scatter is best right over the Ebro Delta, where several sensors are clustered. It deteriorates to 1.5-2.0 km scatter over the Mediterranean almost 100 km from the network center, similar to the northwest sector.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Median flash duration

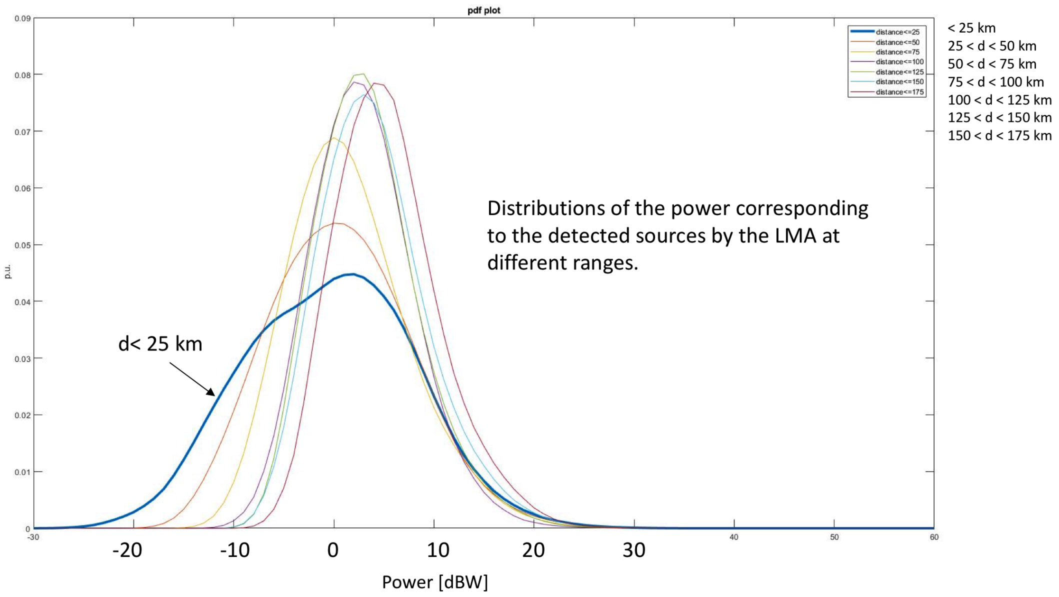


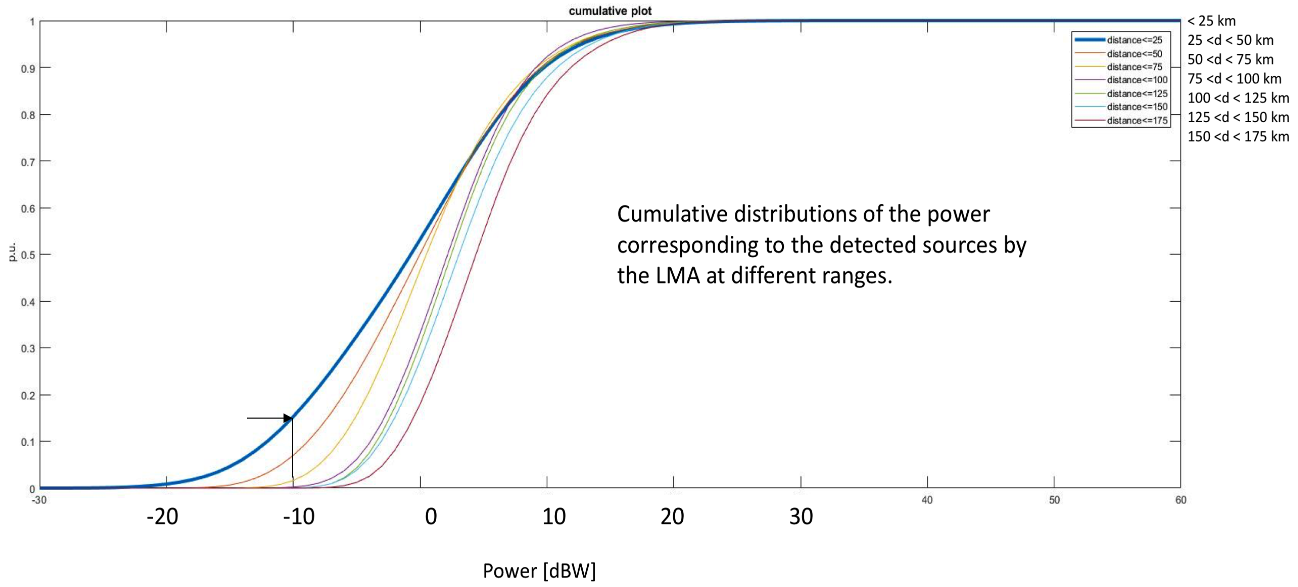
This map is showing more of a characteristic of the lightning flashes themselves, as the duration of a flash is less sensitive to the mapping quality. As result, the median flash duration cannot be used as a metric of the LMA performance.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

RF VHF Power

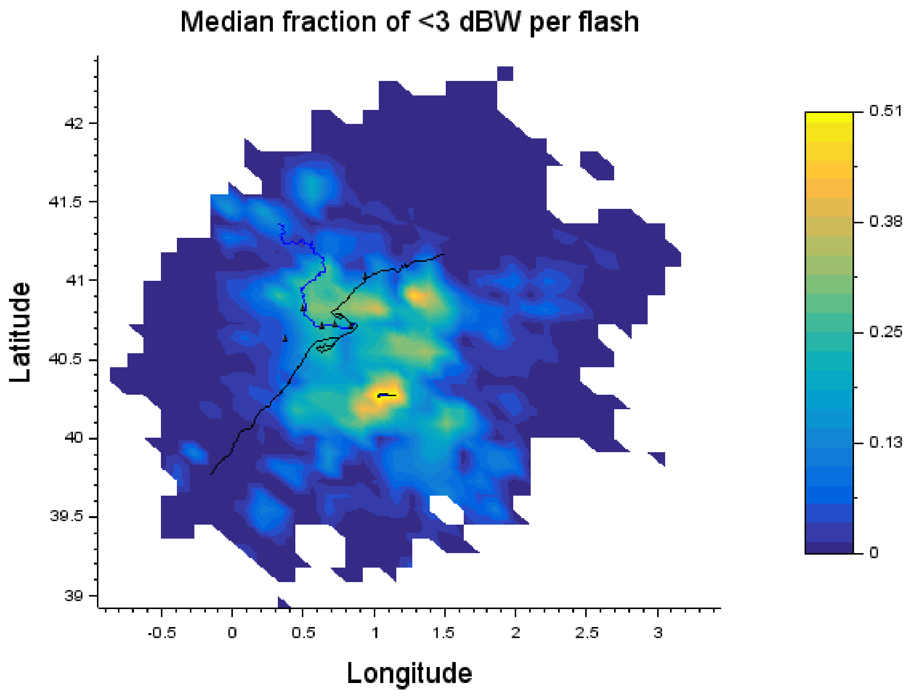


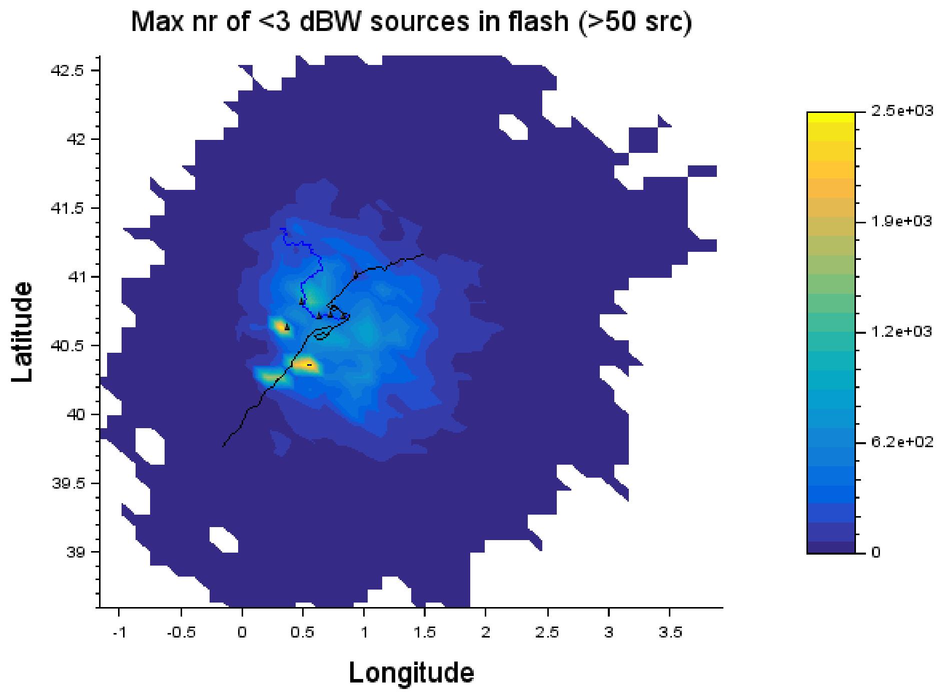


2. Data selection

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.

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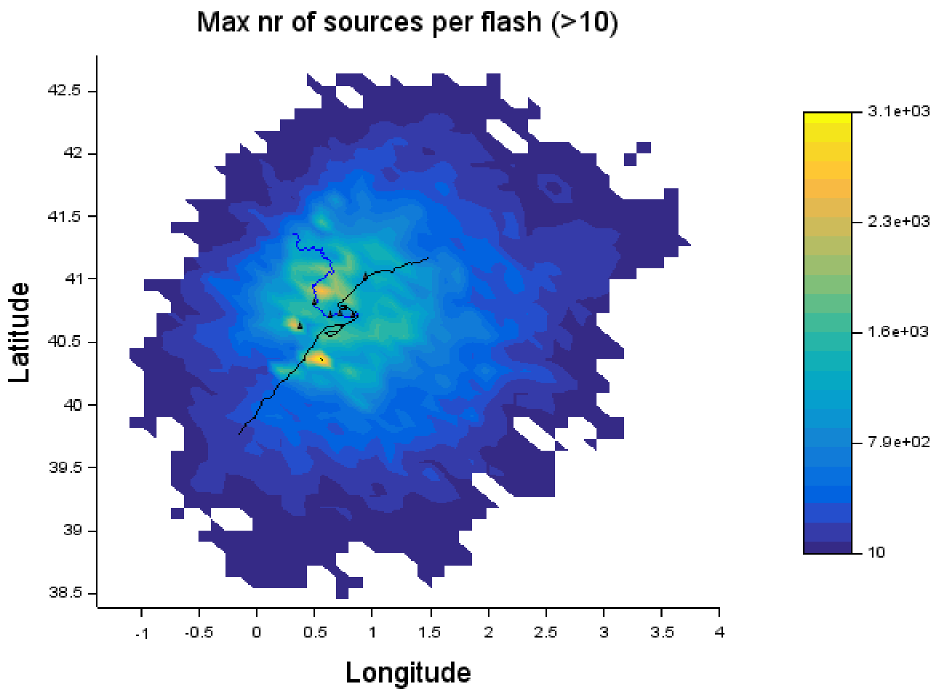
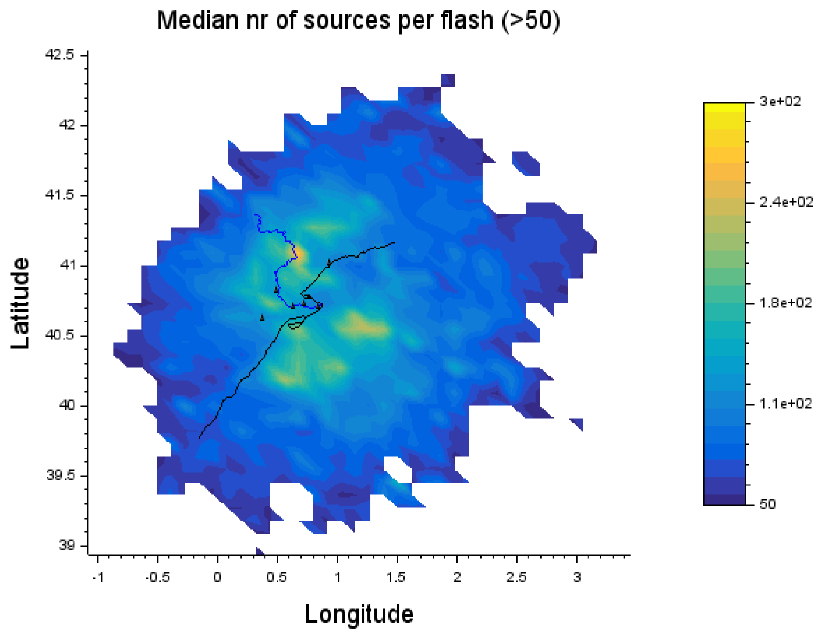
2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Number of sources per flash



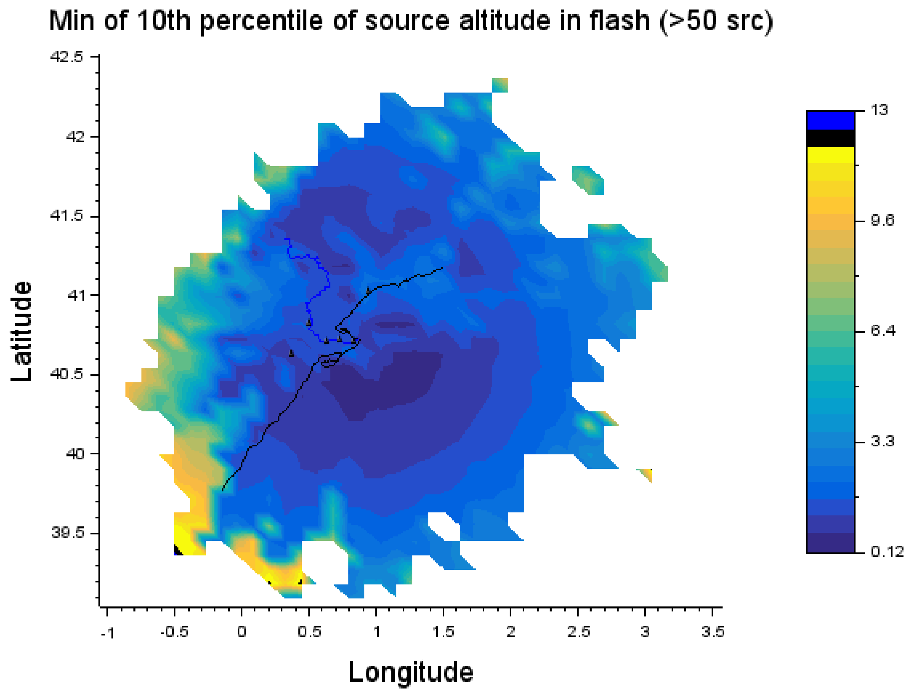


This map shows how many sources (per 10x10 km) can be detected at maximum. The closer the more detail can be provided, with zones of about 60 km radius, then 100 km, and beyond that, never more than a few hundred sources can be detected for a flash.

2. Data selection

2.3 Sensitivity analysis: performance of the LMA

Minimum source altitude

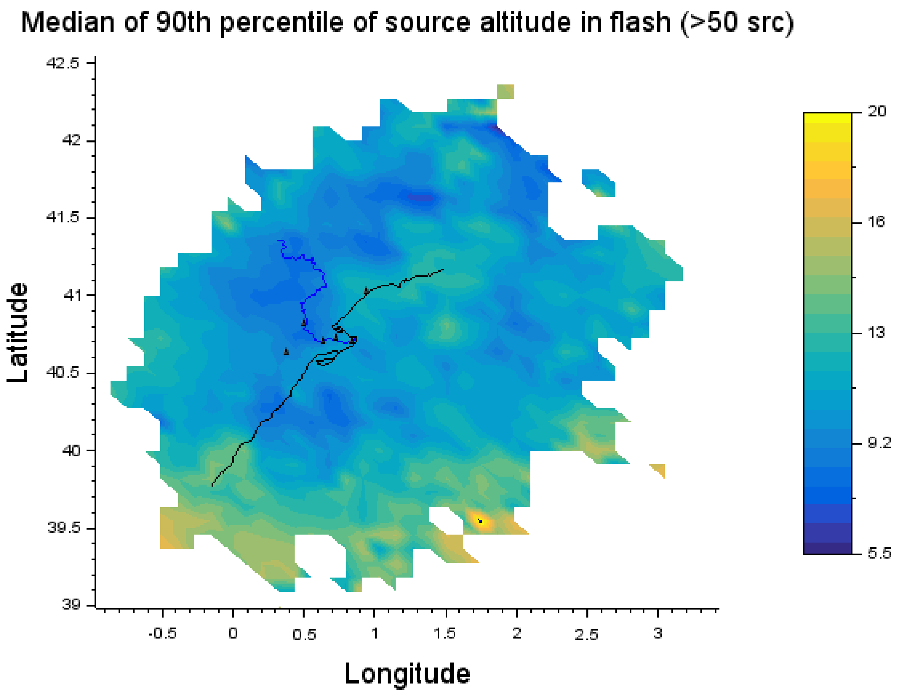


Here we see the absolute lowest source altitudes than can be seen by LMA. The circular part is due to horizon curvature. West and southwest are more blocked by mountains, while also the coast near Tarragona is more blocked for probably the westernmost stations.

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).

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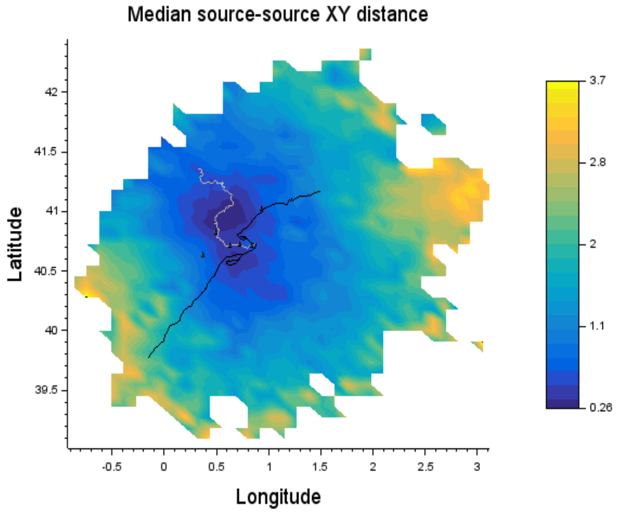
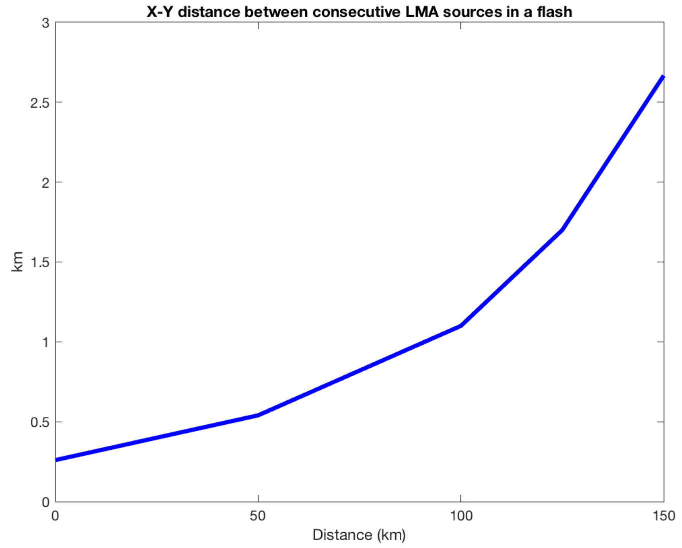
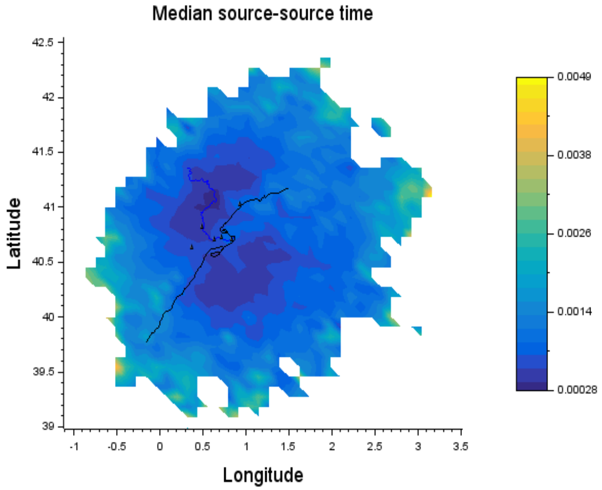
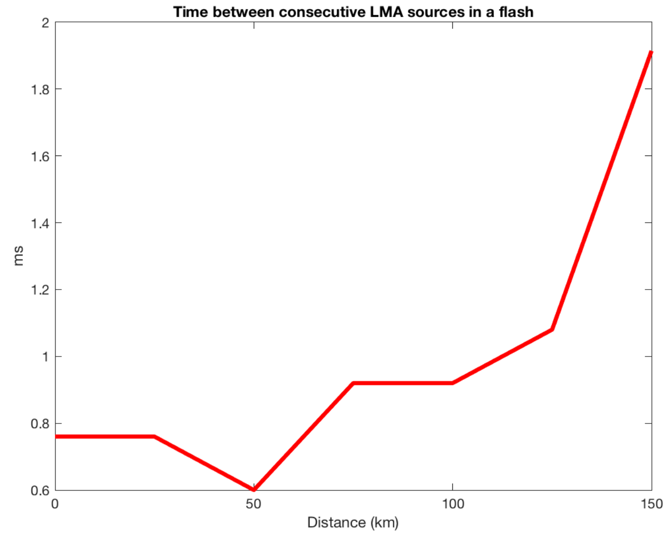
2. Data selection

2.3 Sensitivity analysis: Averaging of the LMA performance



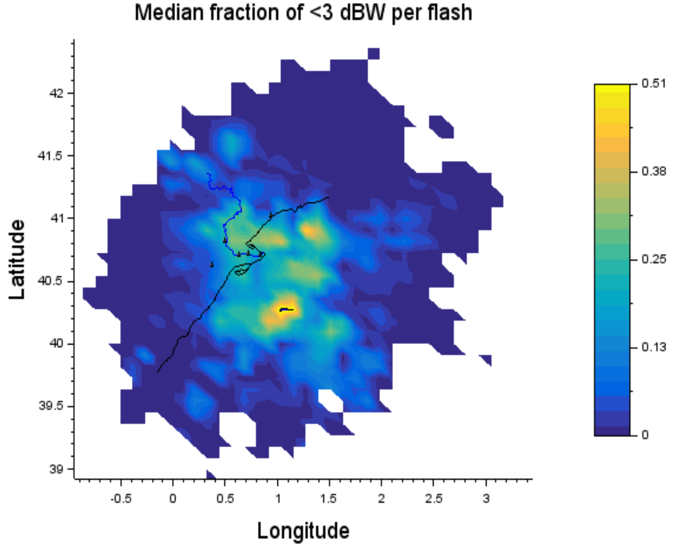


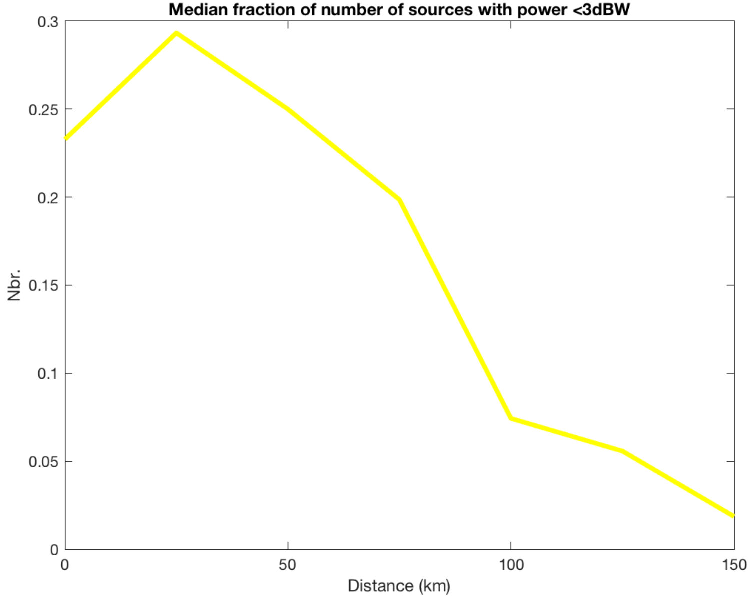


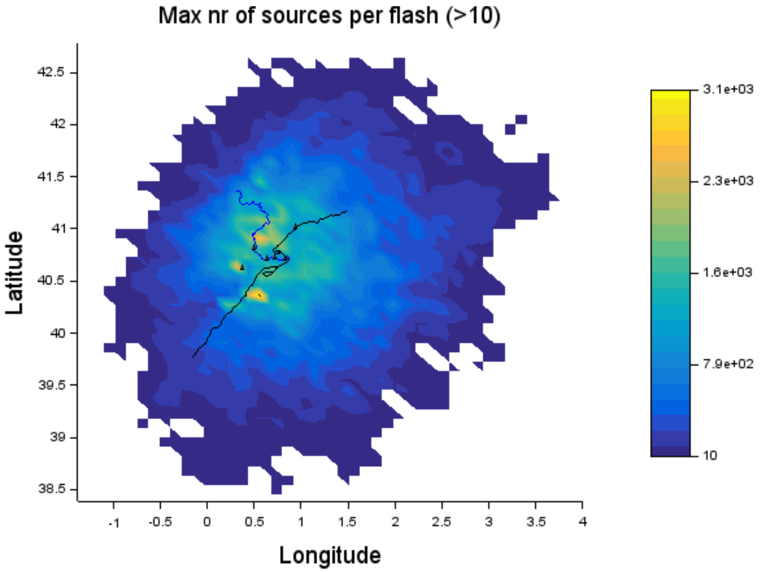


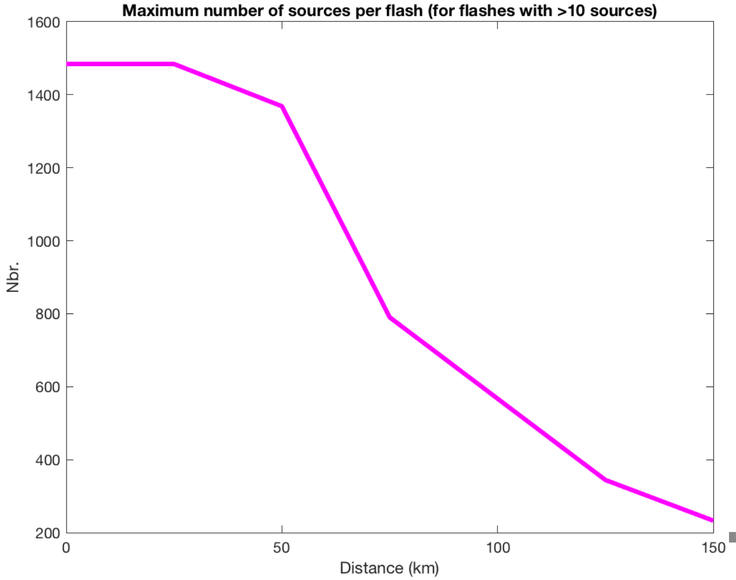
2. Data selection

2.3 Sensitivity analysis: Averaging of the LMA performance



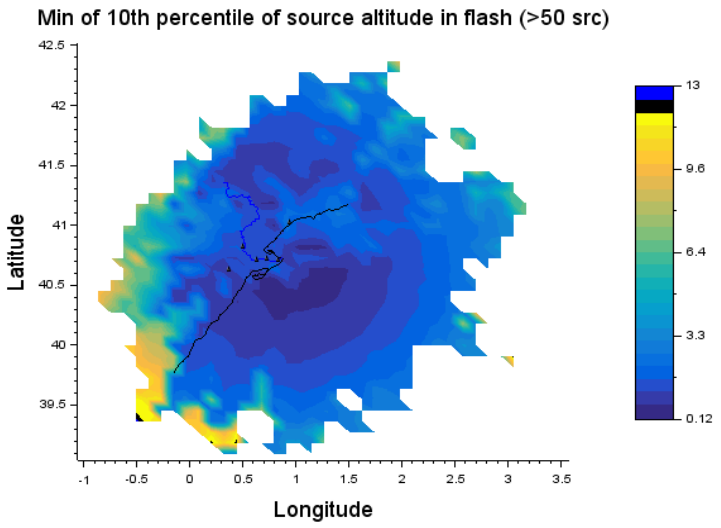


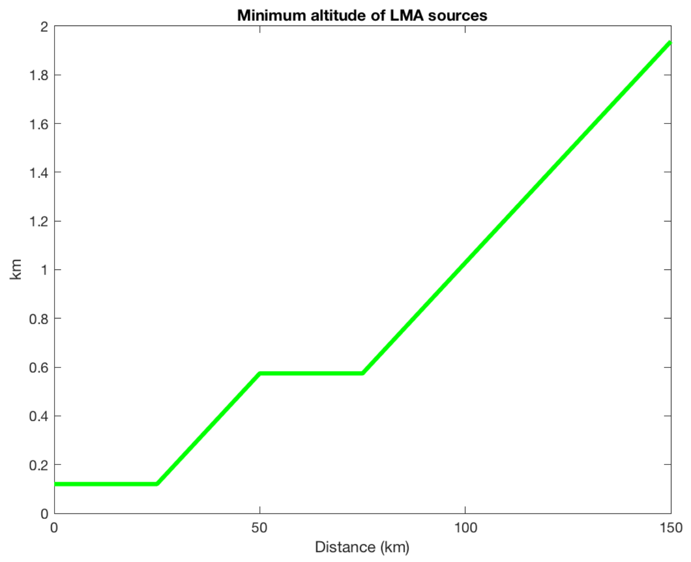


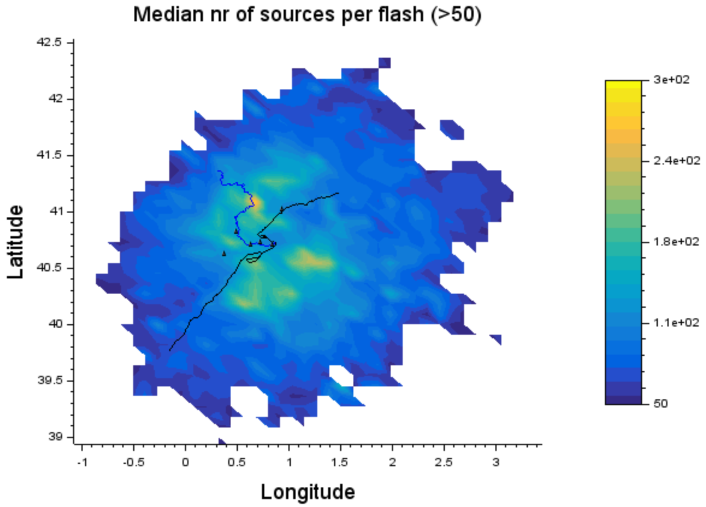


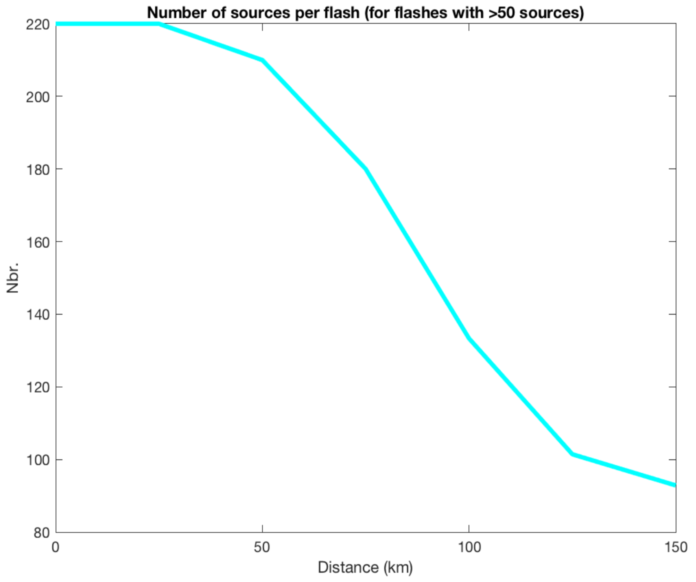
2. Data selection

2.3 Sensitivity analysis: Averaging of the LMA performance





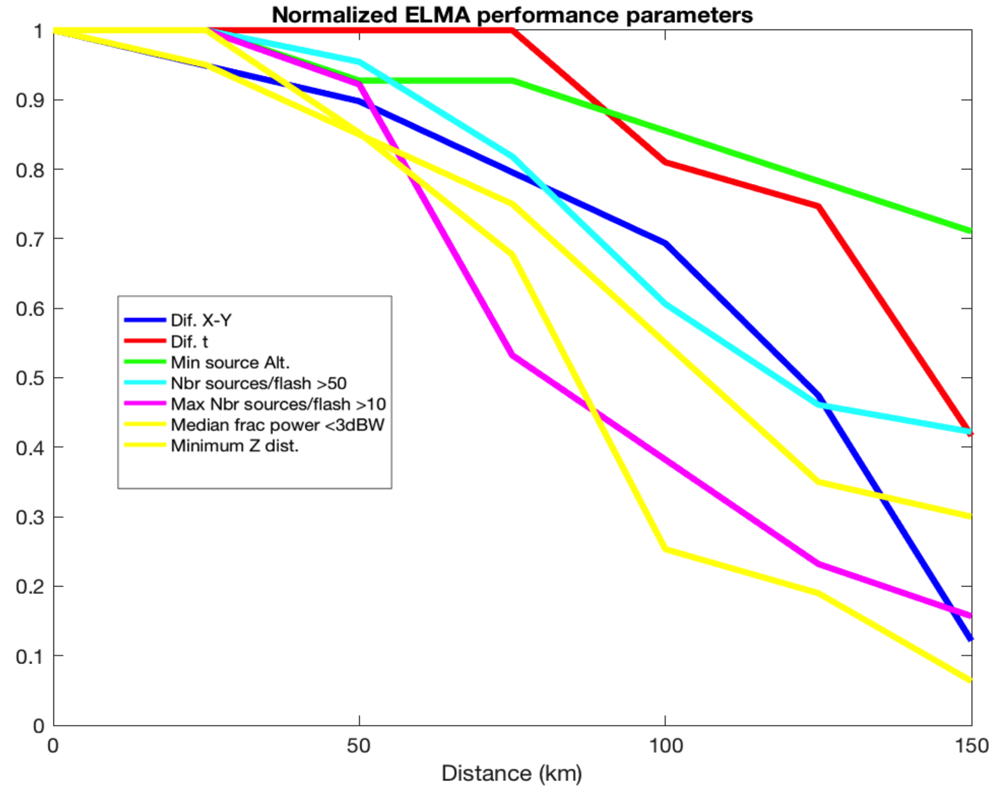




2. Data selection

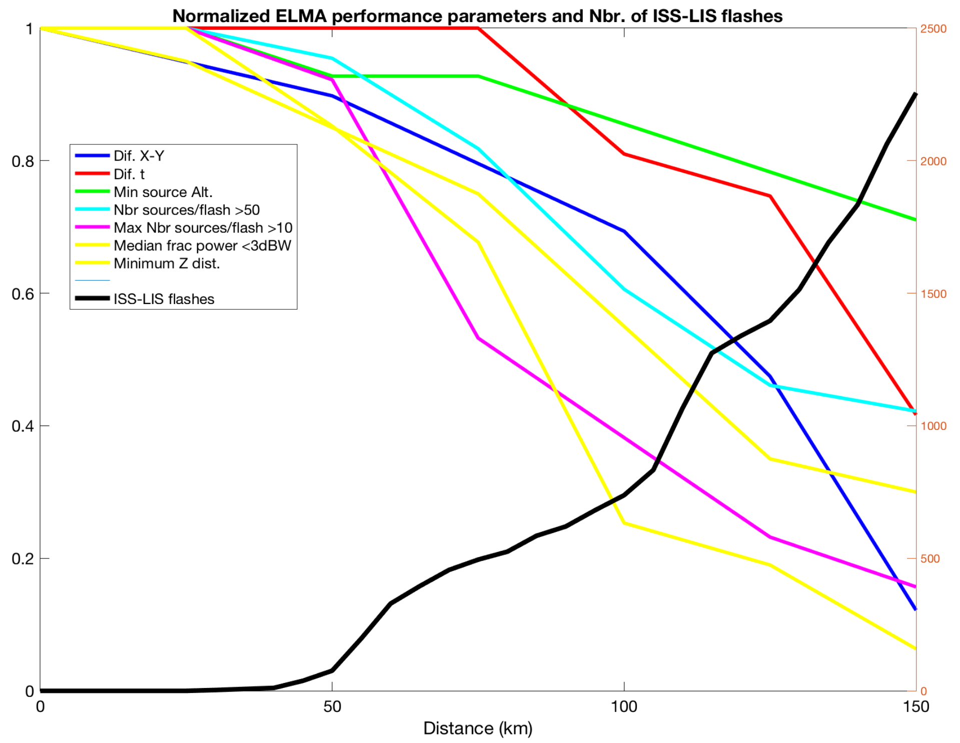
2.3 Sensitivity analysis: Averaging of the LMA performance

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

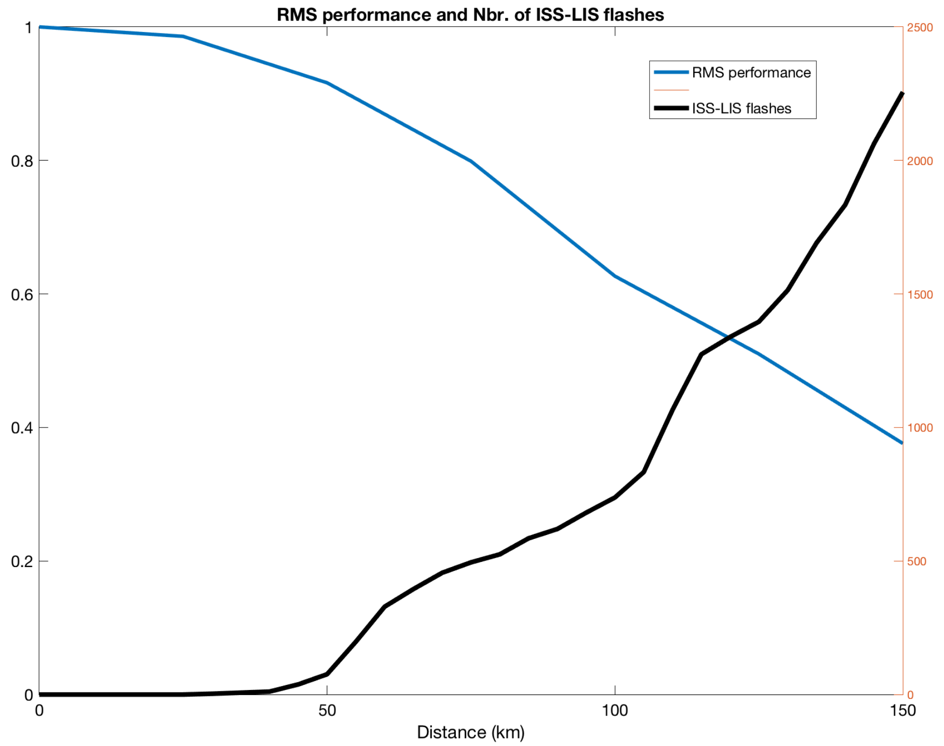


2. Data selection

2.3 Sensitivity analysis: Normalization and analysis

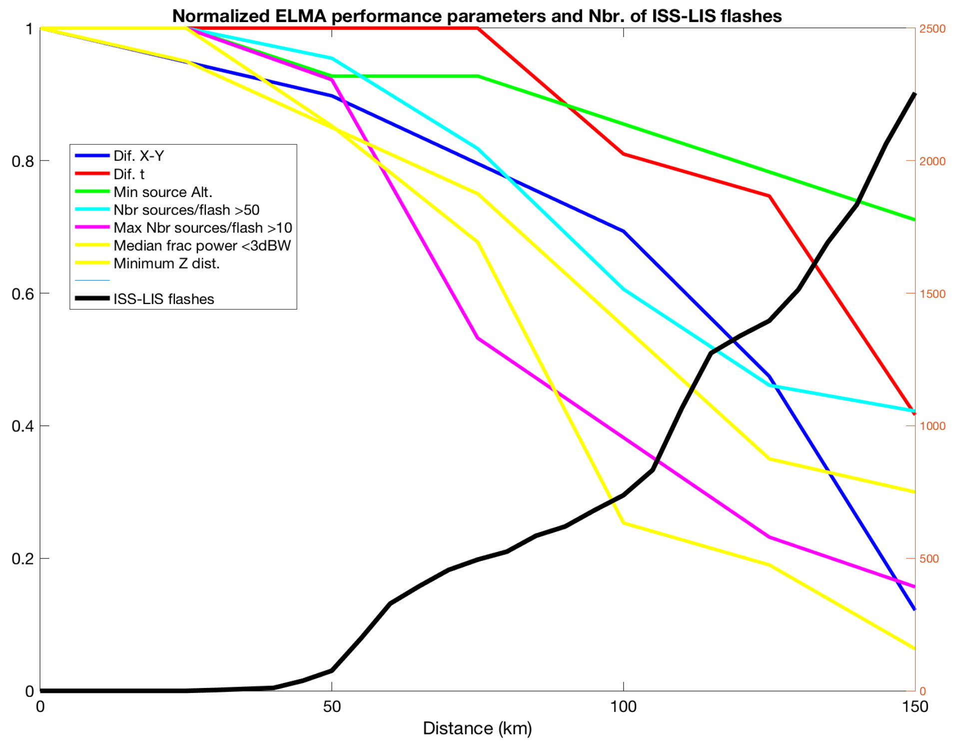


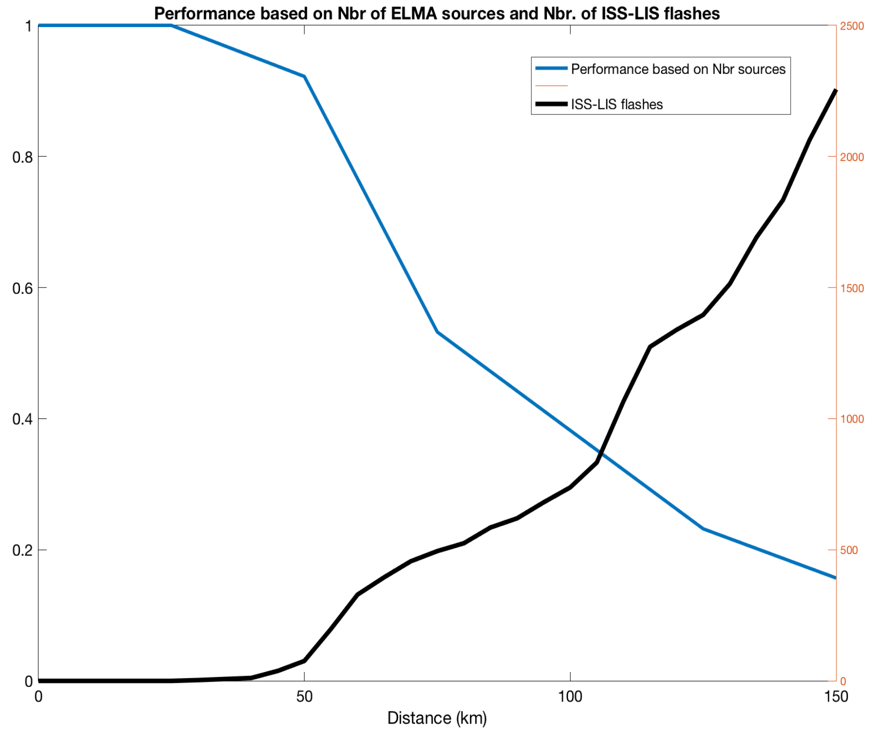
$$RMS = \sqrt{\frac{1}{N}\sum U_j^2}$$



2. Data selection

2.3 Sensitivity analysis: Analysis

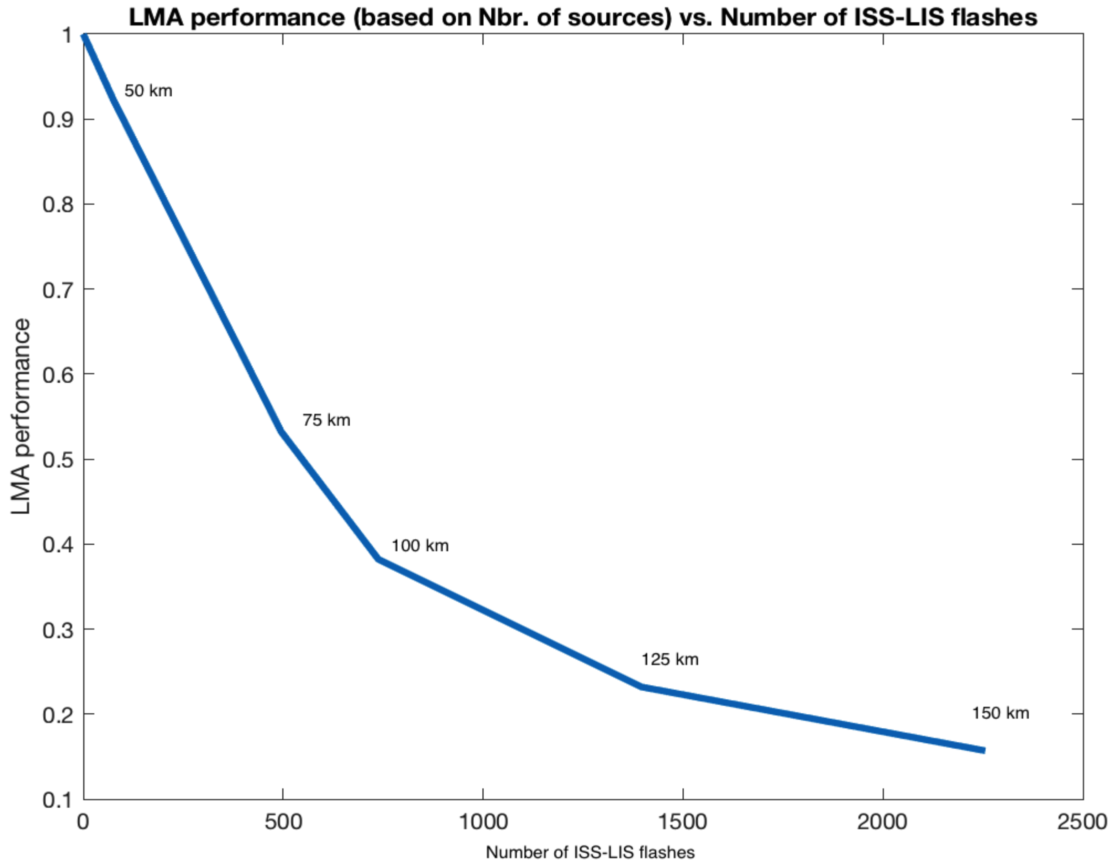




2. Data selection

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

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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
< 75 km	495	20170424	1	-	398
		20170628	7	-	
		20170708	1	-	(402 including data to be processed)
		20170917	4	-	
		20171018	20	20181018	
		20180427	4	20180427	
		20180429	2	20180429 NP	
		20180525	1	20180525 NP	
		20180605	1	20180605	
		20180613	1	20180613 NP	
		20180716	1	-	
		20180809	15	20180809	
		20180822	2	20180822	
		20180831	3	20180831	
		20180917	8	20180917	
		20180918	322	20180918	
		20181010	2	-	
		20181014	77	-	
		20181018	23	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
< 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,…..

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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) LMA noise reduction. Range <80 km	-Statistics of the flash size for ISS-LIS and LMA -Distribution of the size difference between same LMA flash and LIS event.

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.

3. Definition of the evaluation

Detection efficiency (DE)	A flash is detected by the ISS-LIS if there is at least N LMA sources during the duration of the flash defined by the ISS-LIS. N is certain number of sources per time and space interval. Verification of occurrence in the FOV of LIS. A flash is not detected by ISS-LIS if occurrs 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.

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.

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.

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Midterm meeting: ISS LIS evaluation using LMA

EUM/CO/18/4600002153/BV

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Outline

0. Introduction

1. Detection Efficency

2. Duration including the occurrence in time of the ISS-LIS events

3. Occurrence in LMA height and power of ISS-LIS events.

4. Location accuracy

Introduction

In this presentation we show the analysis carried out from the 1st Progress Meeting to the Midterm Meeting (today).

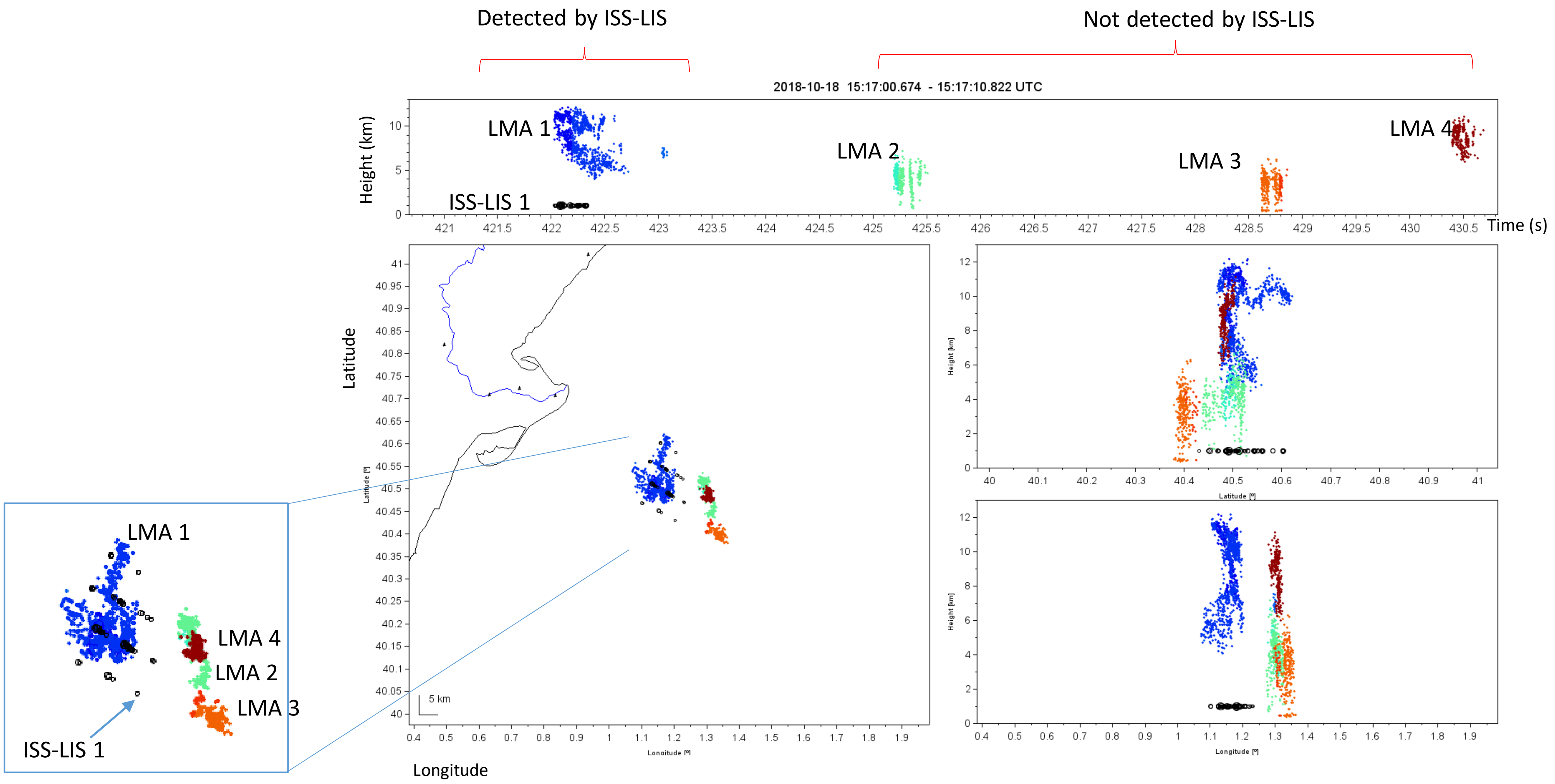
At this phase of the study we have evaluated the performance of the ISS-LIS based on the Lightning Mapping Array.

Detection efficiency, location accuracy and flash duration are the main parts of this study.

Moreover the occurrence of ISS-LIS events in time within a flash, in height and VHF power has been investigated.

Detection Efficiency

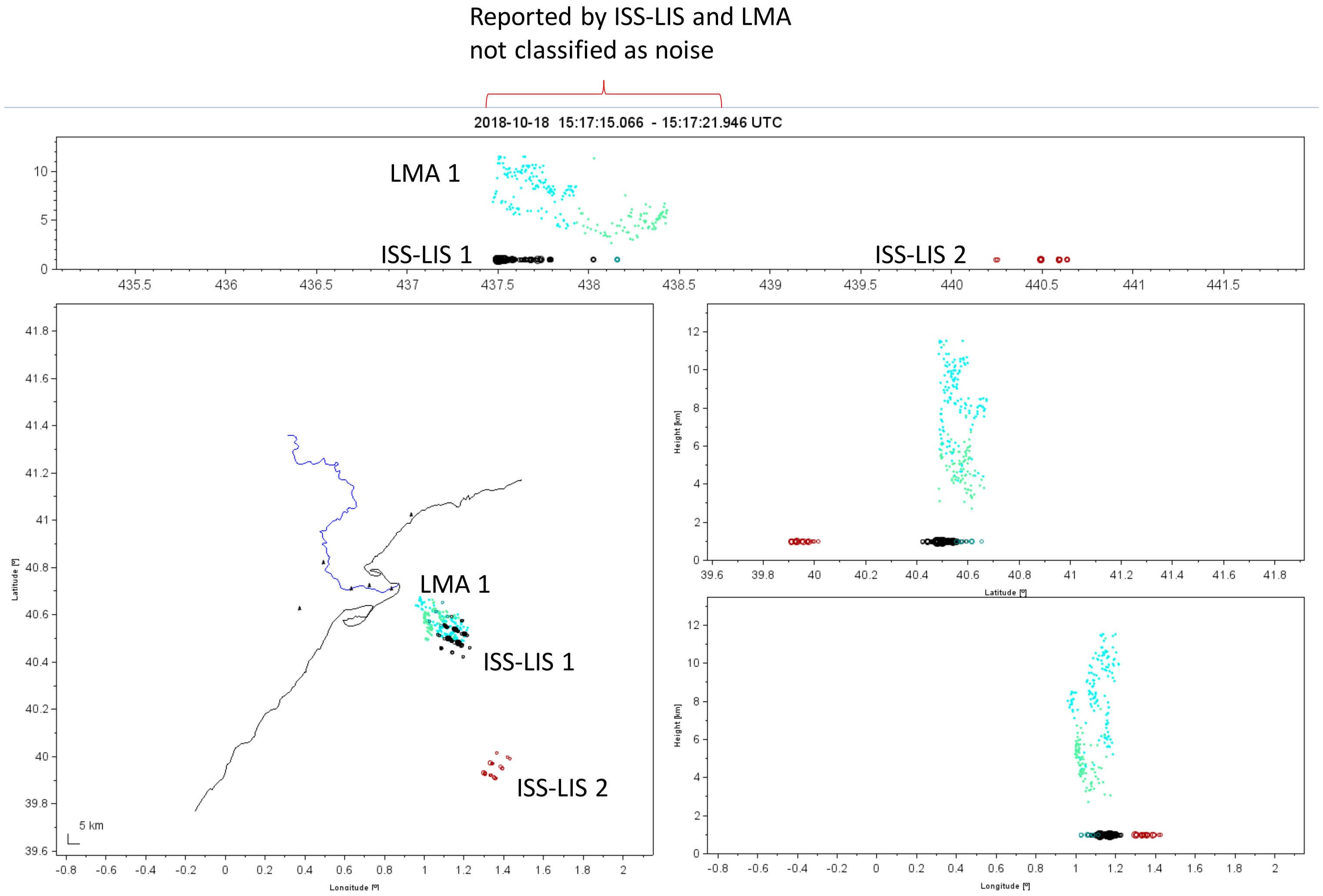
An ISS-LIS flash is detected if it matches in time with an LMA flash in the FOV of ISS-LIS.



IMPORTANT:
In this case all the LMA flashes are identified as good quality flashes (not noise). So these flashes have an ID.

Detection Efficiency

But it can happen that ISS-LIS detected a flash which has no correspondence to a LMA flash not classified as noise.

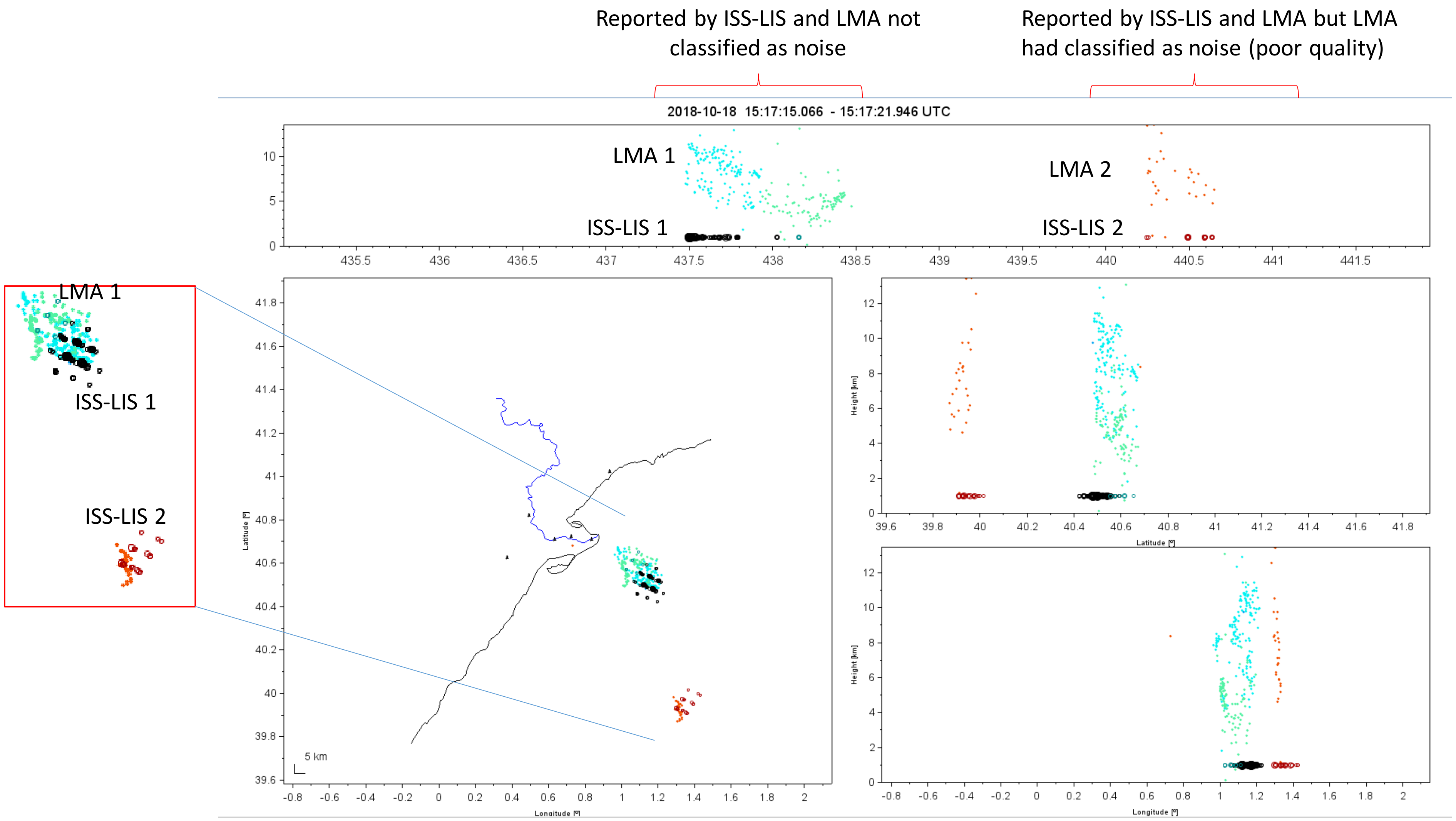


In this case, the flash at 440 s has not an LMA flash with enough quality.

Commonly this is due to the distance of the flash to the LMA network,

When that happens, LMA sources classified as noise are included (next slide)

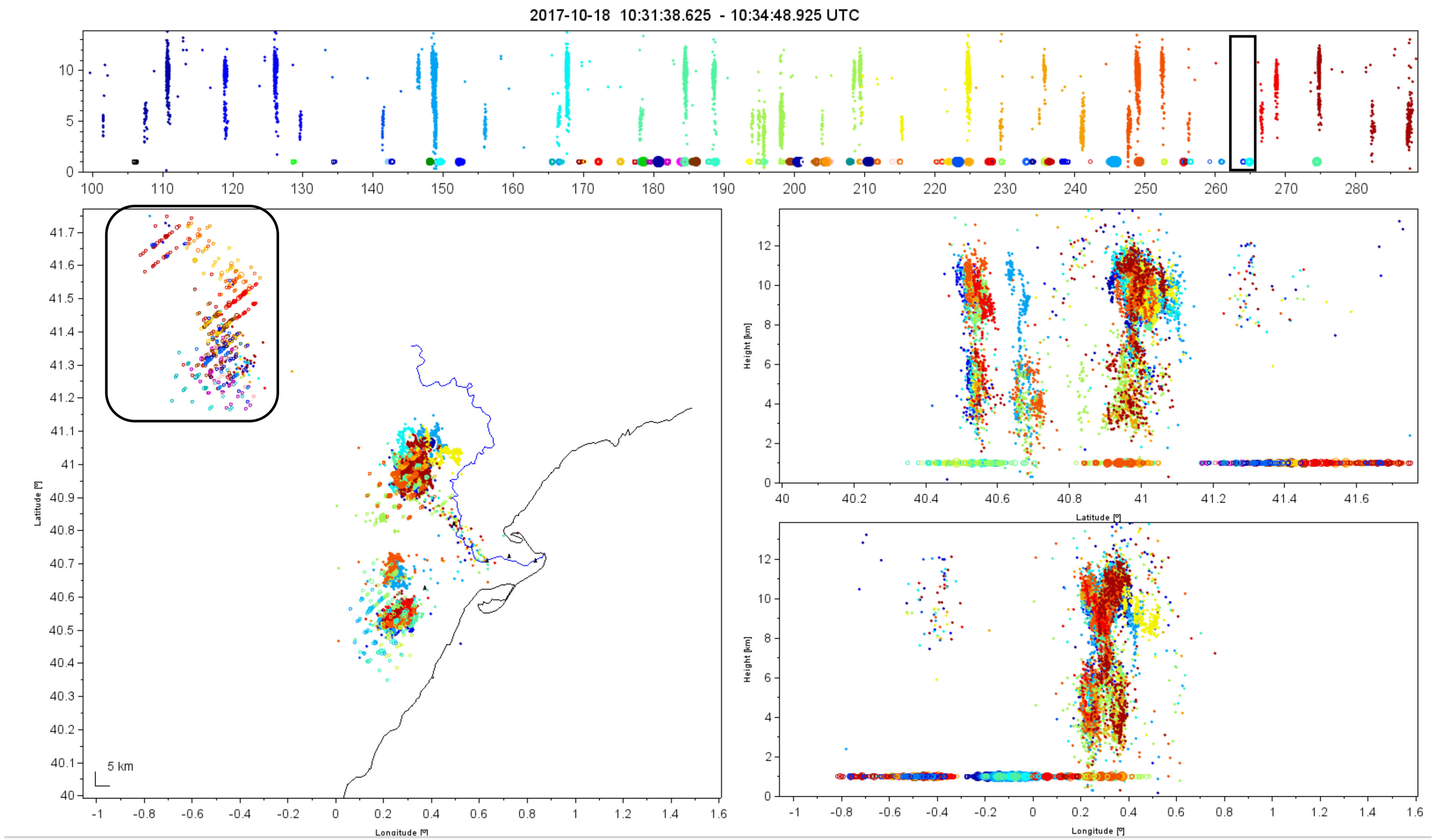
Detection Efficiency



In this case, the LMA flash has not an specific ID. But this flash is considered for the DE.

Detection Efficiency

Another situation might happen for distant ISS-LIS flashes in ‘bad’ directions for the LMA: ISS-LIS can report a flash that has not a LMA correspondence including those LMA sources classified as noise.



These cases do not affect to the DE of the ISS-LIS but are used as a quality indicator of the episode.

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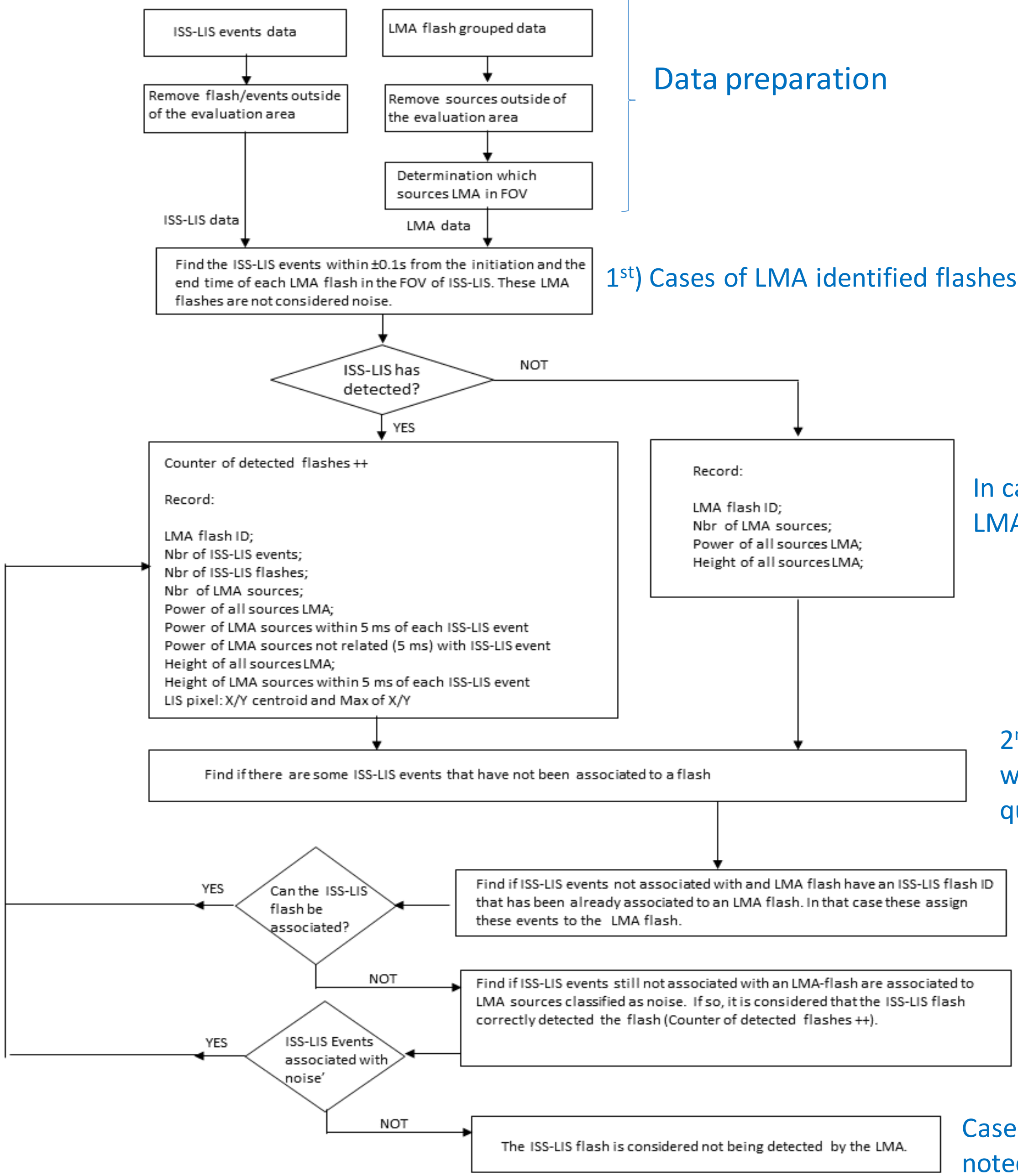


Data preparation

1st) Cases of LMA identified flashes (good quality)

In case ISS-LIS do not detect a LMA flash.

2nd) Treatment for the ISS-LIS events/flashes with no correspondence with a LMA good quality flash.

ISS-LIS events that belong to a ISS-LIS flash already correlated with a LMA flash.

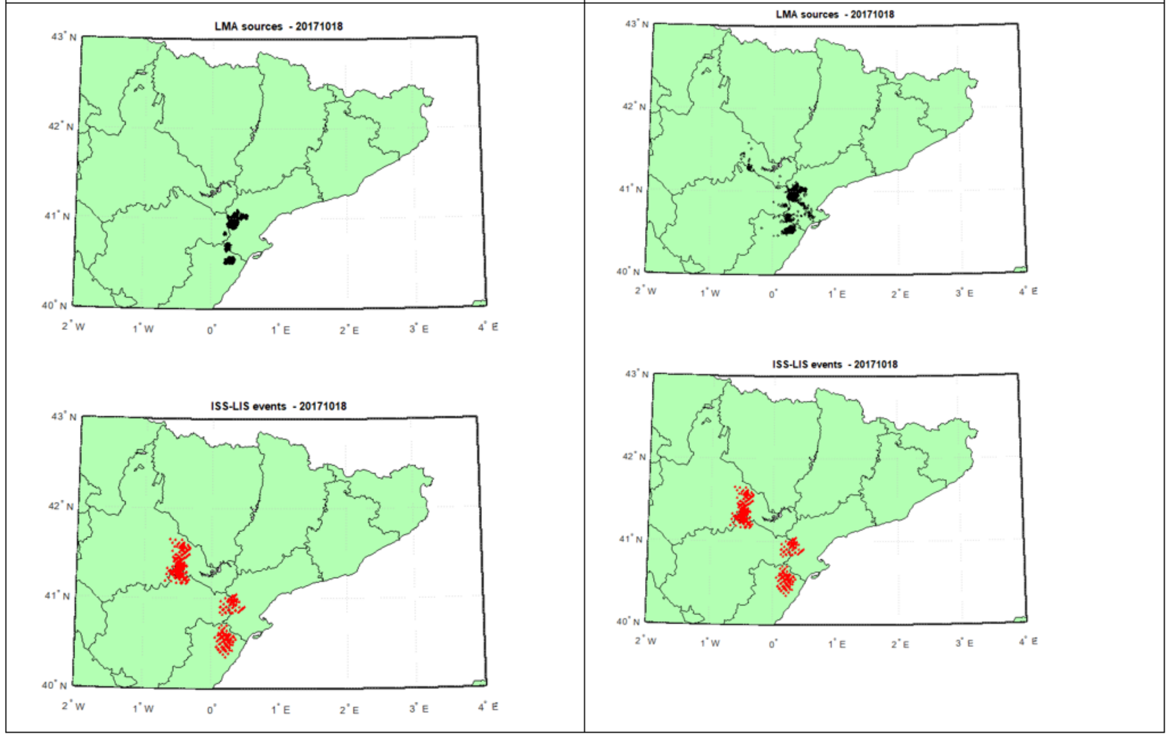
ISS-LIS flashes that match with LMA sources classified as 'noise'.

Case of ISS-LIS flashes missed by LMA (just noted for quality purposes)

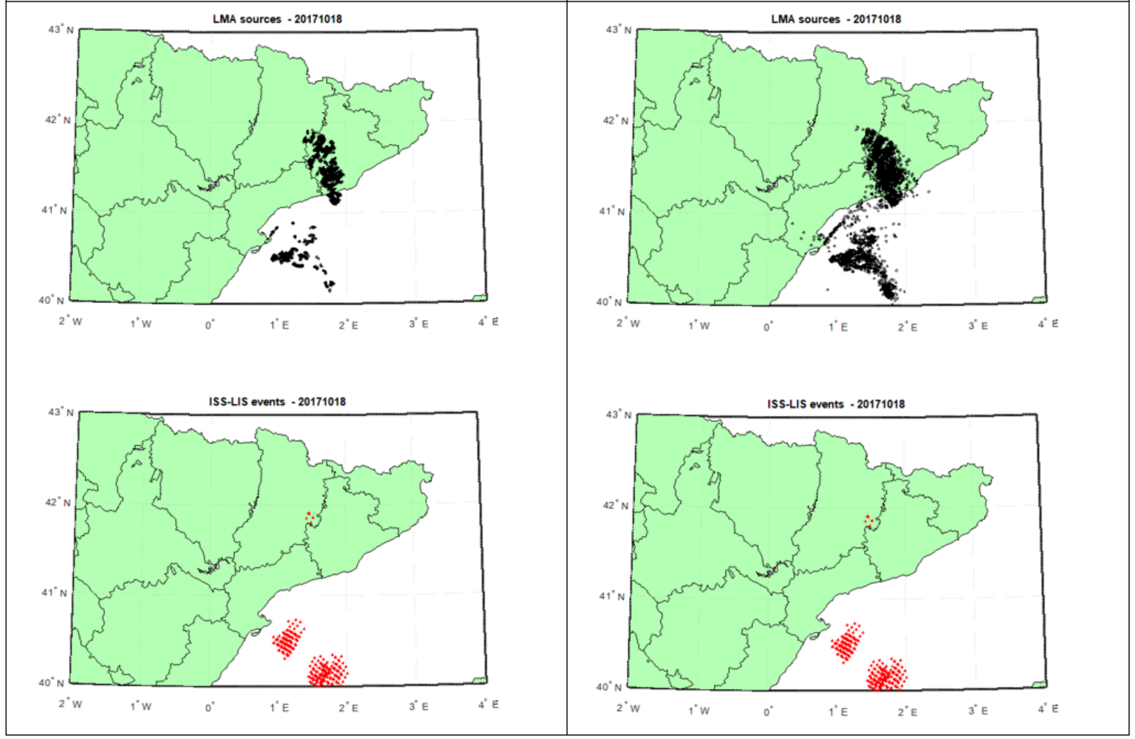
Detection Efficiency

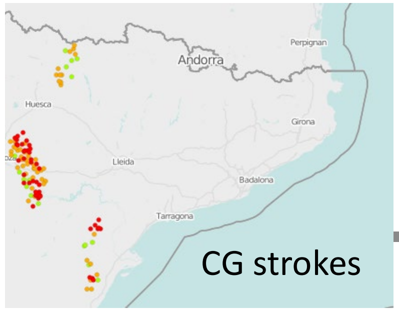
Maps of the LMA sources in the FOV of ISS-LIS and ISS-LIS events

20171018-1 LMA (without noise) and LIS	20171018-1 LMA (noise included) and LIS



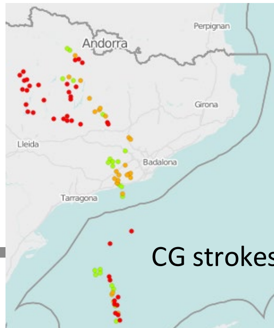
20171018-2 LMA (without noise) and LIS	20171018-2 LMA (noise included) and LIS





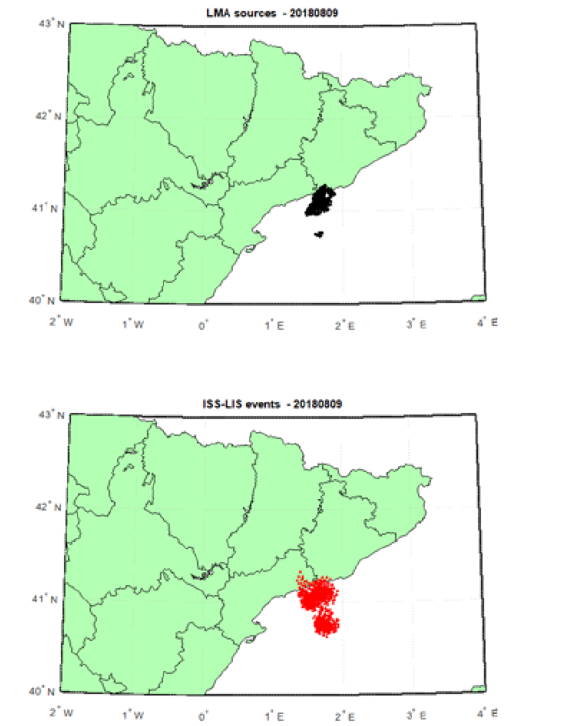
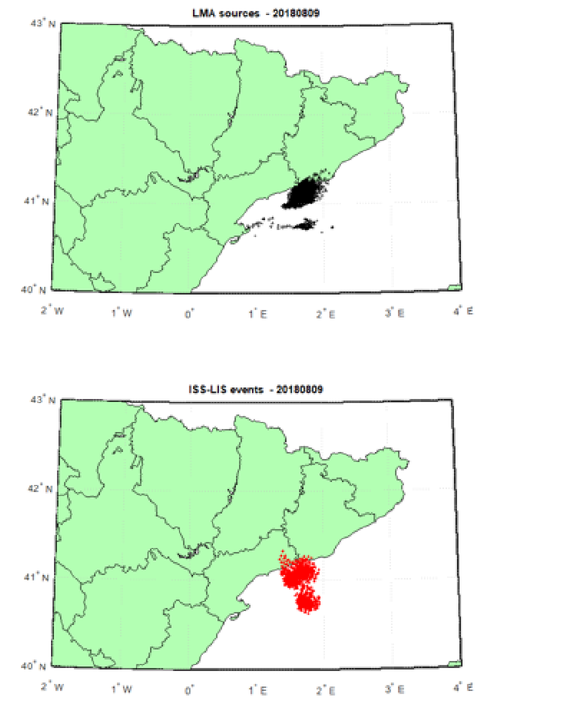
LMA has poor coverage of the storm at the west.

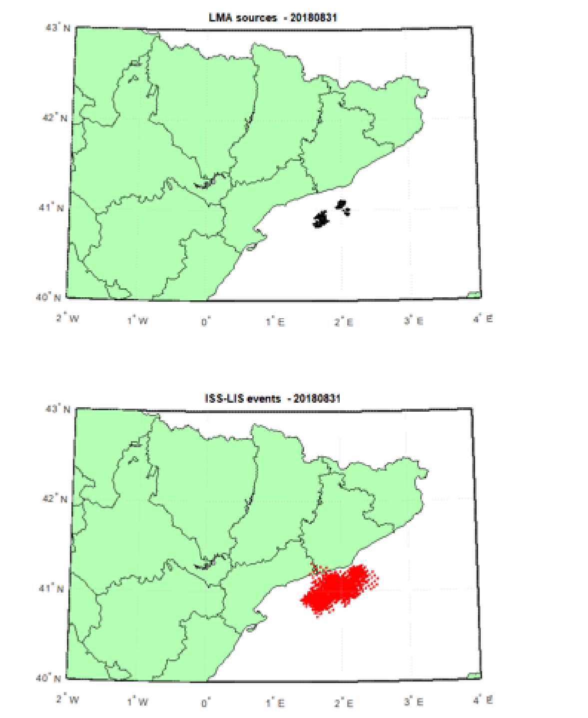
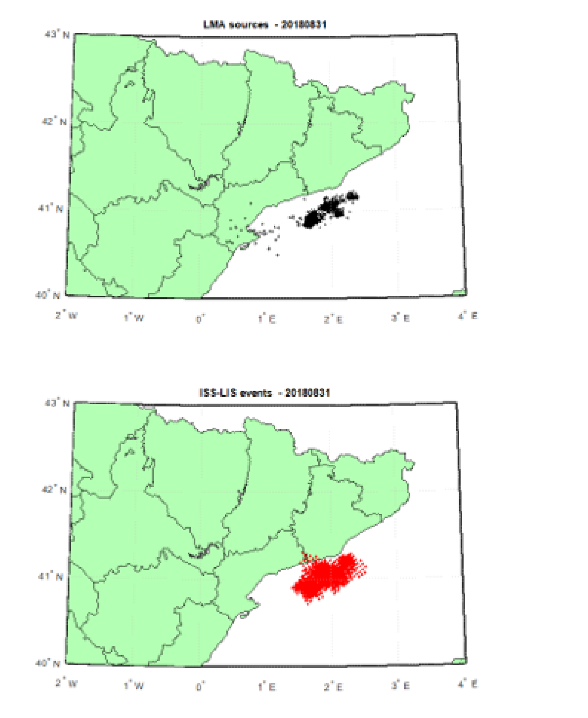
ISS-LIS is not detecting the storm at north of the LMA



Detection Efficiency

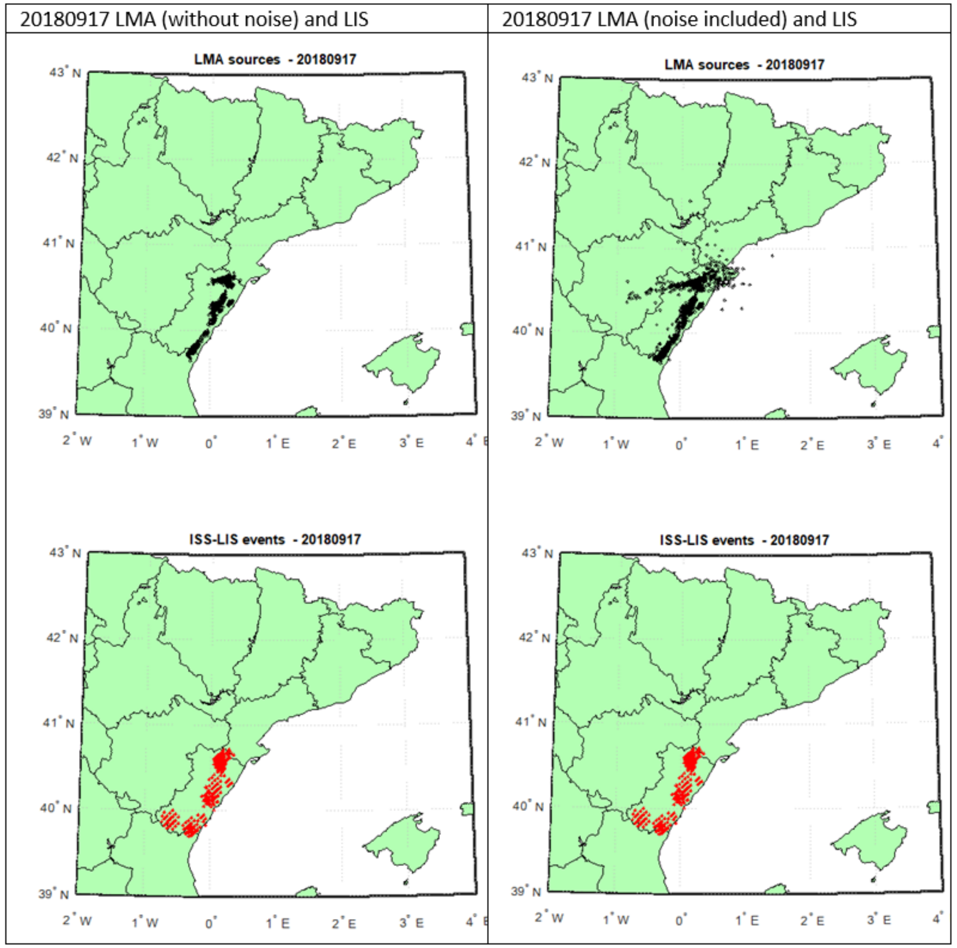
Maps of the LMA sources in the FOV of ISS-LIS and ISS-LIS events

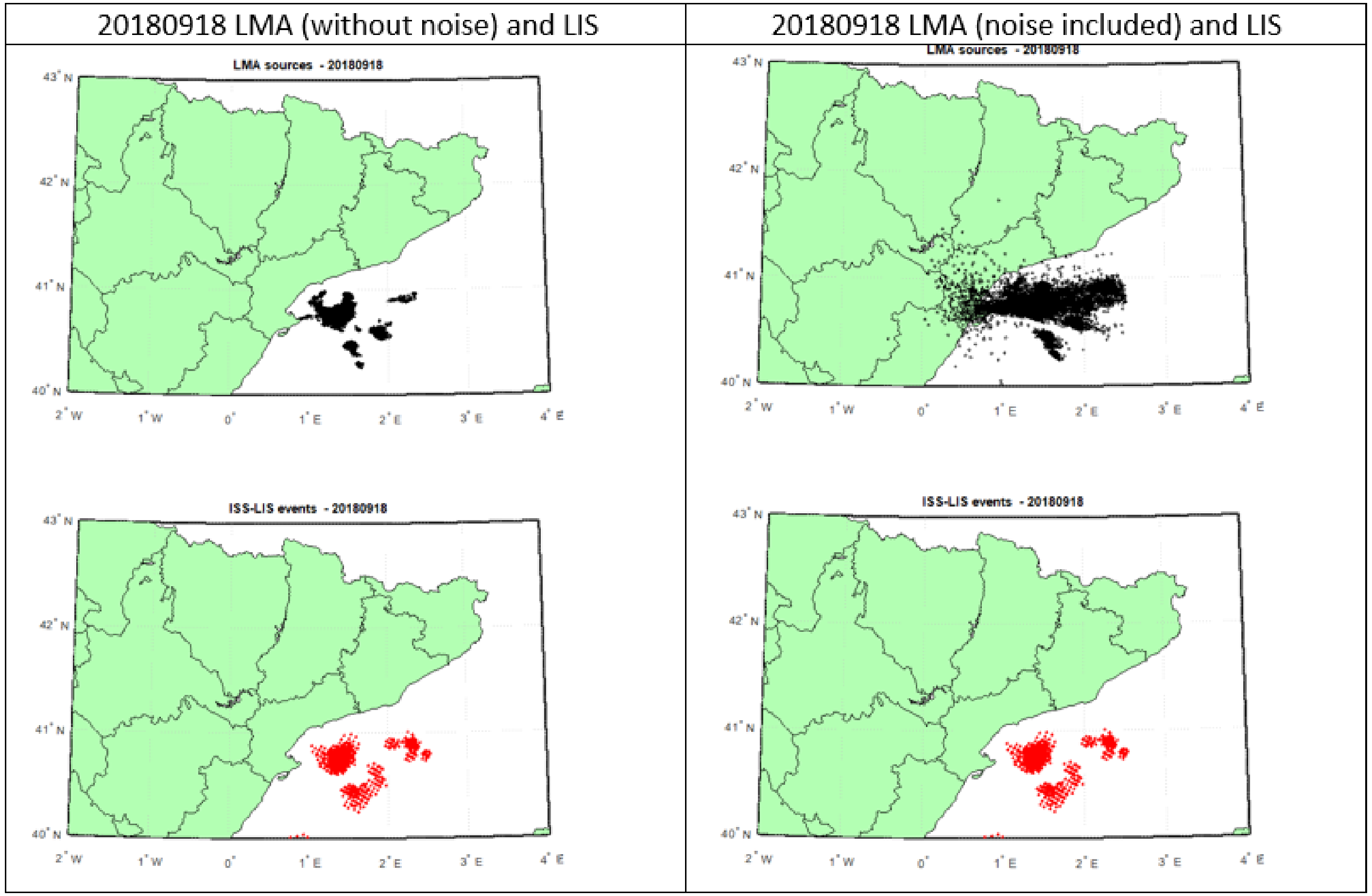
20180809LMA (without noise) and LIS	20180809 LMA (noise included) and LIS
	

20180831 LMA (without noise) and LIS	20180831 LMA (noise included) and LIS
	

Detection Efficiency

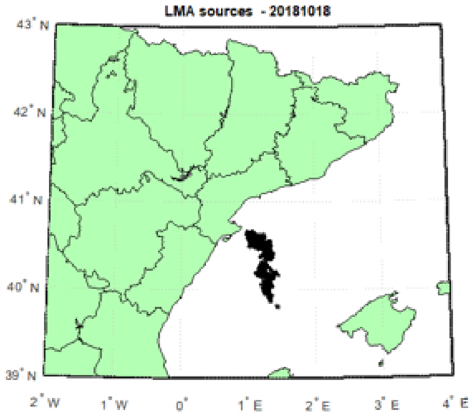
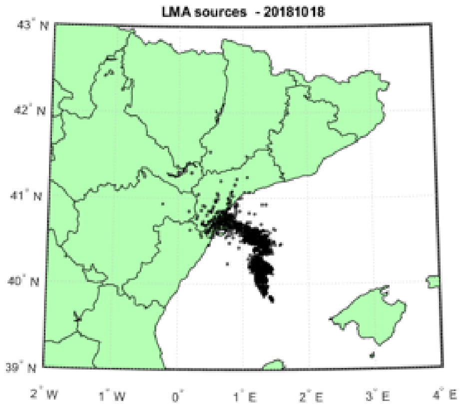
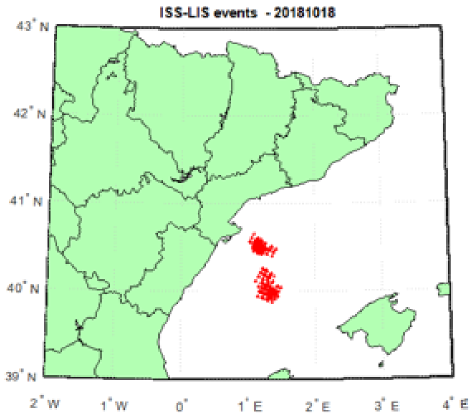
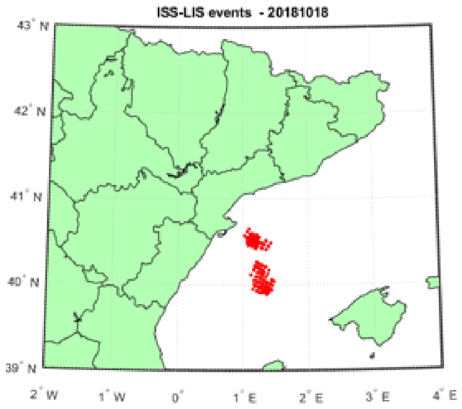
Maps of the LMA sources in the FOV of ISS-LIS and ISS-LIS events



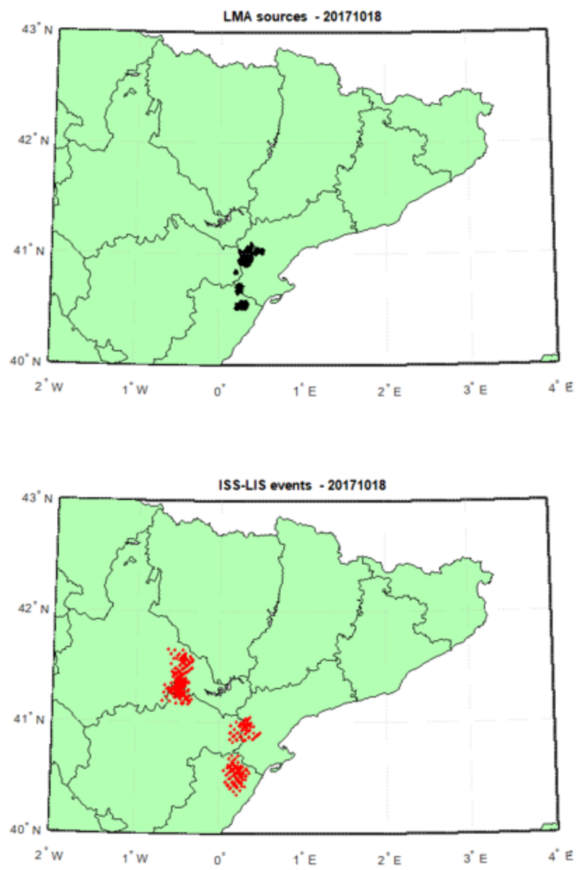
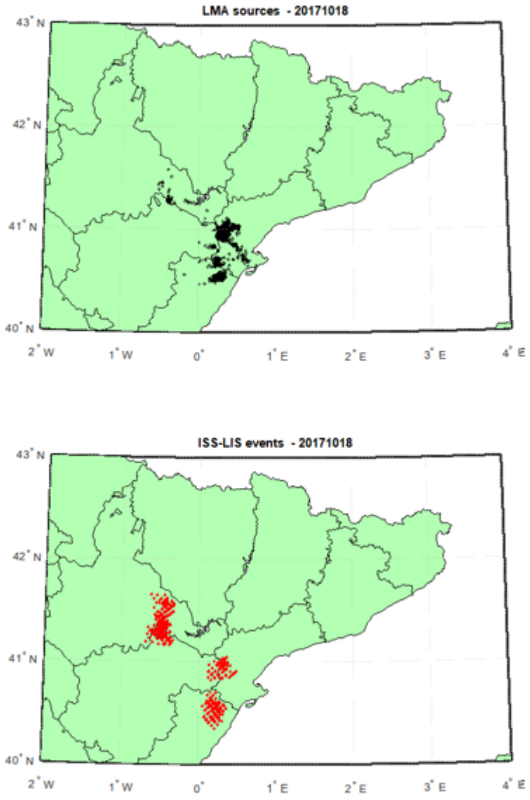


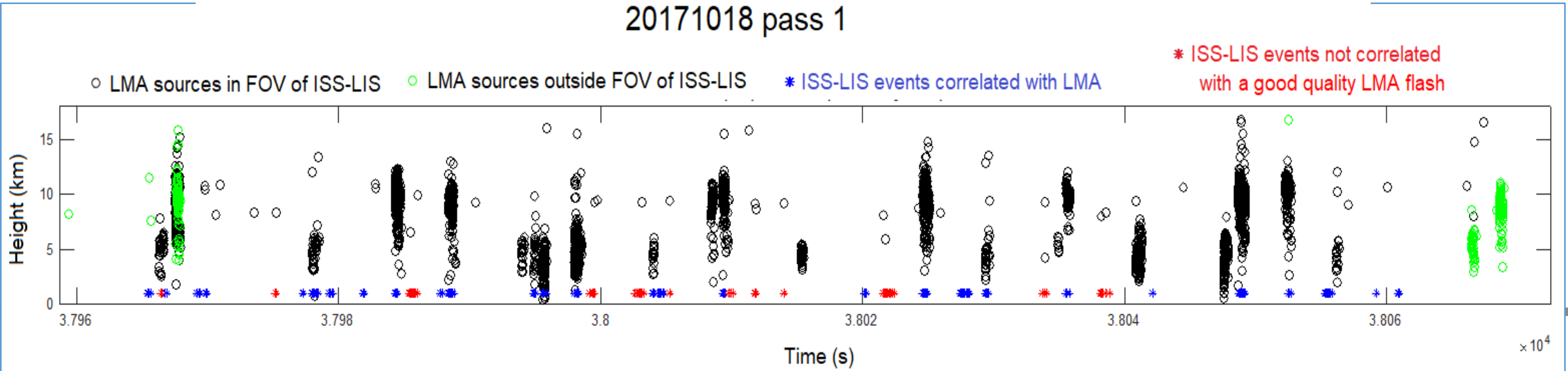
Detection Efficiency

Maps of the LMA sources in the FOV of ISS-LIS and ISS-LIS events

20181018 LMA (without noise) and LIS	20181018 LMA (noise included) and LIS
	
	

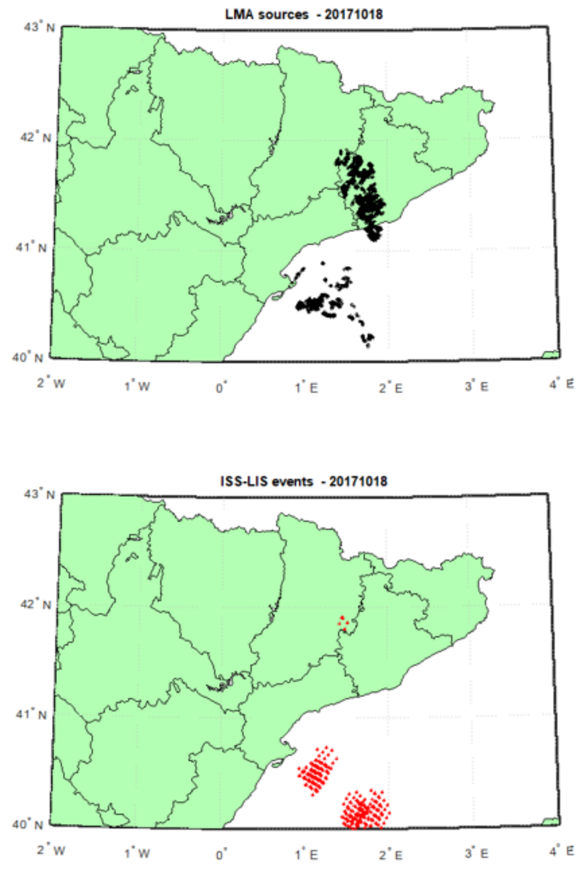
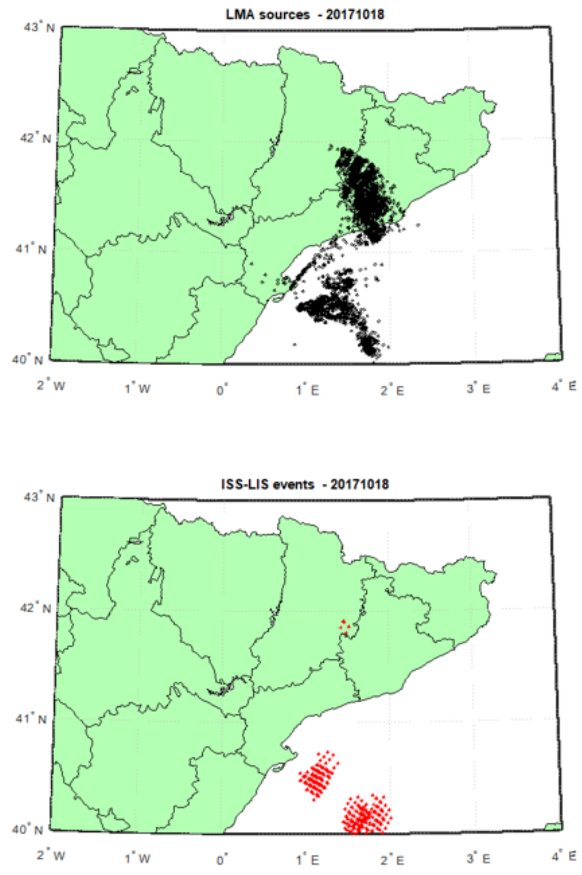
LMA and ISS-LIS events
(maps and time evolution)

20171018-1 LMA (without noise) and LIS	20171018-1 LMA (noise included) and LIS
	

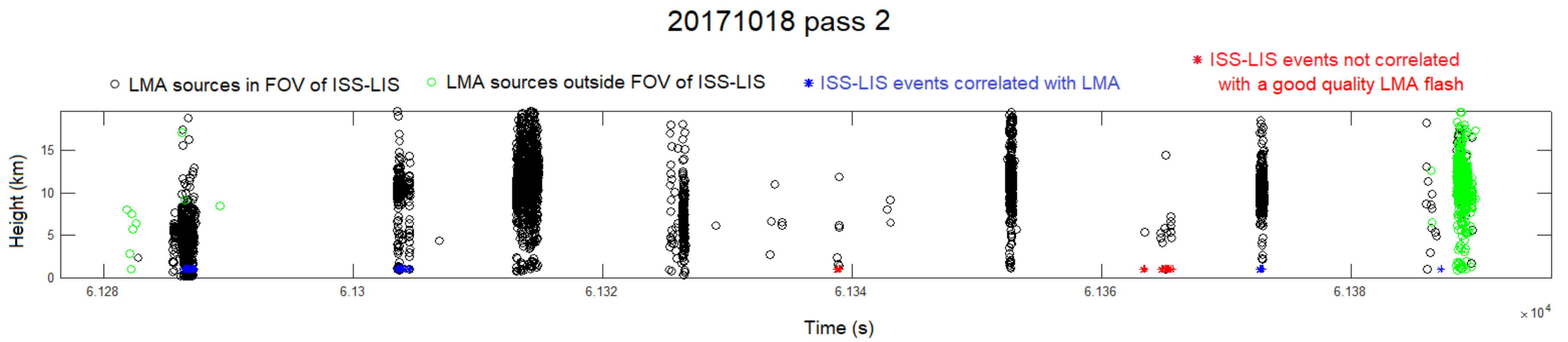


LMA has poor coverage to the north-west. In this cell, most of the LMA sources are classified as noise.

LMA and ISS-LIS events
(maps and time evolution)

20171018-2 LMA (without noise) and LIS	20171018-2 LMA (noise included) and LIS
	

LIS did not detect the storm at the north-east of the LMA.
The storm is in the considered range (<150 km).



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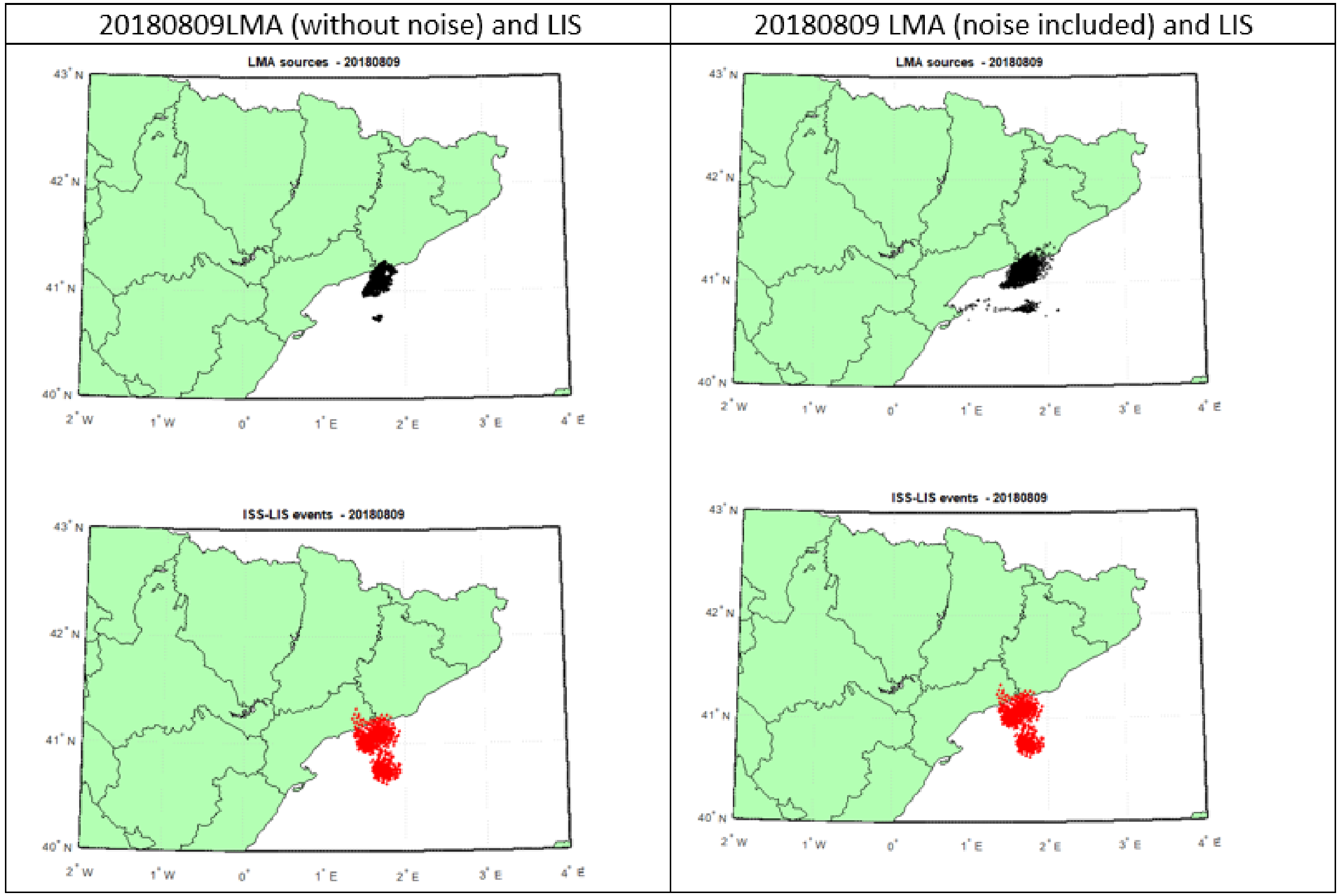
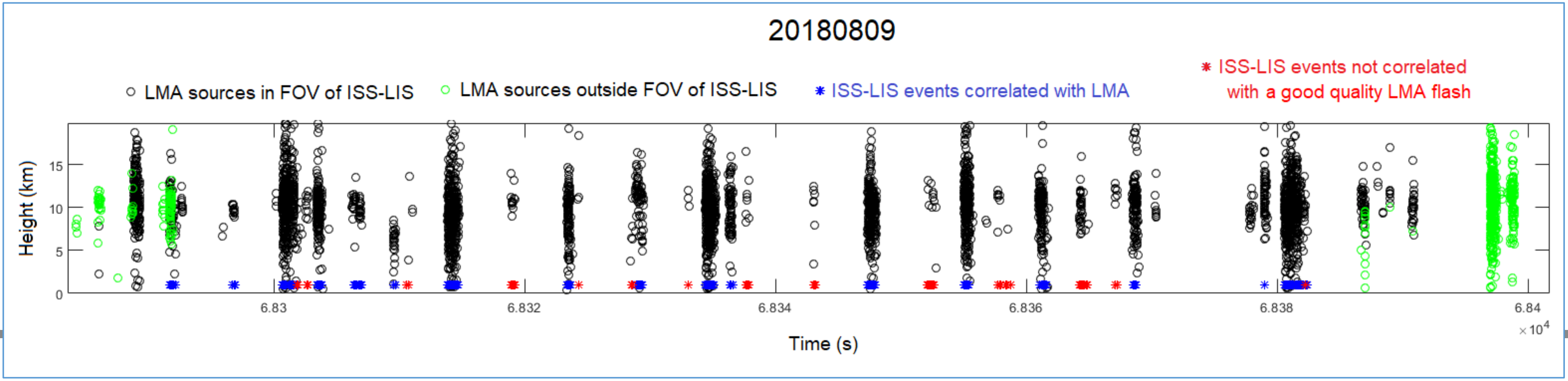
LMA and ISS-LIS events
(maps and time evolution)



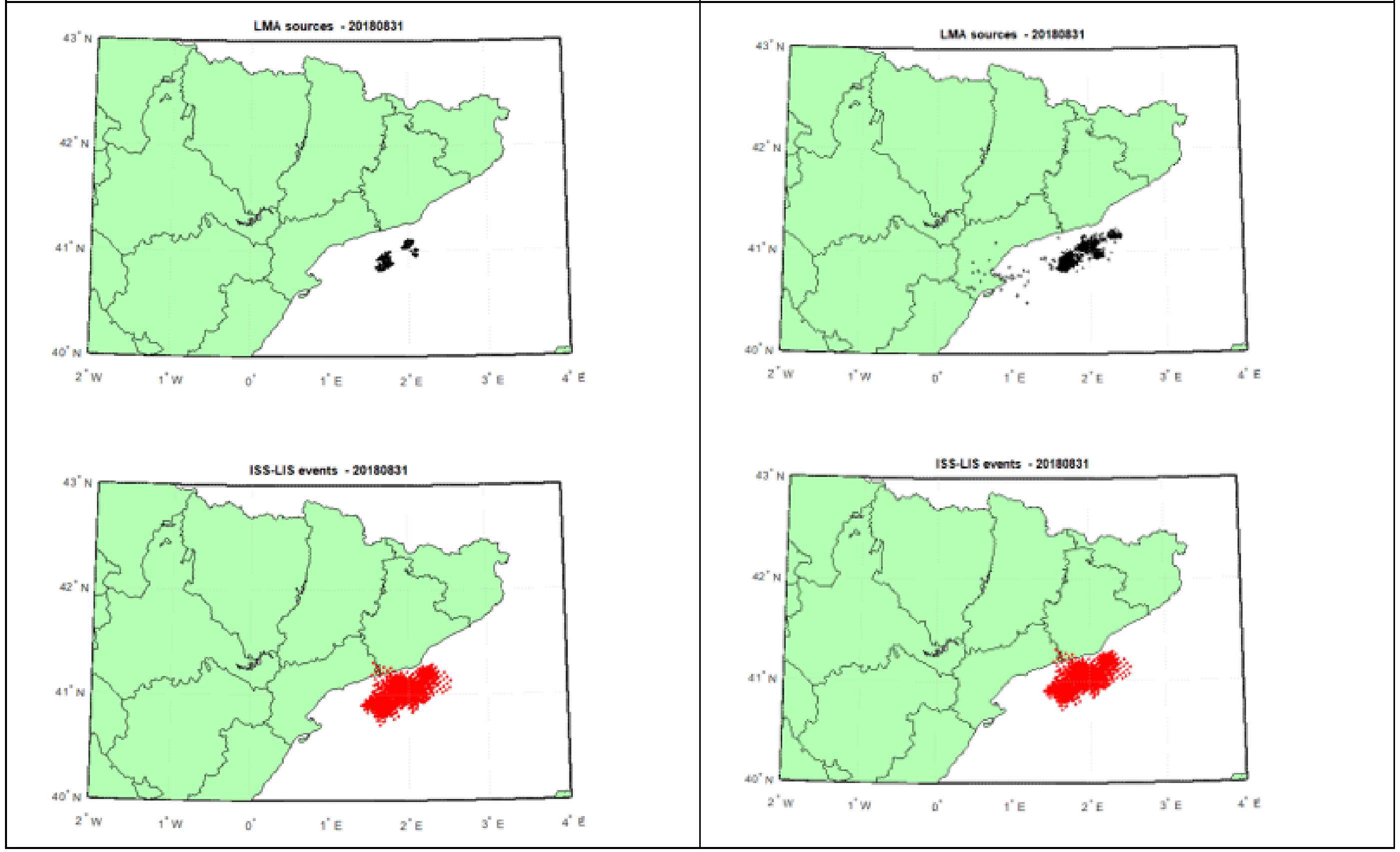
Good case.
Note the difference in the high quality LMA flashes and LMA flashes with poorer quality.

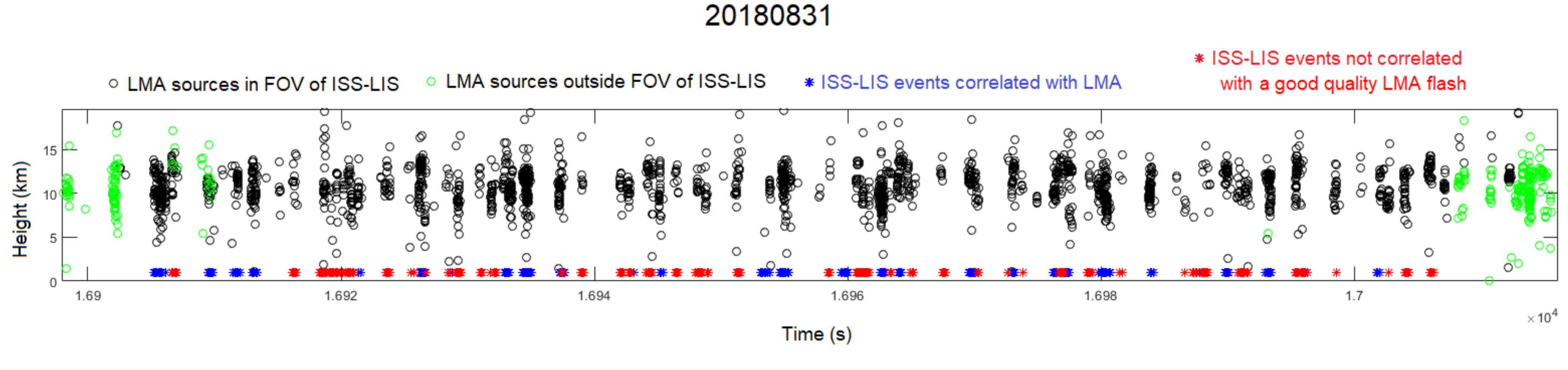


LMA and ISS-LIS events

(maps and time evolution)

20180831 LMA (without noise) and LIS	20180831 LMA (noise included) and LIS





Note in this cases that the LMA does not see sources at low altitudes. Most of the flashes do not match the LMA quality criteria. However there is good agreement in the detections between ISS-LIS and LMA.

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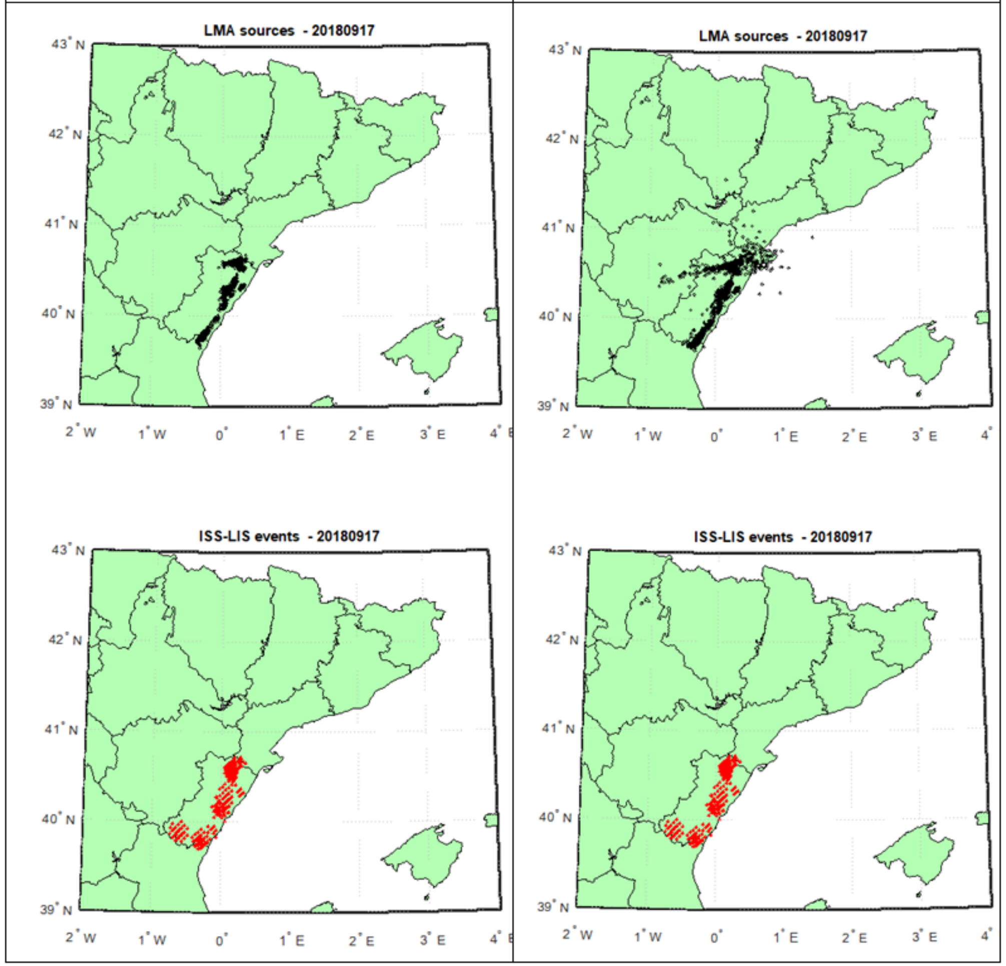
LMA and ISS-LIS events

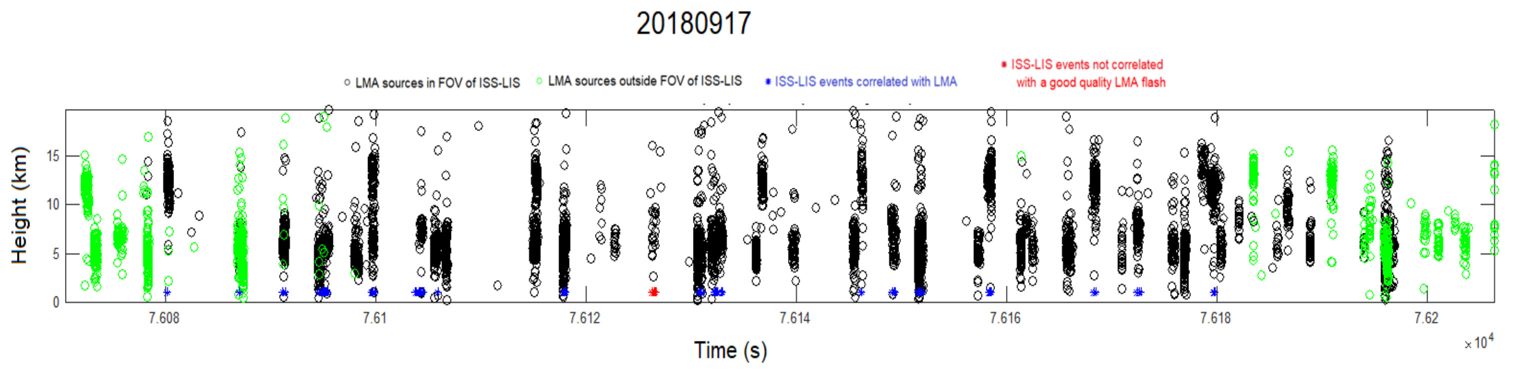
(maps and time evolution)

20180917 LMA (without noise) and LIS	20180917 LMA (noise included) and LIS



Case with good quality of LMA data.

Several flashes are missed by ISS-LIS.



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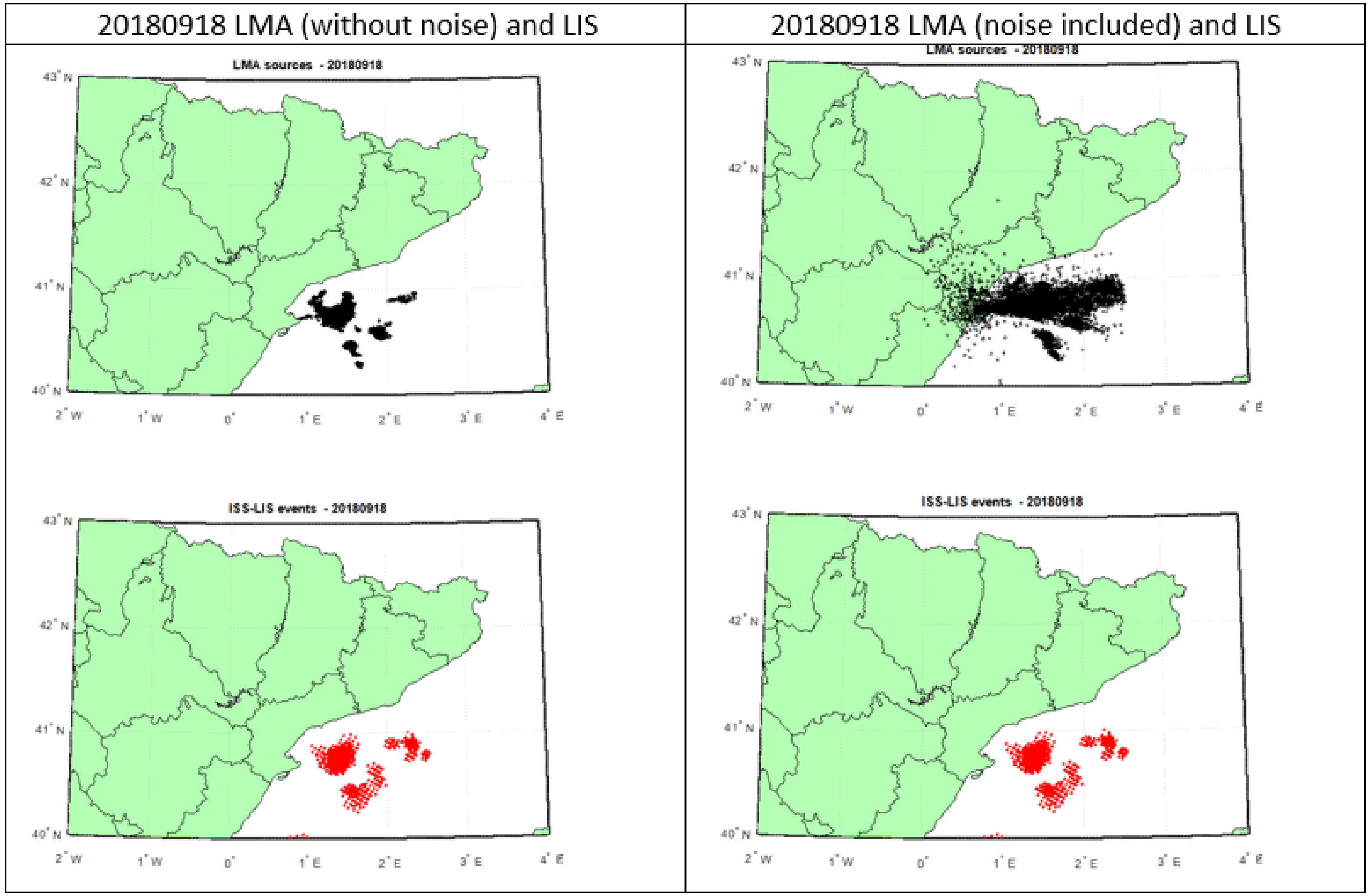
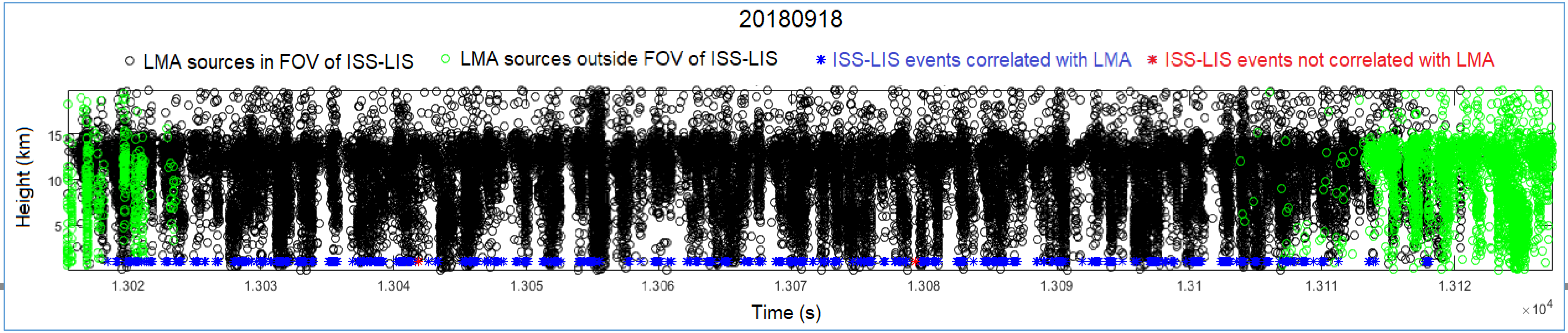
LMA and ISS-LIS events
(maps and time evolution)



Case with high quality of the LMA data.

The storm is extremely intense that in most of the cases the LMA is not able to distinguish when a flash ends and the next one starts.



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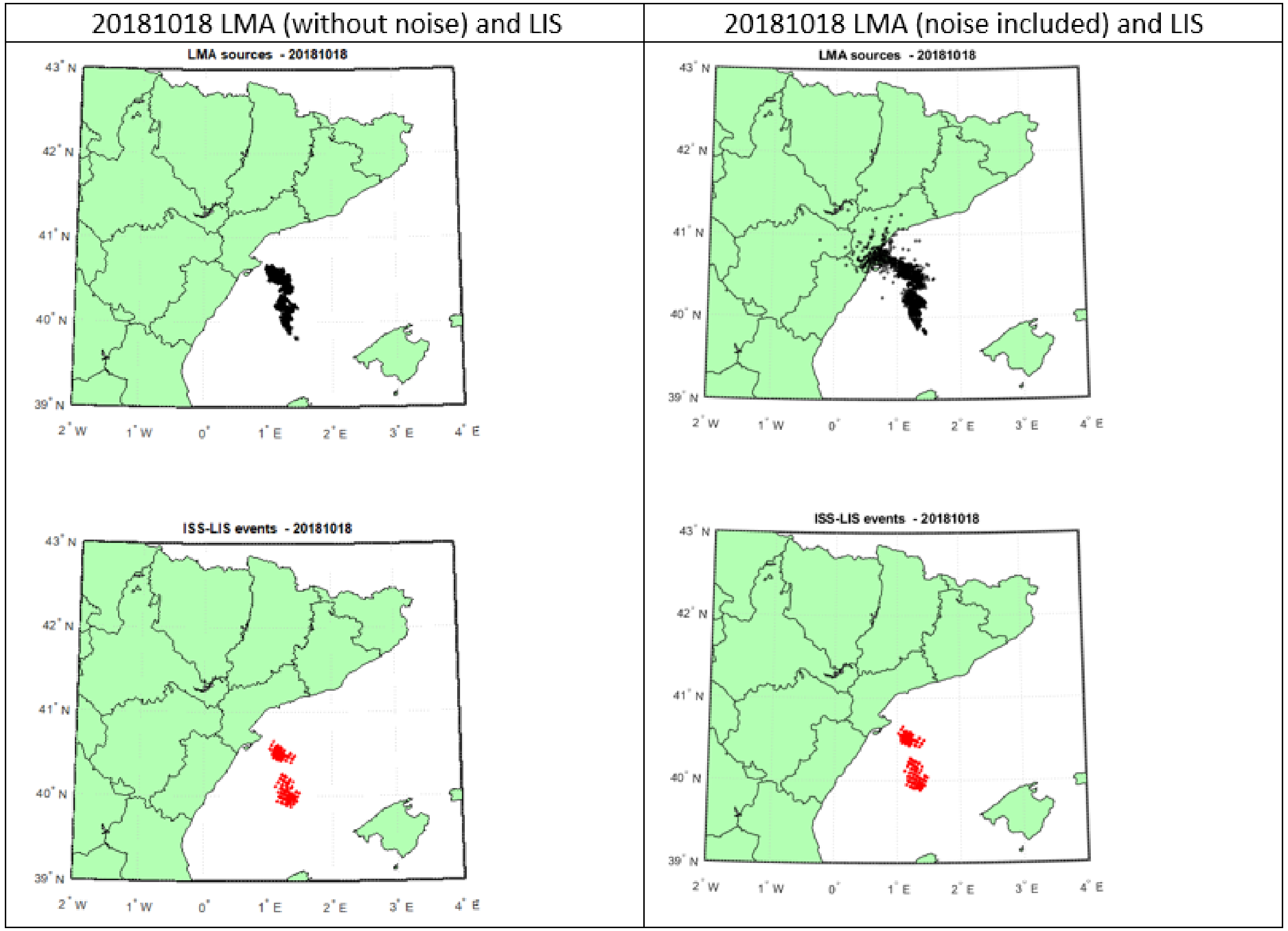
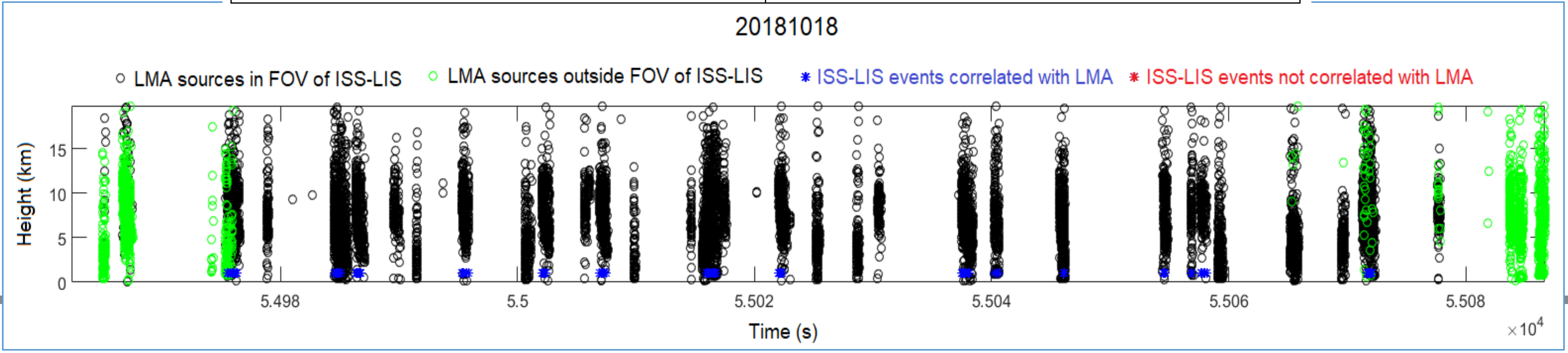
LMA and ISS-LIS events

(maps and time evolution)



Case with high quality of the LMA data.

Note the low performance of ISS-LIS.

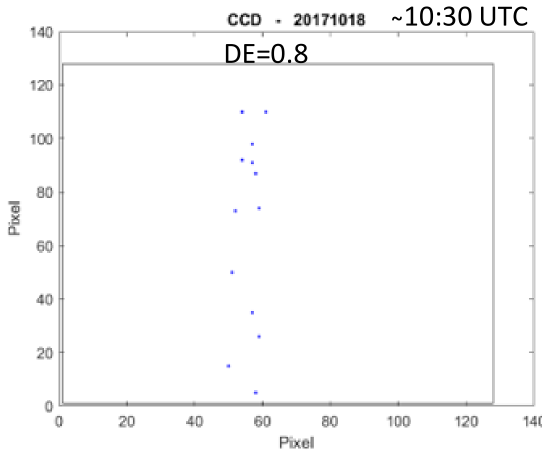


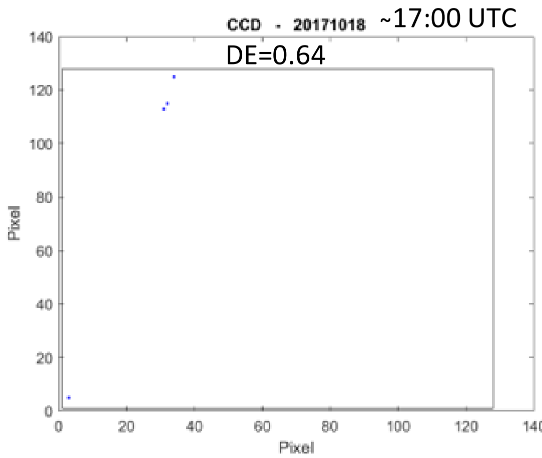
Detection Efficiency

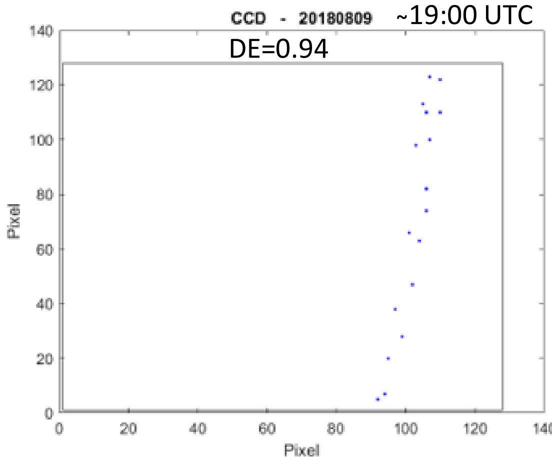
Summary of the results by episode

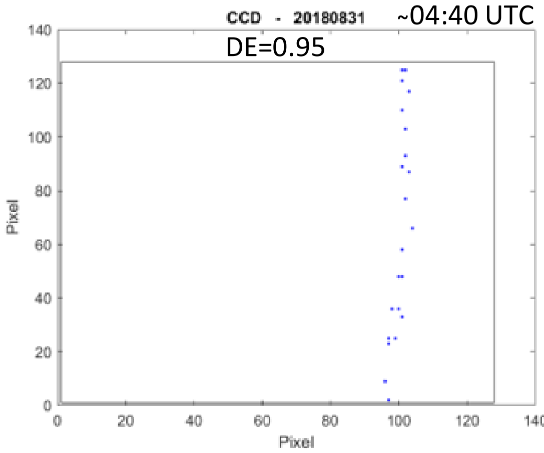
Date	Number of flashes	Average flash rate [min^{-1}]	Average LMA source rate [s^{-1}]	Number of flashes detected by ISS-LIS	Number of ISS-LIS missed by LMA and detected by ISS-LIS	Detection Efficiency DE_f	Comments
20171018-1 ~10:30 UTC	56	33.2	40.9	45	17	0.80	LMA misses flashes of the north-west storm (too far and poor coverage in that area)
20171018-2 ~17:00 UTC	17	9.5	55.5	11	1	0.64	The flashes occurred at the edge of the CCD. That might explain the lack of detection of the storm to the north-east.
20180809 ~19:00 UTC	35	20.0	50.7	33	0	0.94	
20180831 ~04:40 UTC	87	42.4	13	83	6	0.95	Very active episode in terms of flashes but not in terms of LMA sources due to the storm was far from the LMA network.
20180917 ~21:10 UTC	45	22.7	43.3	21	0	0.47	
20180918 ~03:30 UTC	75	36.4	399.1	62	0	0.82	Extremely active episode Night time. Average flash rates are not realistic since many LMA flashes cannot be separated.
20181018 ~15:15 UTC	32	16.4	224.1	16	0	0.50	Moderate flash rate but quite active in terms of LMA sources.

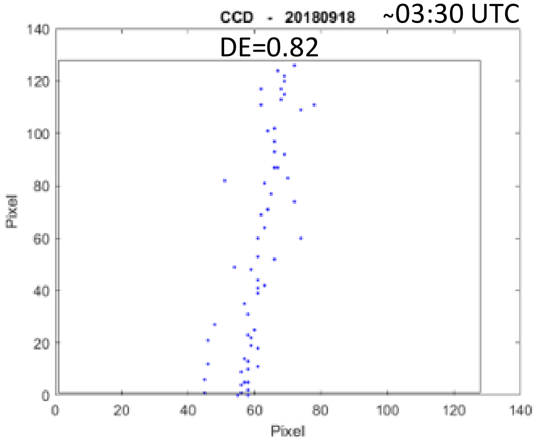
Location of the ISS-LIS flashes in the CCD

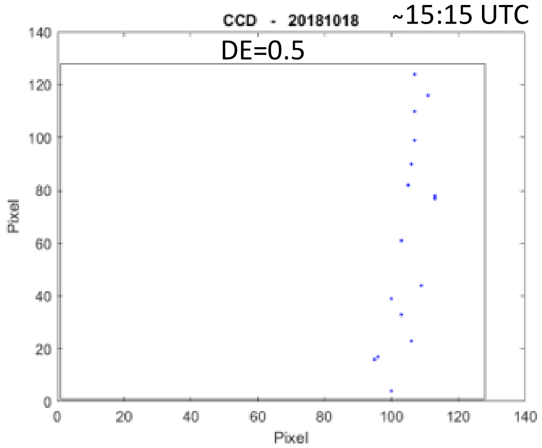


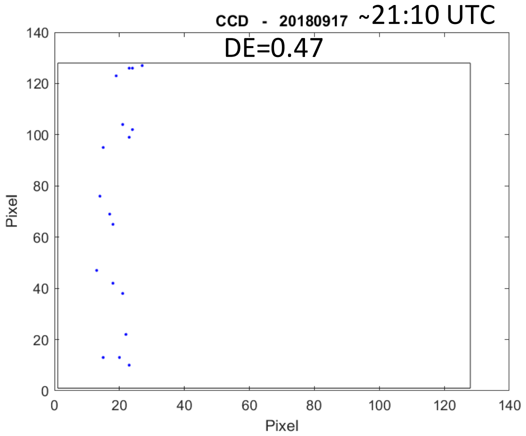












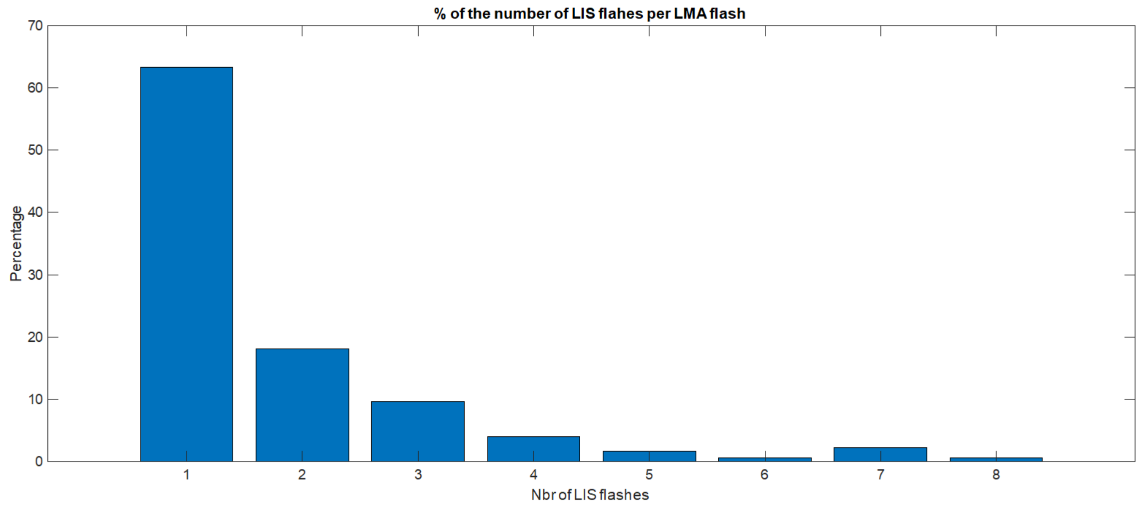
Detection Efficiency

Summary of the results (overall)

a	DE_f	**78.1 %**
b	Total number of flashes	347
c	Number of LMA sources (all flashes excluding noise)	96595
d	Total LMA sources of flashes detected by ISS-LIS	77702
e	Number of LMA flashes detected by the ISS-LIS	271
f	Number of ISS-LIS flashes	312
g	Number of ISS-LIS events	10302
h	Average number of LMA sources per ISS-LIS event (=d/g)	7.5
i	Average number of ISS-LIS flashes per LMA flash (=f/e)	~1.15
j	Average number of ISS-LIS events per LMA flash (=g/b)	~38

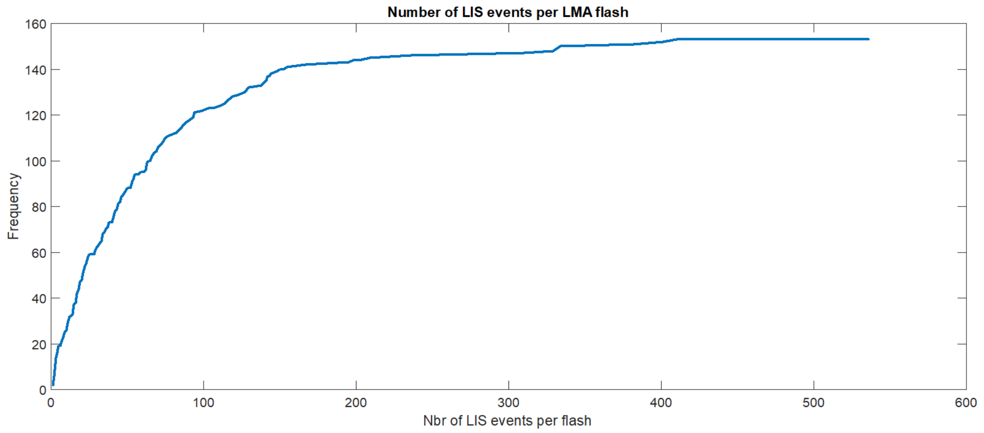
Detection Efficiency

Number of ISS-LIS flashes and events for detected flashes

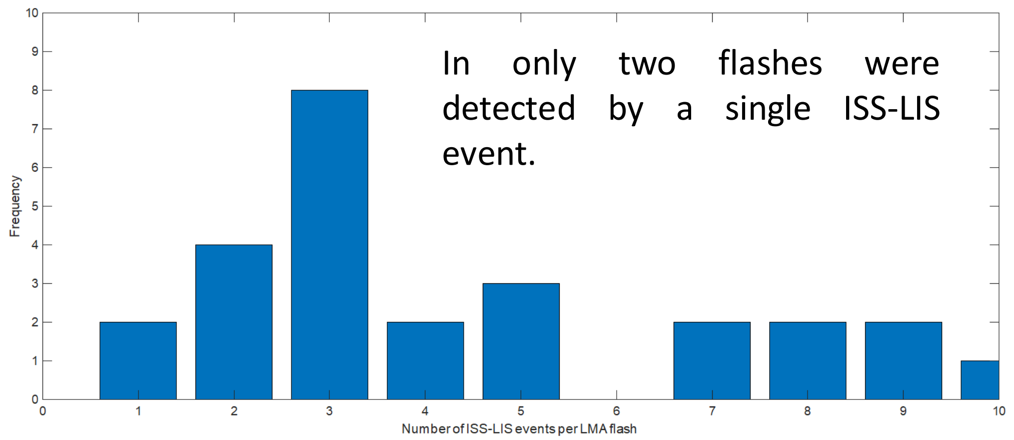


More than 60 % of the LMA flashes have one ISS-LIS flash.
But in about 20 % of the LMA flashes ISS-LIS assigned two flashes

Number ISS-LIS of events per detected LMA flash

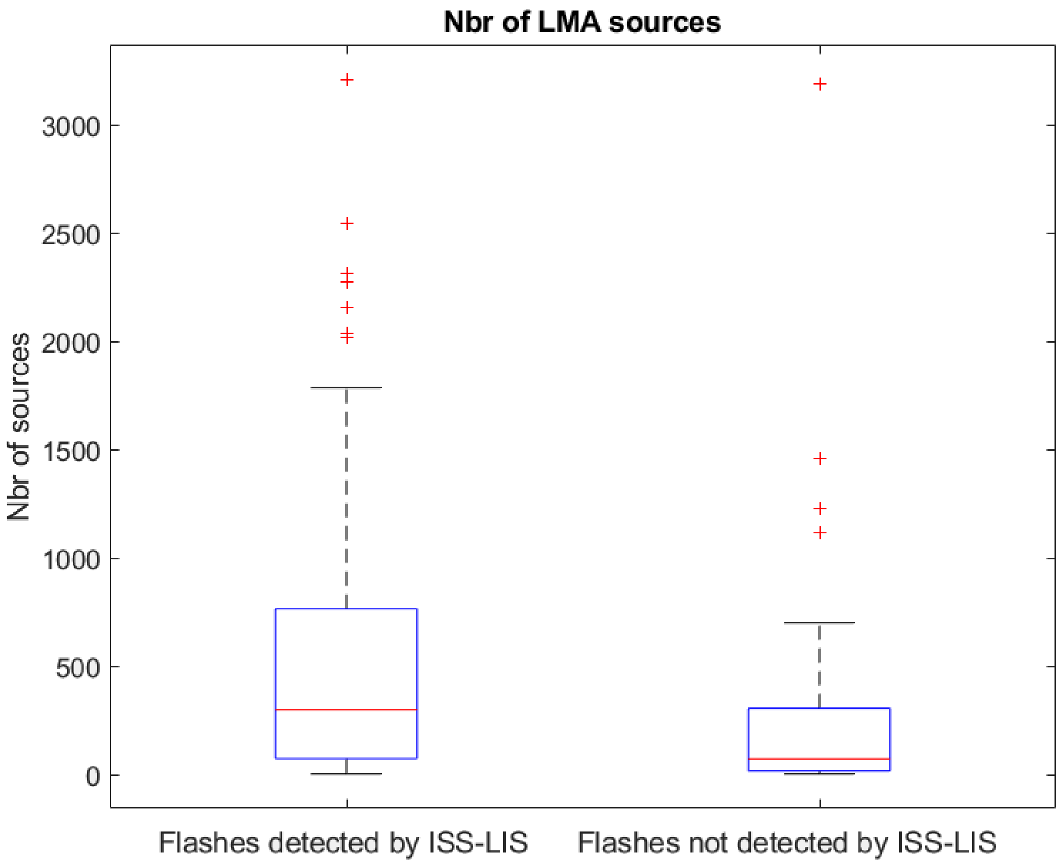


Number ISS-LIS of events per detected LMA flash



Detection Efficiency

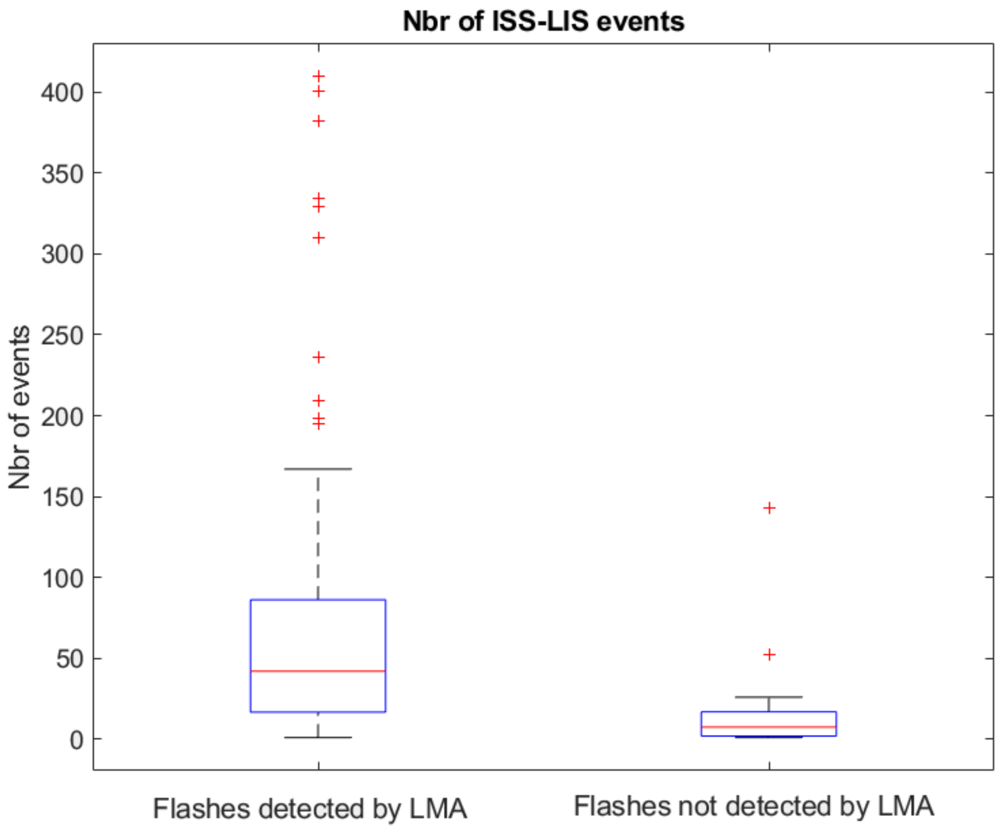
Number of LMA sources for flashes detected and undetected by ISS-LIS



LMA flashes detected by ISS-LIS present a higher median and 75th percentile number of sources.

Detection Efficiency

Number of ISS-LIS sources for flashes detected and undetected by the LMA



For the flashes detected by ISS-LIS and missed by the LMA the typical number of events is low. This is actually below of the 25th percentile of number of ISS-LIS sources in the flashes detected by both systems.

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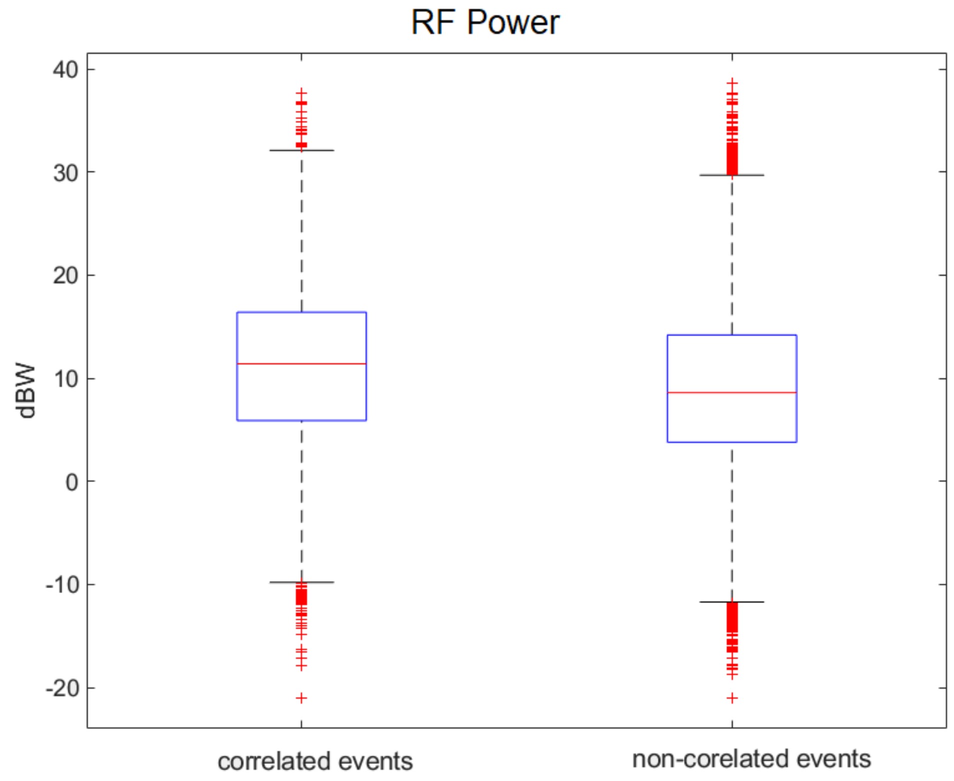
Detection Efficiency

VHF RF power for LMA sources correlated and uncorrelated with ISS-LIS events (within 4 ms)

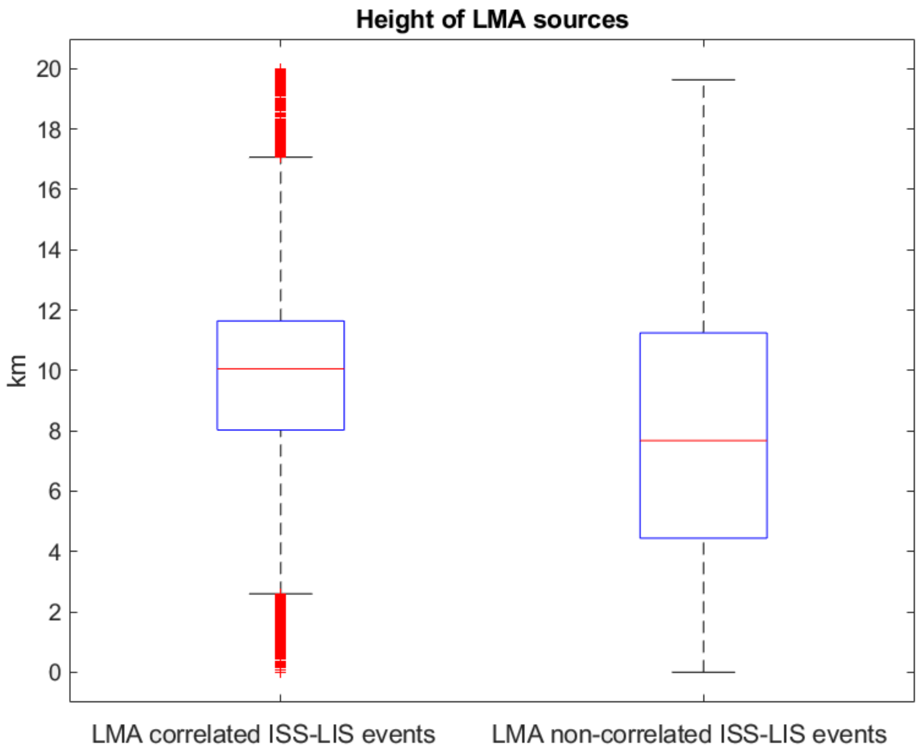


ISS-LIS events correlated with LMA **ISS-LIS events uncorrelated with LMA**

RF power of LMA sources correlated with ISS-LIS events tend to present slightly higher statistics.

Detection Efficiency

Height of LMA sources correlated and uncorrelated (within 4 ms) with ISS-LIS events



ISS-LIS events correlated with LMA **ISS-LIS events uncorrelated with LMA**

Heights of LMA sources correlated with ISS-LIS events corresponds to the higher part of flashes.

Detection Efficiency

General conclusions (Detection Efficiency)

- ISS-LIS DE_f has been evaluated using the LMA as reference.
- For the evaluation a time criterion has been used.
- The study has considered 347 flashes in 7 episodes.

- In general, DE_f of ISS-LIS is >78 %.
- In two cases DE_f dropped to 50 - 47 %.
- This low DE_f might not be attributed to the day/night effect. Probably due to the ISS masking produced by solar panels.

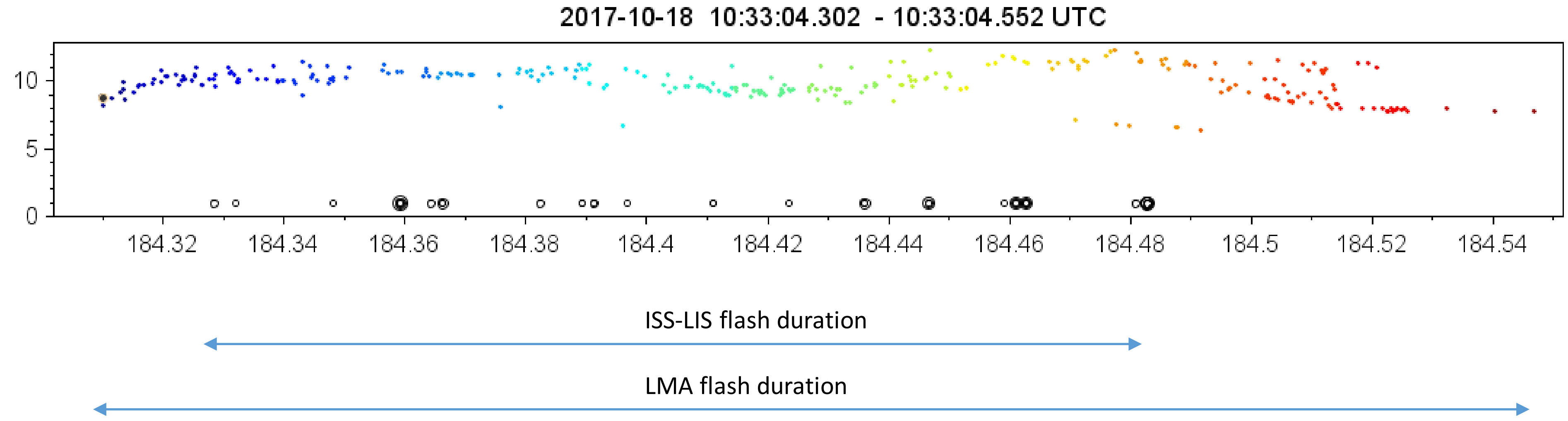
- In the detected ISS-LIS flashes:
    - The flash grouping criteria of ISS-LIS matches 63 % with the LMA.
    - There are very few flashes detected by only one or few ISS-LIS events. So, when ISS-LIS detects a flash, its average number of events is ~38.
    - LMA flashes detected by ISS-LIS presents a higher median, 75th percentile and extreme number of LMA sources.
    - The cases that LMA missed an ISS-LIS, the number of events is low (all below the 25th percentile of the number of events in the cases detected by both systems).
    - LMA sources associated to individual events occur at higher altitudes.
    - Power of LMA sources associated with individual events is slightly higher but no relation is obtained.

Flash duration

Flash duration

Flash duration is calculated as:

- LMA: time difference between the first and the last source (noise sources are ignored).
- ISS-LIS: time difference between the first and the last event in a ISS-LIS flash.
- ISS-LIS: time difference between the first and the last event in a LMA flash.

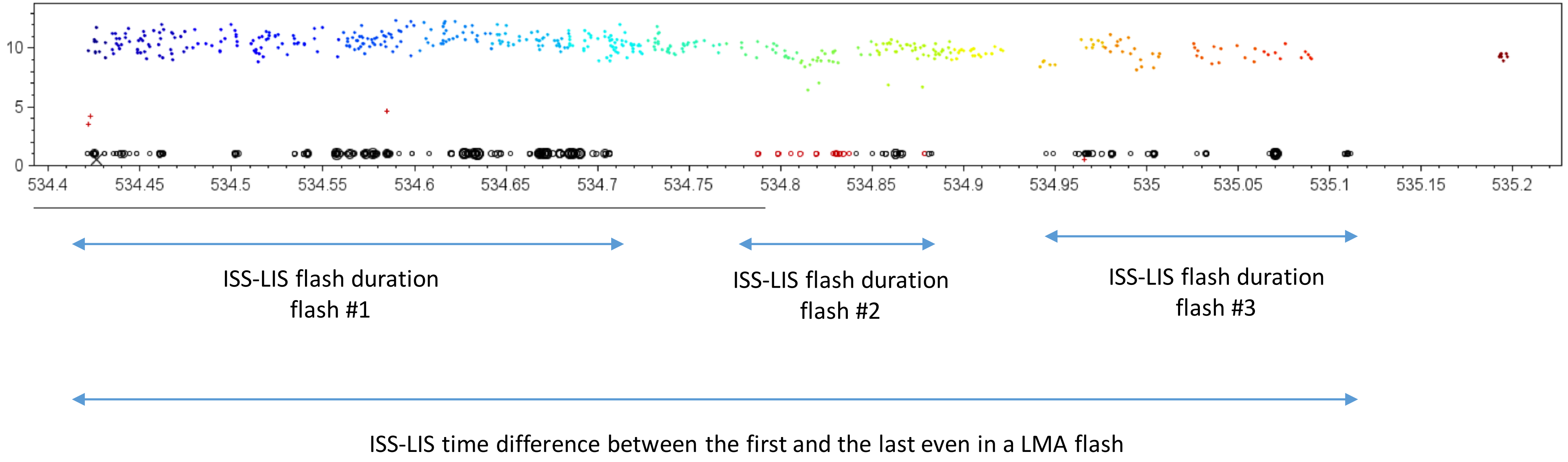


Flash duration

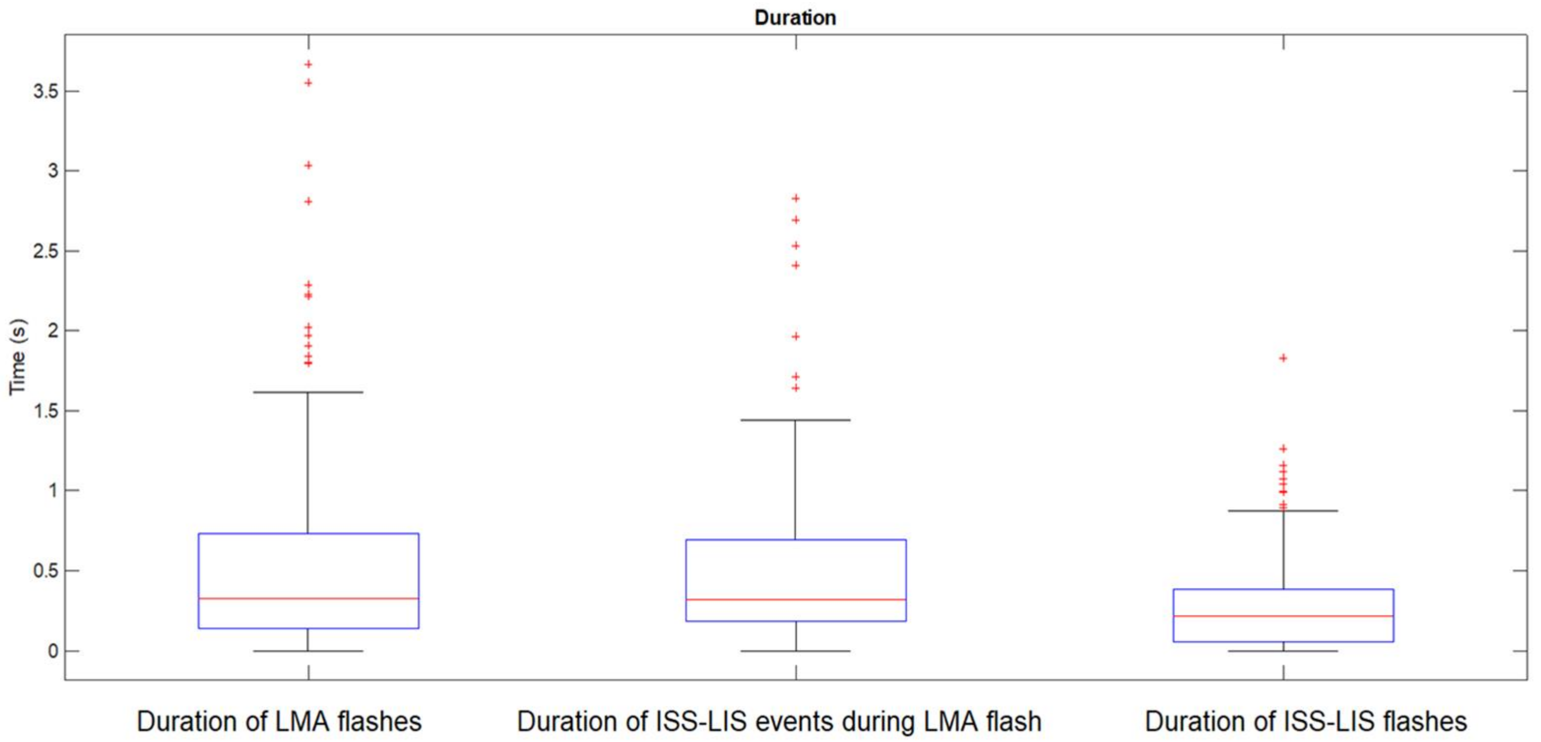
Flash duration is calculated as:

- LMA: time difference between the first and the last source (noise sources are ignored).
- ISS-LIS: time difference between the first and the last event in a ISS-LIS flash.
- ISS-LIS: time difference between the first and the last event in a LMA flash.

Example (it has not been verified that this particular flash is a case of multiple ISS-LIS flashes)



Flash duration



Median: 0.325 s

Median: 0.319 s

Several ISS-LIS flashes can belong to the same LMA flash

Median: 0.215 s

ISS-LIS flashes according to the ISS-LIS grouping

ISS-LIS flash duration is about 70% of the LMA flash duration.

But considering the duration of all the ISS-LIS events during a LMA flash its median is similar to the LMA flash duration.

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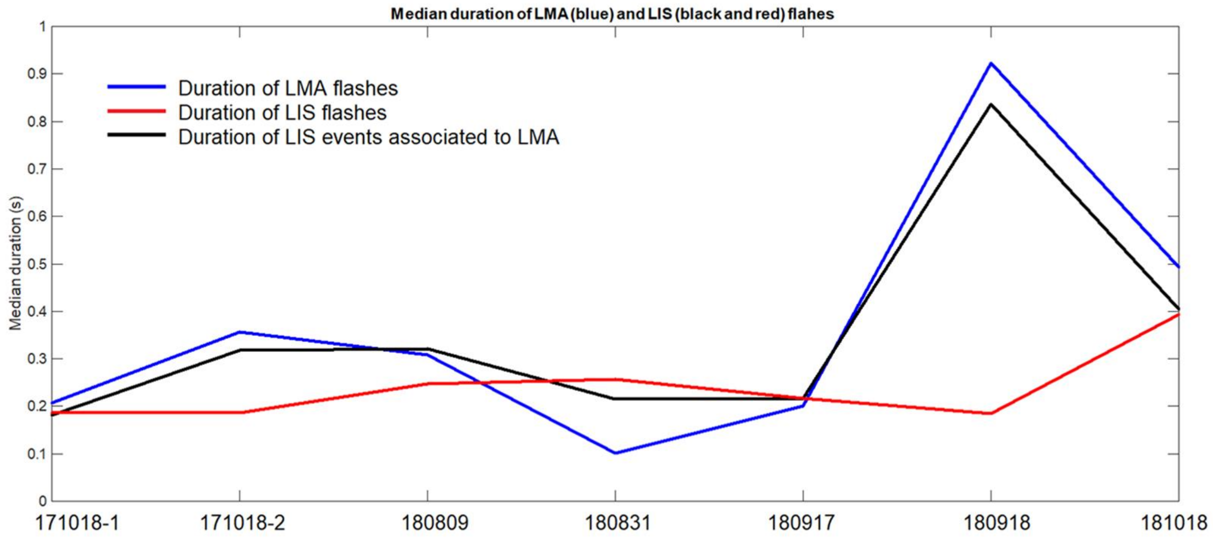
Flash duration

Episode	LMA flash duration (s)	ISS-LIS duration of events corresponding to LMA flash (s)	ISS-LIS flash duration according to ISS-LIS criteria (s)
20171018-1	0.206	0.181	0.185
20171018-2	0.356	0.318	0.185
20180809	0.308	0.321	0.247
20180831	0.101	0.214	0.256
20180917	0.200	0.217	0.216
20180918	0.923	0.836	0.184
20181018	0.493	0.404	0.394



Flash duration

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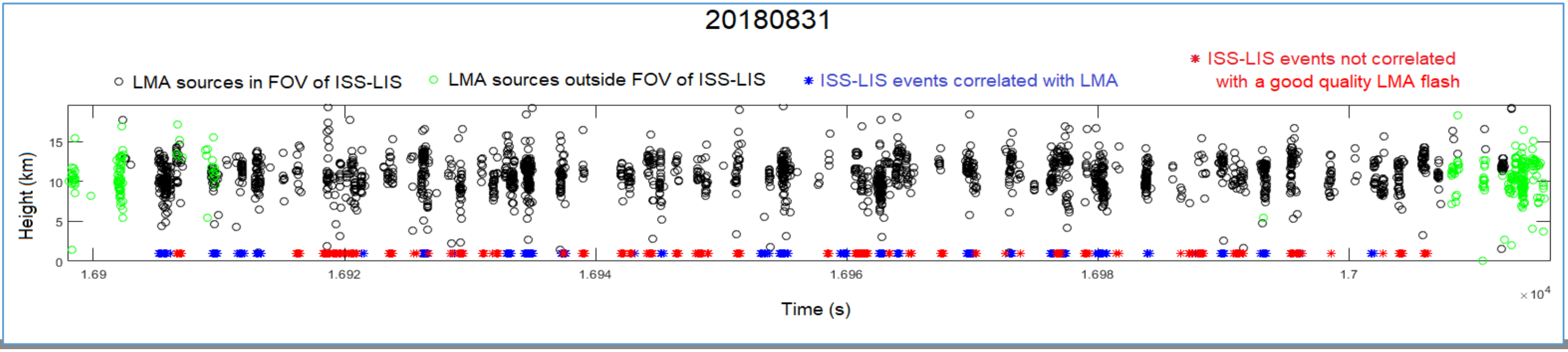
20180917	0.200	0.217	0.216
20180918	0.923	0.836	0.184
20181018	0.493	0.404	0.394

Data for evaluating the duration shall exclude storms far from the LMA.

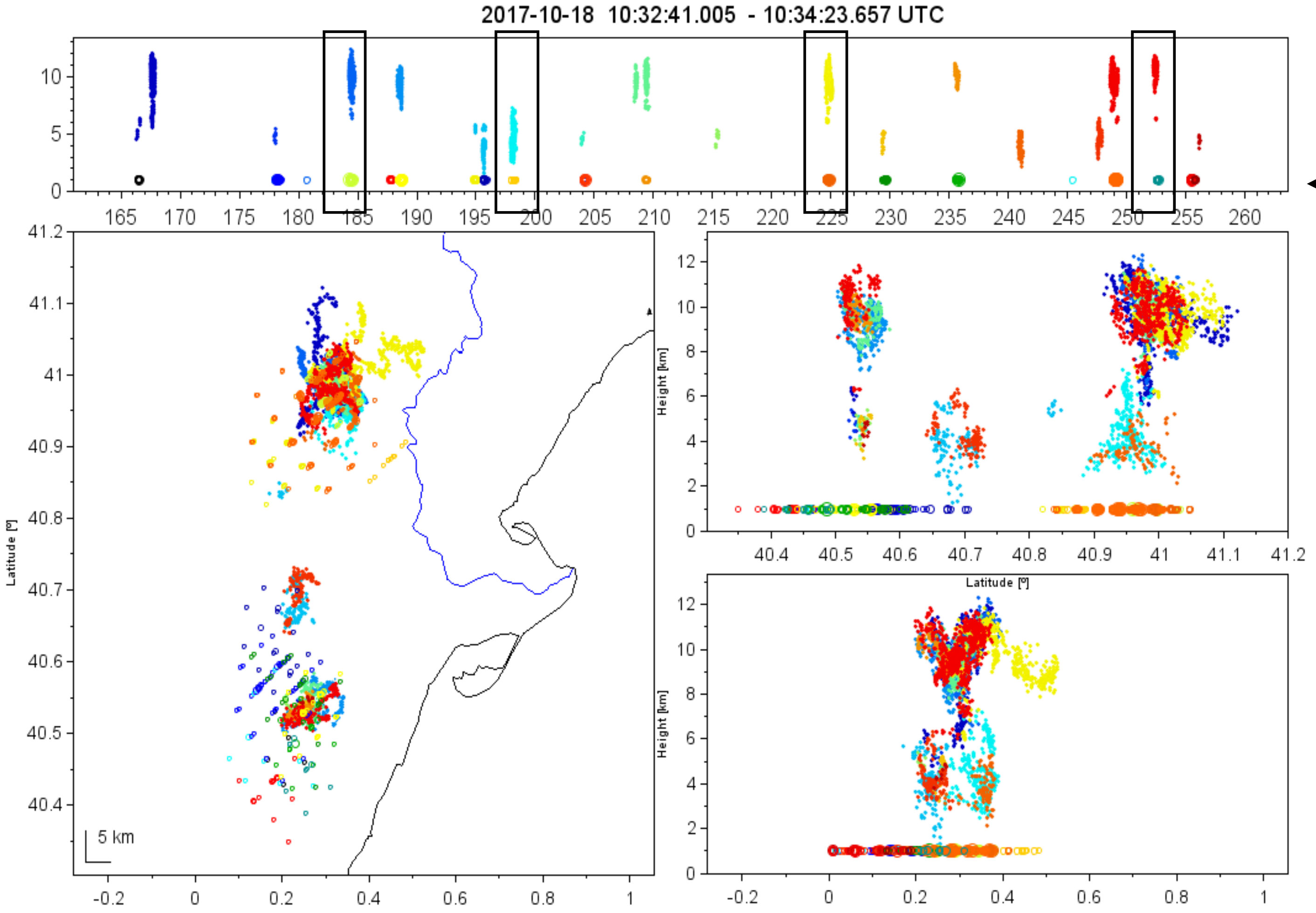
That is the case of the 20180831.

ISS-LIS duration can be > LMA duration because the LMA sources classified as noise but had matched with ISS-LIS.



Flash duration

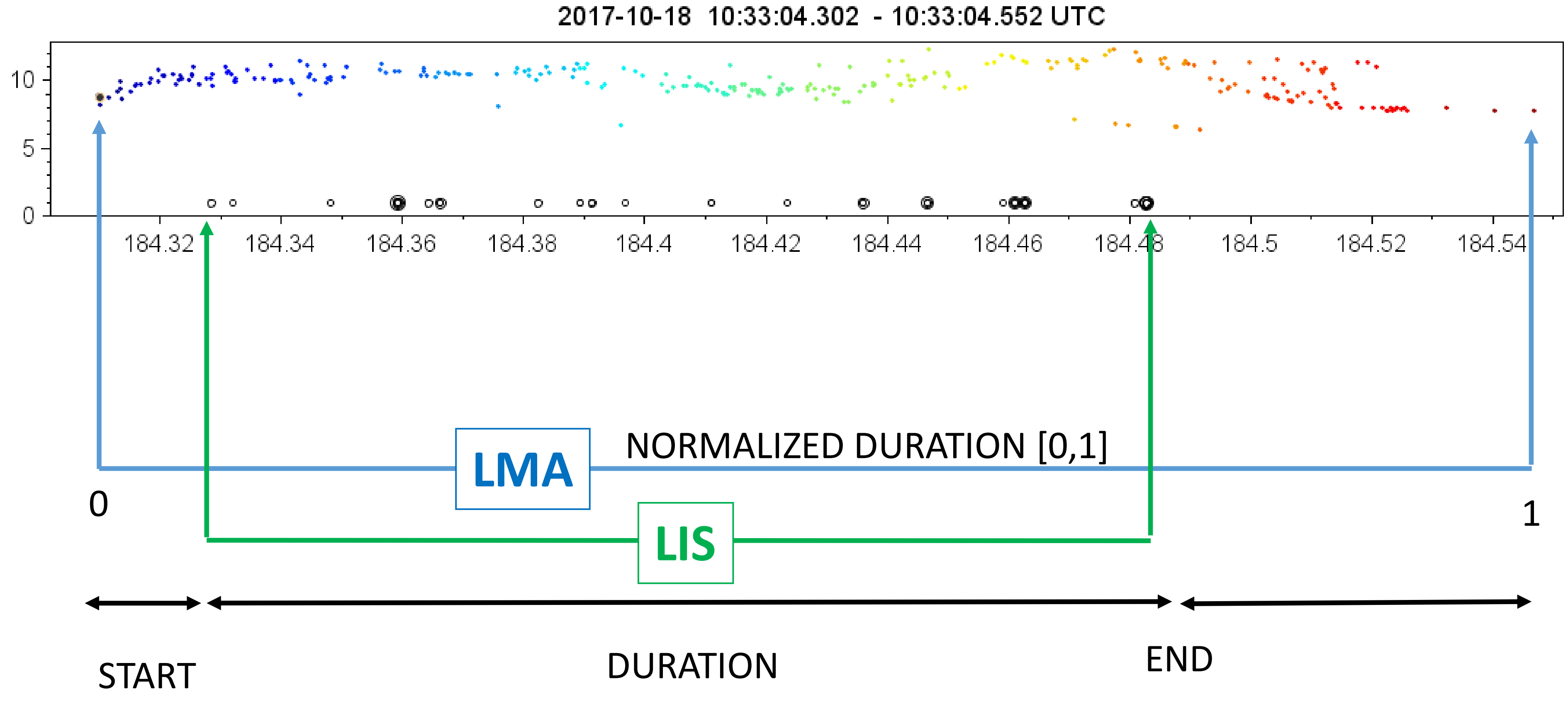
Flash-by-flash duration analysis



ISS-LIS events represented
At 1 km (arbitrary)

Flash duration

Flash-by-flash duration analysis



Flash duration

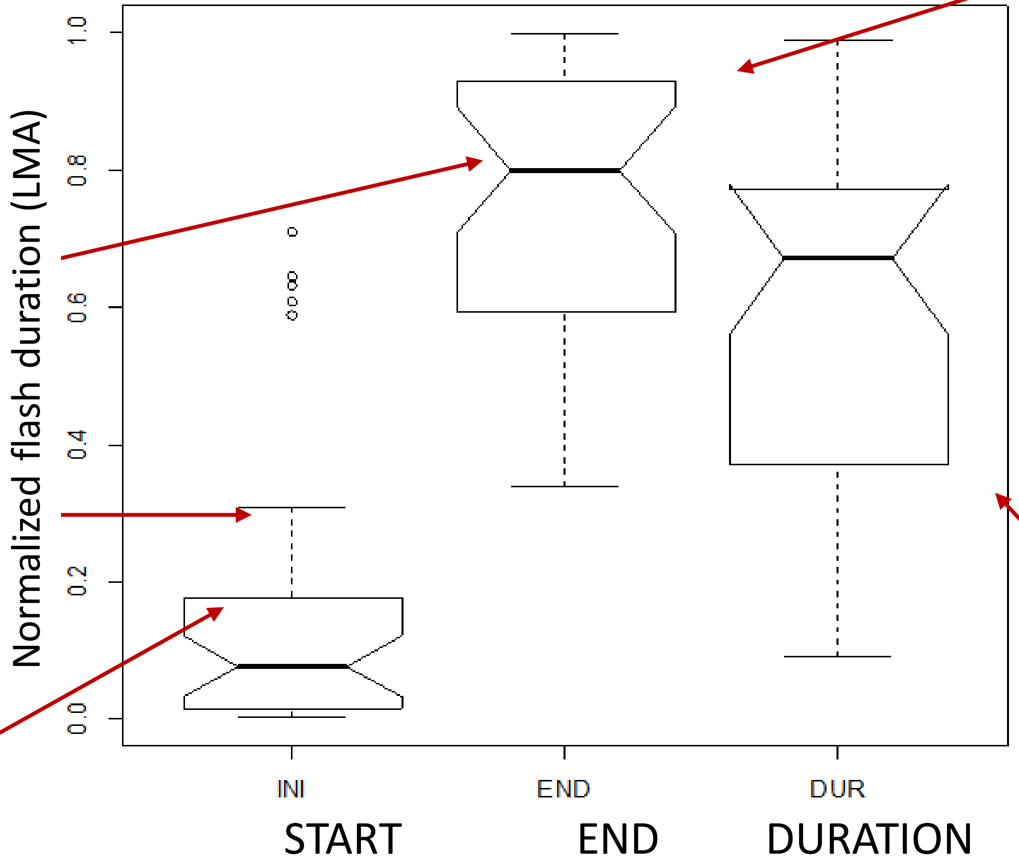
Flash-by-flash duration analysis

(4) End: In most of the cases, the last 10% of a flash is not detected by ISS-LIS

(3) End: Generally, the last ISS-LIS event is detected around the 80% of the flash duration

(5) Duration: The median of the ISS-LIS flash duration is around 70% of the total flash duration (assuming LMA sees all the flash)

(2) Start: Generally, the first ISS-LIS event is detected before the 30% of the flash duration

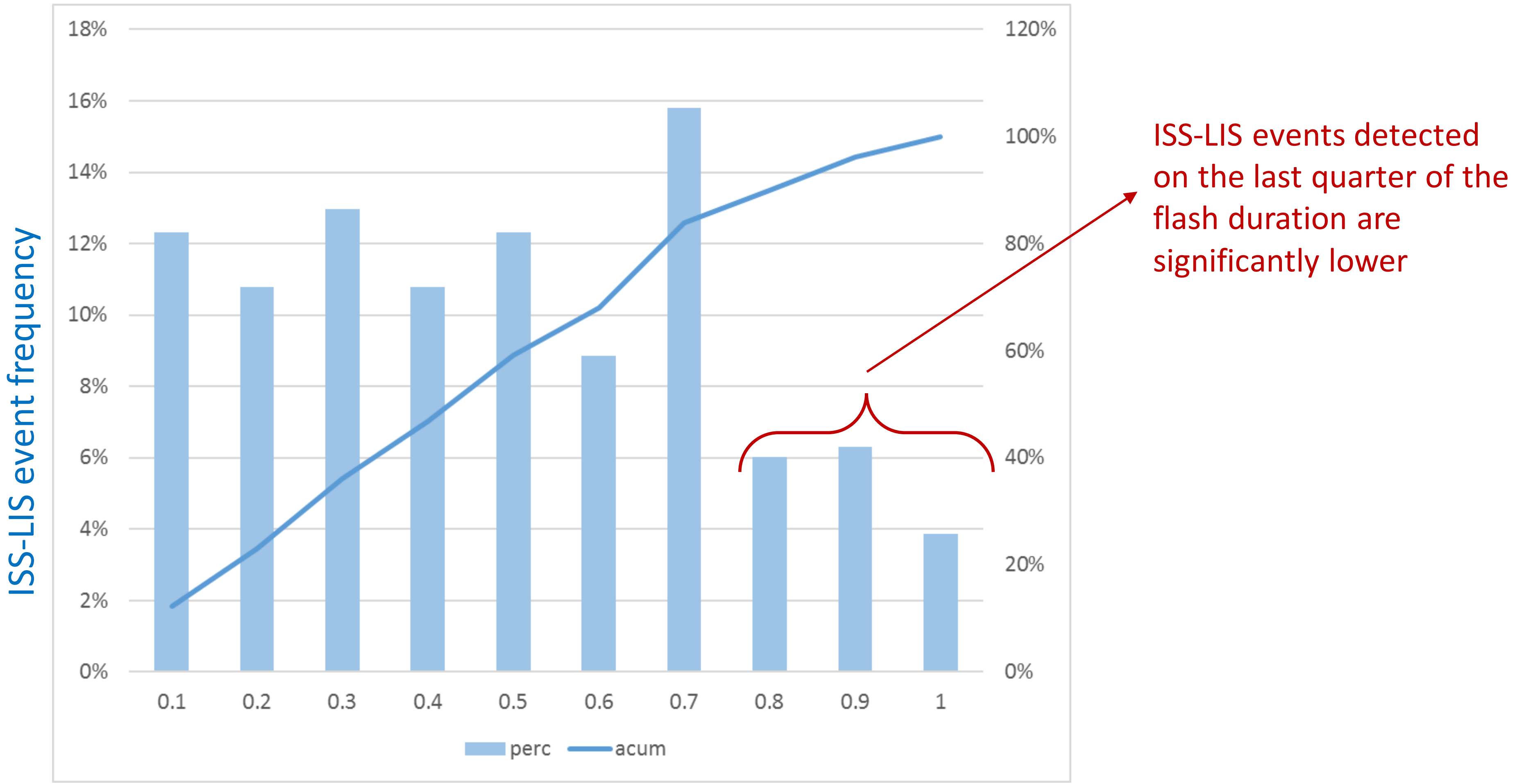


(6) Duration: In most of the cases, the ISS-LIS flash duration is, at least, 40% of the total duration

(1) Start: In most of the cases, the first ISS-LIS event is detected before the 20% of the flash duration

Flash duration

Flash-by-flash duration analysis



The normalized LMA flash duration is divided into ten segments

Flash duration

Conclusions

Conclusions are summarized as follows:

- In general, the duration of ISS-LIS flashes is about 30 % shorter than the duration of an LMA flash.
- The ISS-LIS flash criteria resulted that about 40 % of the LMA flashes have more than two ISS-LIS flashes (section 4.1). That strongly influence the difference pointed in the previous point.

- For the selected cases with good quality in both LMA and ISS-LIS, the time difference in duration decreases to 20 %.

- After the normalization of the LMA flashes, we have shown that:

  - In most of the ISS-LIS cases (>75 %), the first event is detected before the 20 % of the normalized flash duration.
  - Almost all of the analyzed flashes start before the 30 % of the normalized flash duration.
  - The last event of ISS-LIS occurs generally around the 80 % of the normalized flash duration (median value).
  - In most of the ISS-LIS cases (<75 %), the last 10 % of the LMA flash is not detected by ISS-LIS.
  - As obtained before, the median of the ISS-LIS flash duration is around 70 % of the total flash duration (remember that LMA has been taken as reference for normalization).
  - In most of the ISS-LIS cases (> 75 %), the duration is, at least, 40 % of the total duration.

Flash duration

- Location in time of the ISS-LIS events:
  - A rather regular distribution of the occurrence of ISS-LIS events if found in the first 70 % of a flash.
  - The last 30 % of the flash only contains the 16 % of the ISS-LIS events.
  - From the distribution of LMA source heights in the normalized flash, the interquartile distance (from 25th to 75th %) increase with time. That might explain that in the last part of a flash it contains a higher fraction of sources at low levels (cloud channels on the mid regions seem to be more frequent at the end of the flash).
  - However, occurrence of higher channels keeps active at this stage (e.g. recoil leaders).
  - There is not a significant variation in the power of the LMA sources.

- We have not found that brightest optical events tended to occur at the end of intracloud LMA discharges as 'might' be suggested by Thomas et al. (2000). (Note to verify that the flash end corresponded to LMA and not to ISS-LIS)

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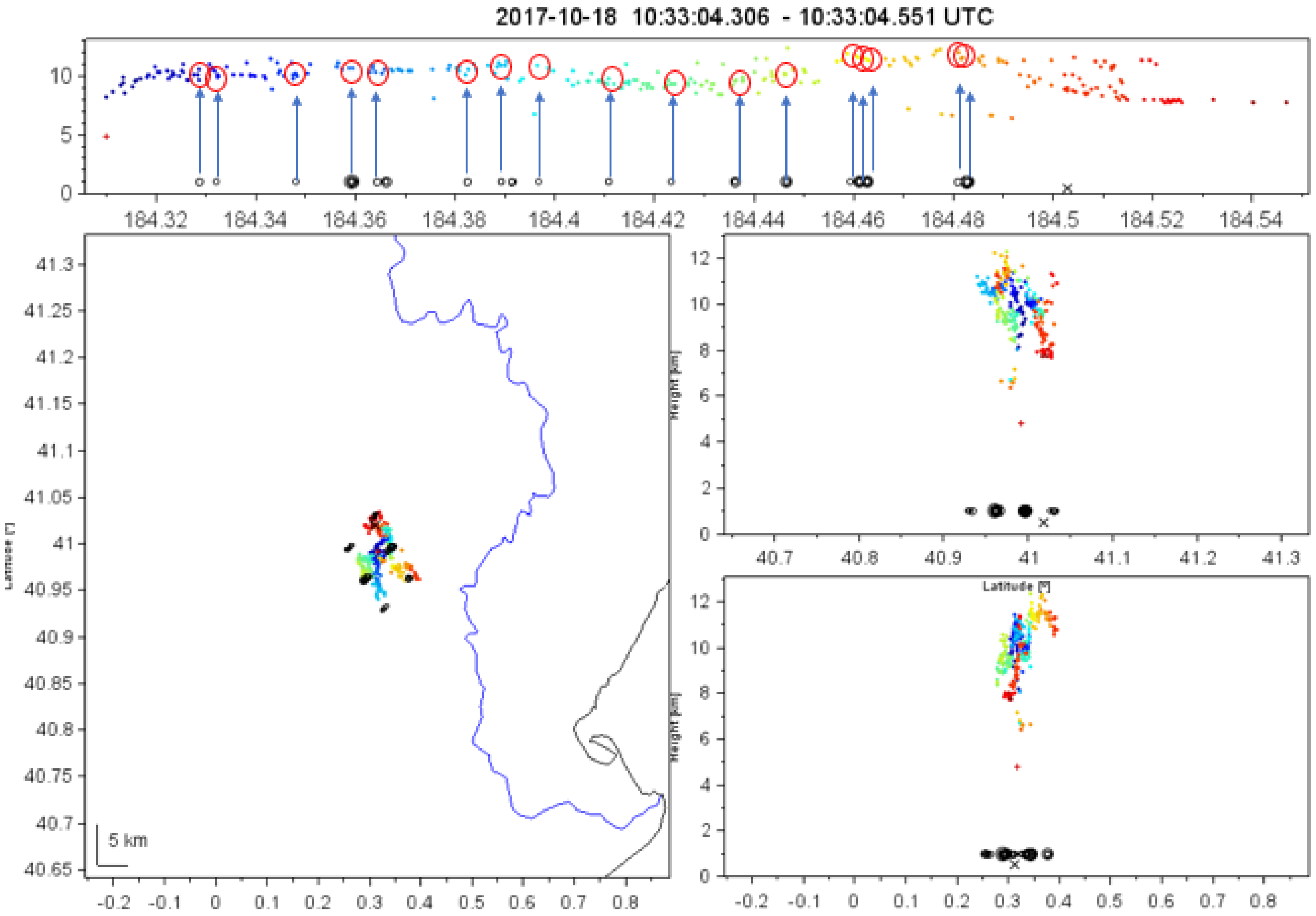
Distribution of Events with height and power

Distribution of Events with height and power

- Flash-by-flash analysis
- Match-up procedure
- Pairs of ISS-LIS - event + LMA source



Does the LMA sources corresponding to ISS-LIS detections have different characteristics?

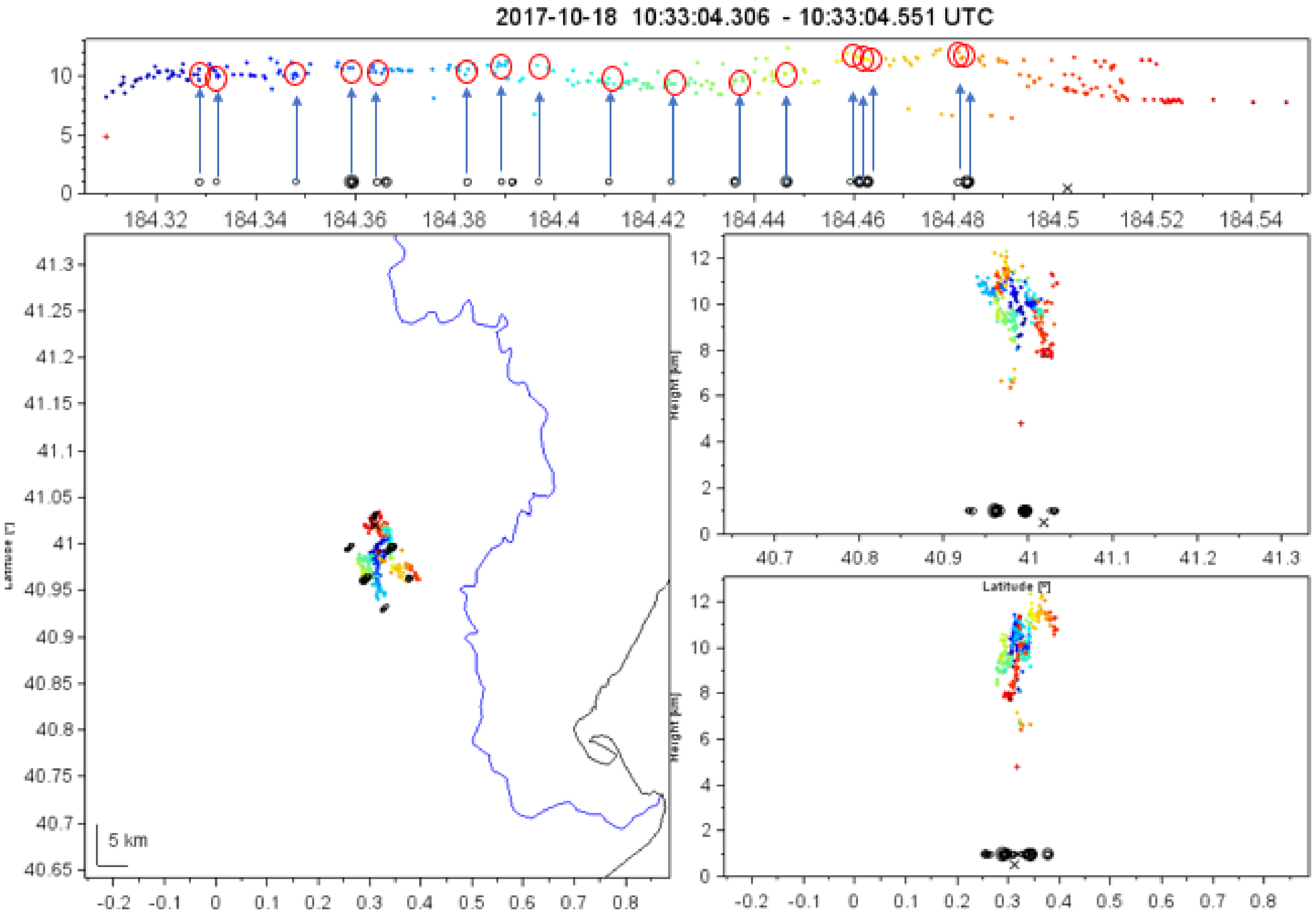
- Are those LMA sources higher in altitude?
- Are those sources more intense in RF power (dBW)?

Distribution of Events with height and power

Flash-by-flash analysis

Match-up procedure

Pairs of ISS-LIS - event + LMA source



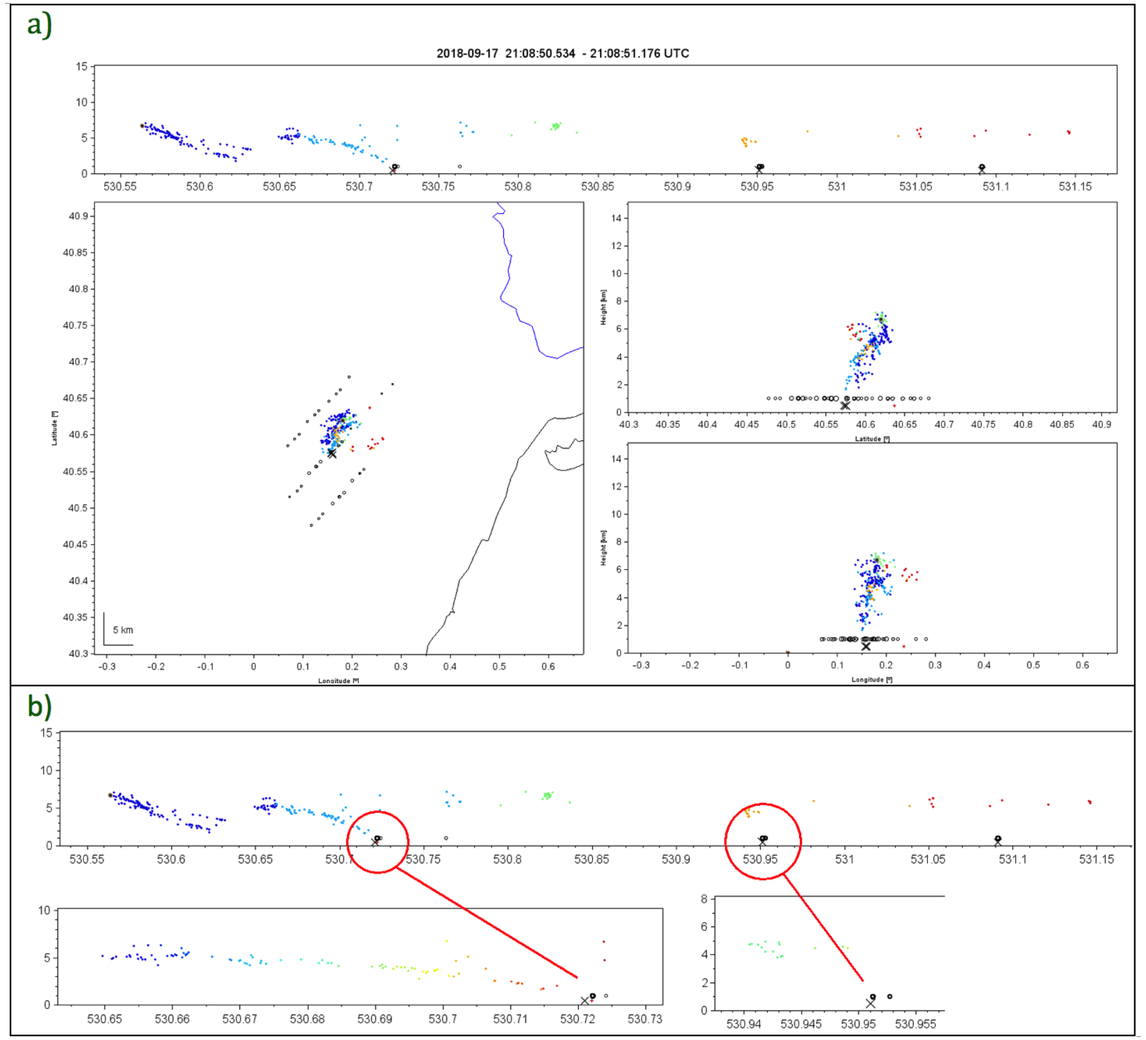
In this case, events and LMA sources are grouped with a time-distance criteria:

- time difference <10 ms*
- distance <10 km

But time difference was not clear:

- LIS had delays of the order of 10 ms (Ushio et al. 2002).
- Doug Mach: time is accurate at ms.

Distribution of Events with height and power



We have evaluated the time accuracy of ISS-LIS selectin typical negative CG flashes with low IC activity. In the selected cases ISS-LIS clearly detected the CG strokes.

We found a systematic delay of 1ms

The analysis is done

- time difference no time difference or with 1 ms delay
- distance <10 km

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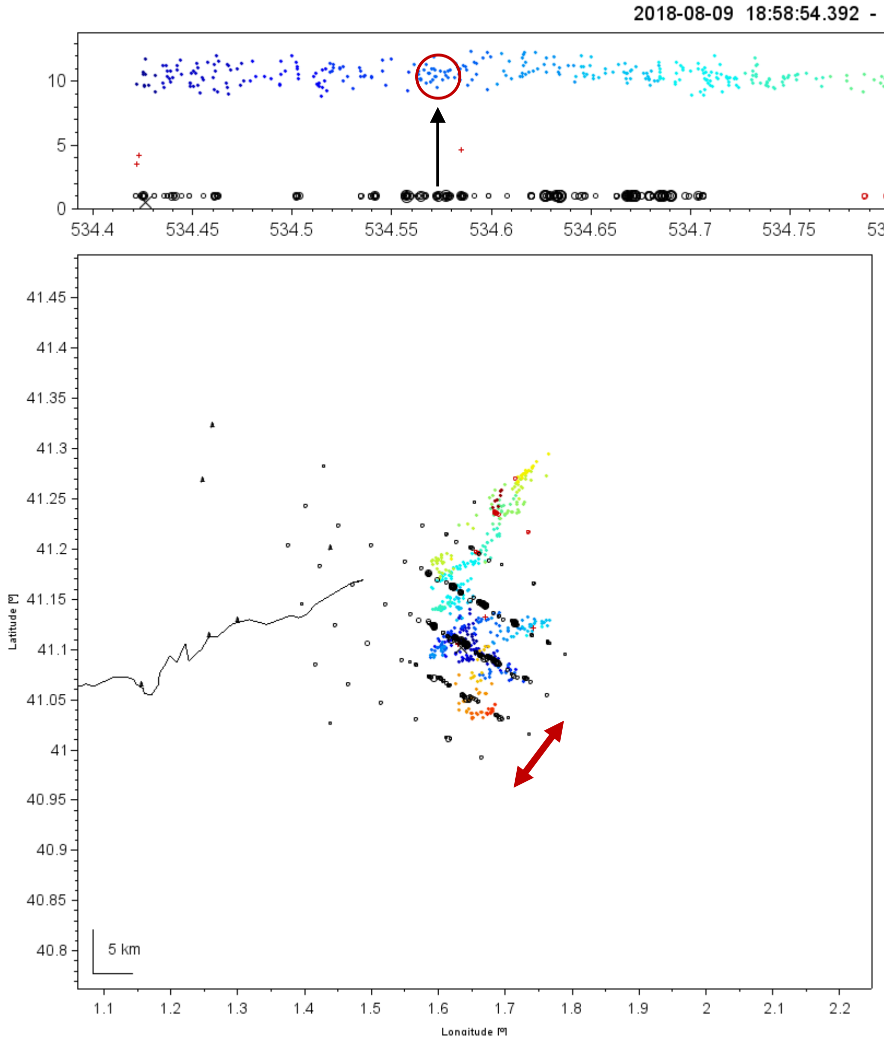
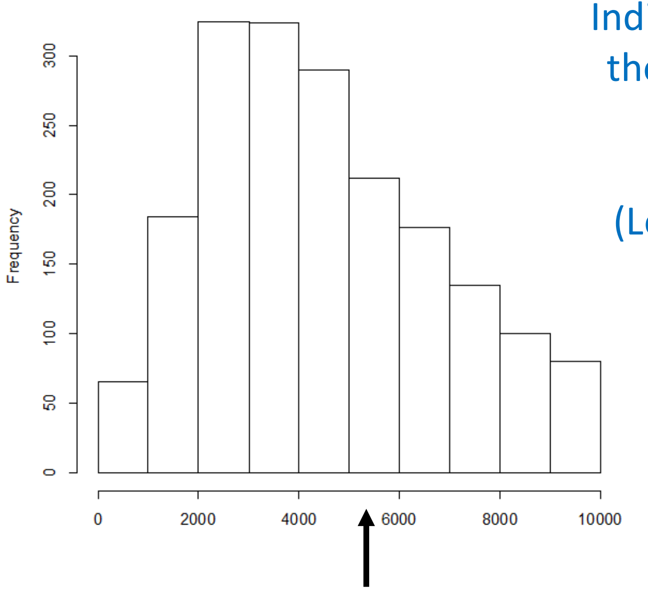
Distribution of Events with height and power

Results





Indirect evaluation on the LIS geographical accuracy

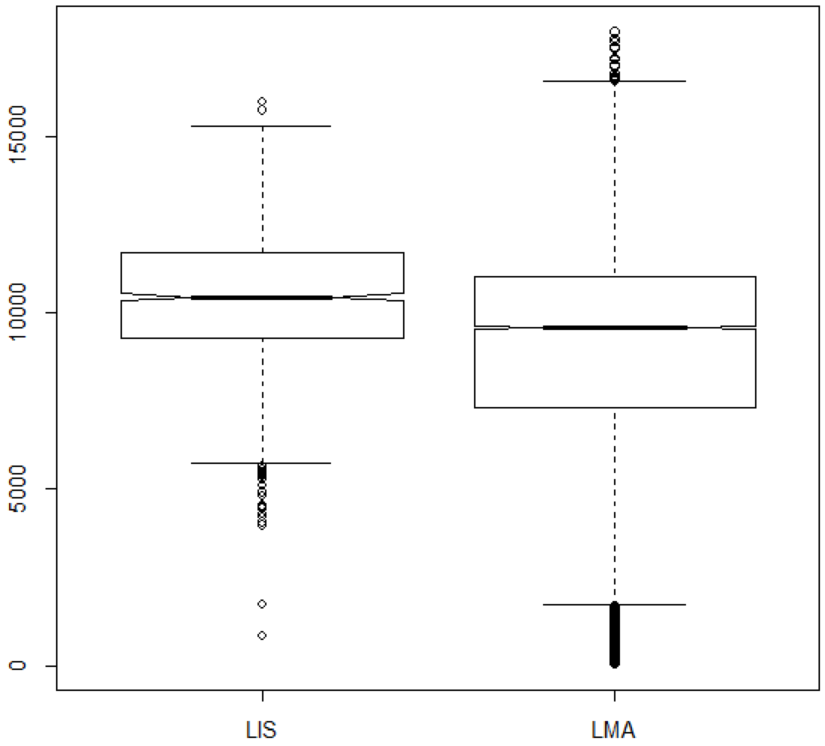
(Location accuracy)

Median distance between the LIS event and the corresponding LMA source: 5.5 km

Distribution of Events with height and power

Results

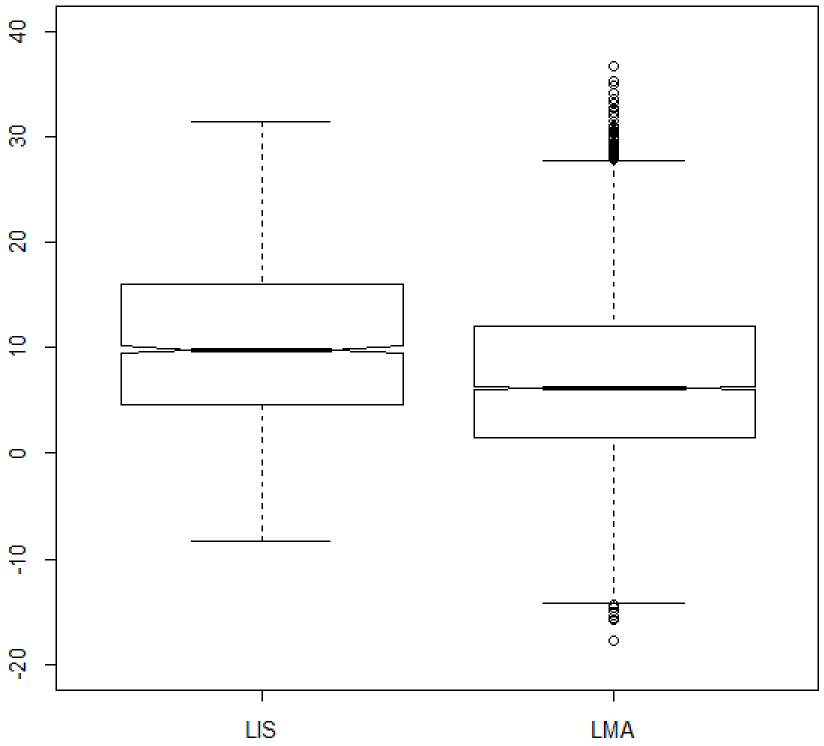
Height (m)



ISS-LIS events matched with LMA sources

LMA source population

Power (dBW)

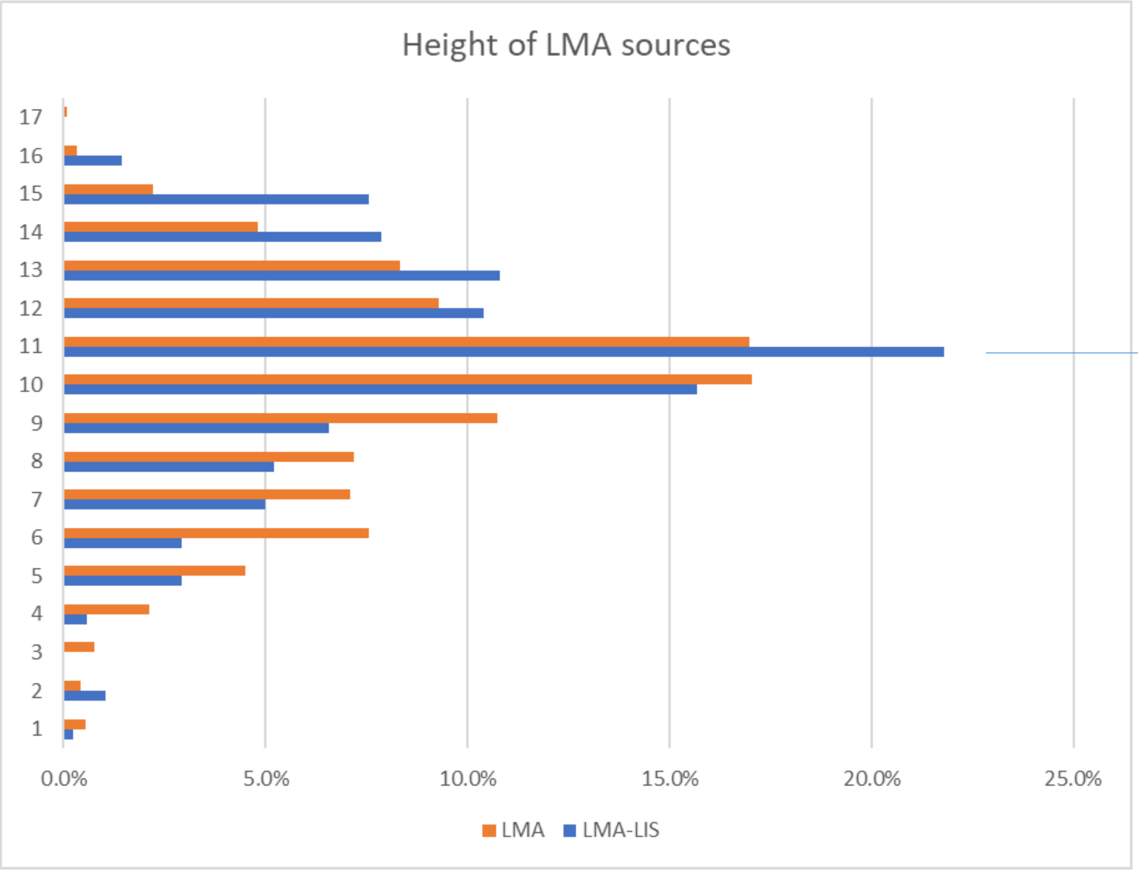


ISS-LIS events matched with LMA sources

LMA source population

Distribution of Events with height and power

Results



discharges which extend into the upper part of the cloud are better detected by ISS-LIS

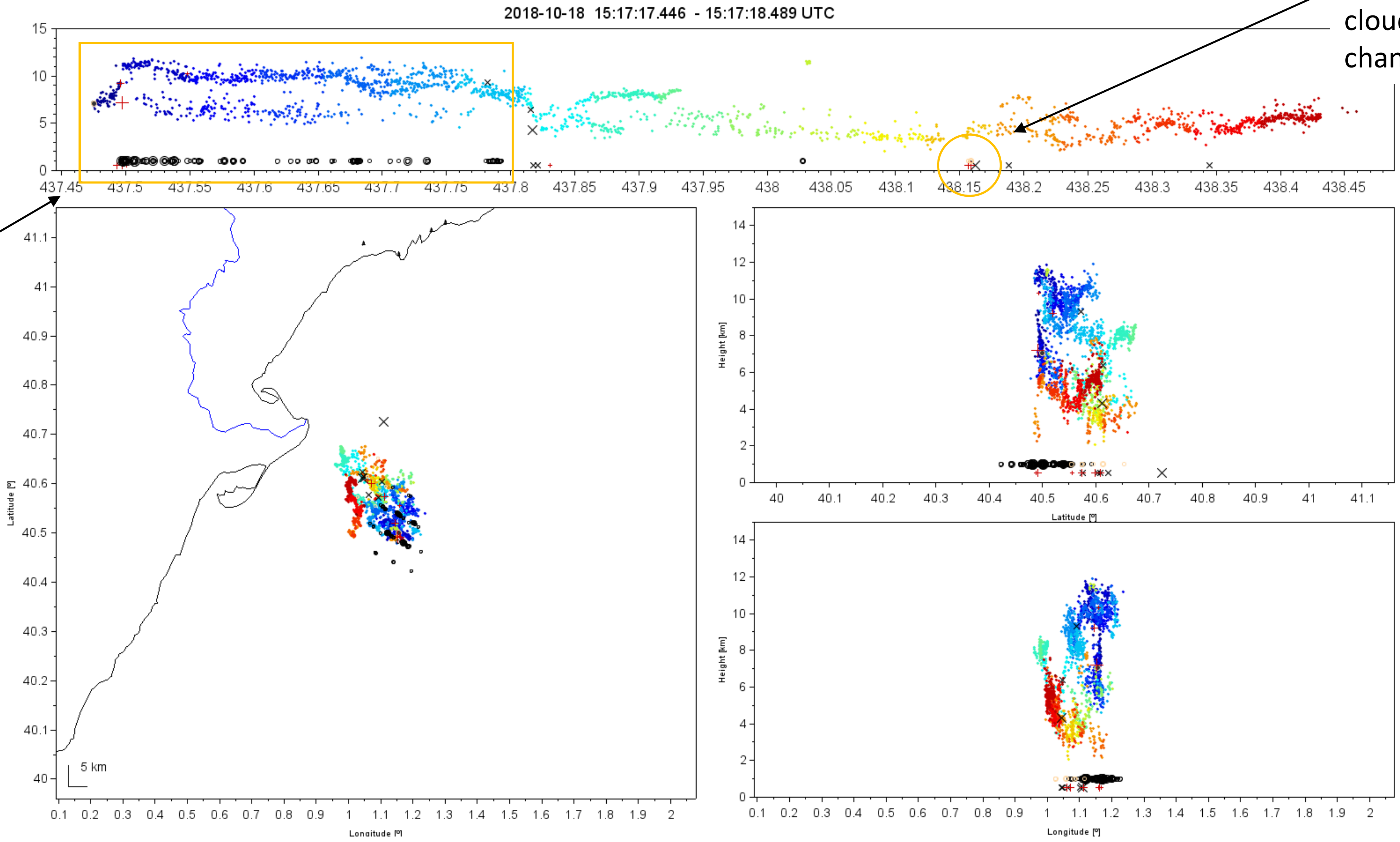
11 km

Relation of Events with lightning processes

Example

LIS events = CG strokes (without upper cloud channels)

LIS events = higher channels

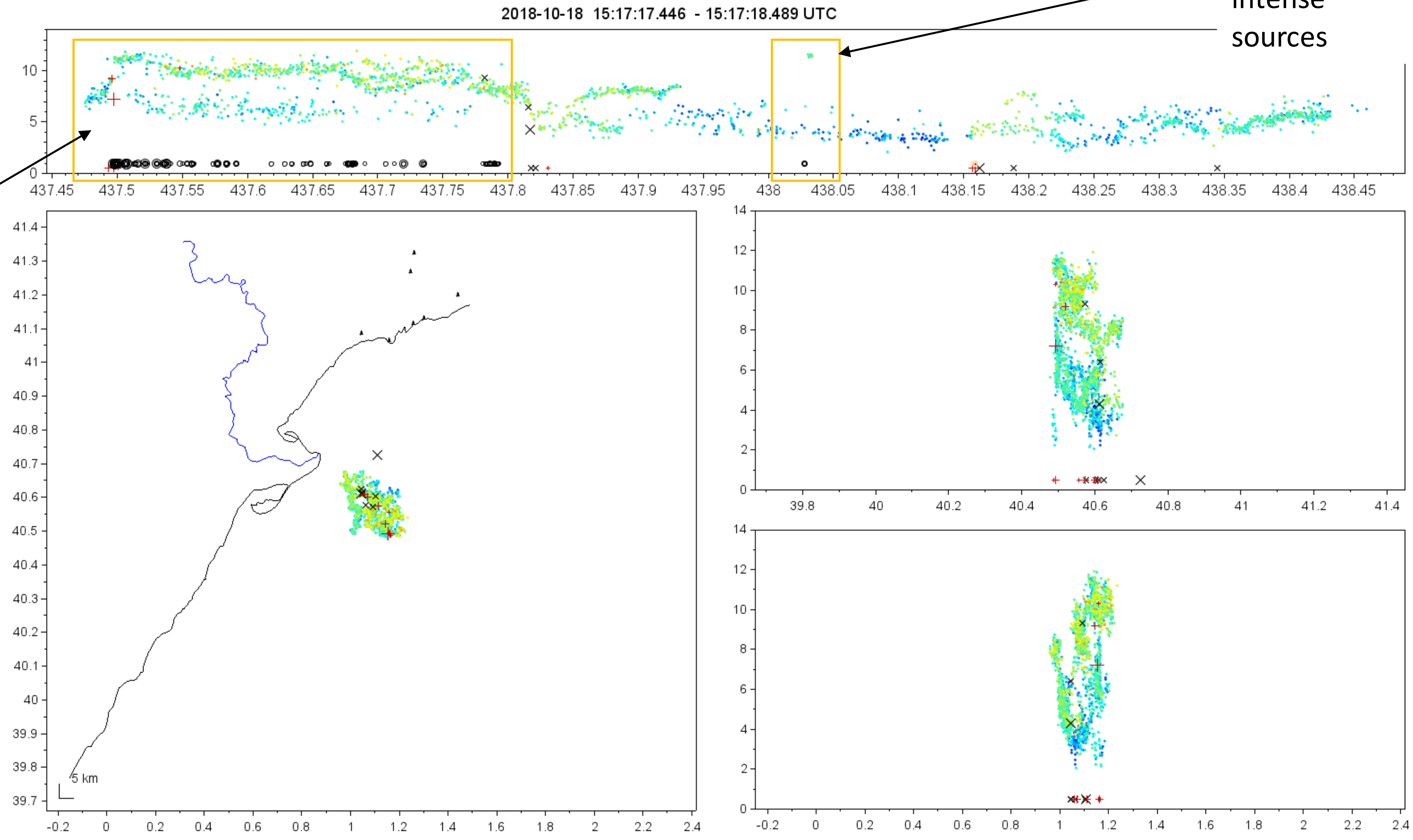


Relation of Events with lightning processes

Example

LIS events = intense sources

LIS events = isolated intense sources



Relation of Events with lightning processes

Conclusions

Summary of the main conclusions:

- A time and location criterion has been used to match ISS-LIS events and LMA sources.
- First, UT time difference has been evaluated and a systematic delay of 1 ms has been found. That agrees with personal communication with Doug Mach.
- For the matched ISS-LIS events/LMA sources in time, a location distance of 5.5 km between them is found in case of no introducing a time delay of 1 ms. When the delay has been introduced this distance grows to 6 km.

Relation of Events with lightning processes

- For those paired event-sources, the median height of the sources are slightly higher than the median height for the LMA source population.

- However, the 25th percentile of the paired events/sources is at much higher altitude (9 km) compared to the overall of the LMA source population (7.5 km). Then, ISS-LIS events are typically paired with LMA sources occurring over the median altitude of the LMA source population.

- Discharges which extend into the upper part of the cloud (> 11 km) are better detected by ISS-LIS. On the other hand, discharges confined below 11 km altitude were less well detected.

- As in the previous sections, the power of LMA sources matched with ISS-LIS events present slightly higher median values. This corresponds to a difference of about 5 dB.

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