EUMeTrain Event Week on MTG-I
25-29 September 2023

Evaluation of the Lightning Imaging Sensor (ISS-LIS) by means of VHF ground-based LLS, as a reference for the upcoming MTG-Lightning Imager

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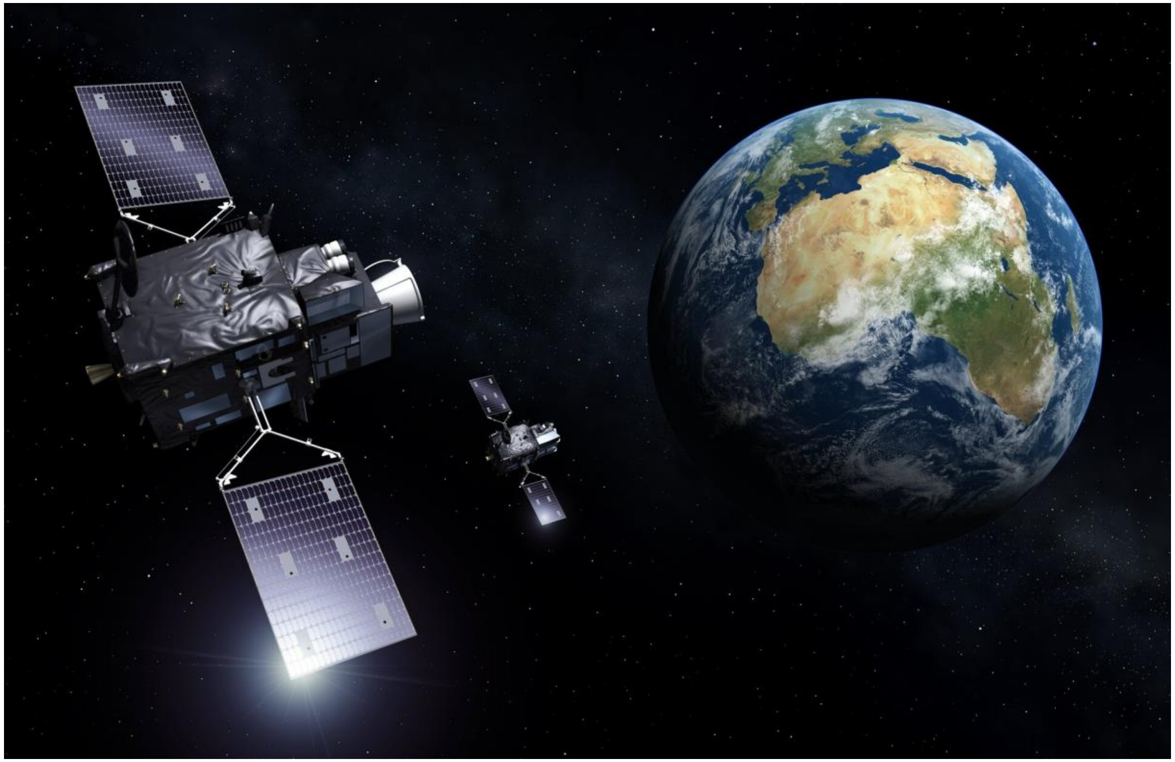
MTG-LI CAL/VAL program



Currently EUMETSAT is conducting the CAL/VAL program for the MTG-LI
Pre-launch activities included studies using Proxy data like the present one
This presentation is based on a work made for this CAL/VAL program, although it has other goals that presenting results

Goal of the talk

Therefore, the goal of this talk is to spotlight the following points:

- Lightning is a complex process that is partially observed from remote sensing systems
- Optical measurements like the ISS-LIS and the coming MTG-LI are different from the observations made with ground-based Lightning Location Systems, based on radio frequency
- Importantly, observations from space platforms and from ground-based systems are not analogous but complementary.
- No system is seeing the whole picture. Every observation systems has Pros/Cons

Scope of the tasks in the CAL/VAL program

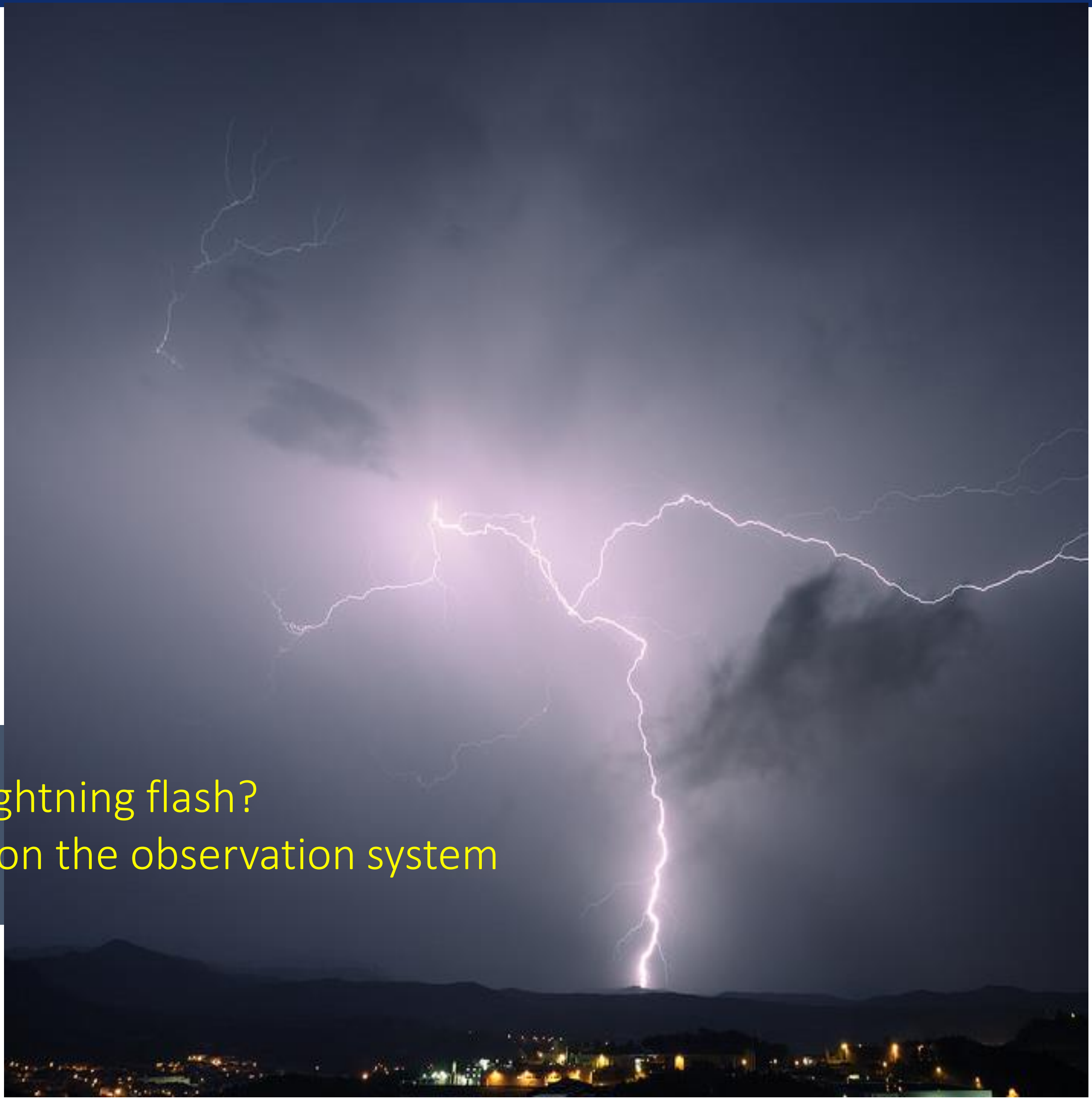
Lightning Imager Calibration / Validation activities:
comparison studies with ground-based Lightning Location Systems are a key point

ISS-LIS as a proxy for the MTG-LI:
same optical length (777.4 ±1 nm)

Lightning Mapping Systems (LMA):
best suited ground-based system for comparison

Comparison Shortcomings: ground-based electromagnetic sensors see different lightning processes compared to optical systems like LIS / GOES-GLM / MTG-LI

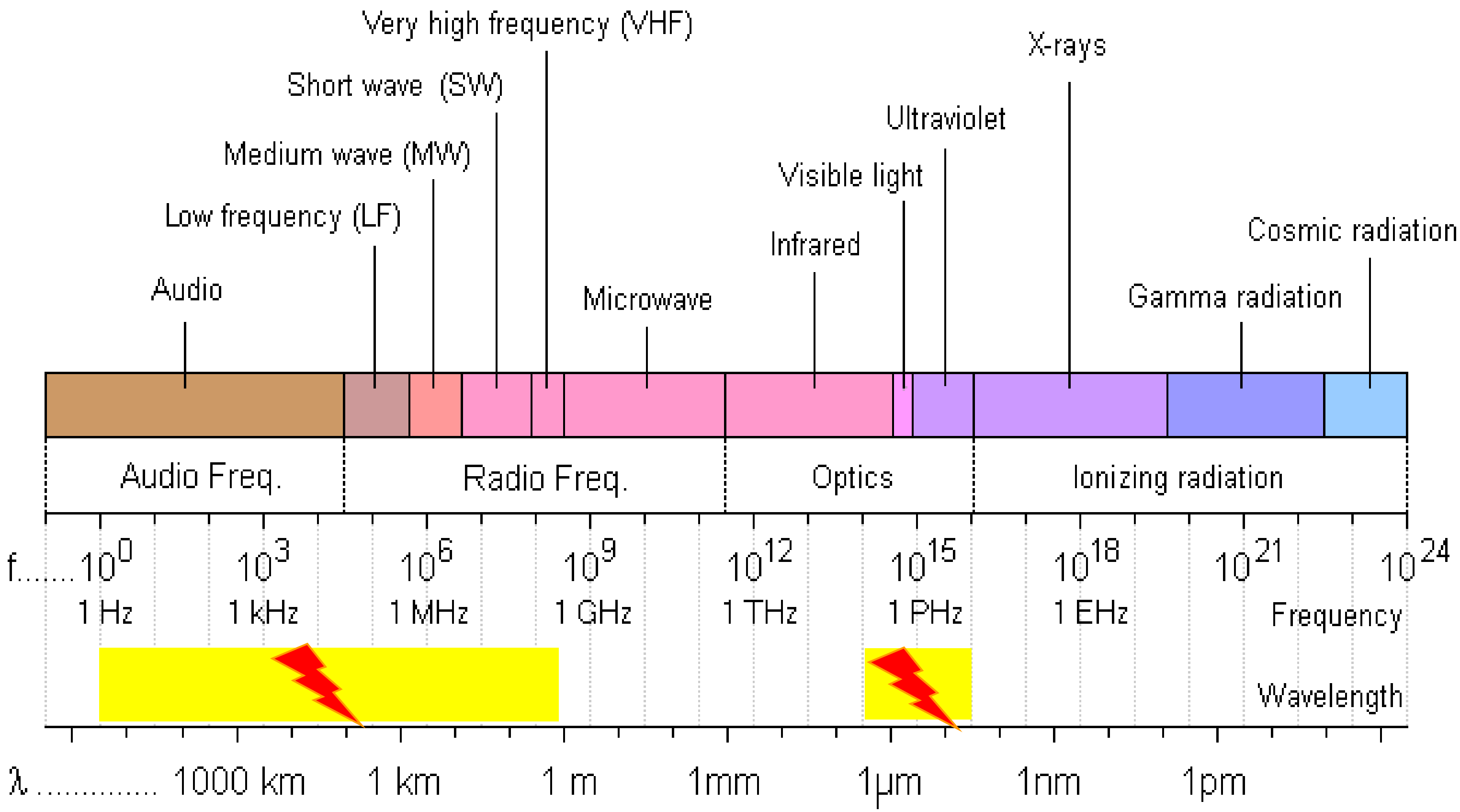
Lightning detection



What is a lightning flash?
It depends on the observation system

Lightning detection

The electromagnetic spectrum

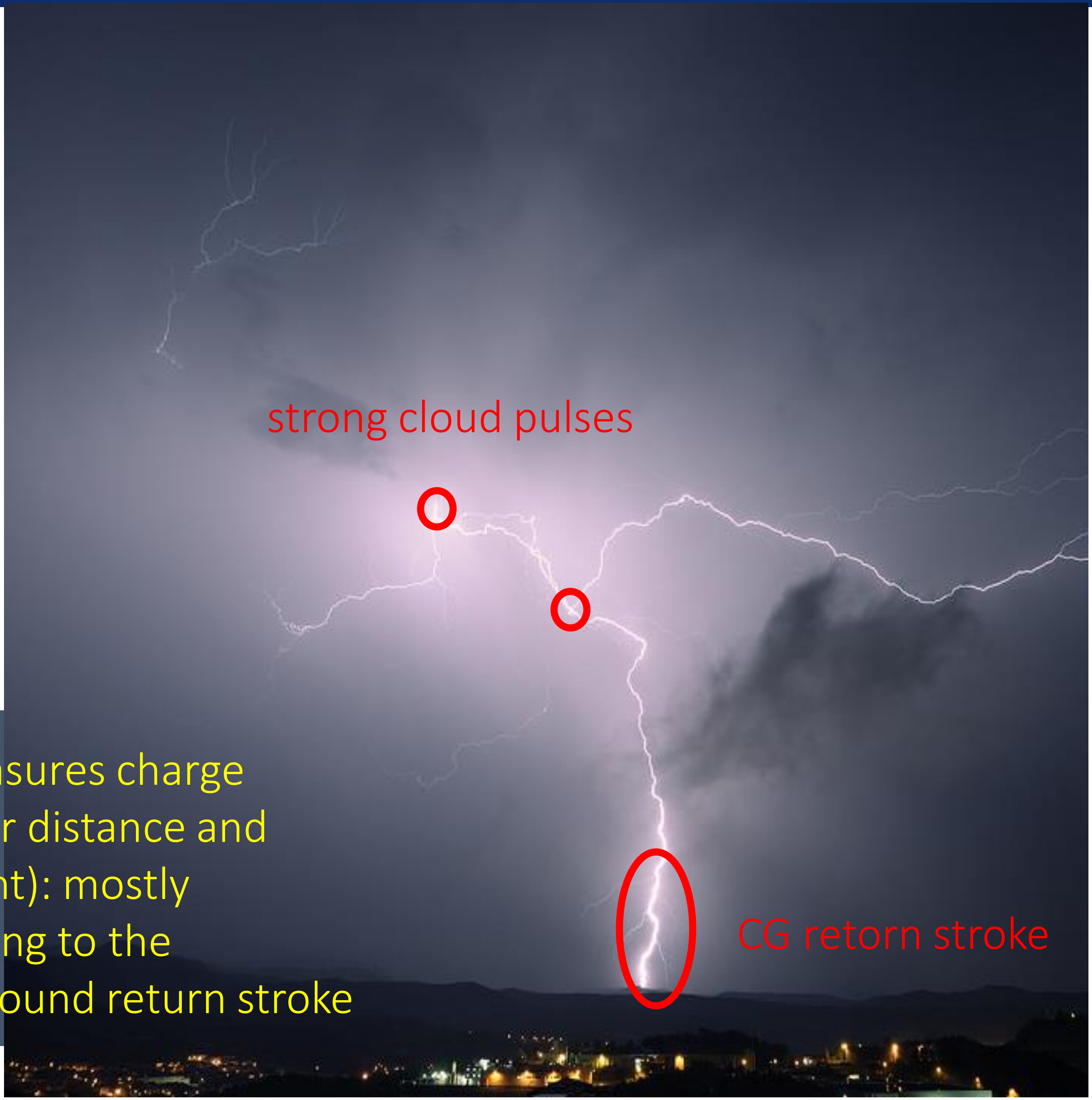


There are systems measuring on the radio frequency (most ground-based location systems) and other systems working in the optical range (e.g. satellites)

Lightning detection

- LF/VLF

[1-10 strokes per flash]

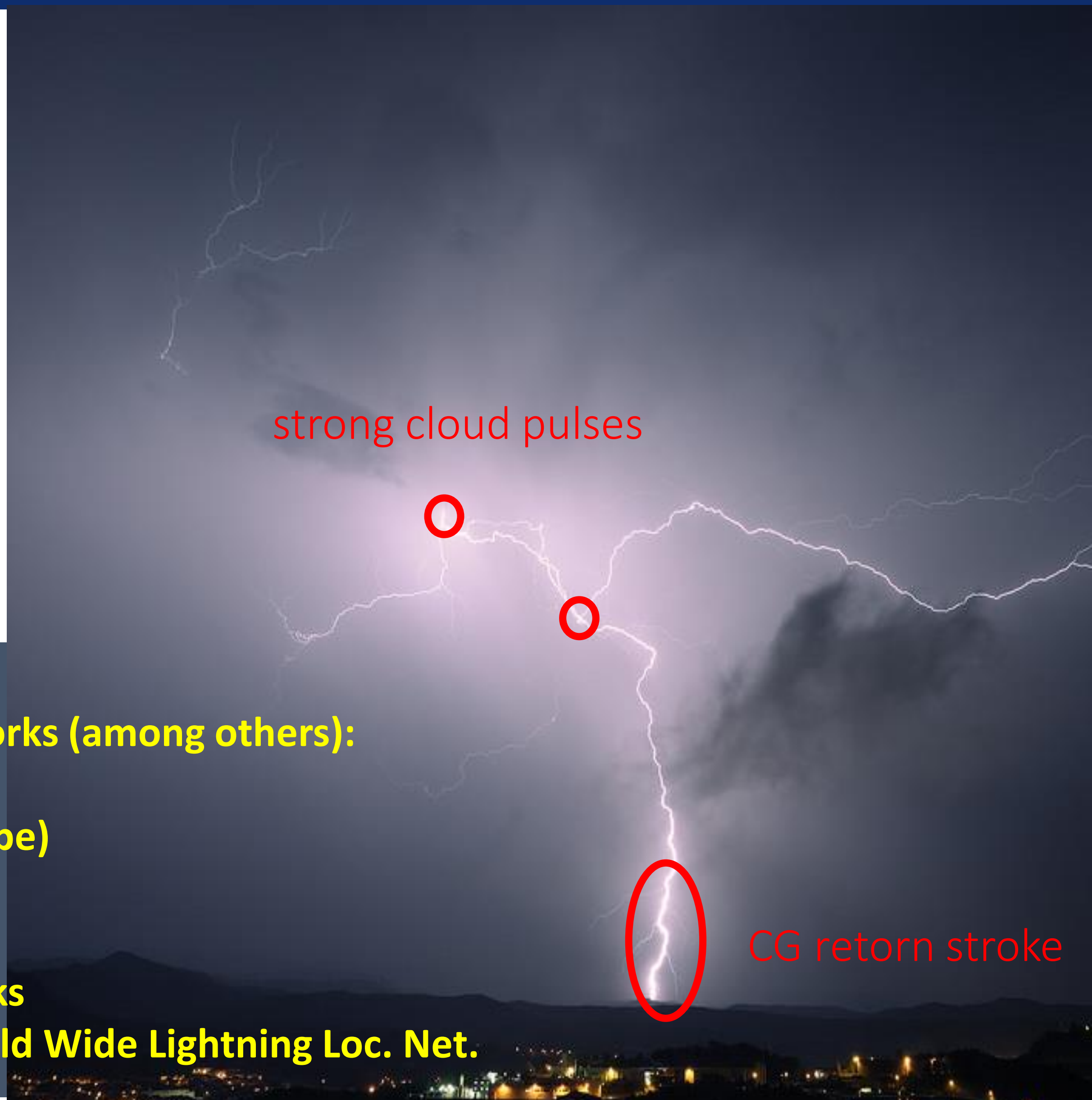


VLF/LF: measures charge transfer over distance and time (current): mostly corresponding to the Cloud-to-Ground return stroke

Lightning detection

○ LF/VLF

[1-10 strokes per flash]



LF/VLF Networks (among others):
NLDN (US)
EUCLID (Europe)
LINET
GLD-360
EarthNetworks
WWLLN (World Wide Lightning Loc. Net.

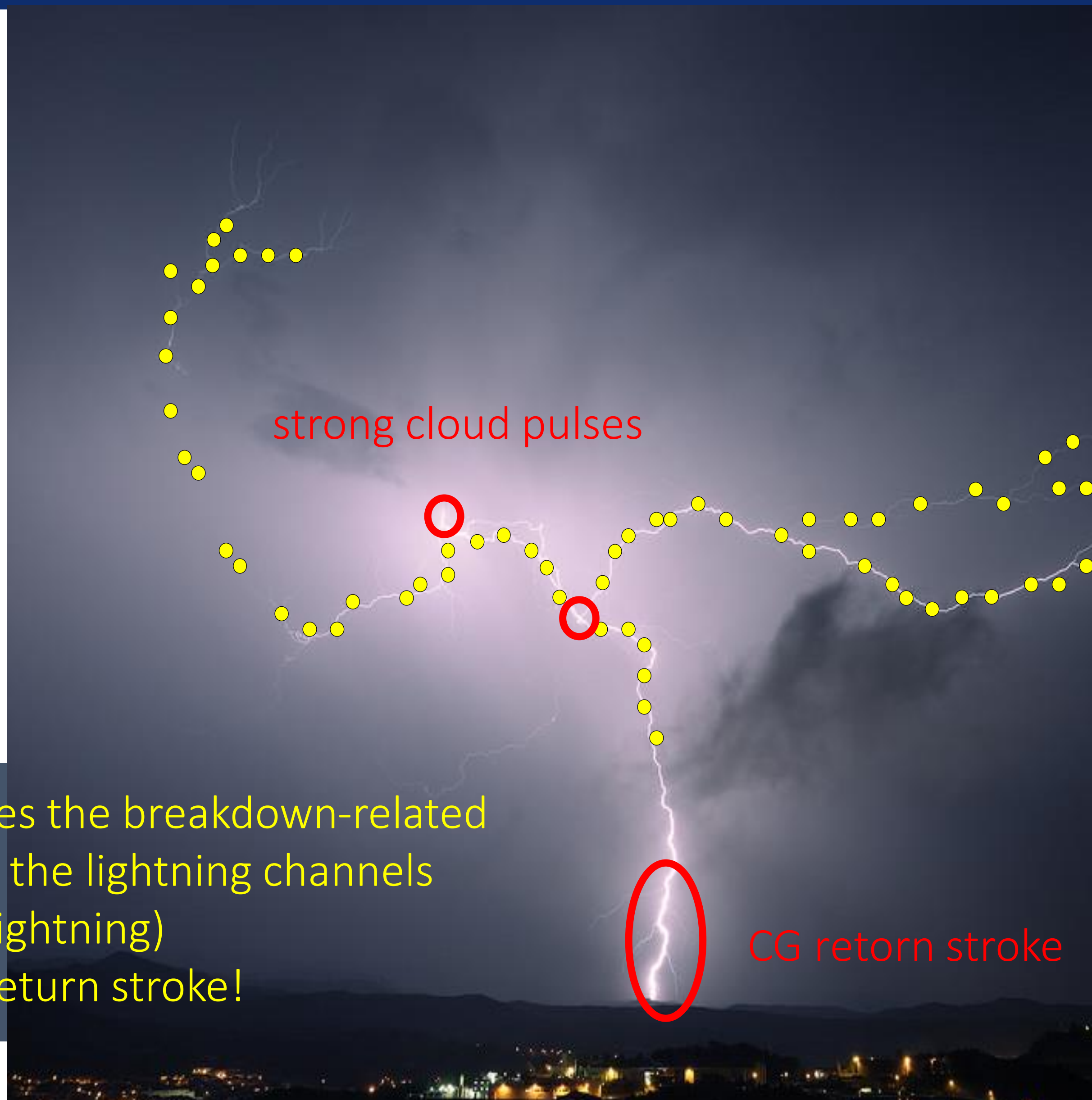
Lightning detection

LF/VLF

[1-10 strokes per flash]

VHF-TOA

[10-10^2 sources per flash]



cloud lightning Pulses (breakdowns)

VHF: measures the breakdown-related processes on the lightning channels (intra-cloud lightning)
But not the return stroke!

Lightning (thunderstorm) footprint

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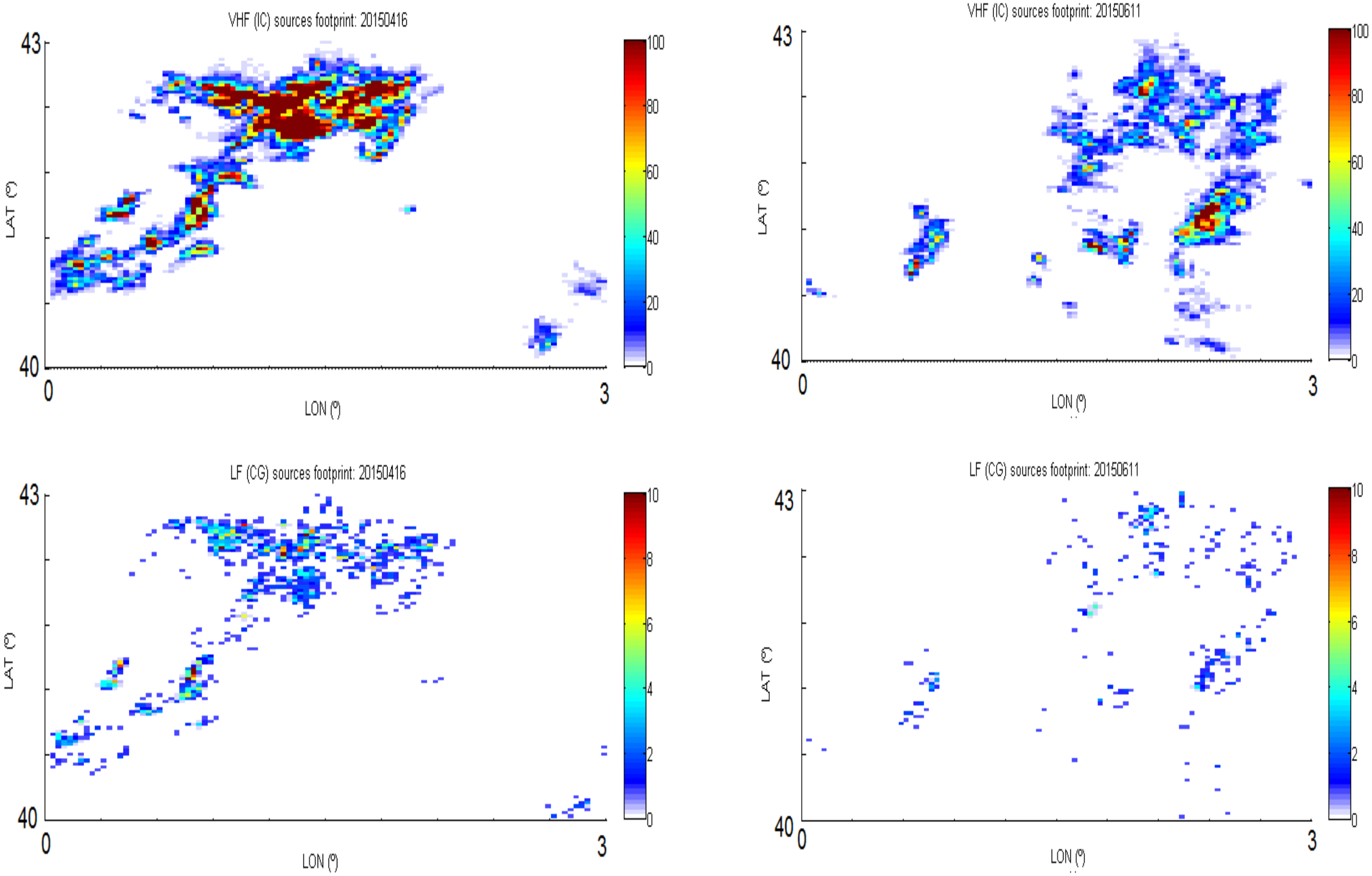
VHF

LF

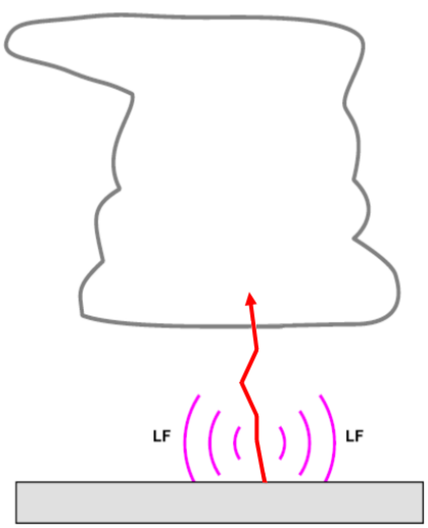


The thunderstorm footprint is better defined when intracloud is also detected (in VHF)

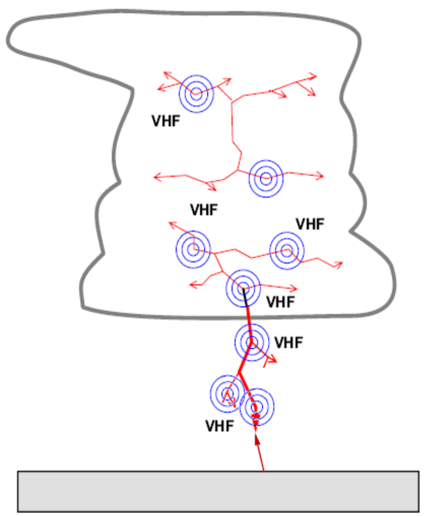
Lightning detection from satellite: optic pulses

Energy reaching the cloud top is influenced by:

- cloud optical depth,
- vertical gradient of scattering
- Lightning channel height

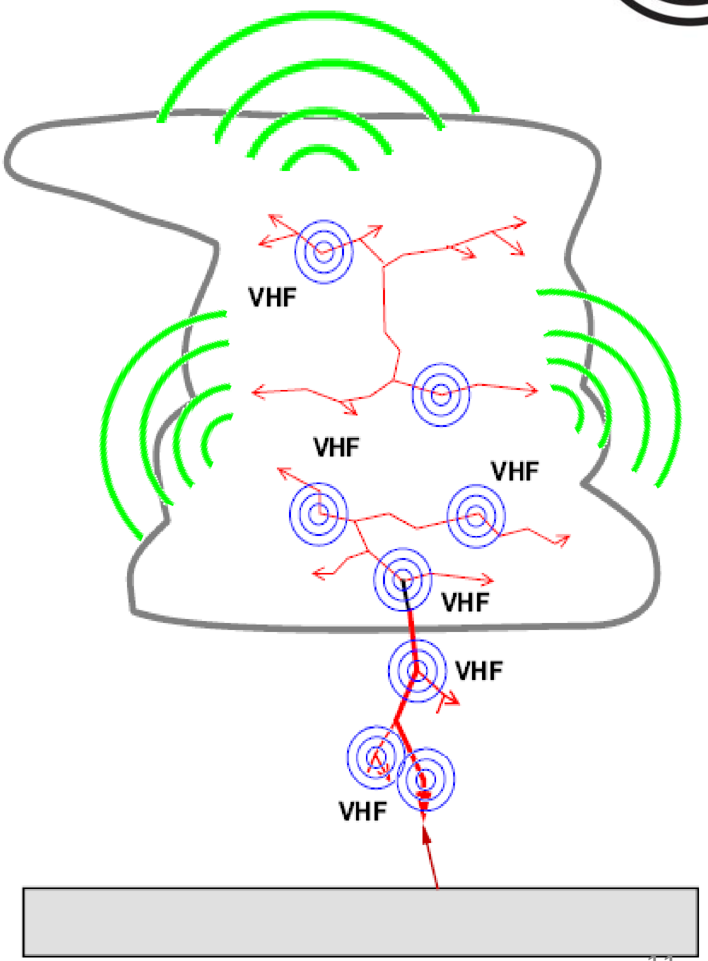


LF/VLF

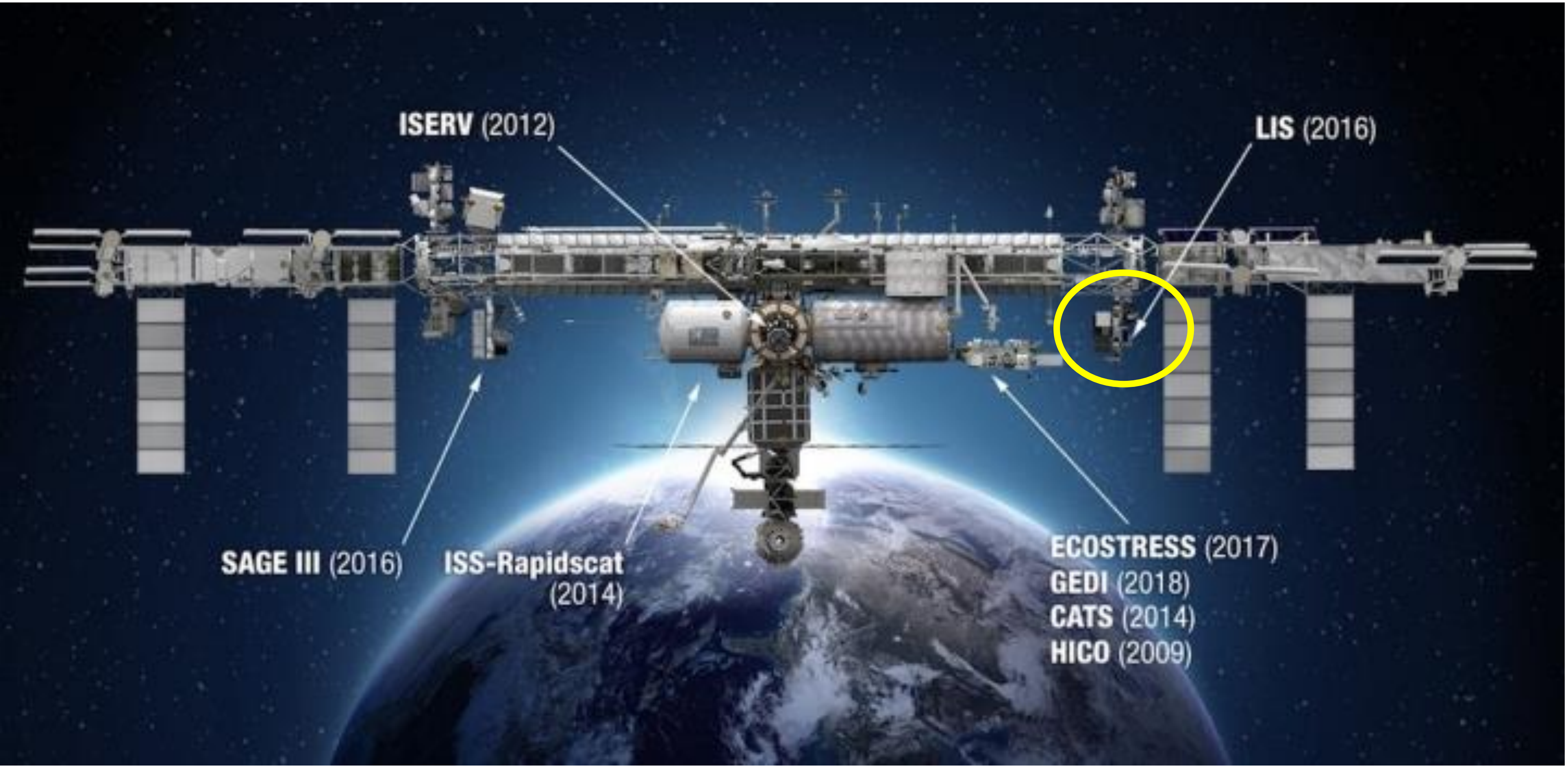


VHF

Optical pulse



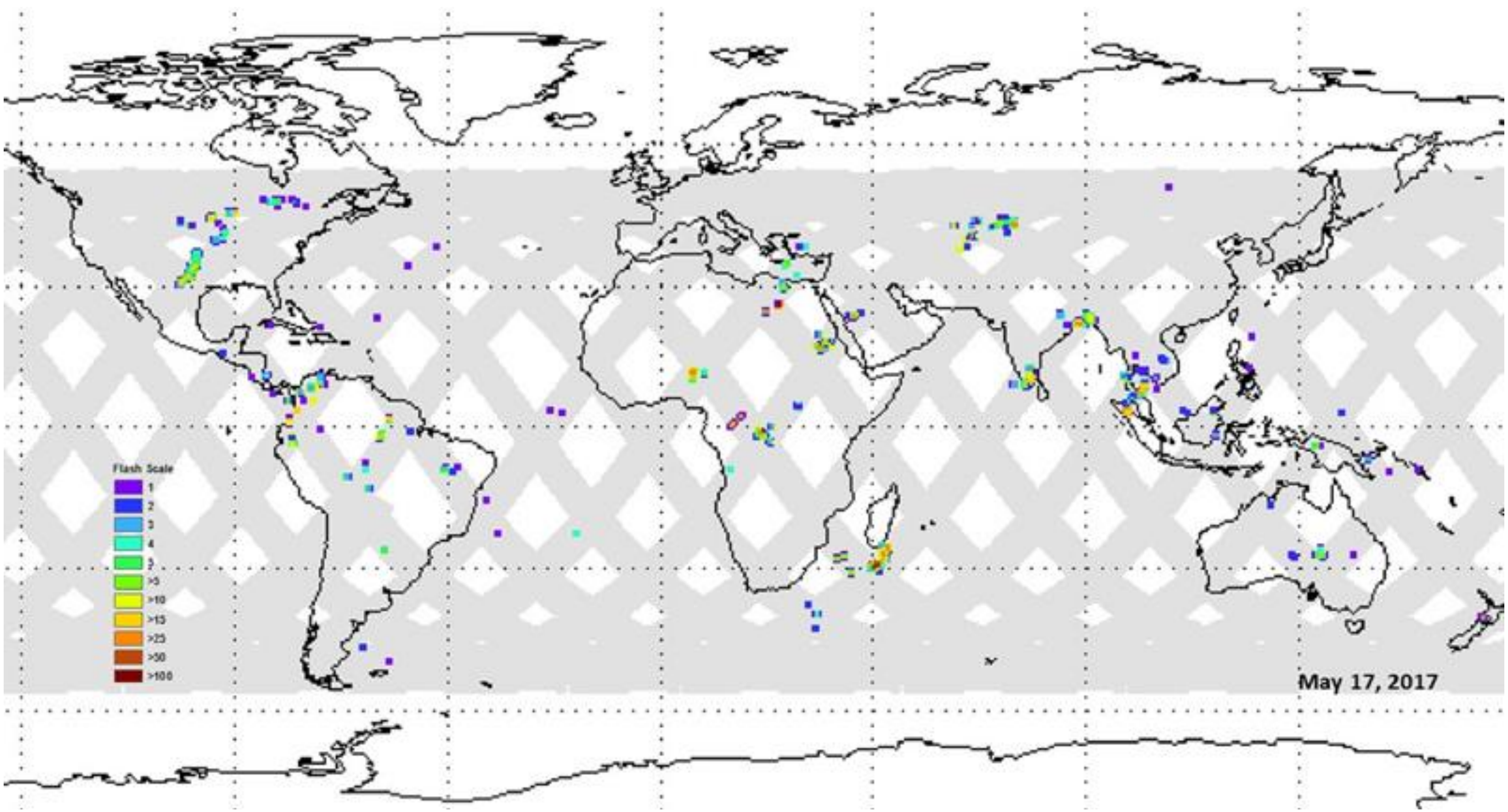
International Space Station -LIS



The Lightning Imaging Sensor (LIS) on the International Space Station (ISS) offers the opportunity to envisage how the MTG-LI data will look like, since it has a similar detection principle.

ISS-LIS

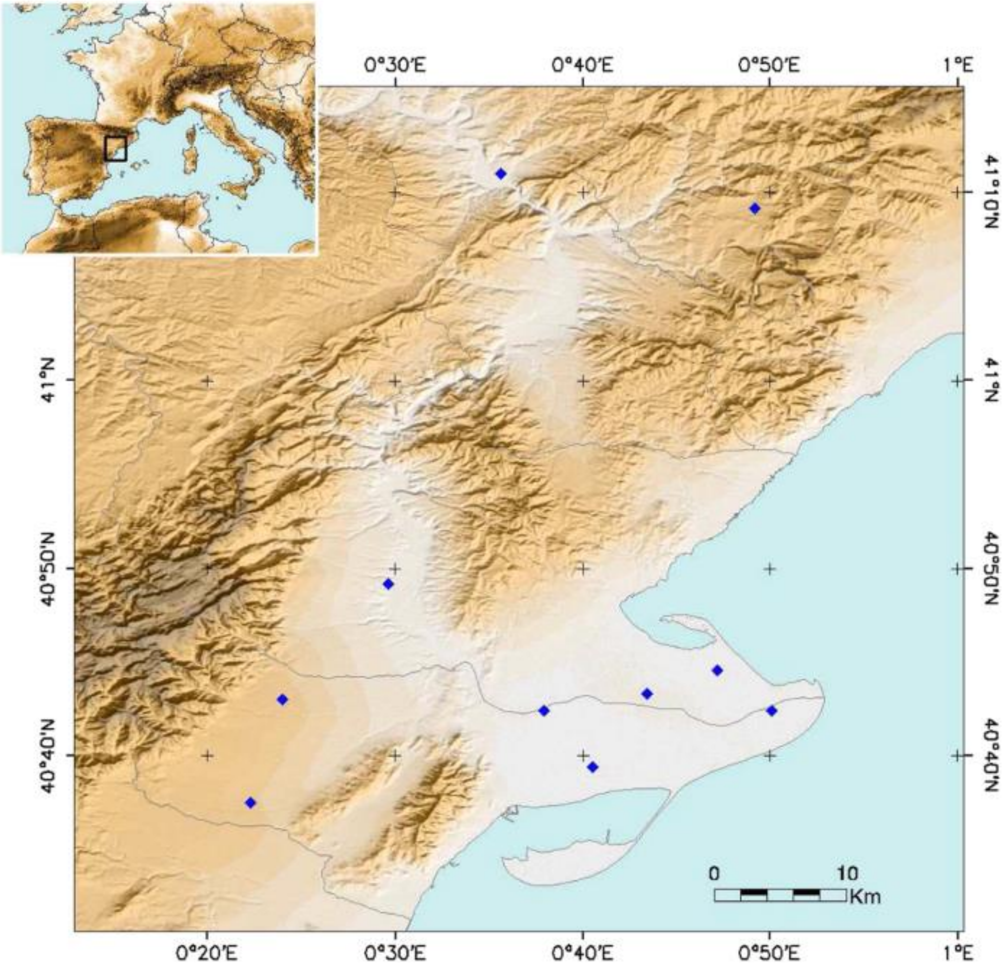
Field-of-View (FOV): 80°x80°
CCD Array Size: 128 x 128 pixels
Dynamic Range: >100
Pixel IFOV: 4 km (nadir) to 8 km
Interference Filter wavelength: 777.4 nm



ISS LIS Data Sets: https://ghrc.nsstc.nasa.gov/lightning/data/data_lis_iss.html

Lightning Mapping Array (LMA)

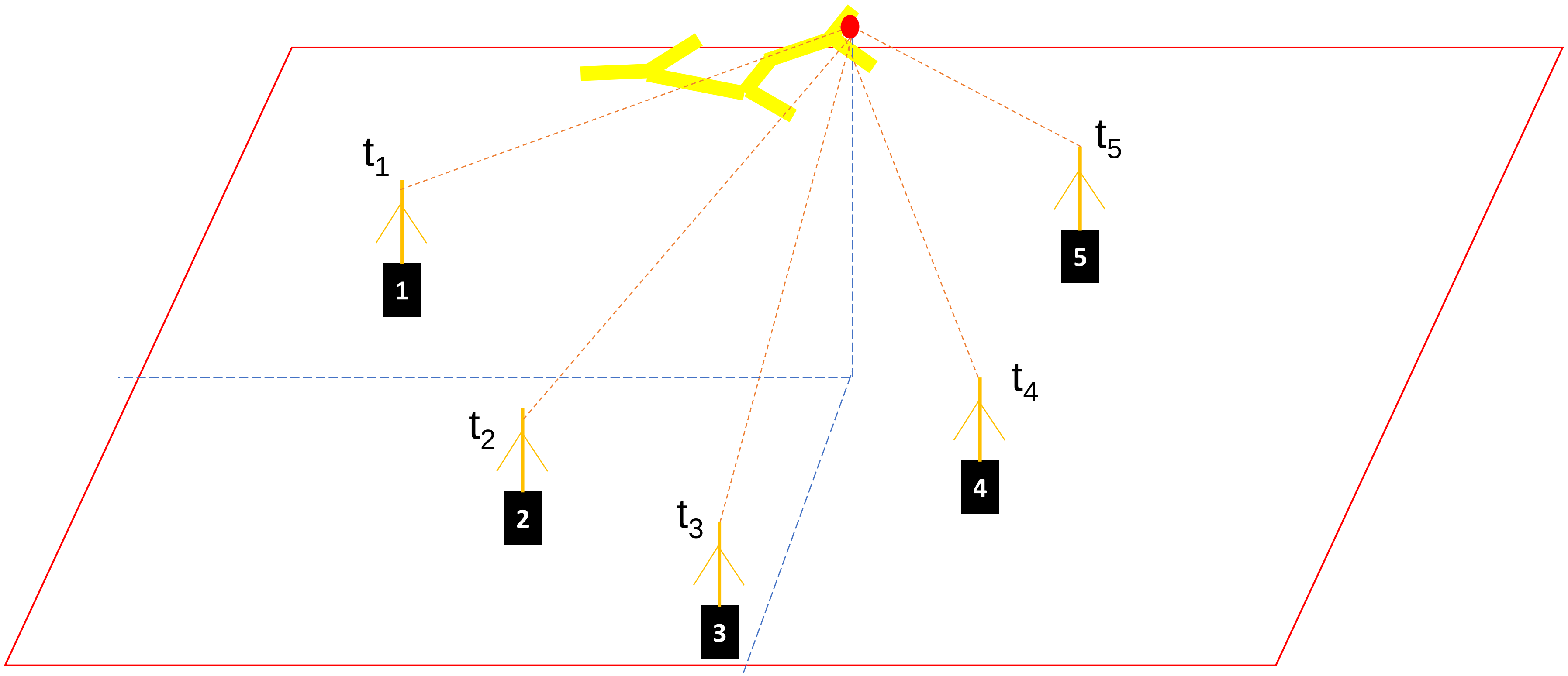
LMA: High-resolution VHF detection of lightning cloud channels



Ebre river delta, NE Spain

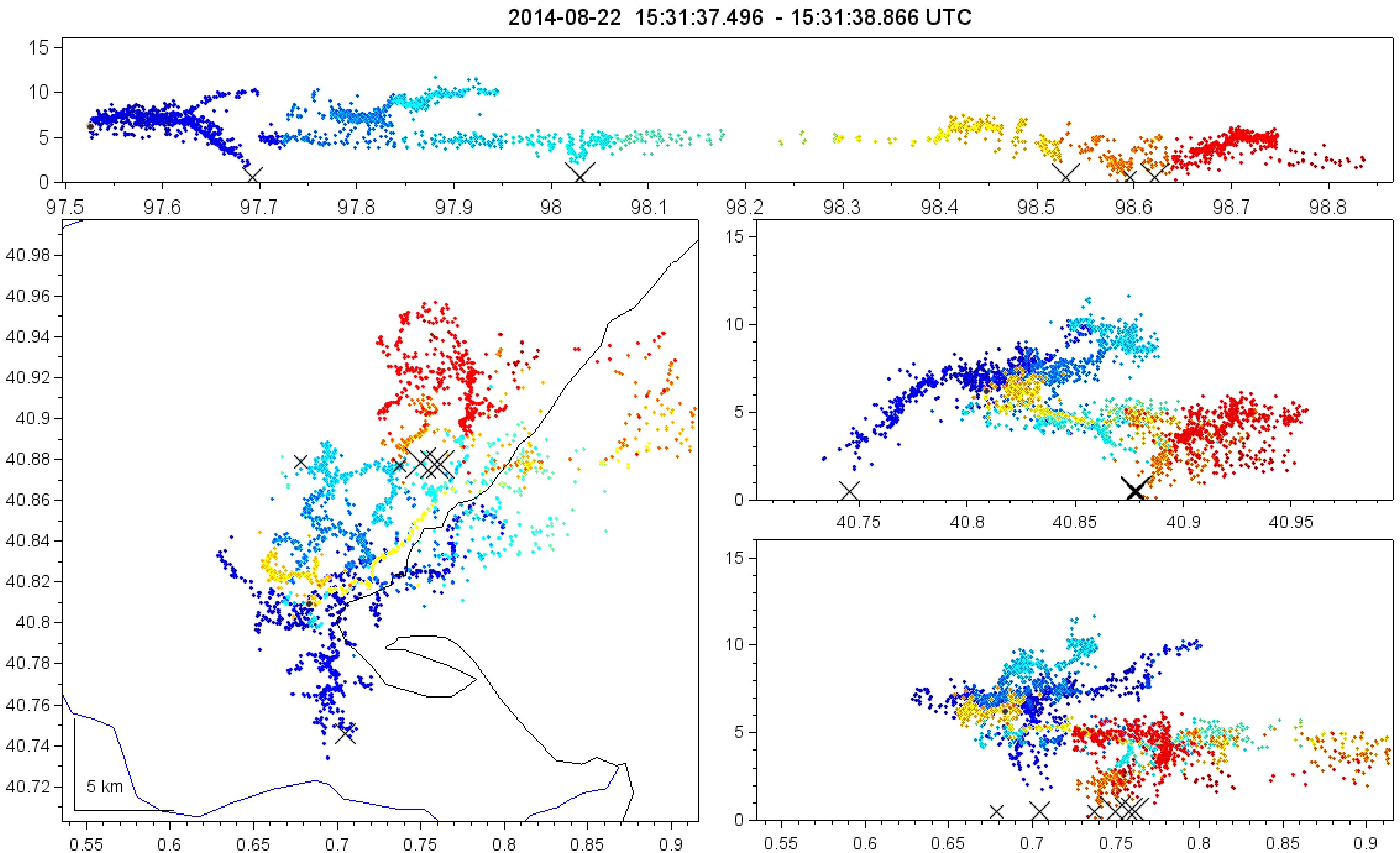
Lightning Mapping Array (LMA)

Lightning leaders are detected in the VHF range.
These RF emissions are measured by several stations
Source locations (X,Y,Z) are determined with Time-of-Arrival techniques

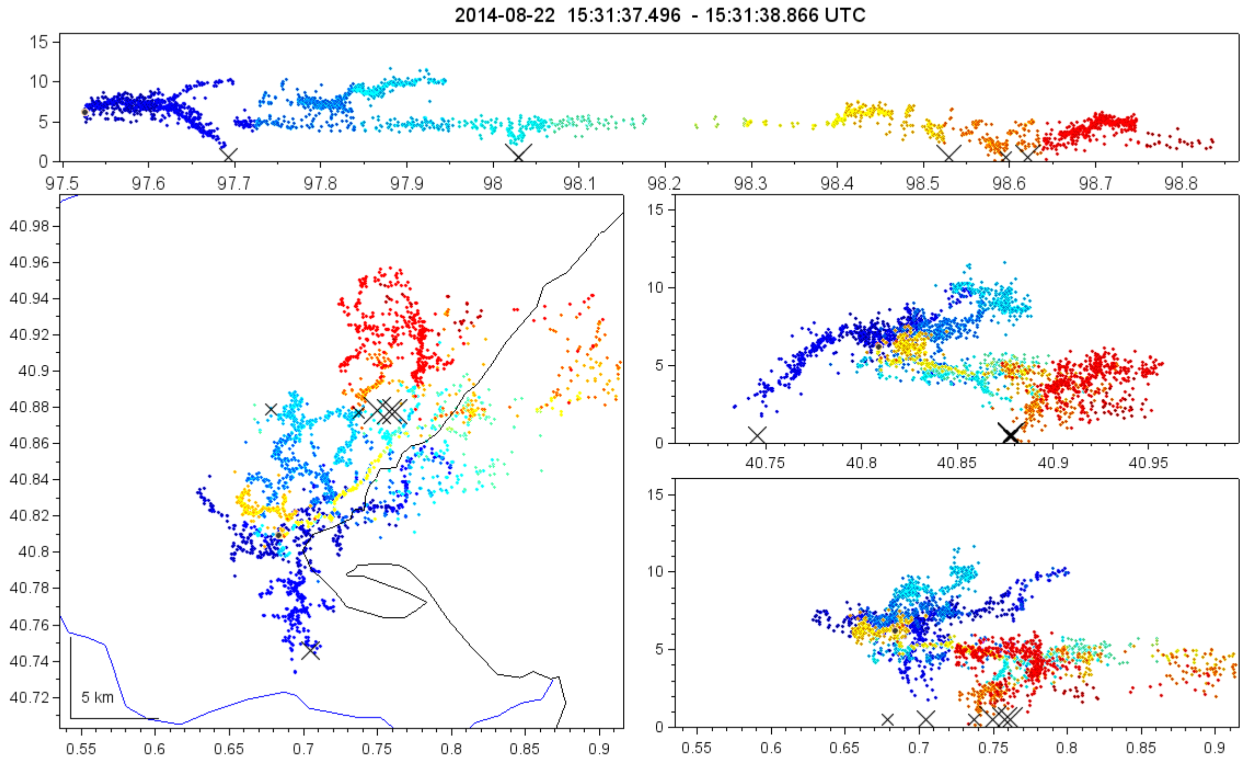


Lightning Mapping Array (LMA)

Respresentation of a single lightning flash as observed by the LMA

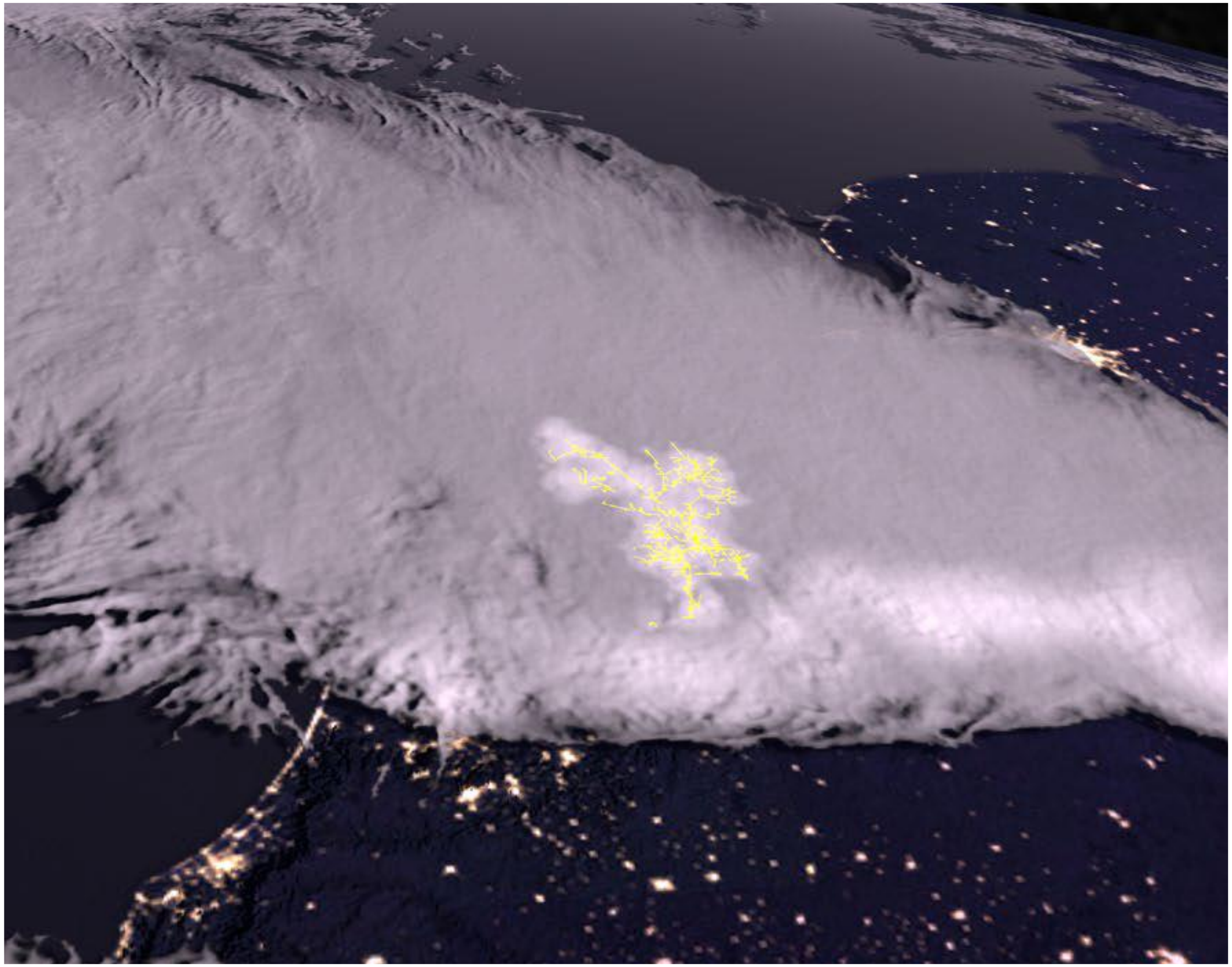


Lightning Mapping Array (LMA)



Previous slide: Multi-panel display of an intracloud lightning flash detected by the LMA. Very high frequency sources are colored with time. The top panel is altitude above mean sea level (km) versus time (seconds). The left panel is a plan view map (0.1° latitude equals 11.1 km) with contours of the coastline (black) and Ebro river (blue) as background. The panels at the right show altitude (km) by latitude and longitude. CG detections from the same flash, detected with another network (VLF/LF) LLS are shown as black cross marks.

What is a lightning flash?



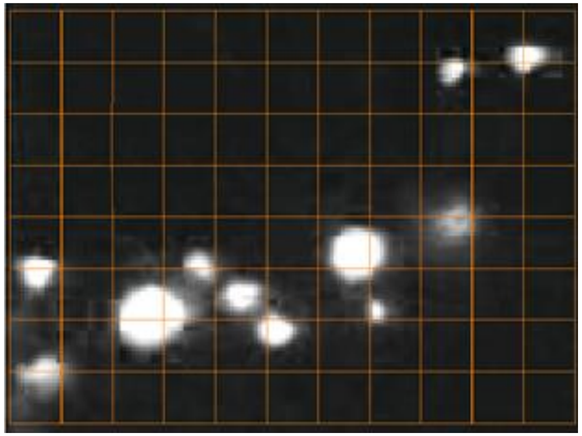
VLF/LF: sequence of return strokes

VHF: lightning channels spreading through the cloud

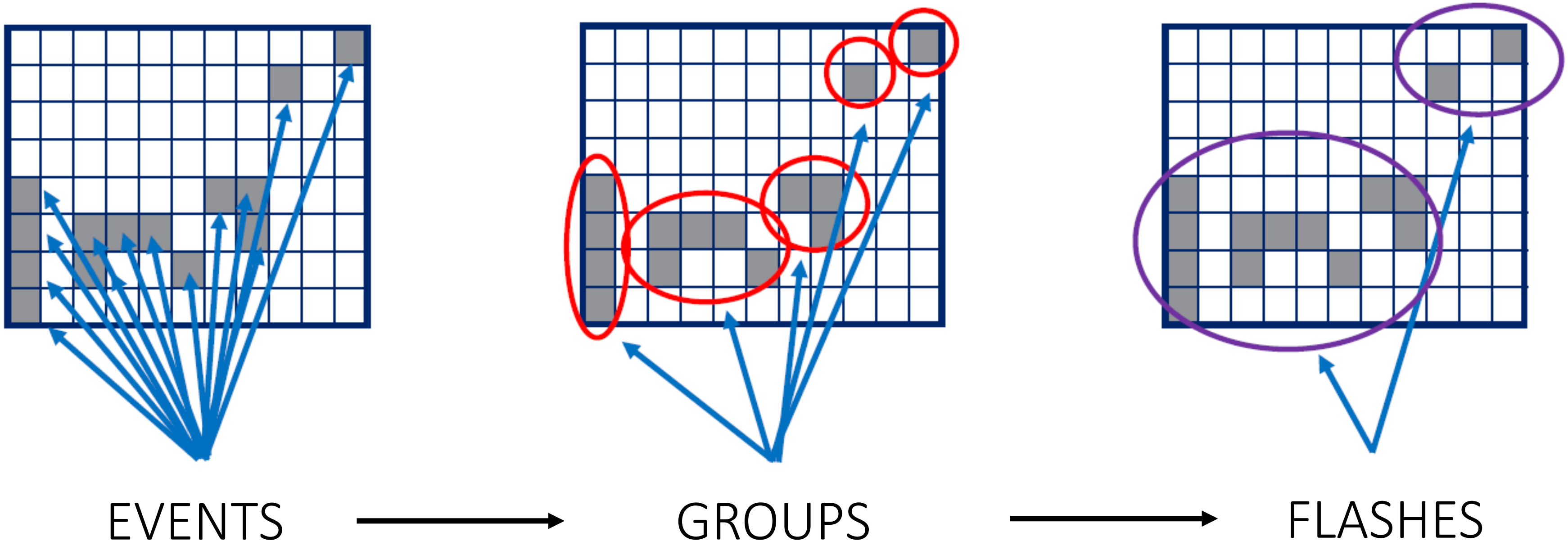
Optical: optical energy reaching the cloud top

What is a lightning flash?

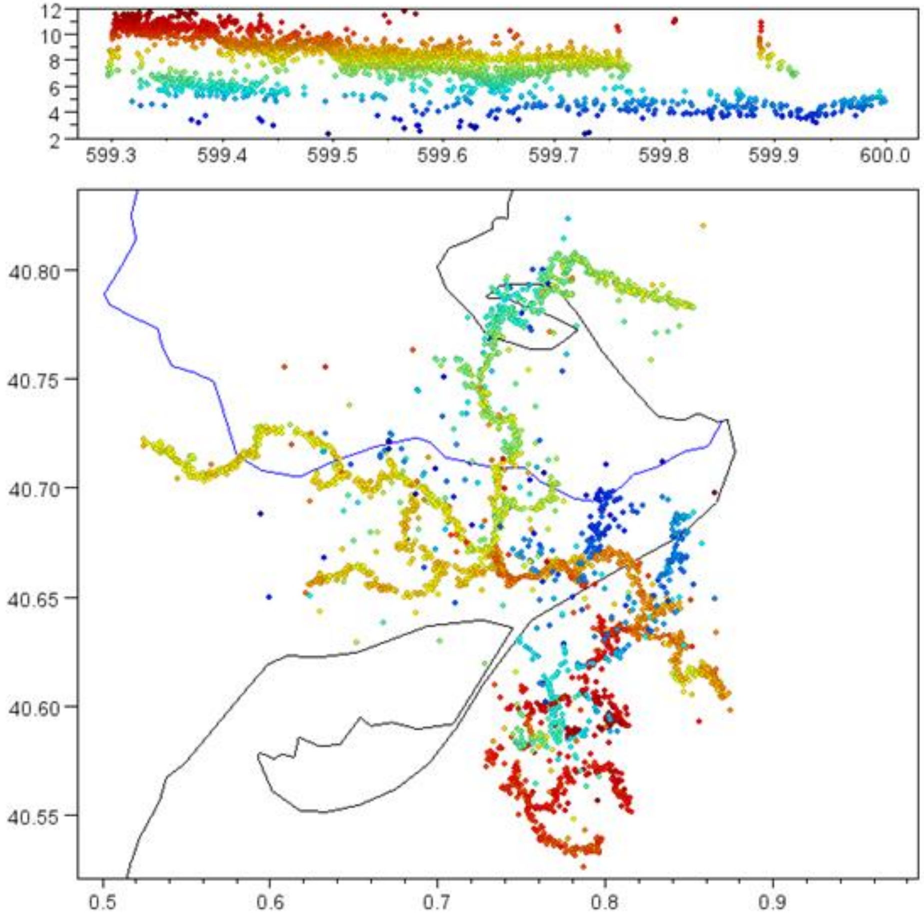
LIS detector grid

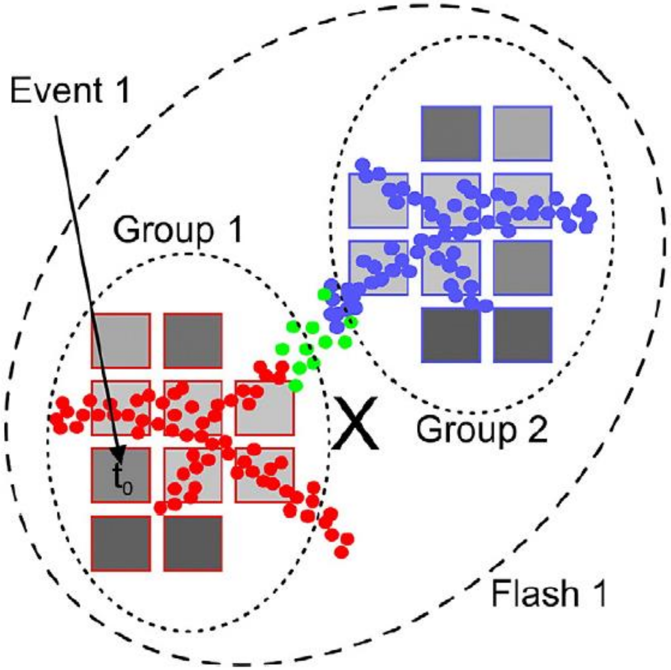


LIS events are first grouped into "groups", a in a second step "groups" are grouped into flashes (the same criteria is used in MTG-LI)



What is a lightning flash?





To allow the comparison between systems, we are using the LIS grid

Data set (8 episodes ~300 concurrent flashes)

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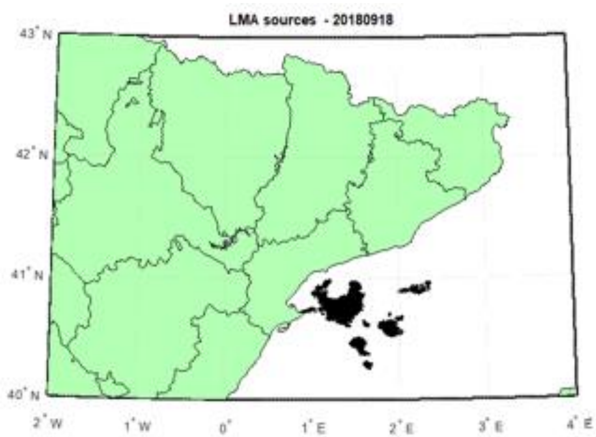
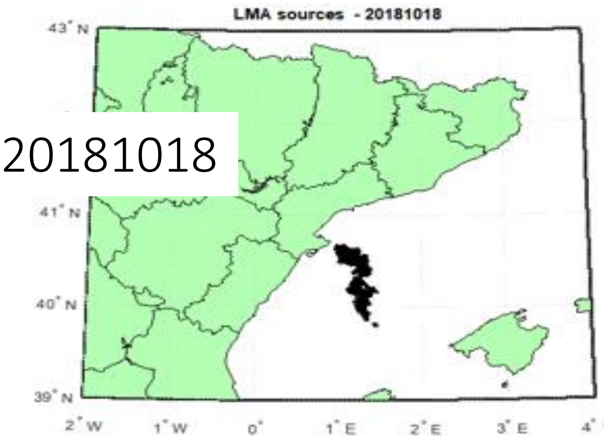
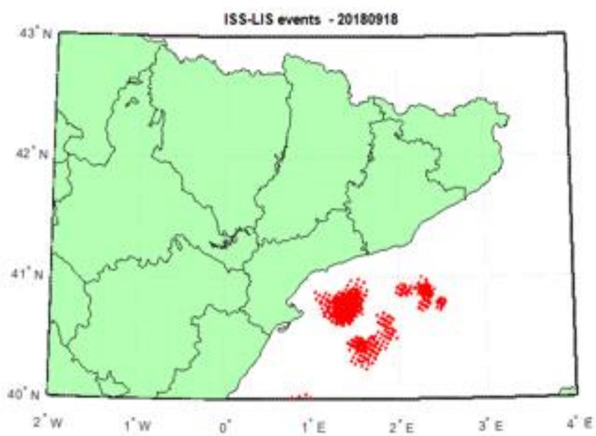


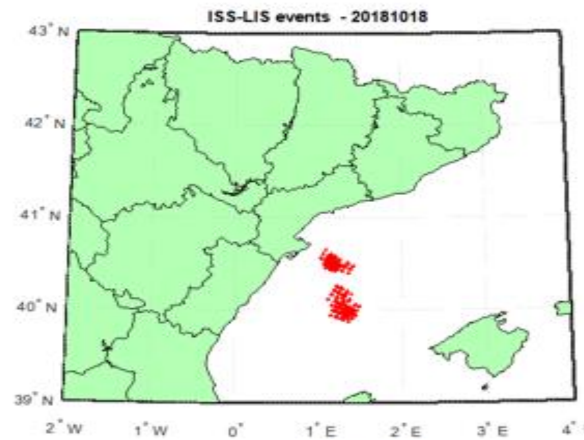
LMA

20181018





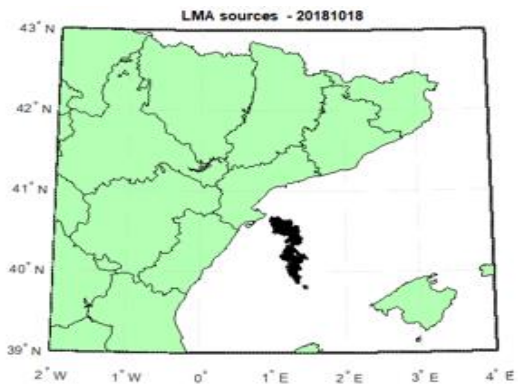
LIS



The data set is made of eight episodies with around 3 hundred LMA / LIS Concurrent measurments, these are two examples (we have to keep in mind that the ISS passes above the region are scarce and has to coincide with thunderstorms around)

Data set

LMA



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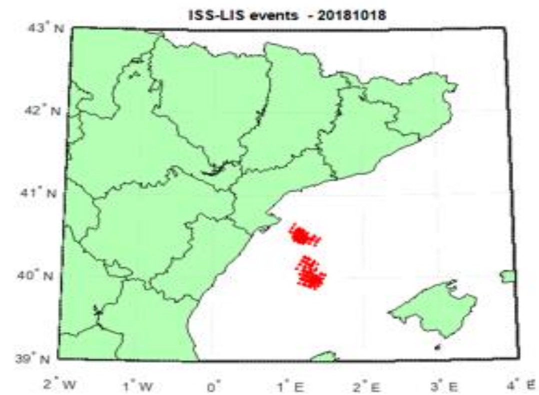
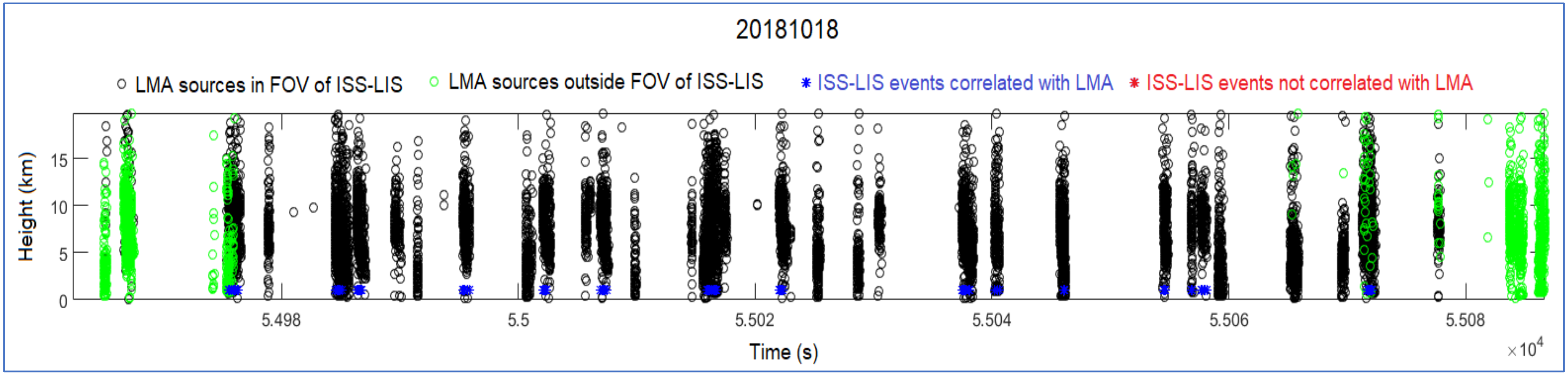
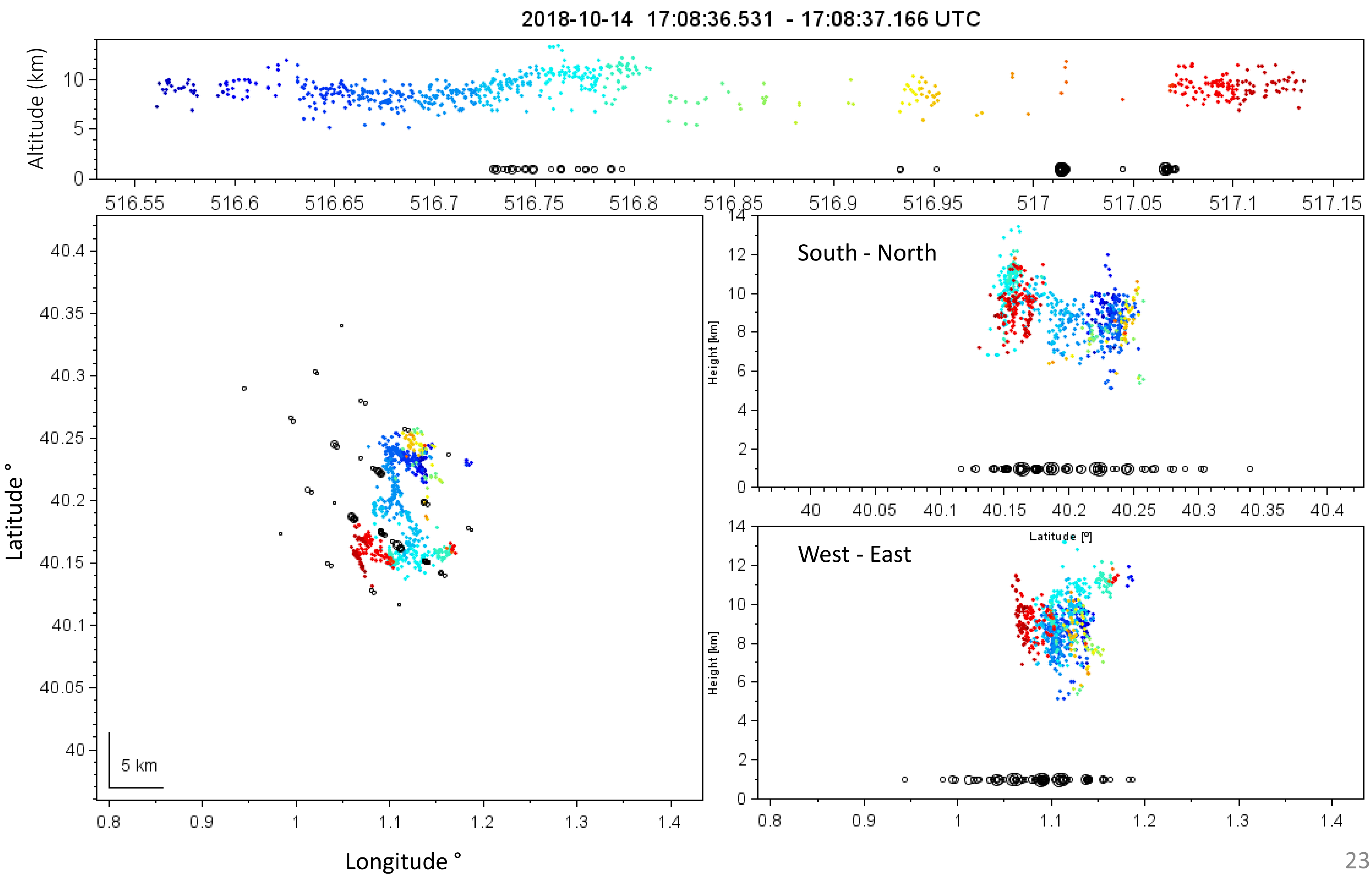


LIS



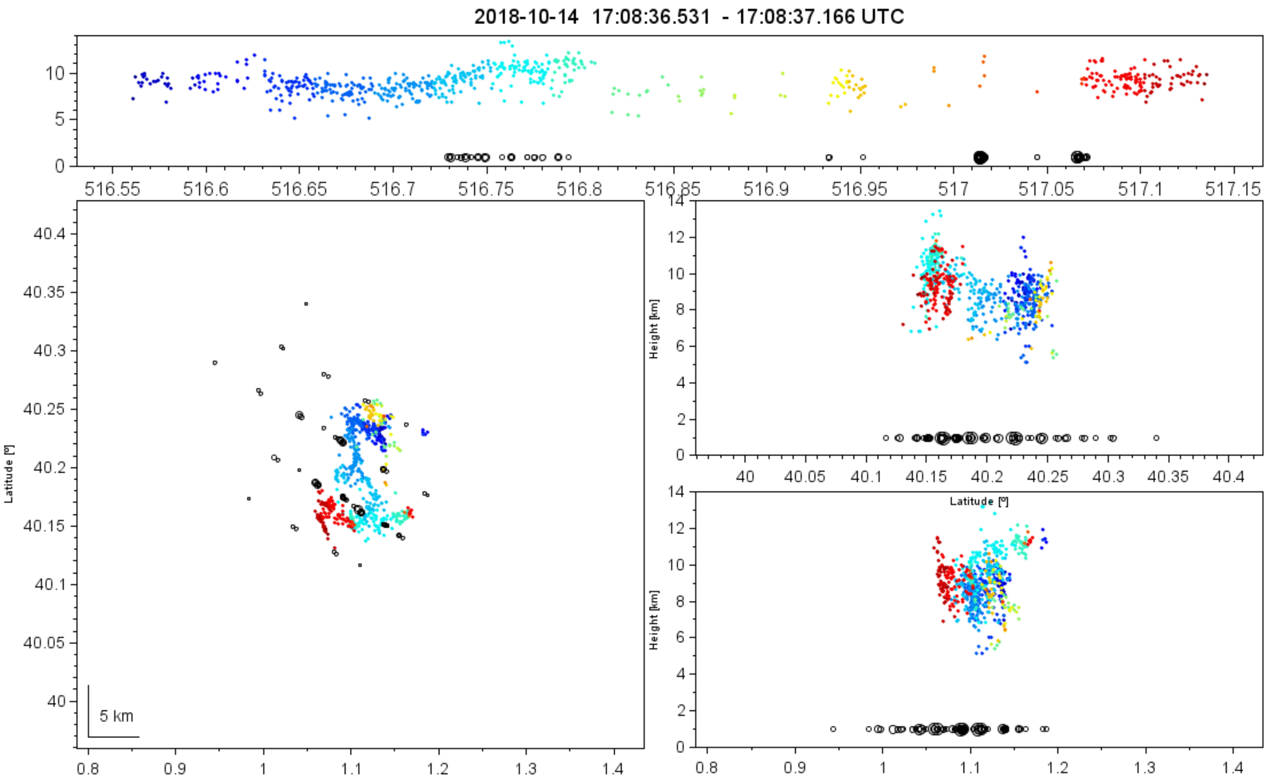
Black circles correspond to LMA sources that have occurred in time and location within the Field of View of ISS-LIS whereas the green ones are those occurring in time and location outside the FOV of ISS-LIS. Each vertical line of sources is a lightning flash Corresponding LIS events are plotted as blue asterisks

ISS-LIS vs LMA (flash-by-flash)

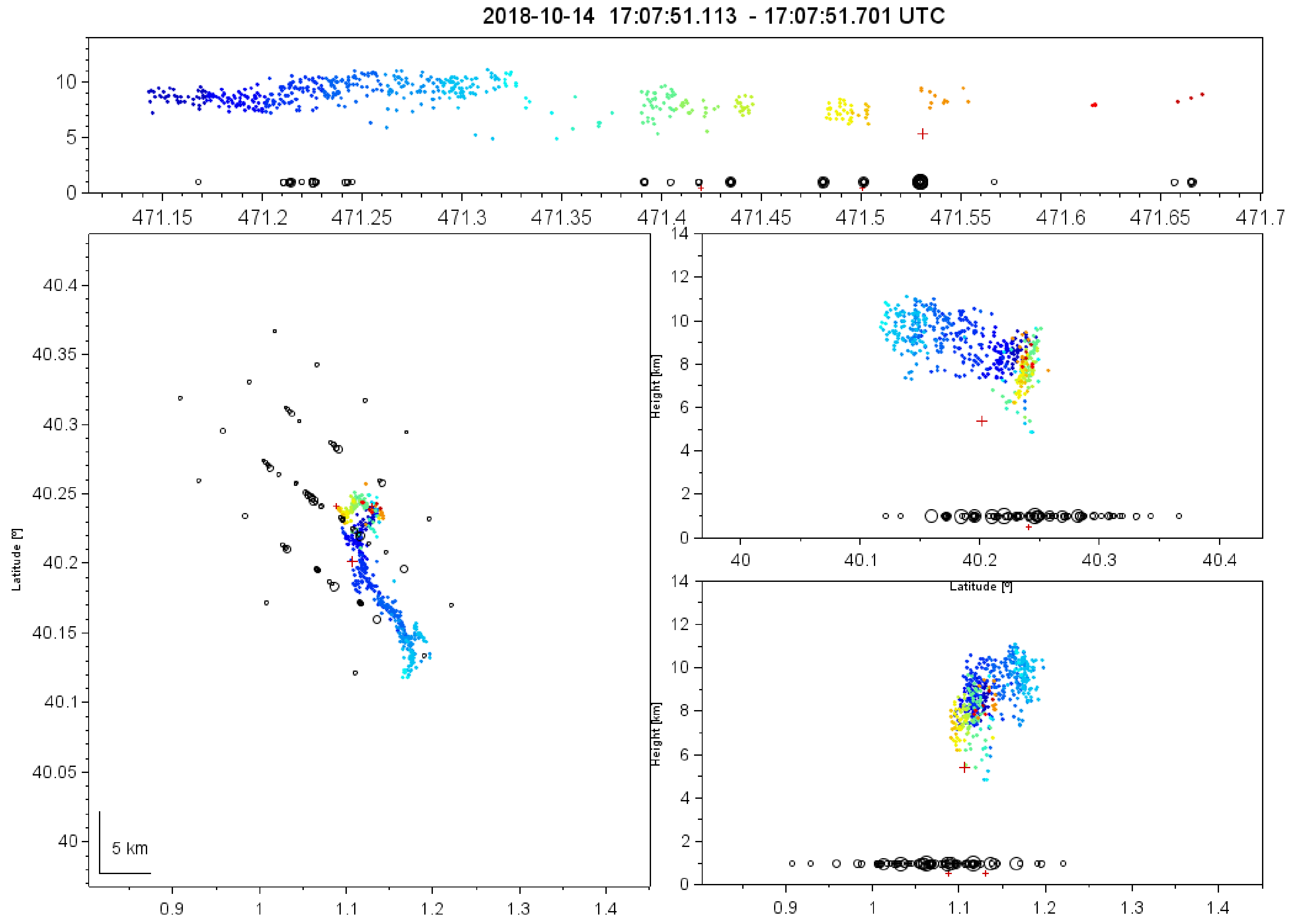


ISS-LIS vs LMA (flash-by-flash)

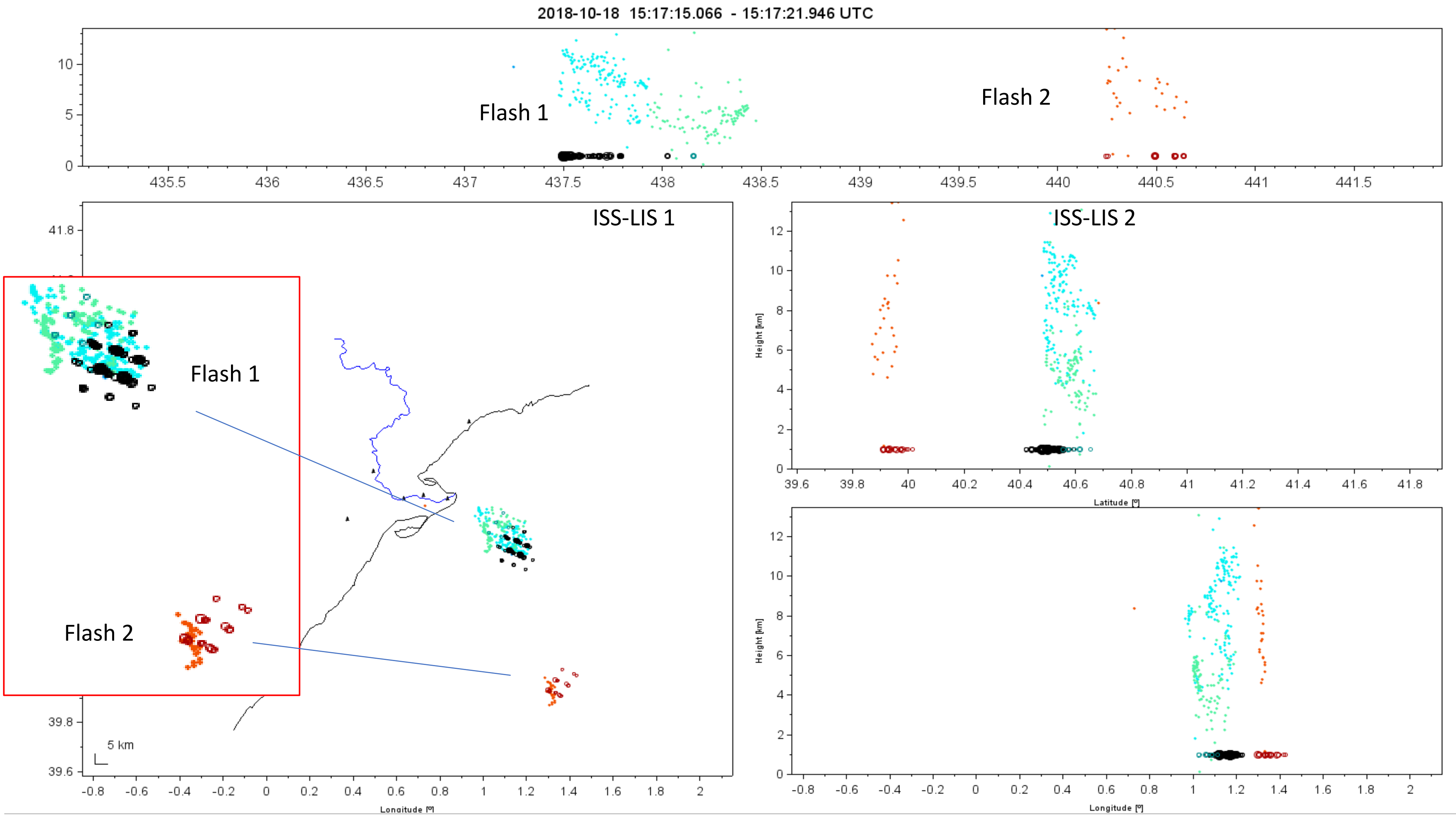
Previous slide: Multipanel display of an intracloud lightning flash detected by the LMA Very high frequency sources are colored with time. Concurrent LIS events are also plotted (black circles, arbitrary height of1 km, circle diameter relative to radiance). The top panel is altitude above mean sea level (km) versus time (seconds). The left panel is a plan view, right panels are Nort-south and West-East views, versus height



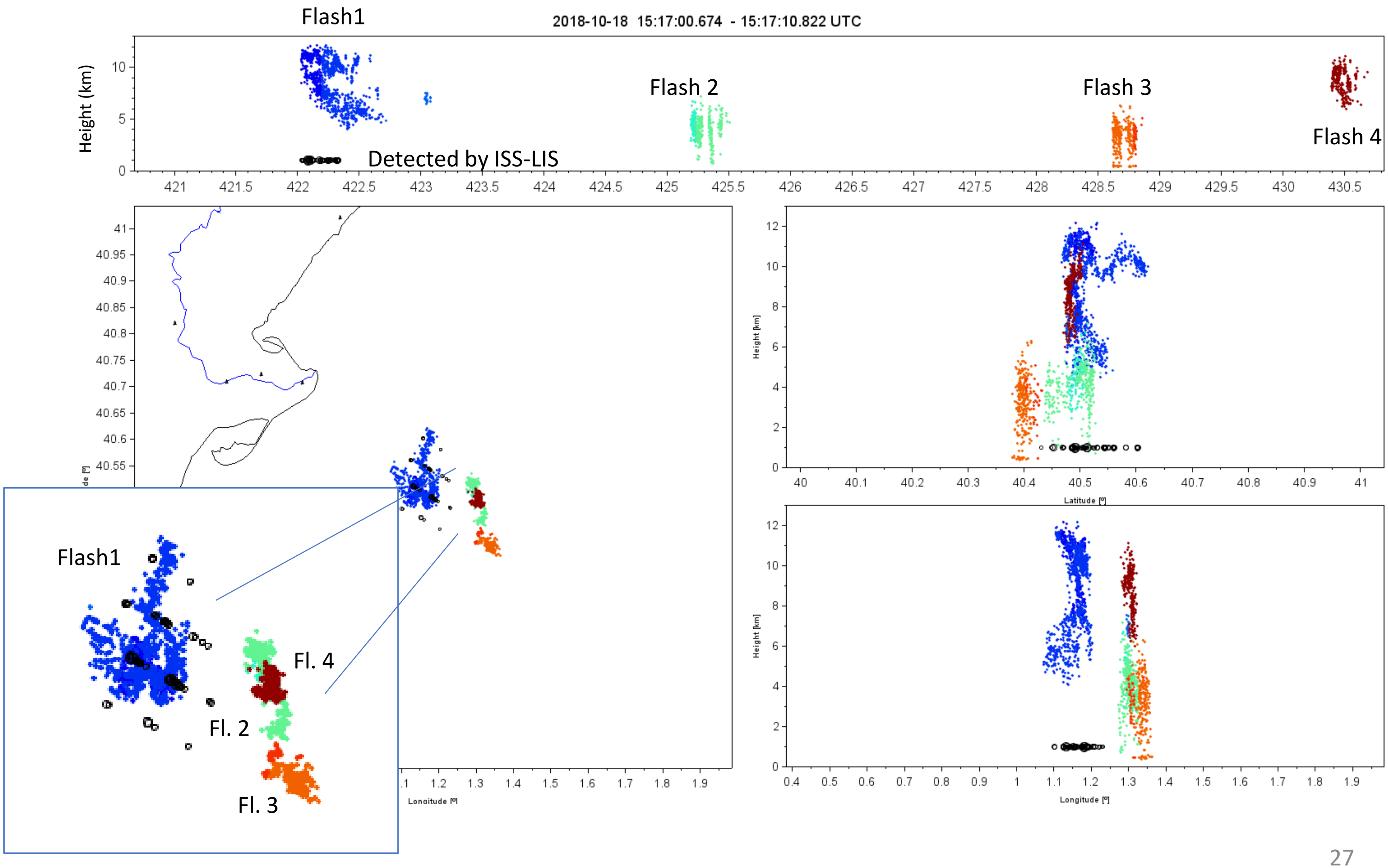
ISS-LIS vs LMA (flash-by-flash)



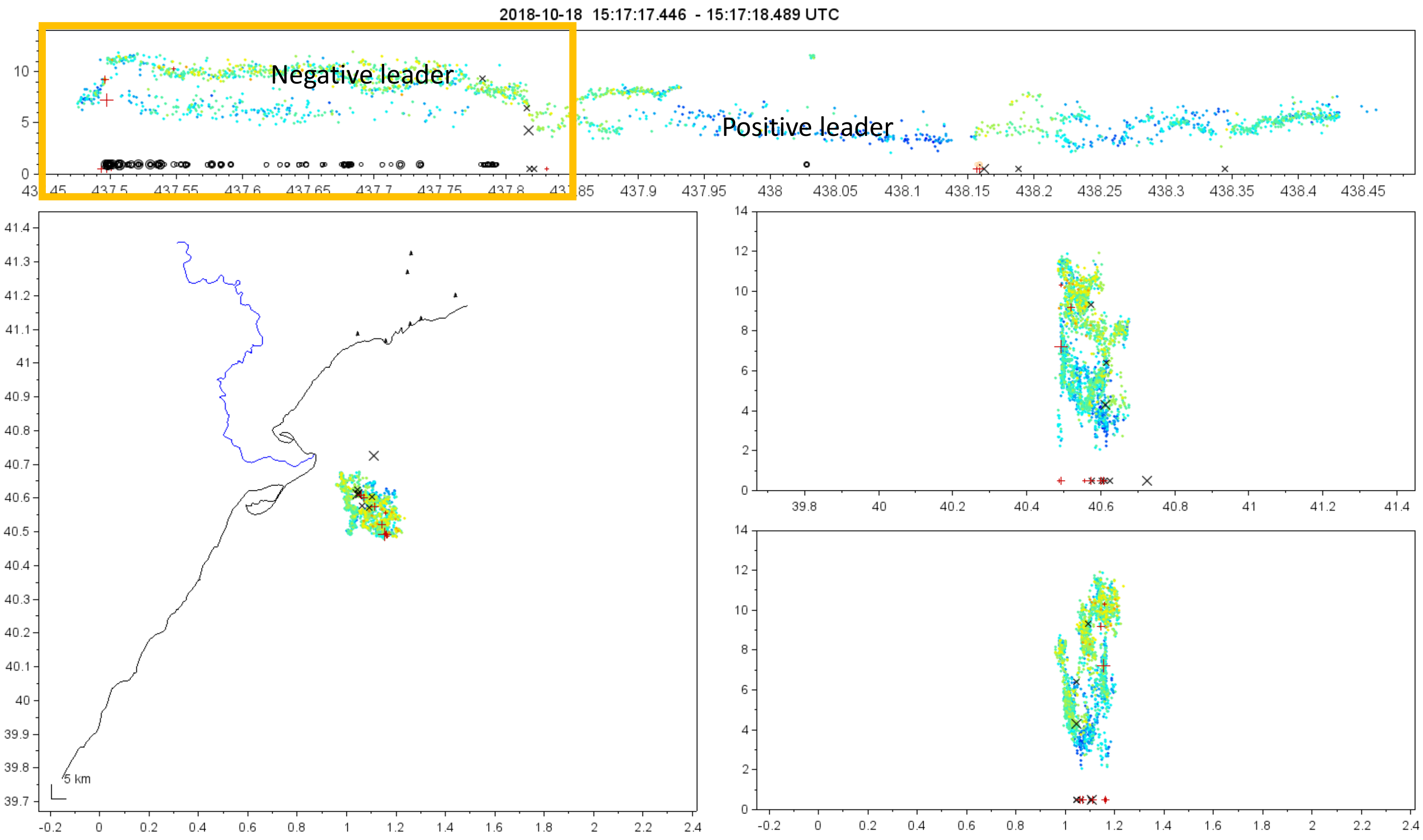
ISS-LIS vs LMA (flash-by-flash)



ISS-LIS vs LMA (flash-by-flash)



ISS-LIS vs LMA (flash-by-flash)



in this example, source color corresponds to LMA source power. Concurrent LIS events occur at the beggining of the LMA flash, and appear to be related to the higher and intense negative leader sources The following positive leaders (lower altitude) has no LIS detections

Results

https://www.eumetsat.int/ISS-LIS-data-analysis

Metrics:

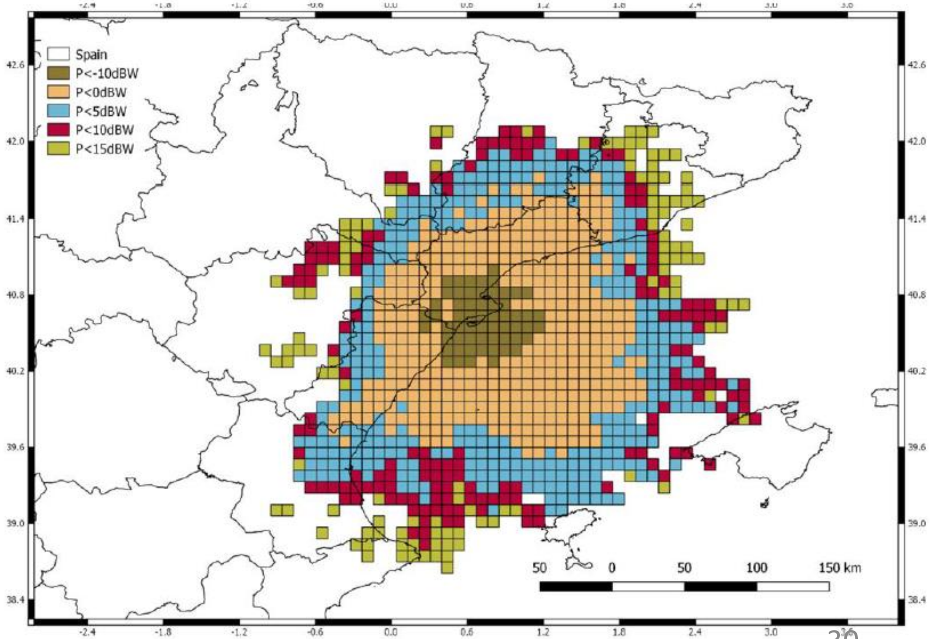
- Detection efficiency
- Location Accuracy
- Flash duration
- LIS flash vs LMA Flash

Results: detection efficiency

Flash Detection Efficiency

$$DE_f = \frac{Nbr\ of\ LMA\ flashes\ detected\ by\ \mathrm{LI}}{Total\ number\ of\ LMA\ flashes}$$

Flashes detected by the LMA are used as reference (ground truth). LMA flashes will be restricted to an area of 150 km around the network to ensure that all flashes are detected properly

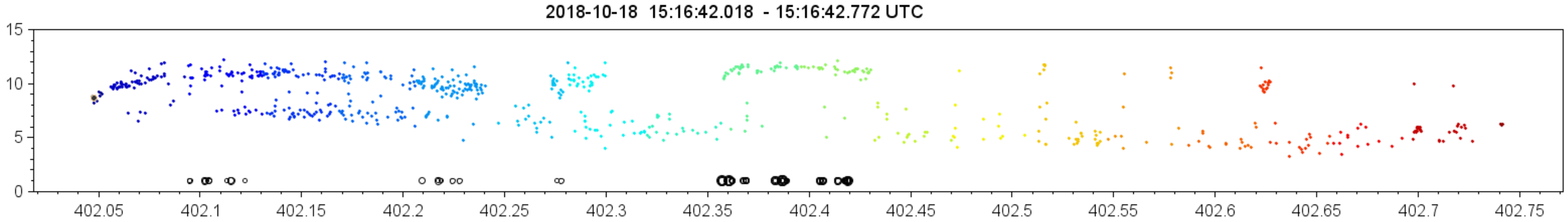


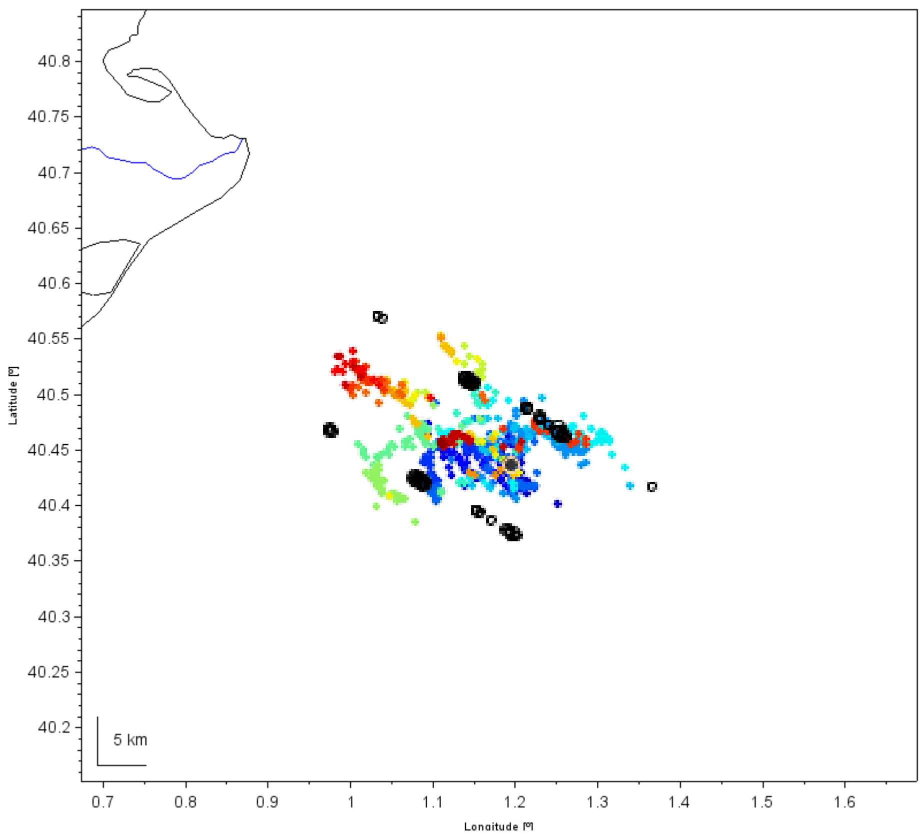
Results: detection efficiency

Flash Detection Efficiency

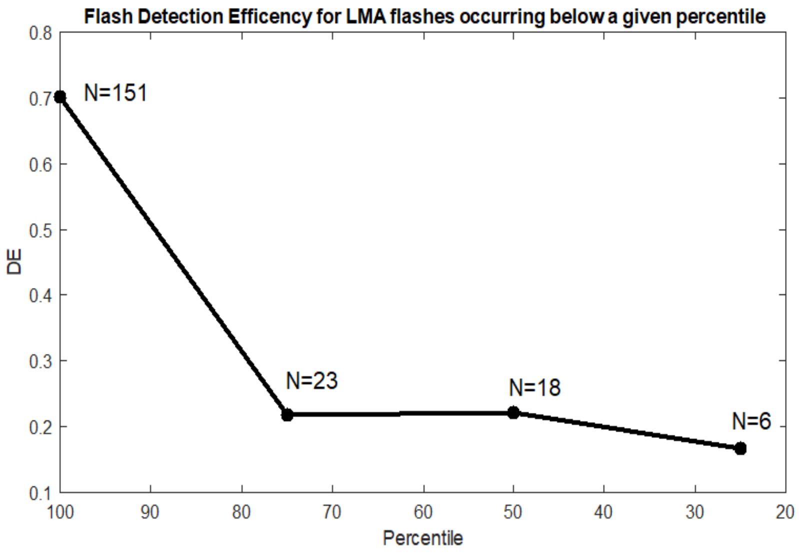
LMA range	**≤ 150 km**
Time tolerance (T)	± 0.1 s
Minimum number of ISS-LIS events to detect a flash	1
Total number of episodes	8
Total number of LMA flashes: 272	272
Total number of flashes detected by LIS	185
Allowed distance between centroids of ISS-LIS and LMA flashes (D)	50 km
Flash Detection Efficiency	68%

Results: detection efficiency



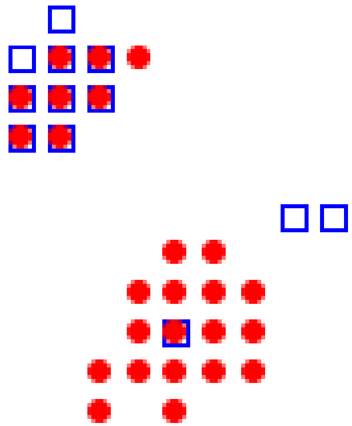


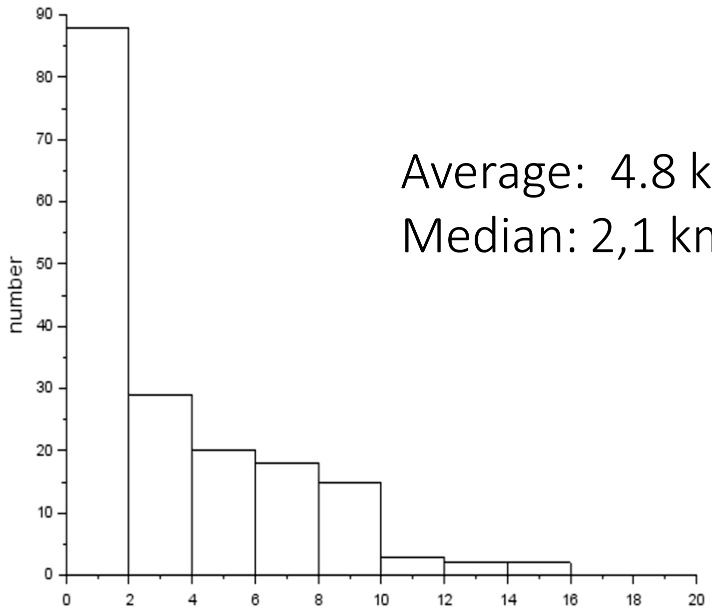
DE in relation to the LMA channel height



Results: location accuracy

Offset in flash location (offset between LMA flash center and LIS events)





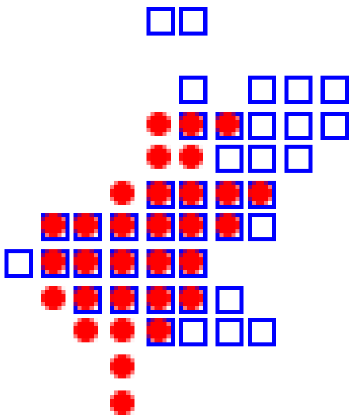
Average: 4.8 km
Median: 2,1 km

Blue squares = LMA
Red circles = ISS-LIS

km

Results: location accuracy

Another way to estimate the location accuracy is through the Spatial overlap:
Percentage of LMA flash area detected by ISS-LIS
Percentage of LIS area not matched by LMA underneath



In this example: 55% of LMA detected by LIS
29% of LIS not matched

Overall average: 47% of LMA detected by LIS

LMA flashes are on average 200 km^2
corresponding LIS events 207 km^2

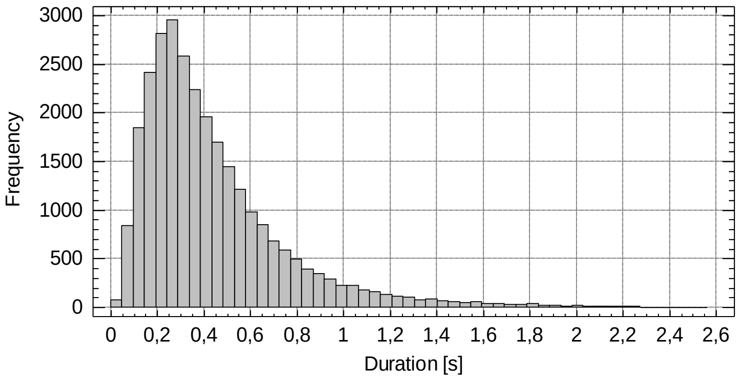
Blue squares = LMA
Red circles = ISS-LIS

Results: flash duration

J.A. López, N.Pineda, J. Montanyà, O.A. van der Velde, F.Fabró, D.Romero, 2017.
Spatio-temporal dimension of lightning flashes based on three-dimensional LMA
Atmospheric Research https://doi.org/10.1016/j.atmosres.2017.06.030

Table. Summer and winter lightning duration (seconds)

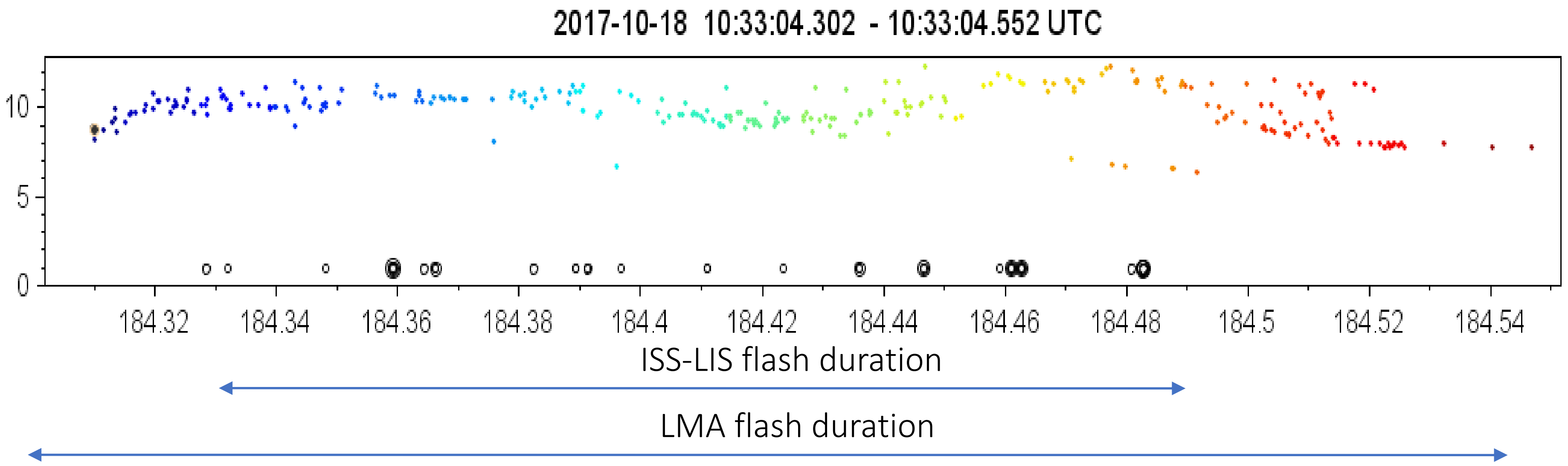
	Summer	Winter
Samples	28527	351
Mean	0.44	0.45
Median	0.35	0.41
Standard dev	0.31	0.25
Percentile 5th	0.15	0.11
Perc 95th	1.05	0.94
Maximum	2.39	1.82



Results: flash duration

Flash duration is calculated as:

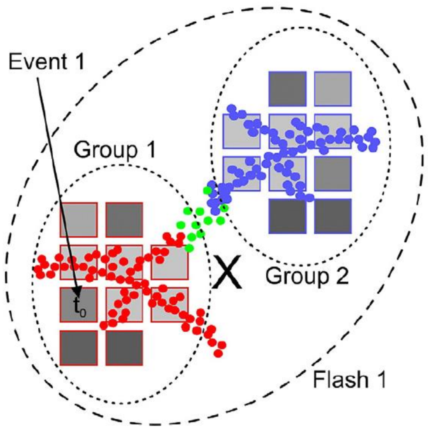
- LMA: time difference between the first and the last source
- ISS-LIS: time difference between the first and the last event in a LMA flash

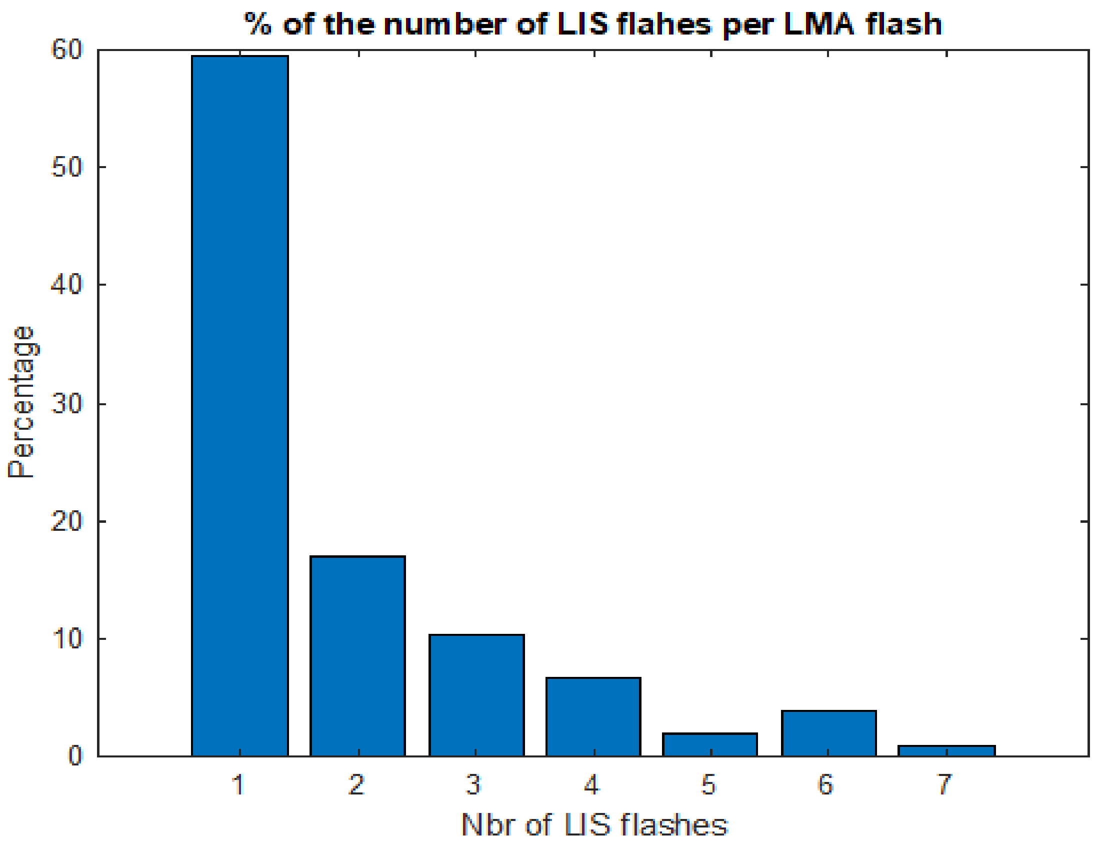


Duration (s)	ISS-LIS	LMA
average	0.691	0.860
min	0.107	0.167
max	2.405	2.272

80%

Results: LIS-flash vs. LMA-Flash





About 60 % of the LMA flashes have one ISS-LIS flash
About 20 % of the LMA flashes ISS-LIS assigned two flashes
The other 20% has 3 flashes or more

Summary

Lightning Mapping Arrays (LMAs)

PROS

- Provide the most comprehensive picture of the lightning channel propagation inside the cloud.
- Typically, hundreds to thousands of sources per lightning flash (also a CON!)
- Allow the discrimination of lightning leader polarity.
- Allows the identification of thundercloud charge regions.

CONS

- Limited range, typically 100-150 km radius from center of the network
- Large amount of data to be processed in real-time.
- Lightning return stroke processes are not detected by the LMA (to be complemented with VLF/LF lightning data)

Summary

ISS-LIS flash detection efficiency resulted to be around 70% (episode sensitive 50-90%)

- Detection efficiency drops to 20% when lightning flashes occur below the 75 % altitude for a giving episode (cloud optical depth, particle scattering)

Location Accuracy

- Average offset between ISS-LIS and LMA flash of 4.8 km
- Pixel overlap: 47 %
- Flash area: ISS-LIS flashes typically larger than LMA (cloud scattering)

Flash duration

- Average duration for an ISS-LIS flash is of 0.7 s (20% more in LMA)

Report

https://www.eumetsat.int/ISS-LIS-data-analysis

Takeaway messages

Take away messages for the EUMETrain community:

- Lightning is a complex process that is partially observed from remote sensing systems

- Optical measurements like the MTG-LI are different from the observations made with ground-based LLS

- Importantly, observations from space platforms and from ground-based systems are not analogous but complementary (don't throw away your current lightning ground-based detection system!)

- No system is seeing the whole picture. Every remote sensing system has Pros/Cons: satellite observations observe most of the cloud fraction of a flash (cloud channels) but does not always see the cloud-to-ground strike