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Progress meeting: ISS LIS evaluation using LMA

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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

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Introduction

Work done after the meeting 20190318:

- DE has been recalculated only using good quality LMA flashes.
- An additional episode has been added.
- DE efficiency has been determined for different altitudes (layers).
- Evaluation of false detections (FFAR).
- Preliminary proposal definition of the methods for DE and FFAR.

- Analysis of the LMA heights and power versus ISS-LIS radiance.

- Location accuracy analyzed by altitude layers.
- Location accuracy summary and tables of main results.

- Started working on the definition of a flash to create test cases

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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.

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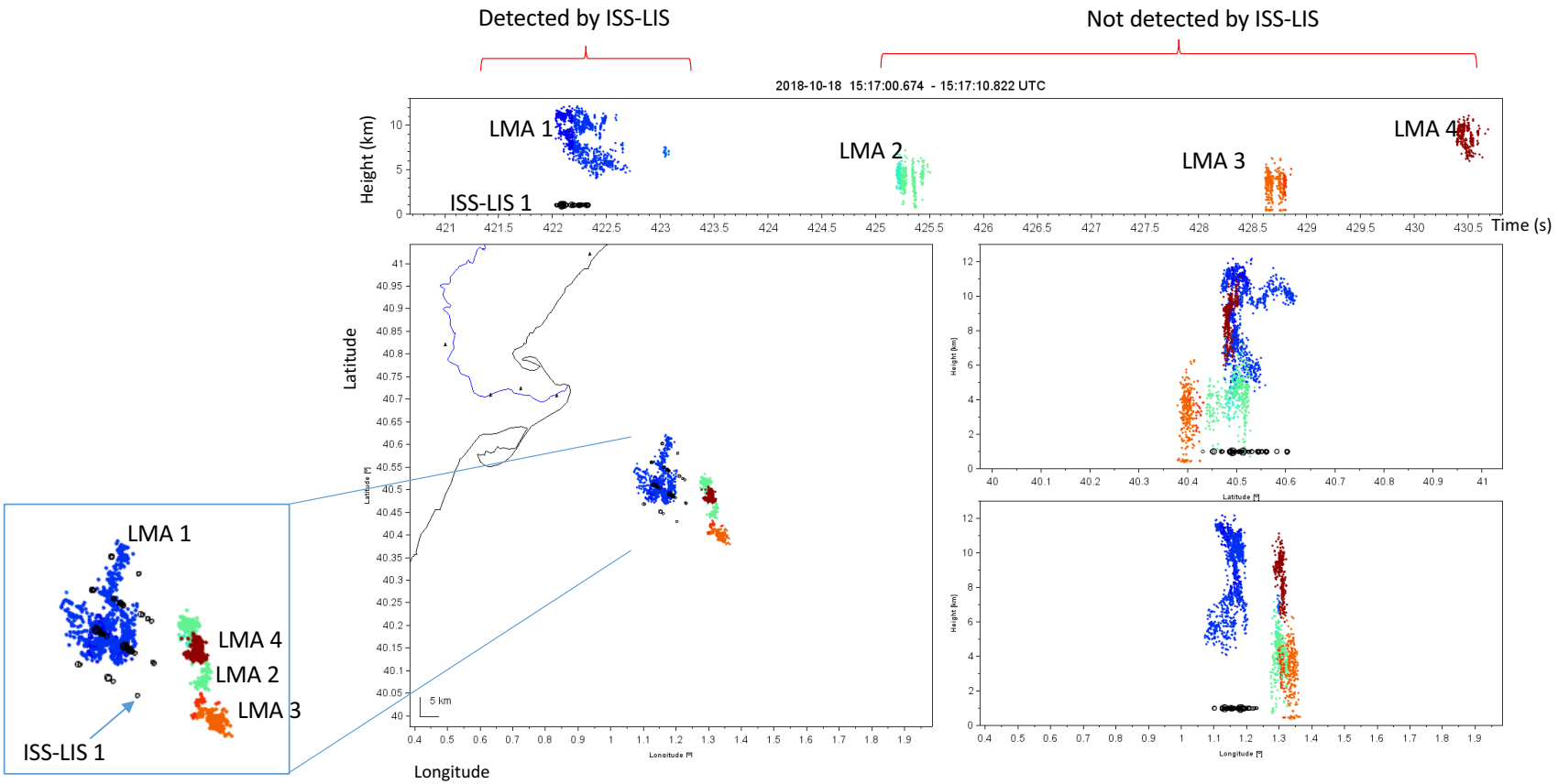
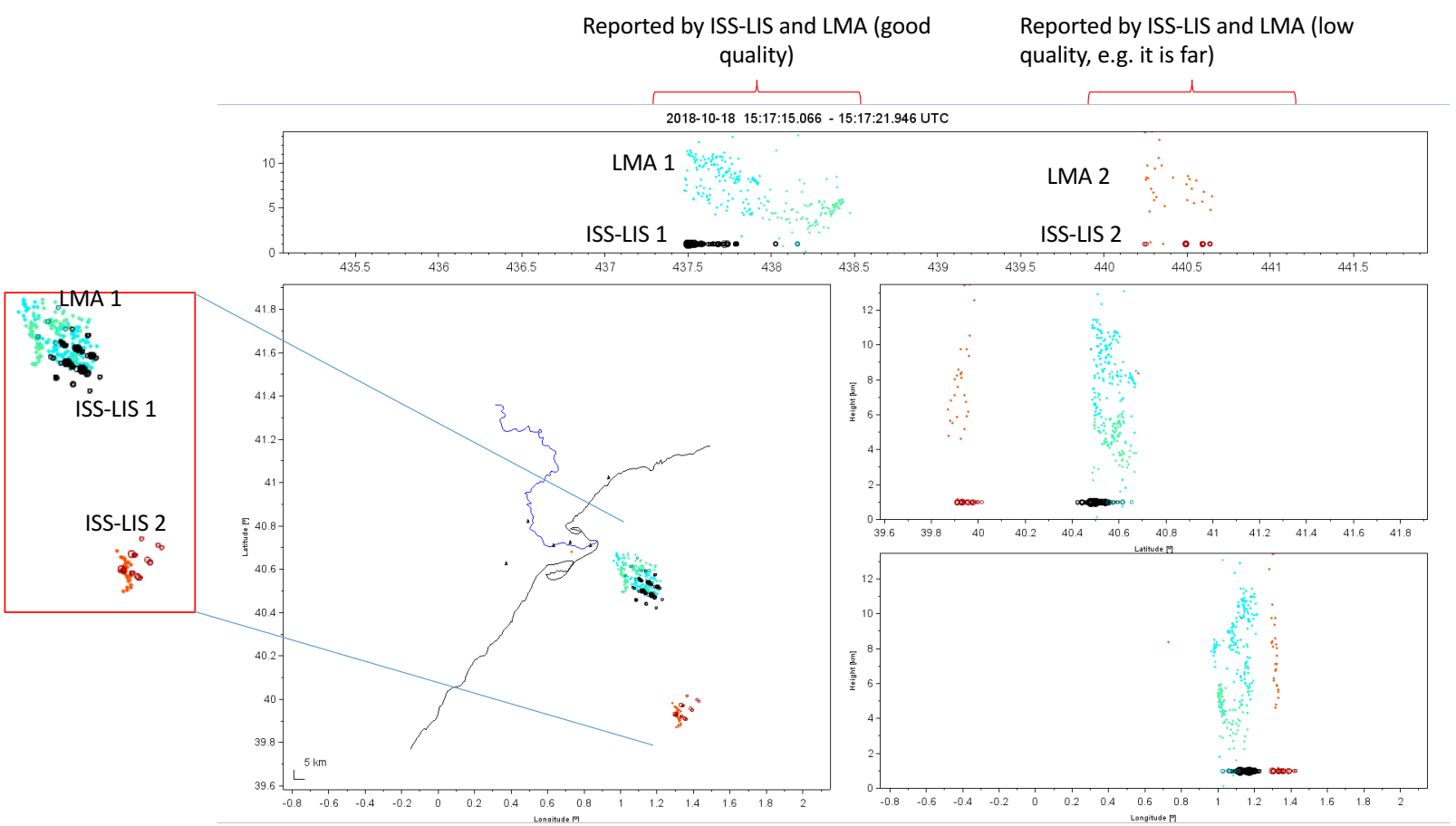
Detection Efficiency

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



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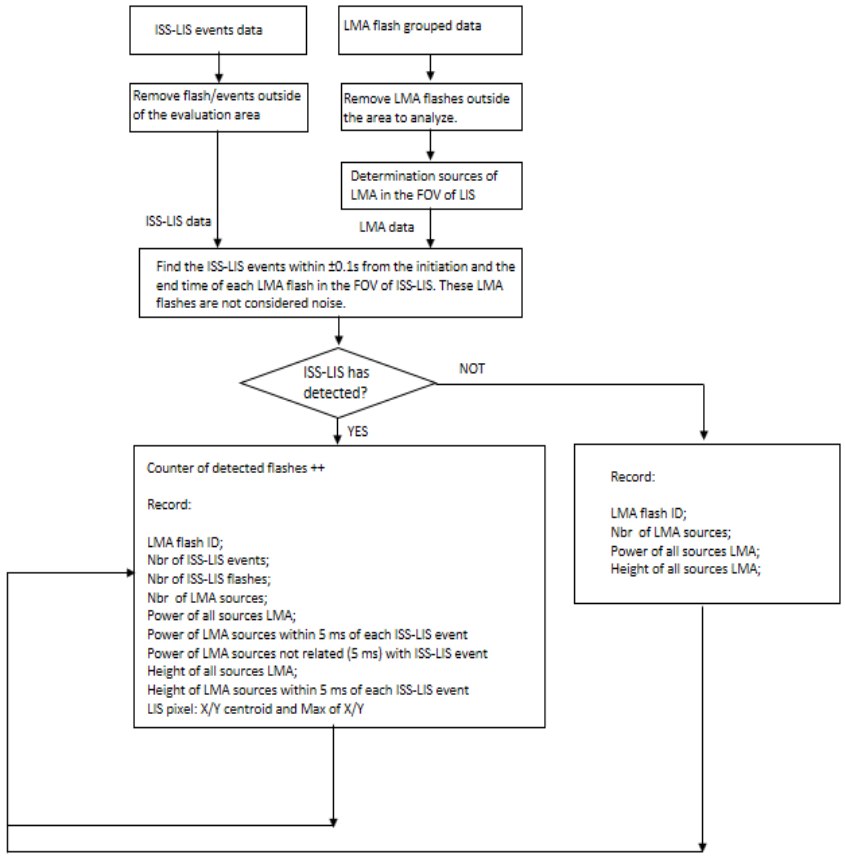
Detection Efficiency



Important: definition of LMA flash

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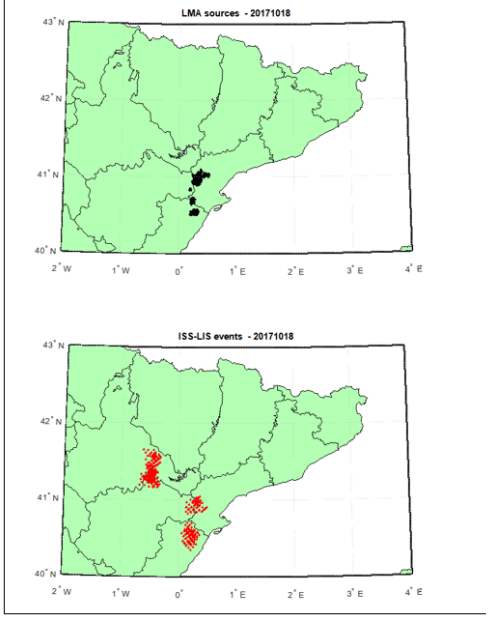
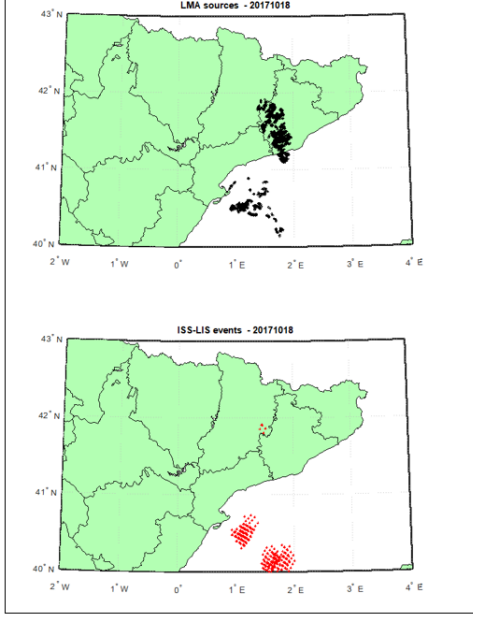
Detection Efficiency

Maps of the LMA sources in the FOV of ISS-LIS and ISS-LIS events (<150 km)

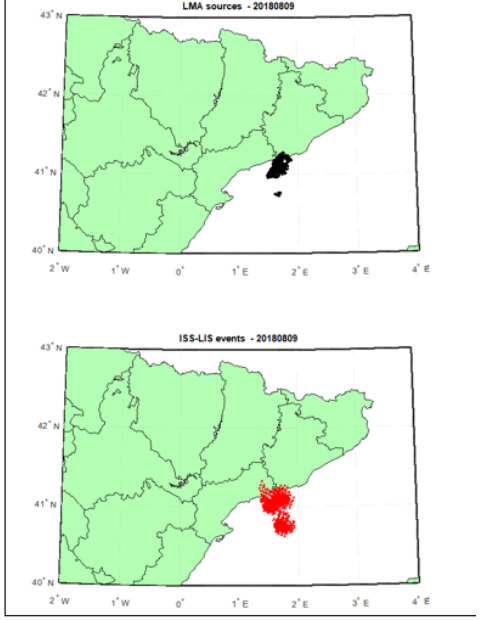
20171018-1 LMA) and LIS



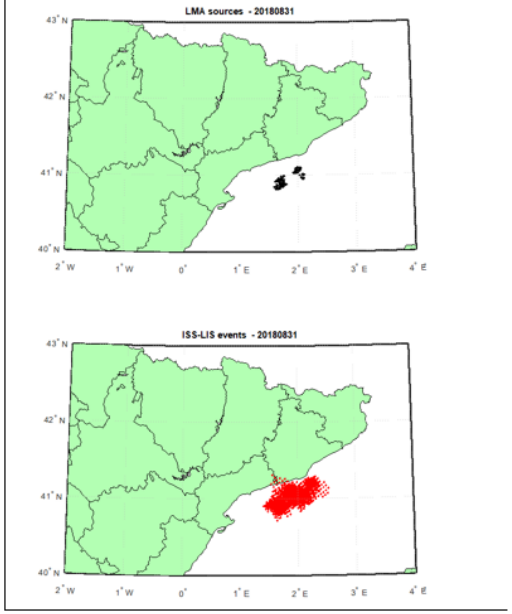
20171018-2 LMA and LIS

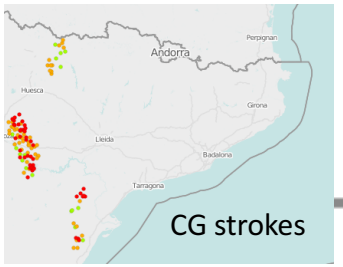


20180809LMA and LIS



20180831 LMA (and LIS





LMA has poor coverage of the storm at the west.

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

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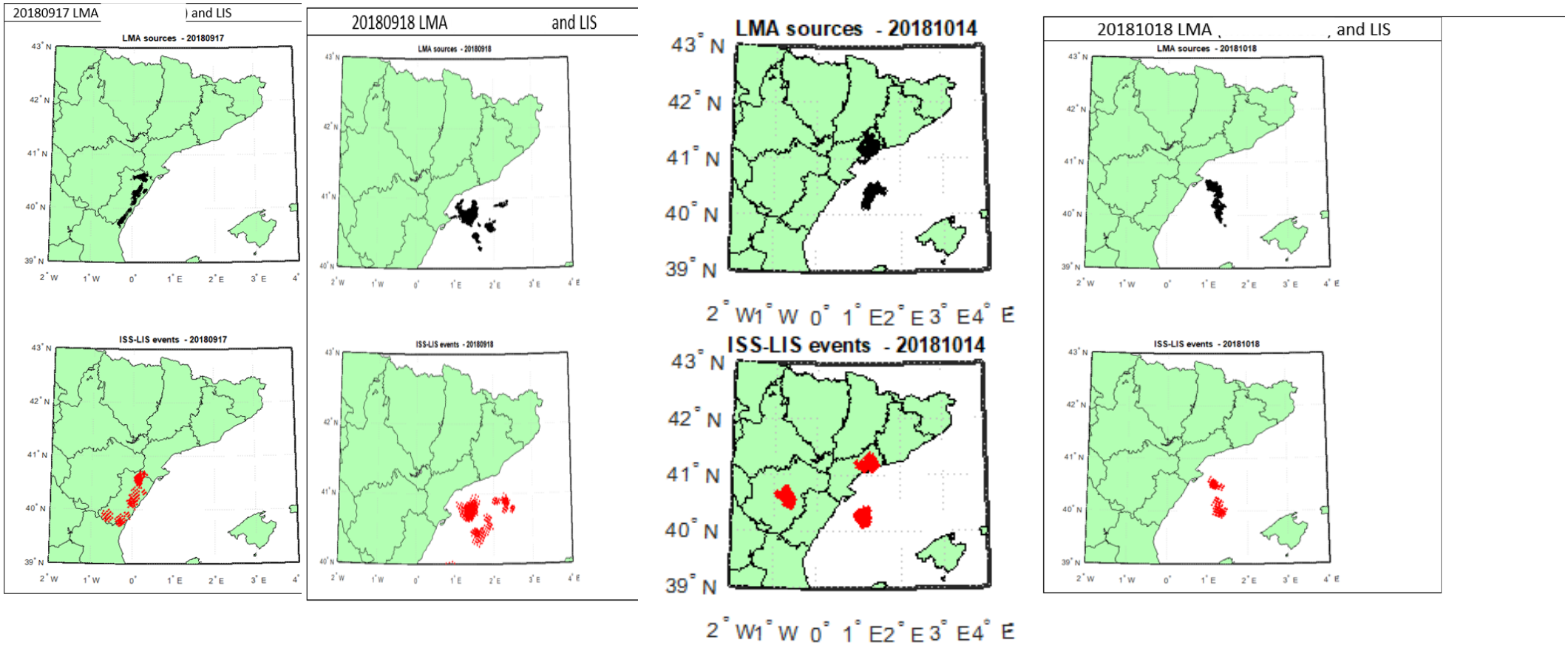
Detection Efficiency

Maps of the LMA sources in the FOV of ISS-LIS and ISS-LIS events (<150 km)



LMA has poor coverage of the storm at the west.

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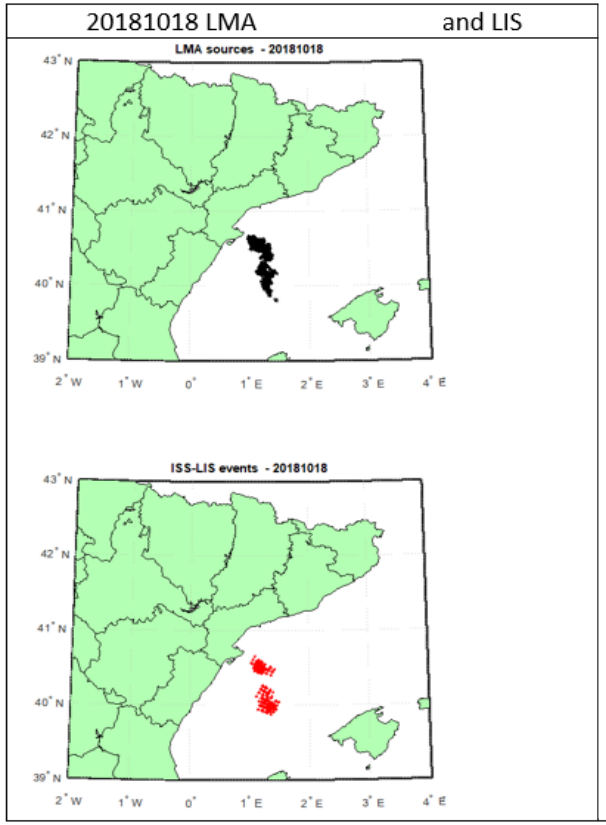
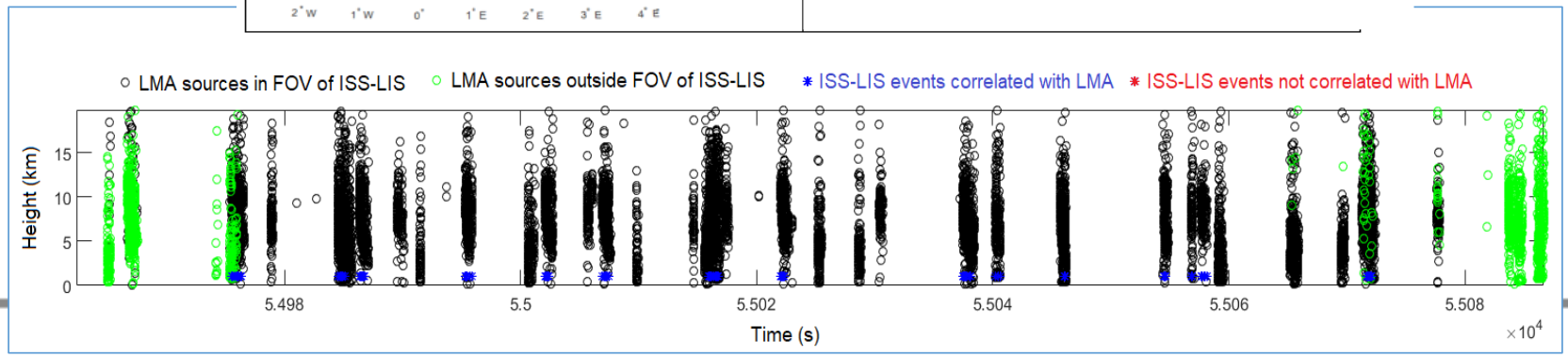
LMA and ISS-LIS events
(maps and time evolution)





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Detection Efficiency

Summary of the results by episode

Episodes with high quality LMA data: distance < 150 km and more than 50 sources per flash						
Date	Number of flashes	Average flash rate [min^{-1}]	Average LMA source rate [s^{-1}]	Number of flashes detected by ISS-LIS	Detection Efficiency DE_f	Comments
20171018-1 ~10:30 UTC	13	8.7	41.5	9	0.69	
20171018-2 ~17:00 UTC	8	4.6	49.8	3	0.37	The flashes occurred in the edge of the CCD.
20180809 ~19:00 UTC	14	8.6	29.5	13	0.93	
20180831 ~04:40 UTC	2	1.1	1.1	2	1	Not representative.
20180917 ~21:10 UTC	24	12.3	32.4	15	0.62	
20180918 ~03:30 UTC	62	35.1	301.4	57	0.92	Extremely active episode Night time. Average flash rates are not realistic since many flashes cannot be separated
20181014 ~17:00 UTC	39	22.6	224.0	32	0.82	Moderate activity
20181018 ~15:15 UTC	31	18.2	214.2	16	0.51	Moderate flash rate but quite active in terms of LMA sources
Total number of LMA flashes: 193						
Total number of flashes detected by LIS: 147						
DE_f = 0.76						

Episodes with high quality LMA data: distance < 150 km NO minimum number of sources per LMA flash						
Date	Number of flashes	Average flash rate [min^{-1}]	Average LMA source rate [s^{-1}]	Number of flashes detected by ISS-LIS	Detection Efficiency DE_f	Comments
20171018-1 ~10:30 UTC	24	16.0	43.2	13	0.54	
20171018-2 ~17:00 UTC	10	5.8	50.3	4	0.40	The flashes occurred in the edge of the CCD.
20180809 ~19:00 UTC	20	12.2	30.7	18	0.90	
20180831 ~04:40 UTC	28	15.7	4.5	24	0.85	Flashes occur far from the network
20180917 ~21:10 UTC	42	21.61	36.3	18	0.43	
20180918 ~03:30 UTC	73	41.3	303.4	60	0.82	Extremely active episode Night time. Average flash rates are not realistic since many flashes cannot be separated
20181014 ~17:00 UTC	43	24.9	225.3	32	0.74	Moderate activity
20181018 ~15:15 UTC	32	18.7	214.3	16	0.50	Moderate flash rate but quite active in terms of LMA sources
Total number of LMA flashes: 272						
Total number of flashes detected by LIS: 185						
DE_f = 0.68						

Episodes with high quality LMA data: distance < 75 km and more than 50 sources per flash						
Date	Number of flashes	Average flash rate [min^{-1}]	Average LMA source rate [s^{-1}]	Number of flashes detected by ISS-LIS	Detection Efficiency DE_f	Comments
20171018-1 ~10:30 UTC	13	8.6	41.5	9	0.7	
20171018-2 ~17:00 UTC	2	1,2	12.0	1	0.5	The flashes occurred in the edge of the CCD.
20180809 ~19:00 UTC	4	2.4	3.5	4	1	
20180831 ~04:40 UTC	0					No flashes at the given distance and quality
20180917 ~21:10 UTC	16	8.2	25.0	9	0.56	
20180918 ~03:30 UTC	56	31.7	276	51	0.91	Extremely active episode Night time. Average flash rates are not realistic since many flashes cannot be separated
20181014 ~17:00 UTC	32	18.5	155	26	0.81	Moderate activity
20181018 ~15:15 UTC	28	16.4	206.15	13	0.46	Moderate flash rate but quite active in terms of LMA sources
Total number of LMA flashes: 151						
Total number of flashes detected by LIS: 113						
DE_f = 0.75						

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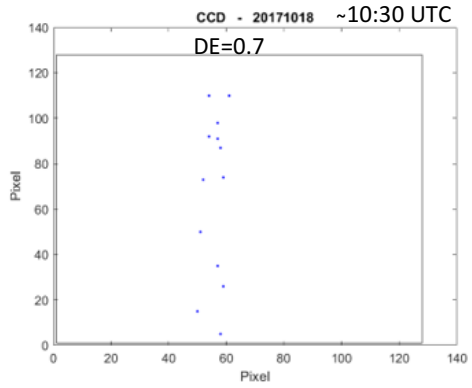
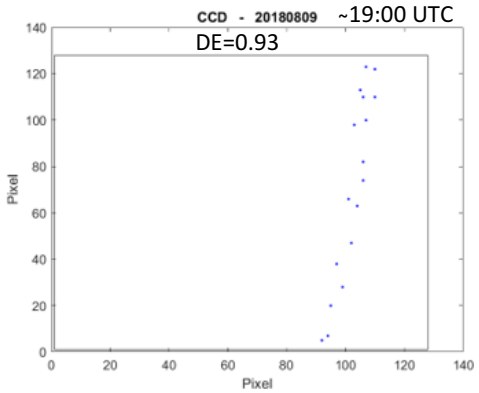
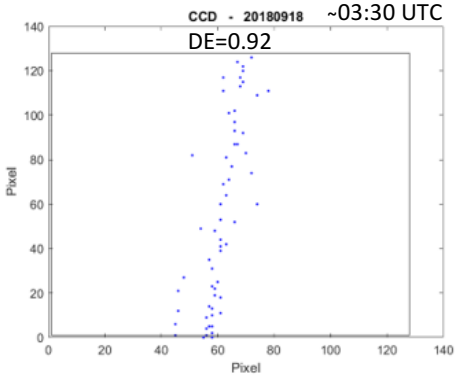
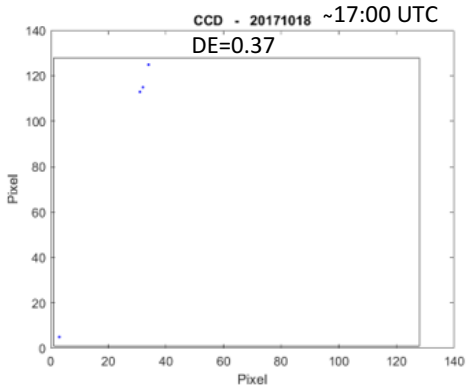
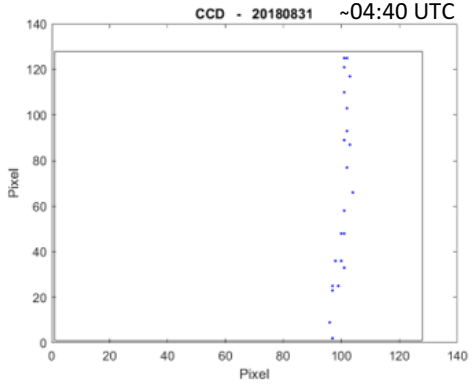
Location of the ISS-LIS flashes in the CCD

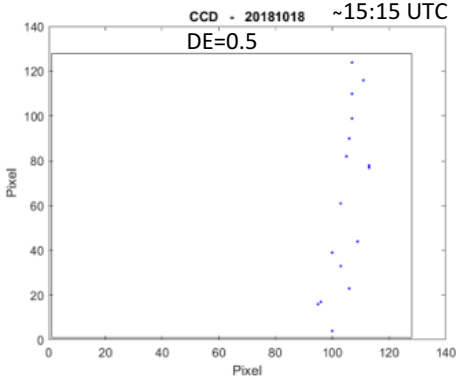


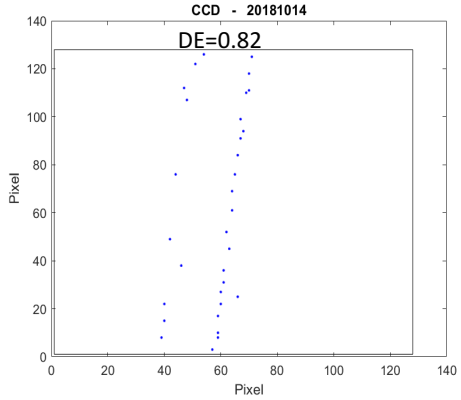


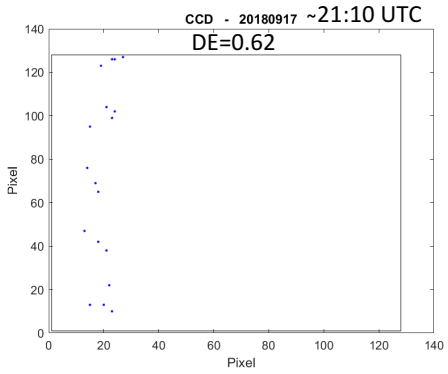












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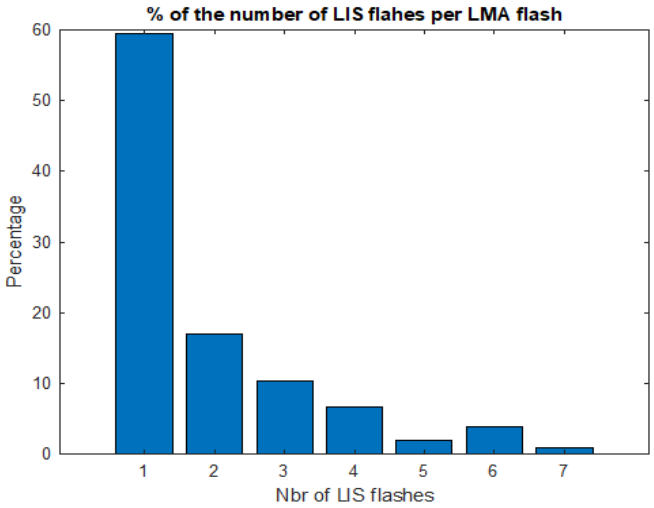
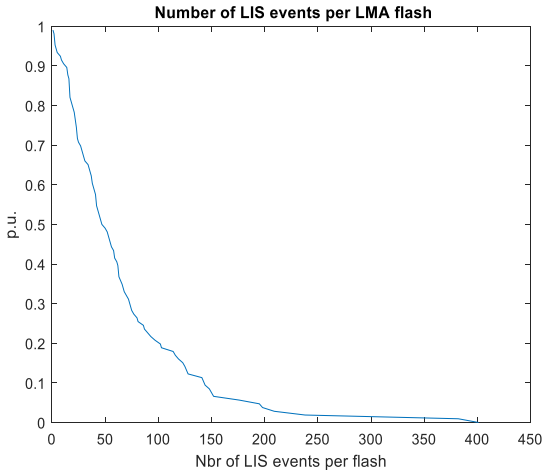
Detection Efficiency

Number of ISS-LIS flashes and events for detected flashes



About 60 % of the LMA flashes have one ISS-LIS flash.
About 20 % of the LMA flashes → ISS-LIS assigned two flashes

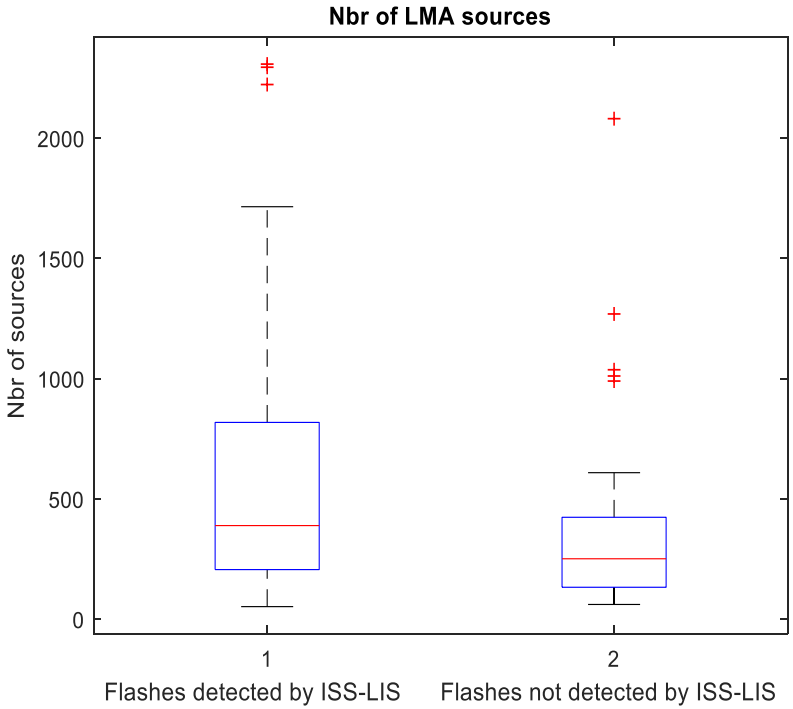
Number ISS-LIS of events per detected LMA flash



More than 98 % of the flashes has more two or more ISS-LIS detections

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.

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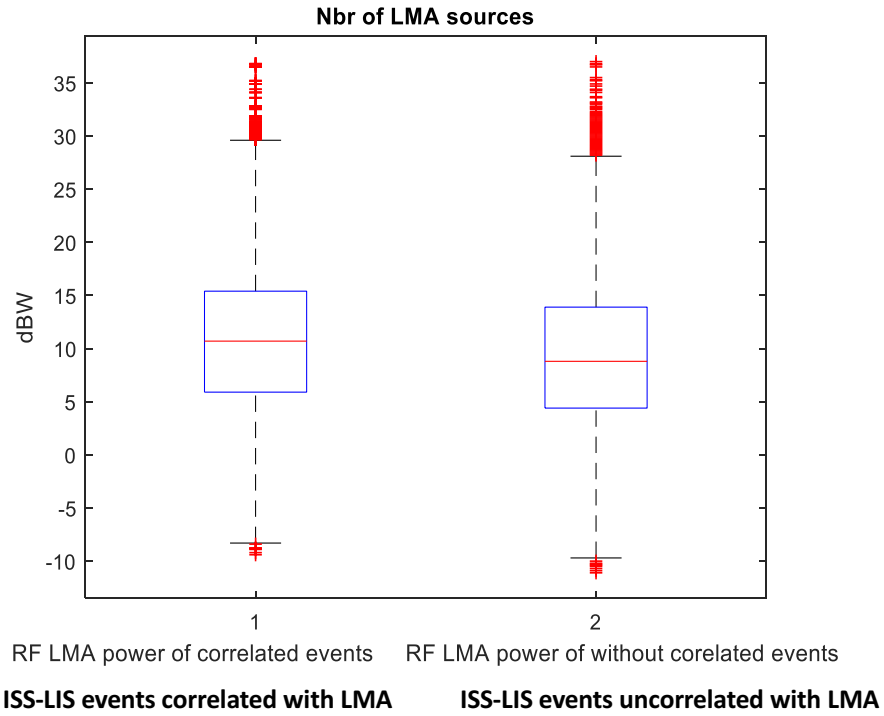
Detection Efficiency

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



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

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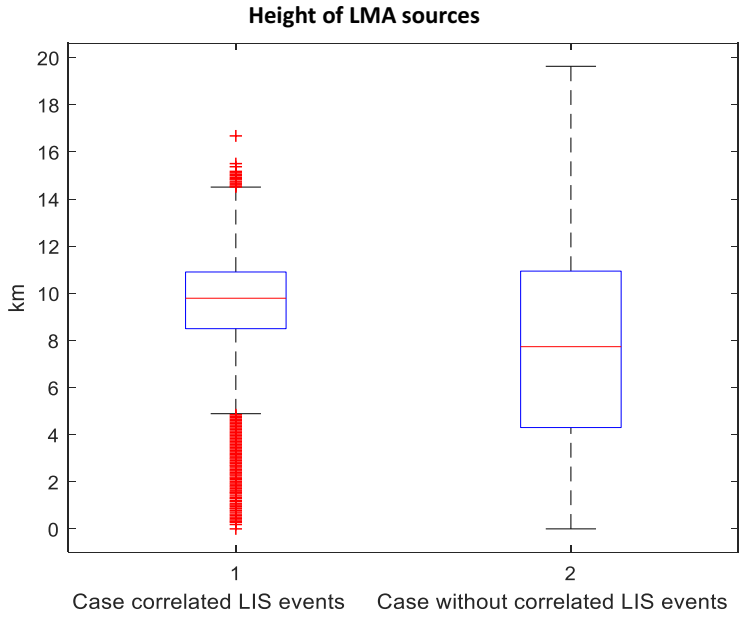
Detection Efficiency

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.

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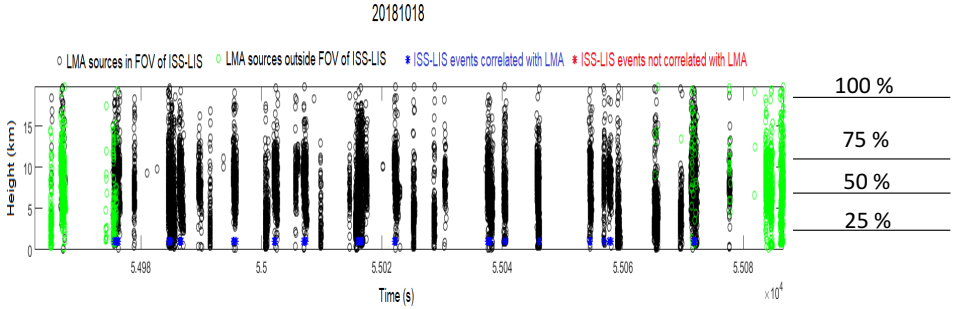
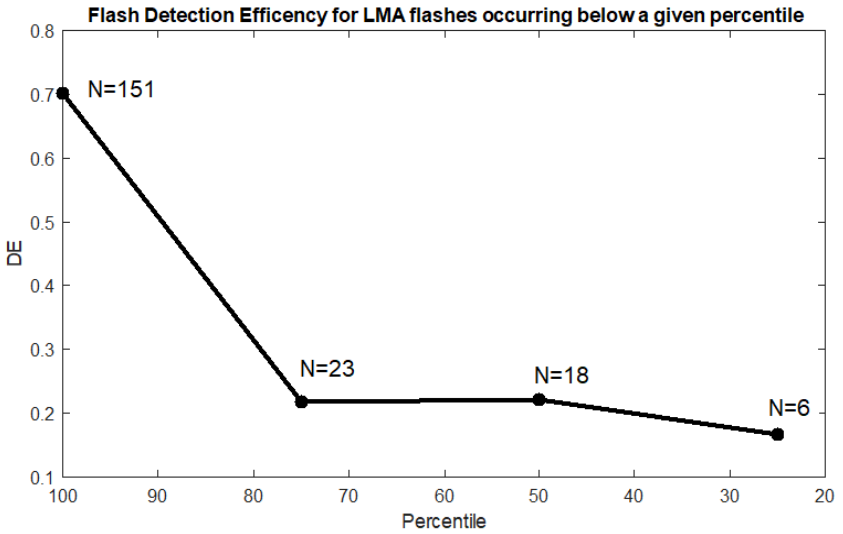
Detection Efficiency

Detection efficiency by LMA flash height



Percentiles instead of absolute height are used due to different thunderstorms present different occurrence heights of lightning (e.g. winter thunderstorms tops are at lower altitudes compared to summer thunderstorms)

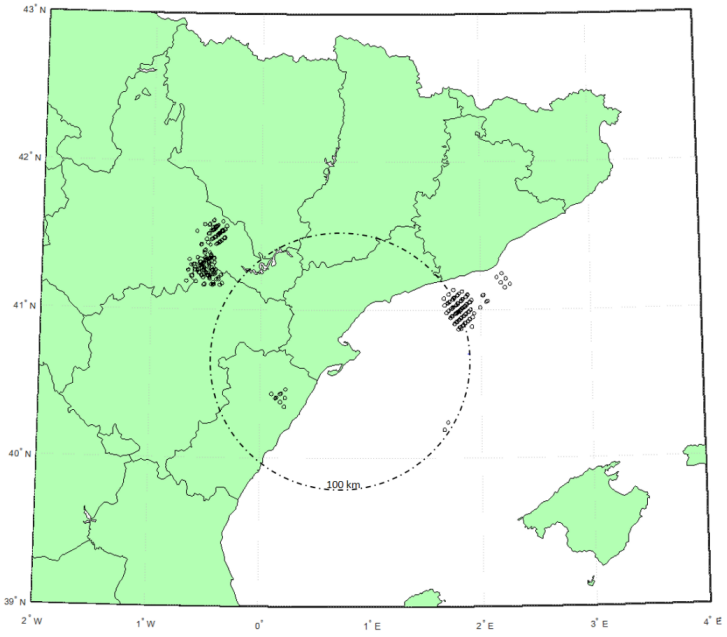


DE rapidly falls for flashes occurring below the percentile 75 %.

Flash “False Alarm”

Candidates not detected by the LMA → candidates to False Alarms

Candidates to ‘false alarm’



The situations where ISS-LIS report a flash and it is not detected by LMA will be called as a candidate for flash ‘False Alarm’ or Flash FAR. These cases need special treatment for definitive confirmation:

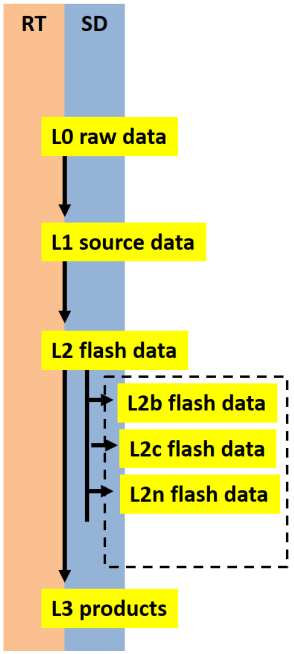
- Verification that these cases do not occur in areas of reduced detection efficiency by the LMA.
- Verification that these cases might be related to an existing flash but not reported by the LMA due to some technical issues, e.g.: not enough sensors to compute solutions, high noise at some of the stations, etc. In that case, raw data of single stations can be inspectional to confirm the existence of a flash.
- Additional data can be used: VLF/LF LLS data, satellite and radar to confirm the presence of a storm cell at the location of the false flash.

- In this analysis all candidates were due to the distance and/or locations where the LMA has poor DE.
- All cases except one where identified with LMA flashes with low quality due to distance and location.
- Only one case was not reported by the LMA but it was due to the low number of LMA sensors available that day.

Methods (summary)

LMA flash definition

LMA data levels



LMA flash definition:

L2a:

- Time criteria: commonly not less than 150 ms, but extreme flash rate thunderstorms can happen (e.g. 20180918).
- Distance criteria between sources: sources of the same flash cannot be located in a distance higher than the one reached by fast leader propagation (e.g. 10^6 m/s).
- Minimum number of sources.

L2b:

- Time criteria: commonly not less than 150 ms, but extreme flash rate thunderstorms can happen (e.g. 20180918).
- Distance criteria between sources: sources of the same flash cannot be located in a distance higher than the one reached by fast leader propagation (e.g. 10^6 m/s).
- Minimum number of sources.
- The flash must be located within a good coverage area for the day. The e.g. <3dBW seems to be suitable. This power level shall be the level that the LMA is able to map positive leaders. This area shall be defined by episode or day due to it is affected with the number of active sensors, local noise at the sensors, etc.

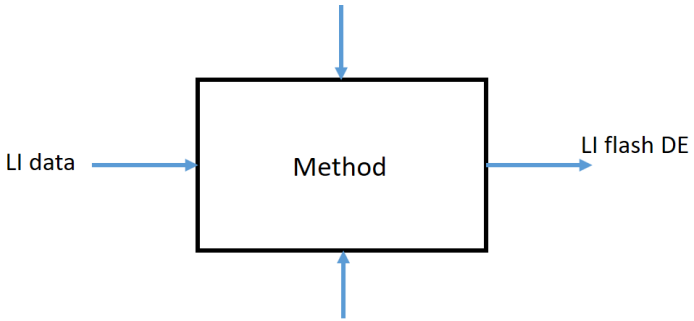
Methods (summary)

Detection efficiency

Option 1: maximize the number of samples (flashes)

LMA data:

L2 Flash data: L2a Sources grouped in flashes with time-distance criteria.



Configuration:

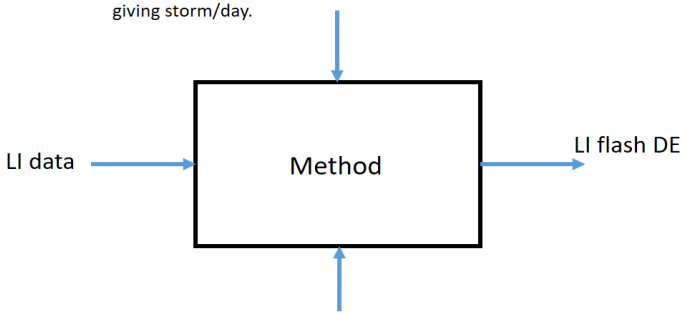
Time tolerance of coincidence between LI events and LMA flash

Distance tolerance between LMA and LI centroids.

Option 2: keep the properties of the flashes

LMA data:

L2 Flash data: L2b Sources grouped in flashes with time-distance criteria. Flashes occur within a region where the LMA detects < 3 dBW for the giving storm/day.



Configuration:

Time tolerance of coincidence between LI events and LMA flash

Distance tolerance between LMA and LI centroids.

Method: It is considered that LI detects a flash if during a LMA flash LI has reported events. A tolerance in time and distance are assumed. Detection efficiency is computed by the number of flashes reported by LI versus the number of flashes reported by the LMA.

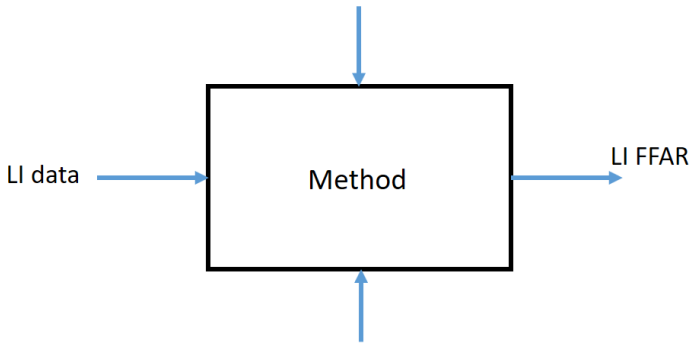
In addition, in Option 2, statistics of lightning flashes can be provided and DE for different type of flashes/storms can be computed.

Methods (summary)

False alarm

LMA data:

L2 Flash data: L2b Sources grouped in flashes with time-distance criteria. Flashes occur within a region where the LMA detects < 3 dBW. Alternative L1 data for the region of <3dBW.
L0 data



Configuration:
Time tolerance of coincidence between LI events and LMA flash
Distance tolerance between LMA and LI centroids.
Area to analyse based on the <3dBW range.

Method: It is considered that LI has a candidate of a false detection if LMA has not reported a flash.
A tolerance in time and distance are assumed.

Once a candidate is identified, L0 data at the time of occurrence of the LI FFAR candidate will be verified.

If during this period there is no signs of a flash, the LI candidate will be approved as a false detection.

VLF/LF data from a LLS can also be used to confirm false LI detections. Additionally, satellite or radar data can also be used to identify the lack of clouds.

Flash duration

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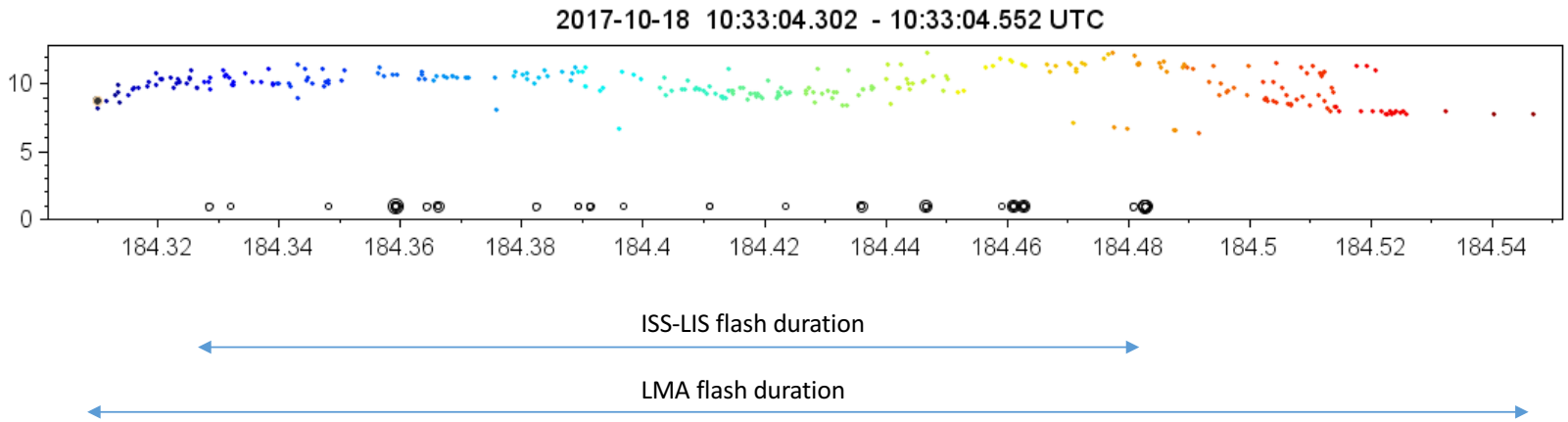
Flash duration

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.

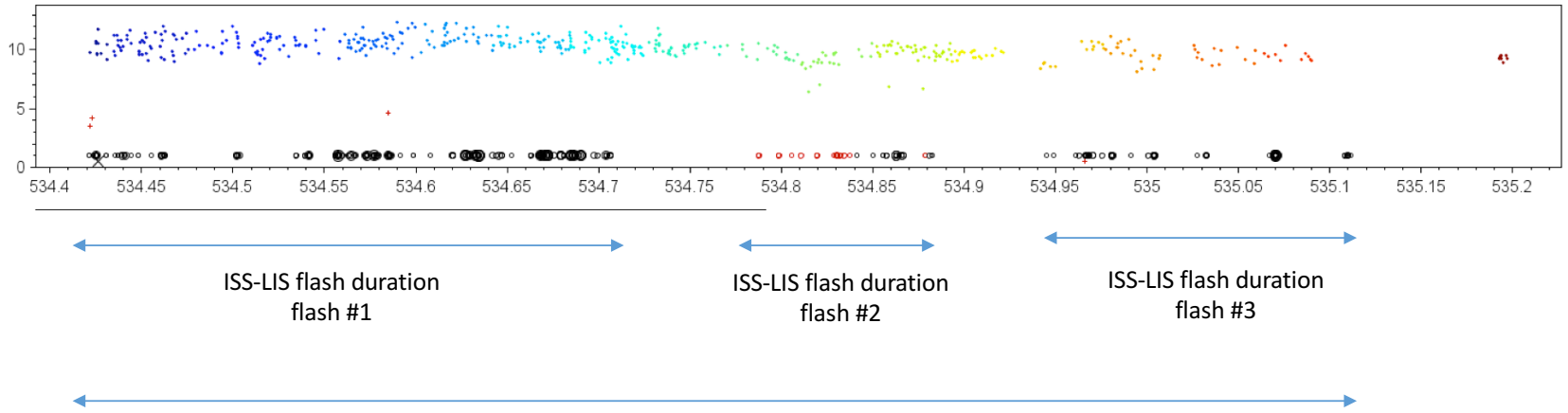


Flash duration

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)



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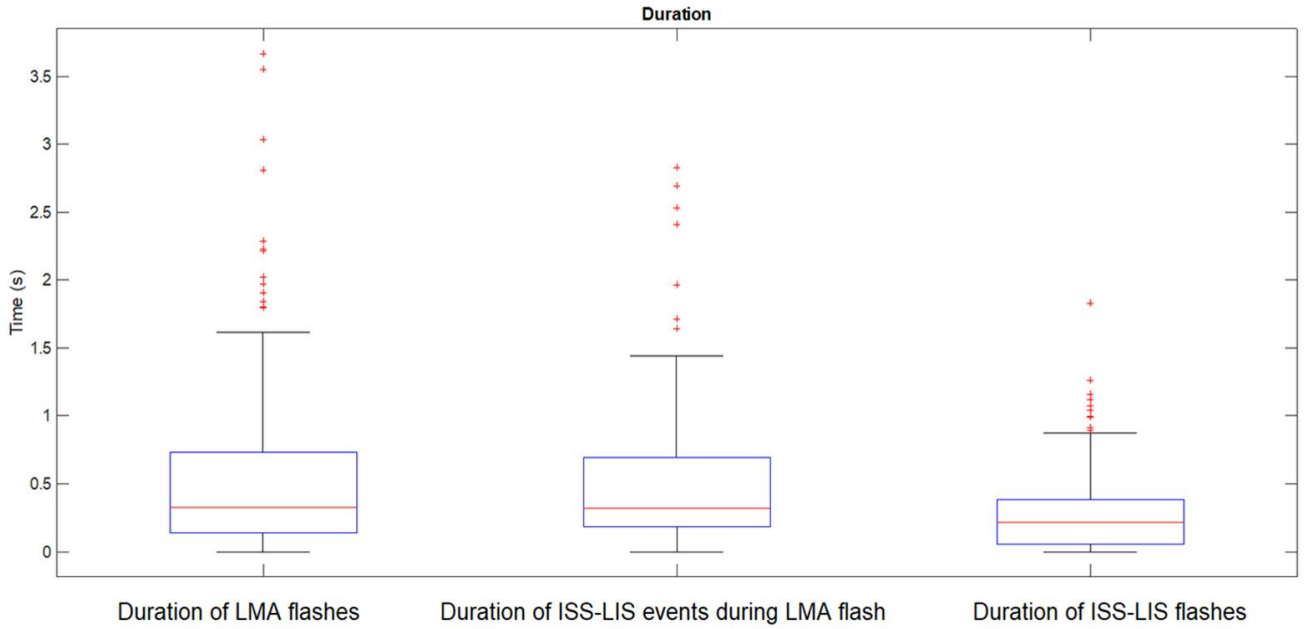
Flash duration



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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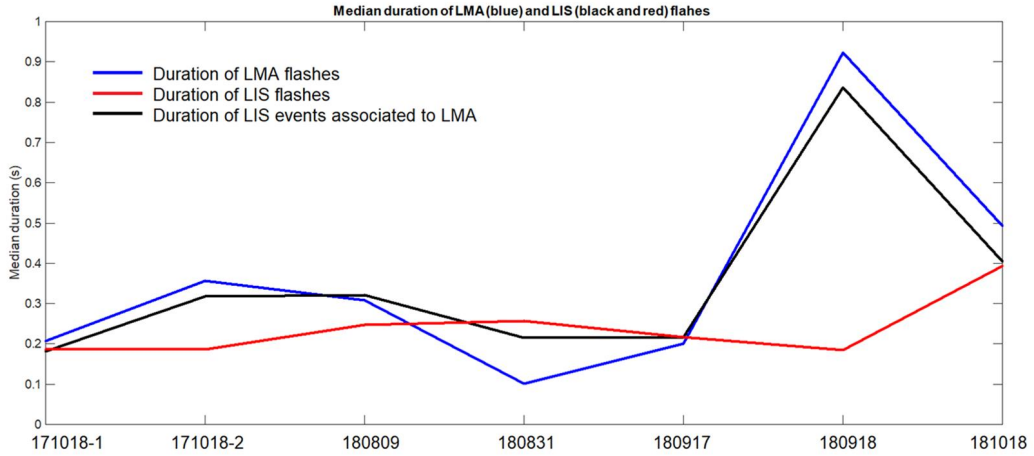
Flash duration

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



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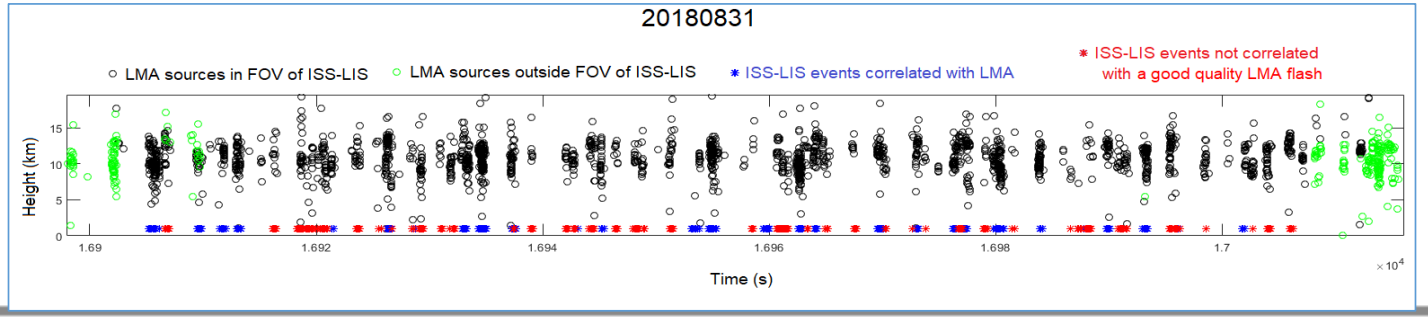
20181018	0.493	0.404	0.394

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.



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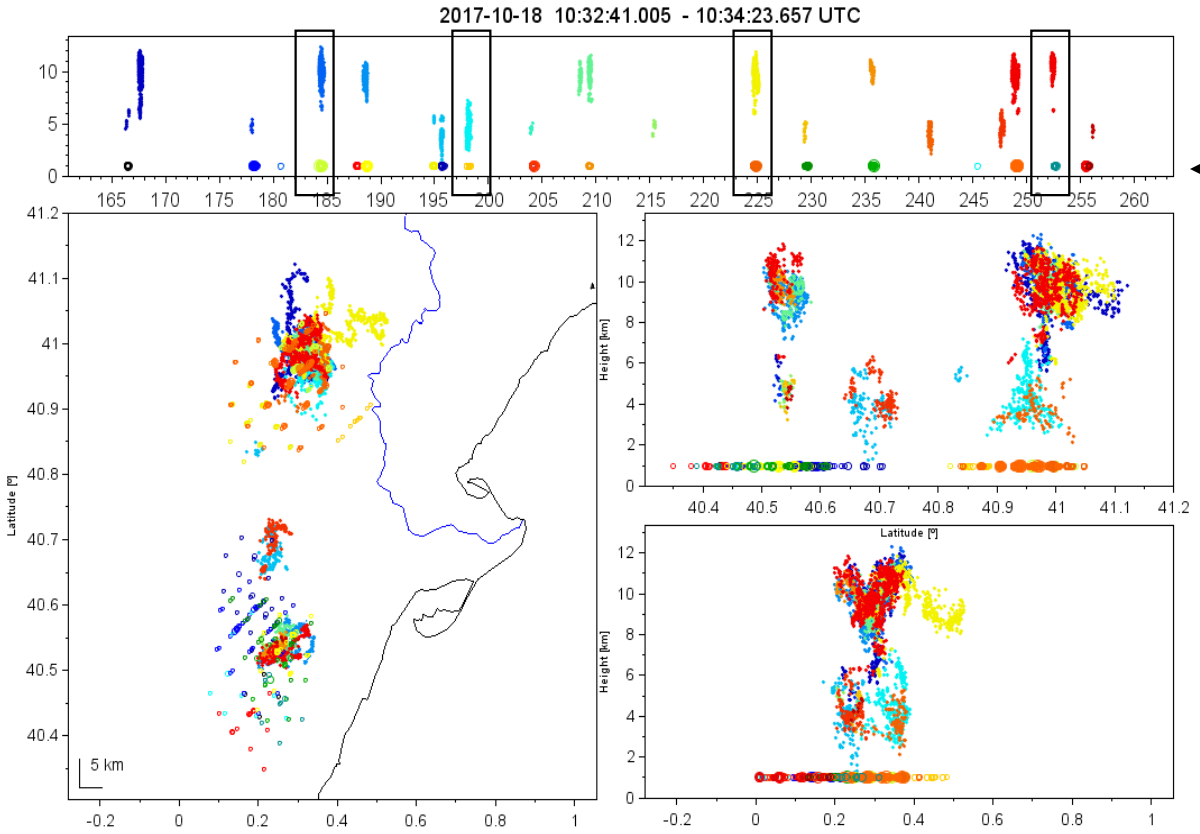
Flash duration

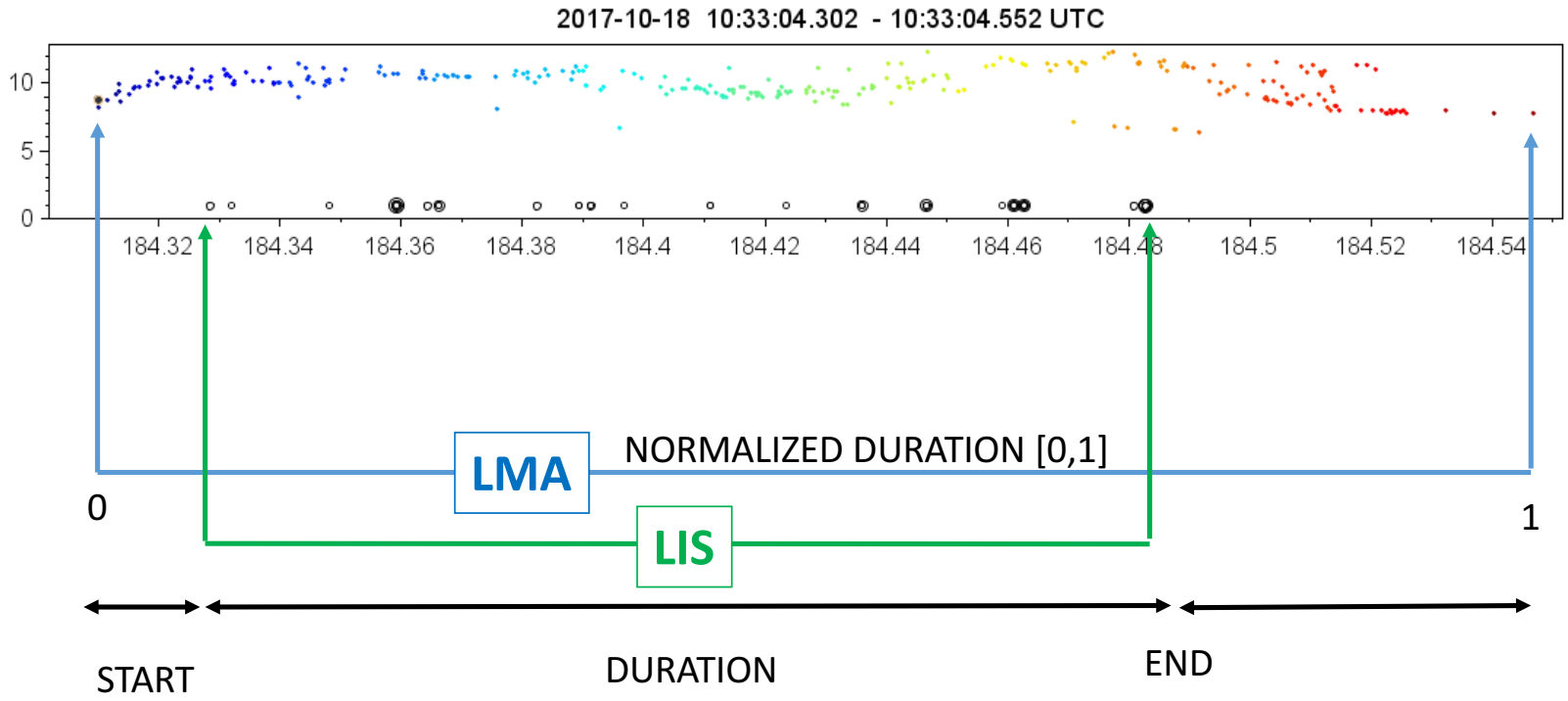
Flash-by-flash duration analysis



ISS-LIS events represented
At 1 km (arbitrary)

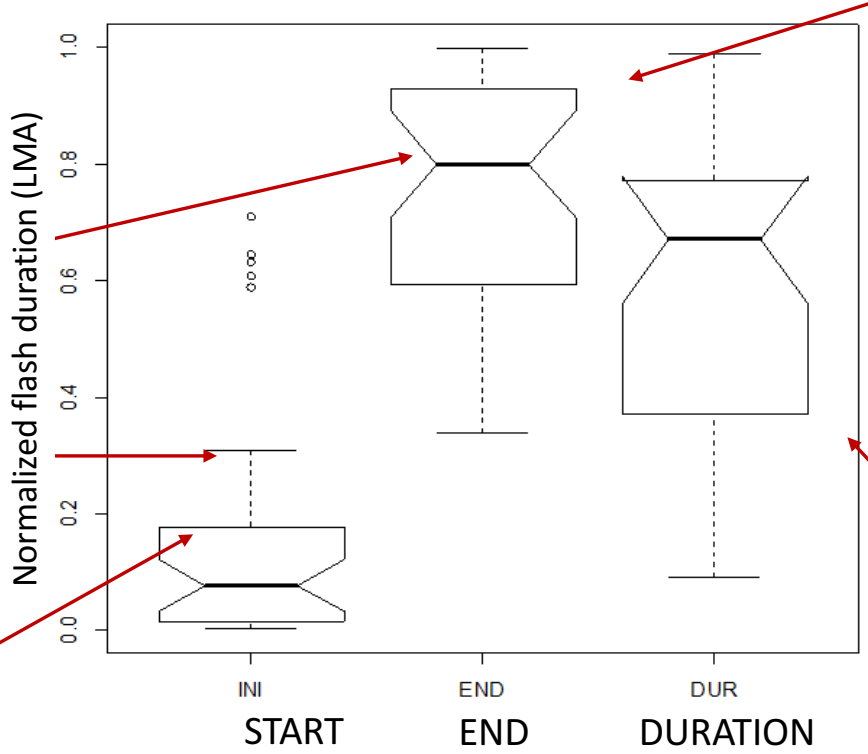
Flash duration

Flash-by-flash duration analysis



Flash duration

Flash-by-flash duration analysis



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

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

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

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

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

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

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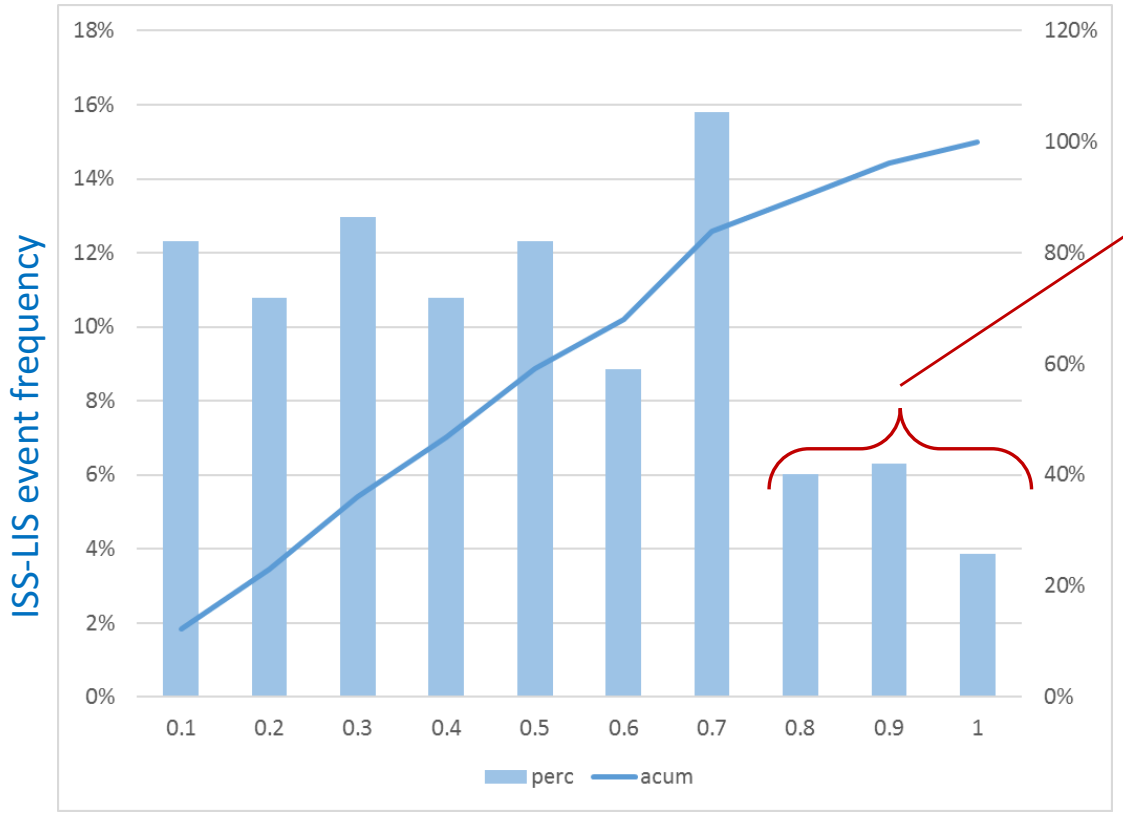
Flash duration

Flash-by-flash duration analysis



ISS-LIS events detected on the last quarter of the flash duration are significantly lower

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.

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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)

Distribution of Events with height, power and radiation

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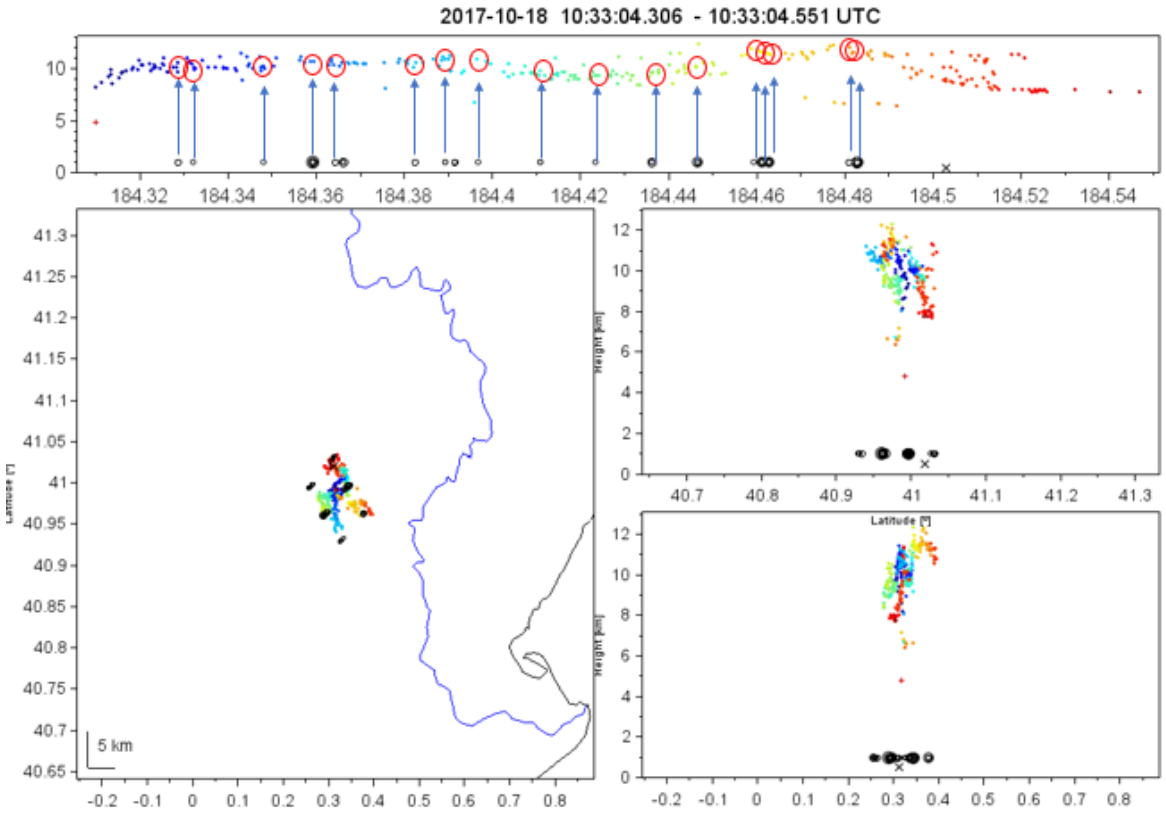
Distribution of Events with height, power and radiation

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?

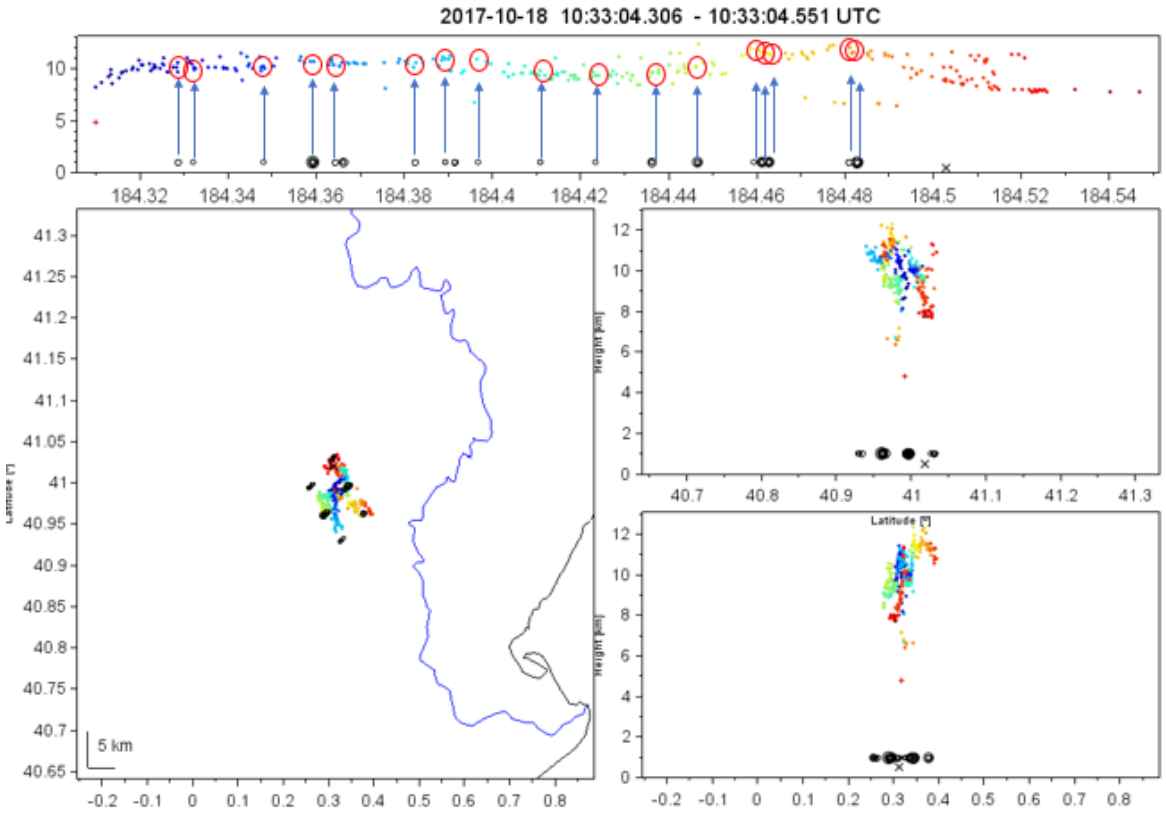
- Are those LMA sources higher in altitude?
- Are those sources more intense in RF power (dBW)?

Distribution of Events with height, power and radiation

Flash-by-flash analysis

Match-up procedure

Pairs of ISS-LIS - event + LMA source



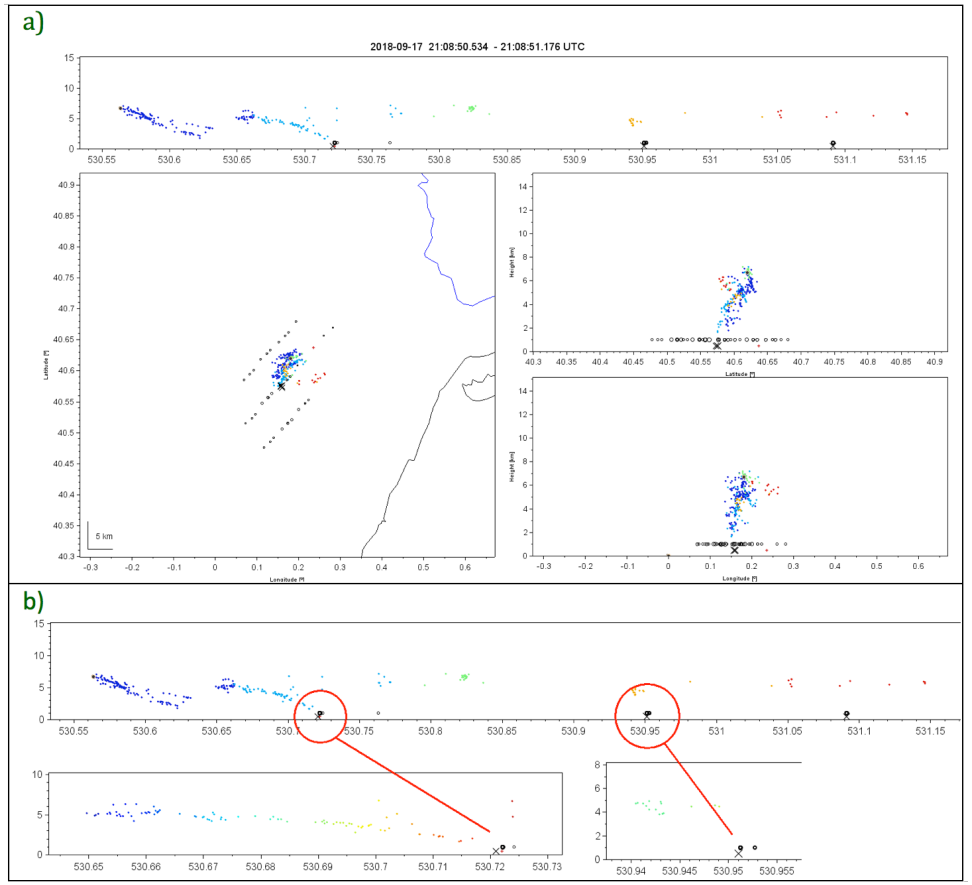
In this case, events and LMA sources are grouped with a time-distance criteria:

- 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, power and radiation



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.

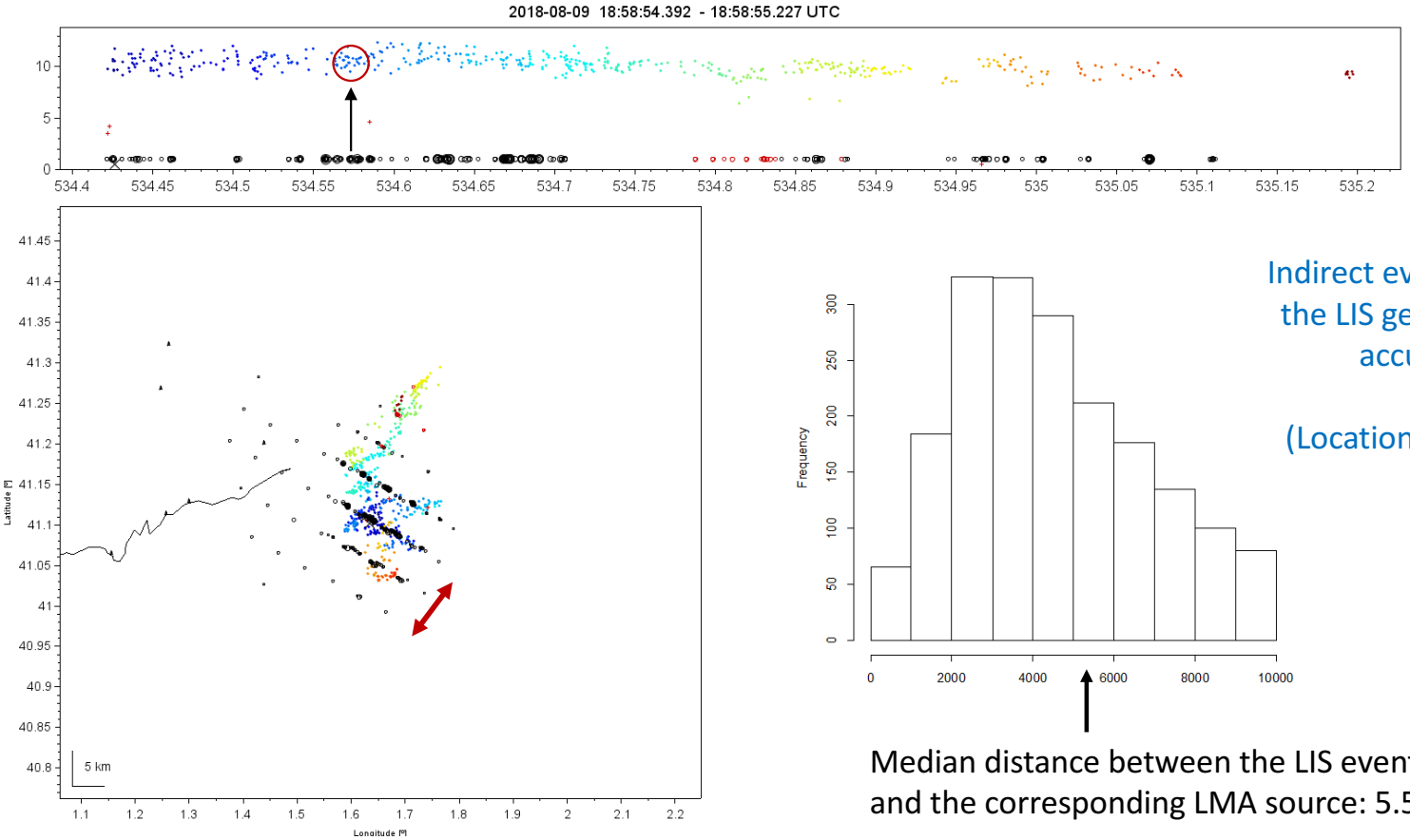
We found a systematic delay of 1ms

The analysis is done

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

Distribution of Events with height, power and radiation

Results



Indirect evaluation on the LIS geographical accuracy

(Location accuracy)

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

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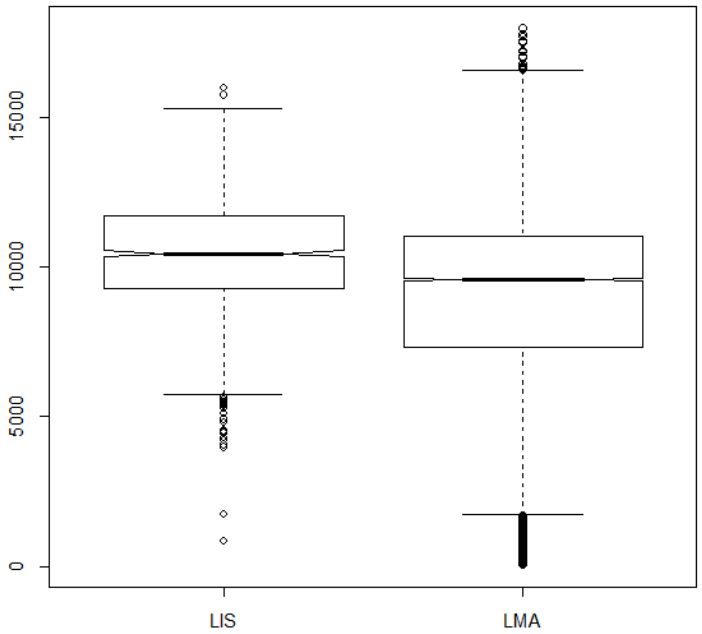
Distribution of Events with height, power and radiation

Results

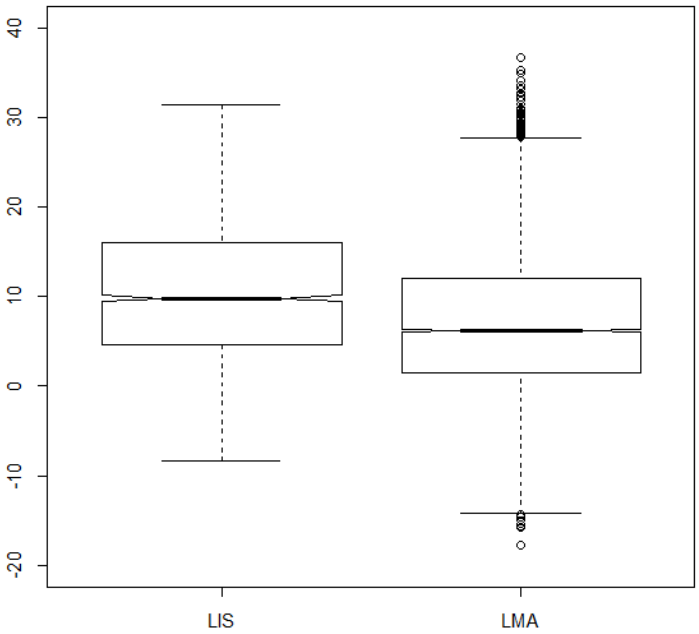
Height (m)



ISS-LIS events matched with LMA sources

LMA source population

Power (dBW)



ISS-LIS events matched with LMA sources

LMA source population

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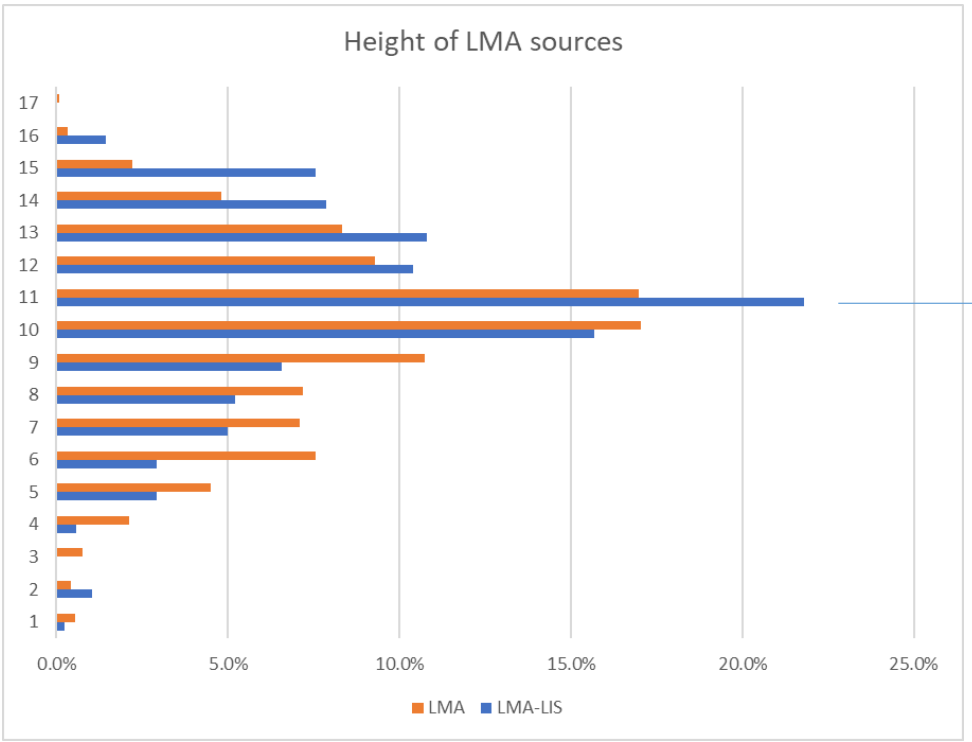
Distribution of Events with height, power and radiation

Results



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

11 km

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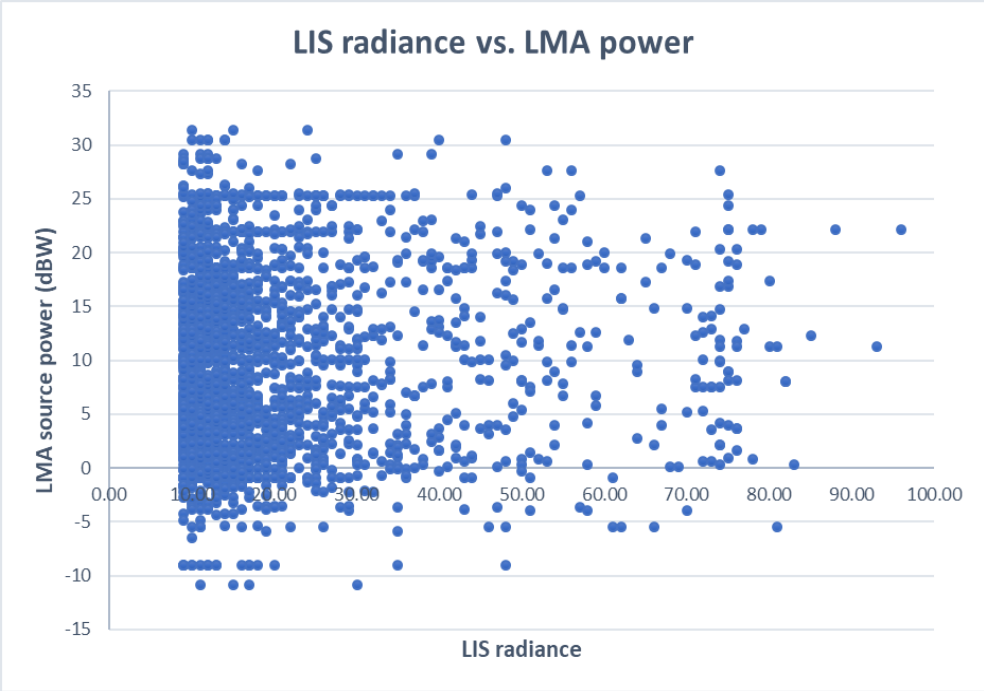
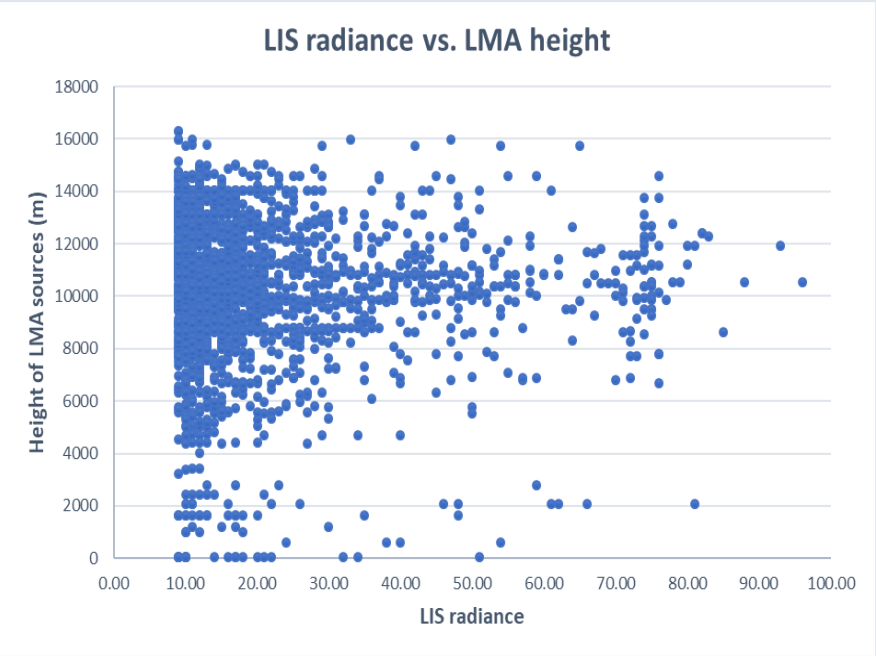
Distribution of Events with height, power and radiation





It seems that there is not a straight relation between radiance and altitude of the source. In general there is a peak at 11 km where is the typical upper altitude of most of the flashes (where leaders propagate).

However: That might depend on the size/duration of the flash. That is the case of Africa: high rates, small flashes, less bright

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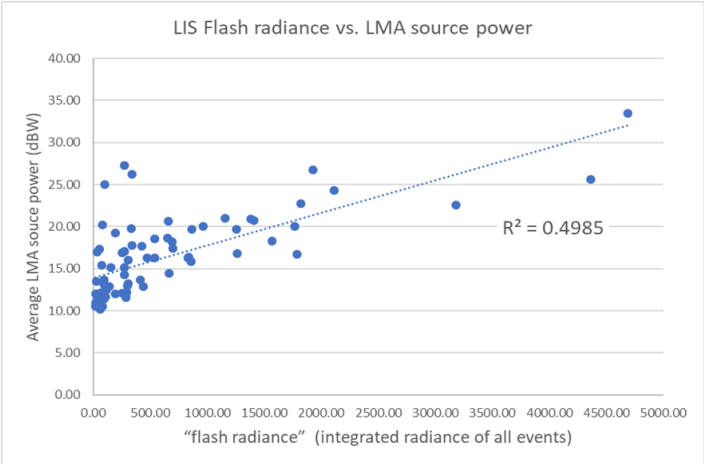
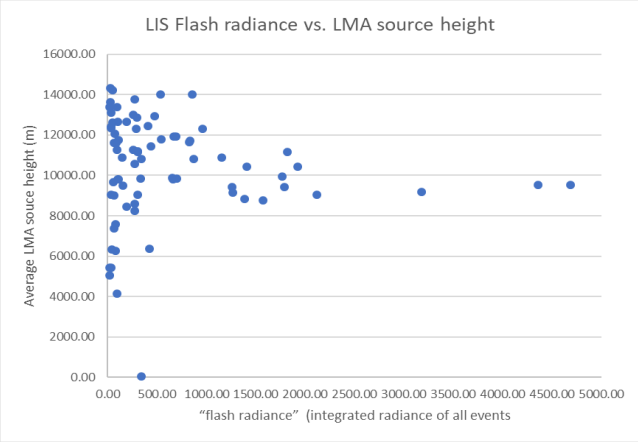
Distribution of Events with height, power and radiation

The previous plots corresponds to one-to-one LMA sources and ISS-LIS events.
Two alternatives can be adopted:

1) Time binning of the LMA and obtain the average or maximums of the LIS radiance
2) According to Beirle et al 2014 use the “total flash radiance”





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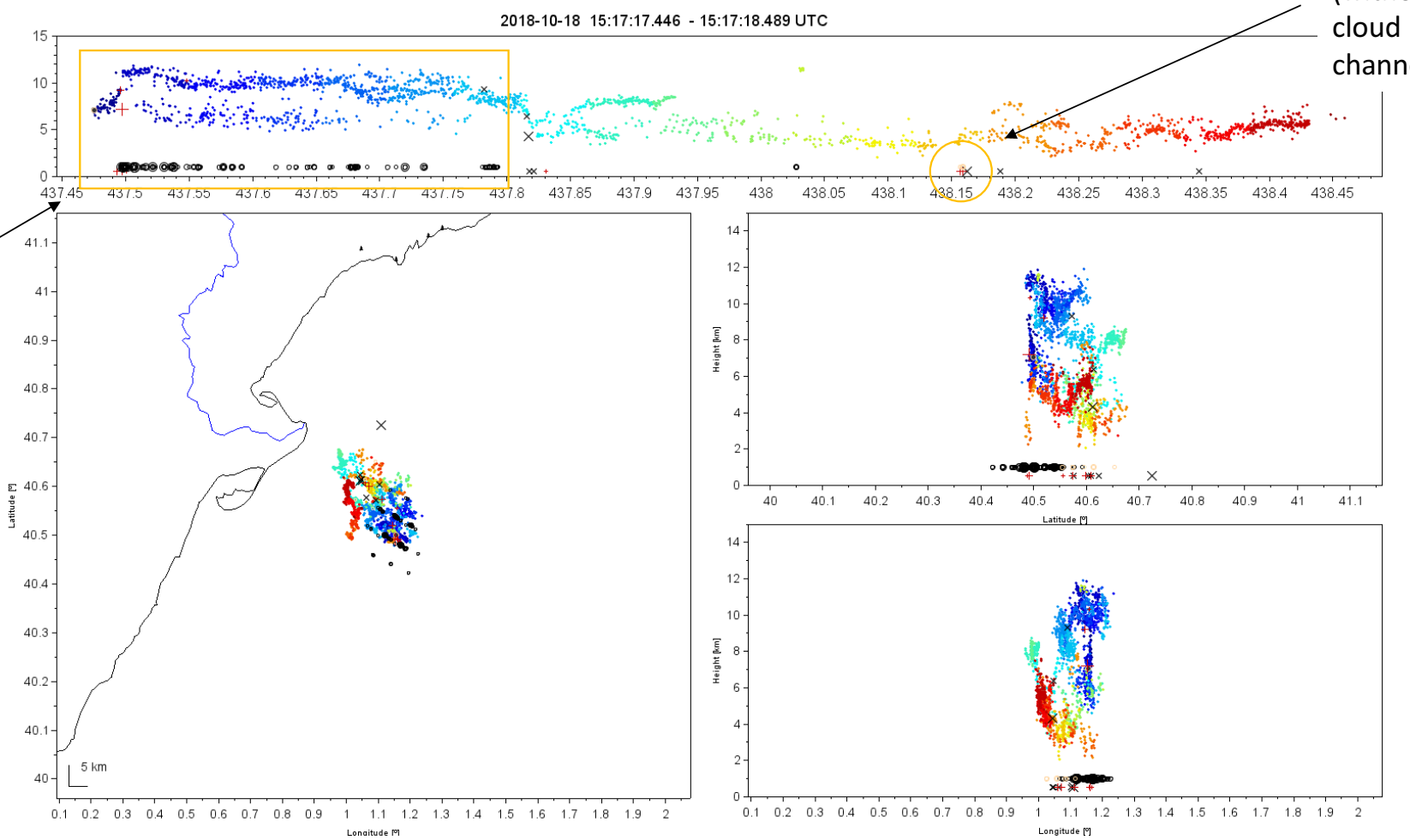
Relation of Events with lightning processes

LIS events = CG strokes (without upper cloud channels)

Example



LIS events = higher channels

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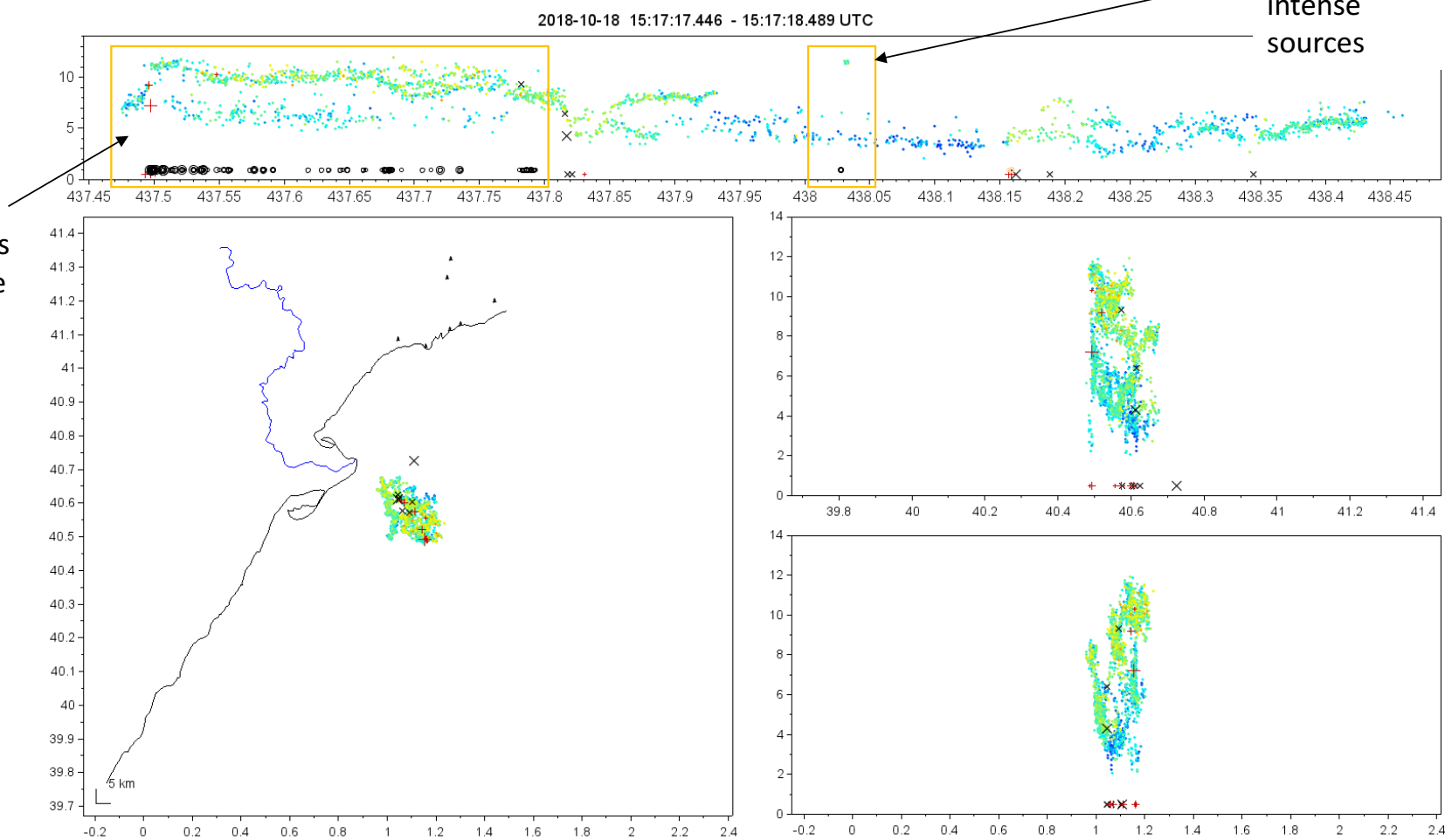
Relation of Events with lightning processes

Example

LIS events = isolated intense sources

LIS events = 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.

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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.

Lightning model for test cases

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Lightning model for test cases

Model based on statistics of different parameters obtained by the LMA:

Duration:

Log-normal distribution

Summer:
Median: 0.35 s
Stdev: 0.31 s

Winter:
Median: 0.41 s
Stdev: 0.25 s

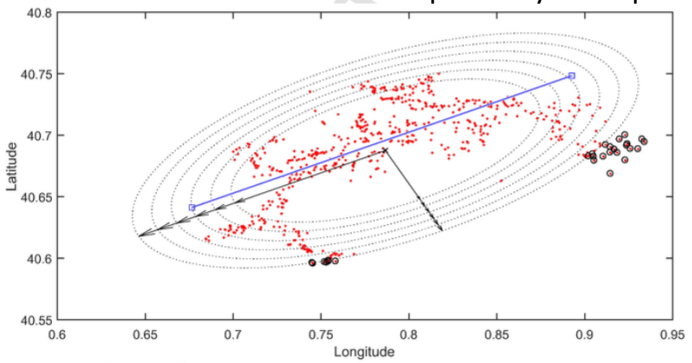
Size:

Summer:
Median: 10.3 km
Stdev: 13.9 km
Maximum 143 km

Winter:
Median: 15.6 km
Stdev: 10.9 km
Maximum 70 km

Ellipse excentricity minor/major axes
Median: 0.75
Stdev: JESUS

The size of a flash can be simplified by an ellipse



López et al. (2016)

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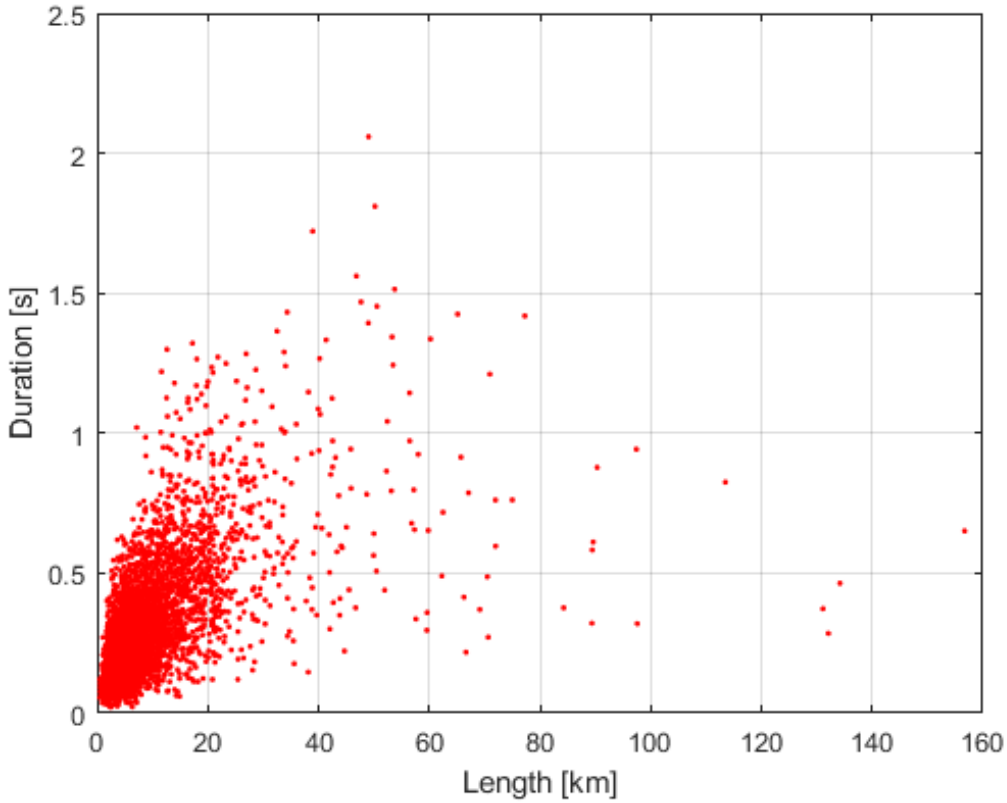
Lightning model for test cases

Flash size-duration relationship:



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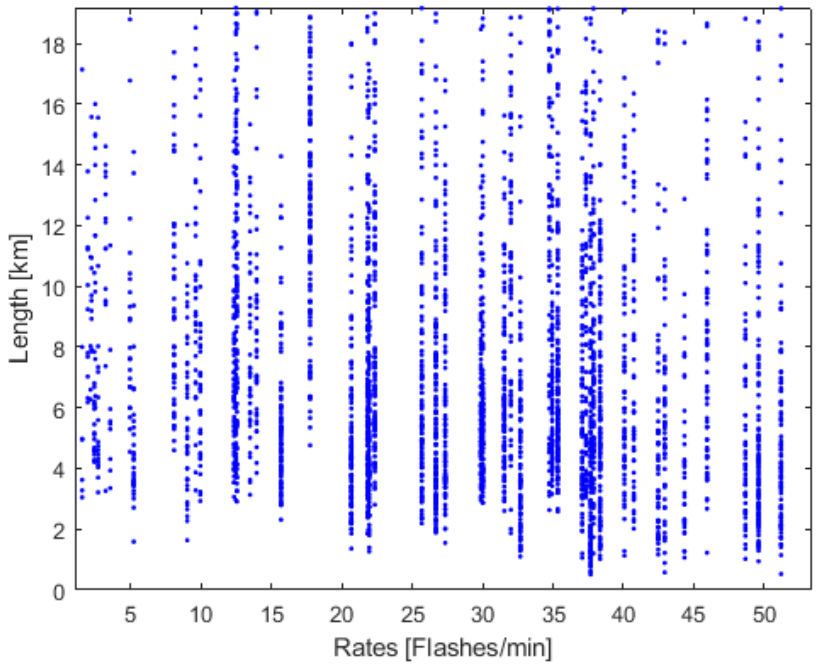
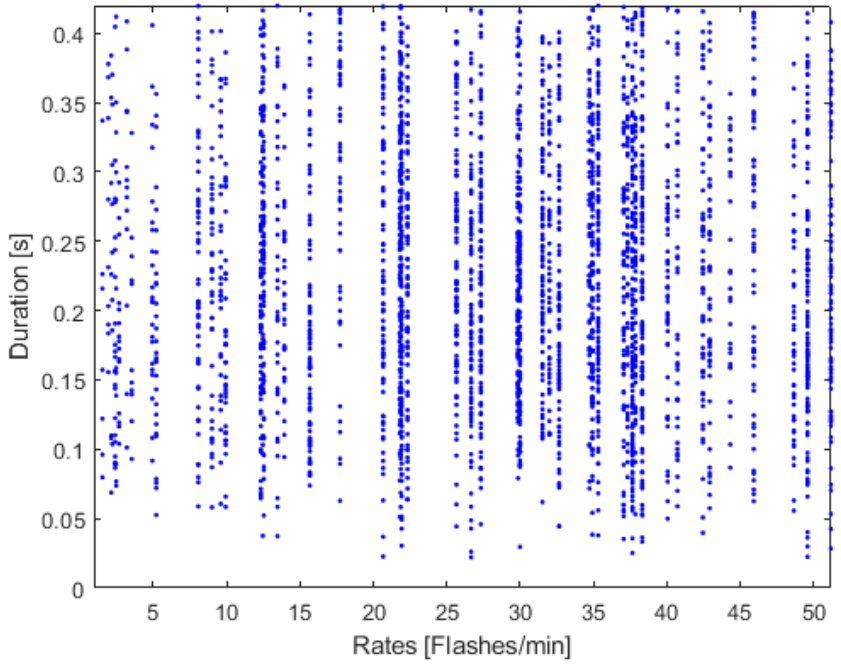
Lightning model for test cases

Flash size and duration vs. storm activity:



Small flashes seem to occur in periods with high flash rates



Short duration flashes seem to occur in periods with high flash rates

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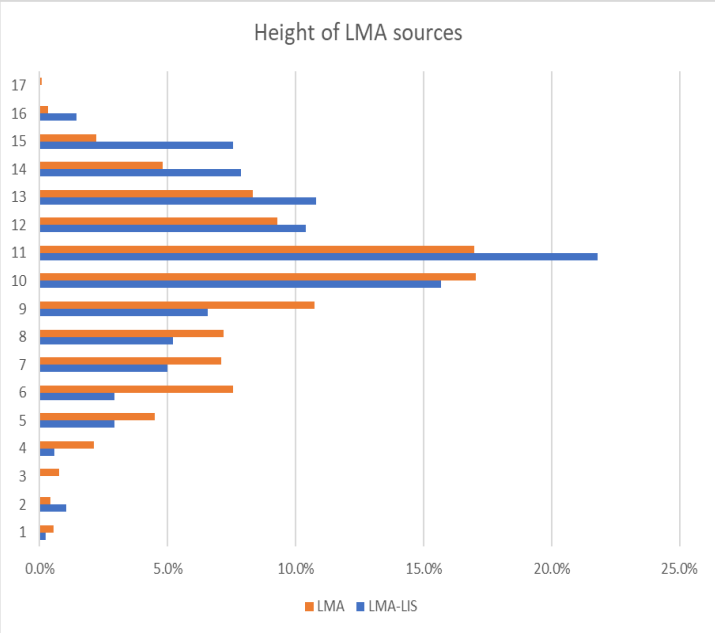
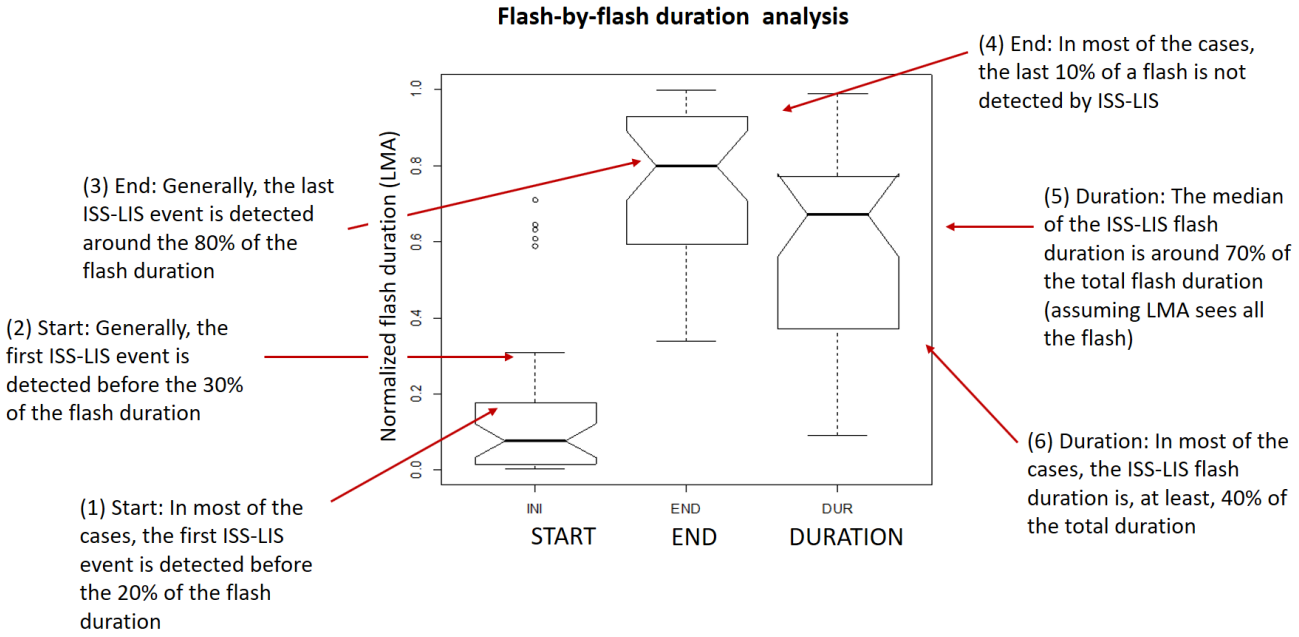
Lightning model for test cases

Heights:



Lightning model for test cases

LIS duration:



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Lightning model for test cases

LIS duration:

LIS size: → Oscar's section

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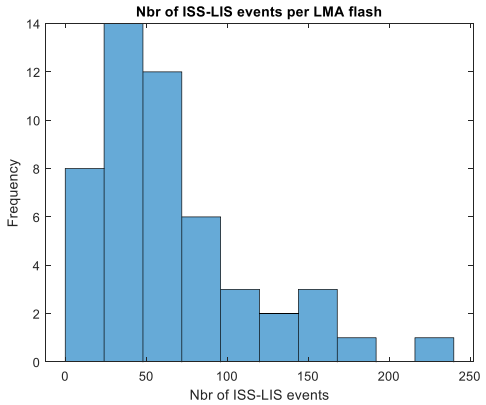
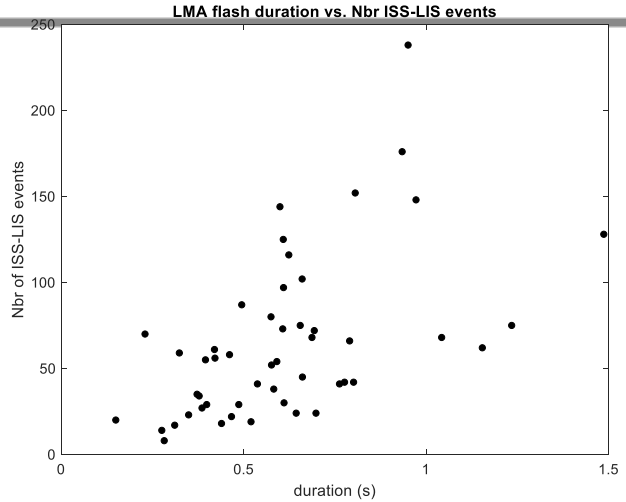
Lightning model for test cases

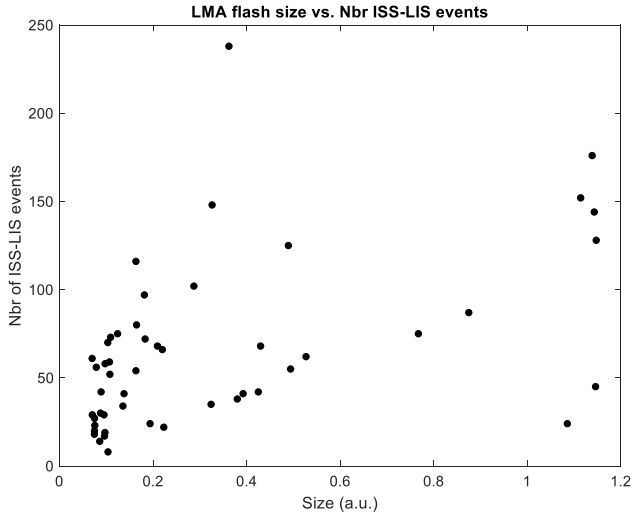
LIS duration:

LIS size:

<u>Number of LIS events per flash:</u>







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Lightning model for test cases

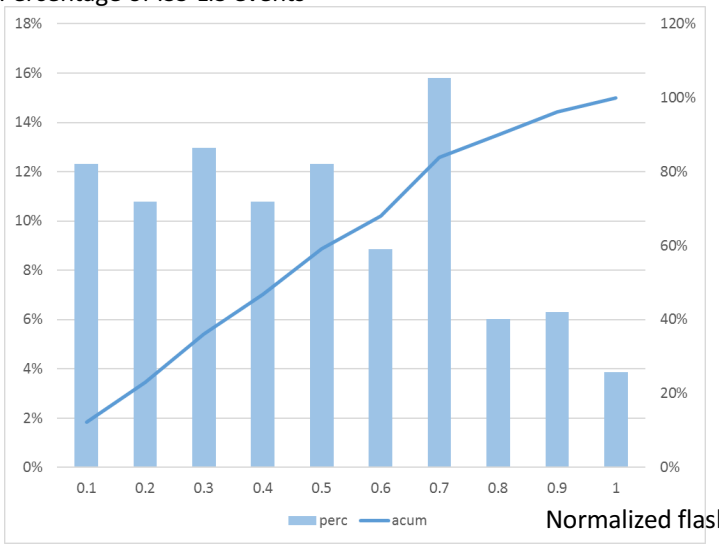
LIS duration:

LIS size:

Number of LIS events per flash:

<u>Distribution of the ISS-LIS events within a flash:</u>

Percentage of ISS-LIS events



Normalized flash duration

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Lightning model for test cases

Discussion:

How the cases shall be defined for the end-to-end processor?