MTG-LI for the continuous monitoring of fireballs

Bartolomeo Viticchiè, Sven-Erik Enno & Jochen Grandell

EUMETSAT Remote Sensing and Products (RSP) Division

EC-ESA WS on NEO Imminent Impactors Warning Coordination

ESOC, December 12-14, 2022

Lightning imagers and detection of fireballs

From the LI Mission Advisory Group meeting #9 (January 2020)

"*Bolide detection through GLM*" of R. Longenbaugh et al.

Take-home messages

- GLM measurements can complement bolide studies
- GLM and MTG-LI can be combined for monitoring bolides entering the Earth atmosphere
- Usage of Level 0 vs Level 2 data for bolide detections:
  - *Having adjacent pixel information has proven very useful and simplifies bolide detection algorithms* (here referring to Level 0)
  - *Level 0 data is not filtered and processed which gives access to what is happening on the detector during a bolide event*
  - *Once we find a detection in Level 0 we then look for it in the calibrated Level 2 data*
- Stereo measurements for trajectory reconstruction by mean of GLM-16 and GLM-17 (now also GLM-18 is being employed; see GLM Science Meeting 2022)

MTG-I satellites

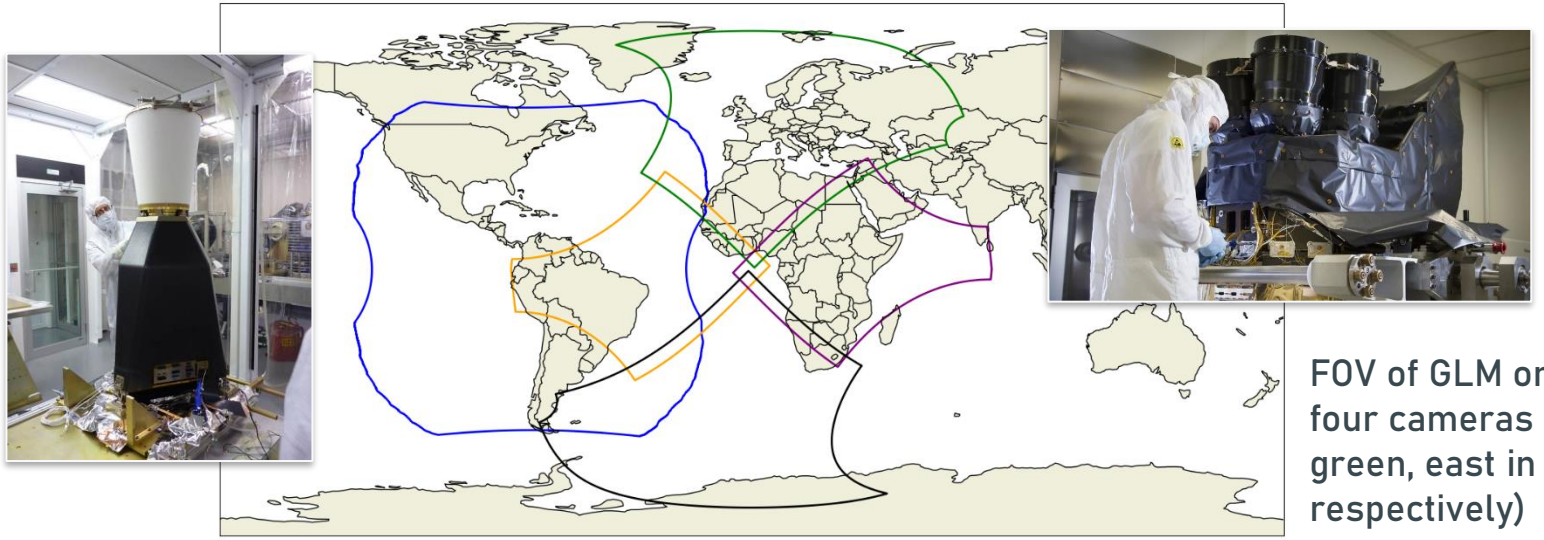
- Imagery mission implemented by two MTG-I satellites
- Full disc imagery every 10 minutes in 16 bands (FCI)
- Fast imagery of Europe every 2.5 minutes (FCI)
- New Lightning Imager (LI)
  - The current EUMETSAT baseline is to have only one operational LI
- Operational exploitation: 2023-2042
  - MTG-I1: December 2022 (3.4 deg East)
  - MTG-I2: 2025
  - MTG-I3: MTG-I1 launch + 10 years
  - MTG-I4: MTG-I3 launch + 10 years

Outreach videos
MTG-I: LI and FCI
MTG-S: IRS and UVN

LI key design features

Key design feature	LI*	GLM
Detector	1000x1170 (x4) pixels CMOS	1372x1300 pixels CCD
Spatial resolution	4.5 km at Nadir (variable within the FOV; about 8 km over Europe)	8 km (nearly constant; 14 km at FOV edge)
Coverage	84% of the GEO disk (up to 80 degrees North)	Up to 52 degrees North
Spectral band	777.4 nm with 1.9 nm bandwidth	777.4 nm with 1 nm bandwidth
Integration time (processing rate)	1 ms (1 kHz)	2 ms
On-board processing	Lightning detection and data filtering	Lightning detection
Bandwidth	30 Mbps	7.7 Mbps
Latency (timeliness)	1 min	20 sec
Detection efficiency	70-90% flash detection efficiency (expected)	70-90% flash detection efficiency

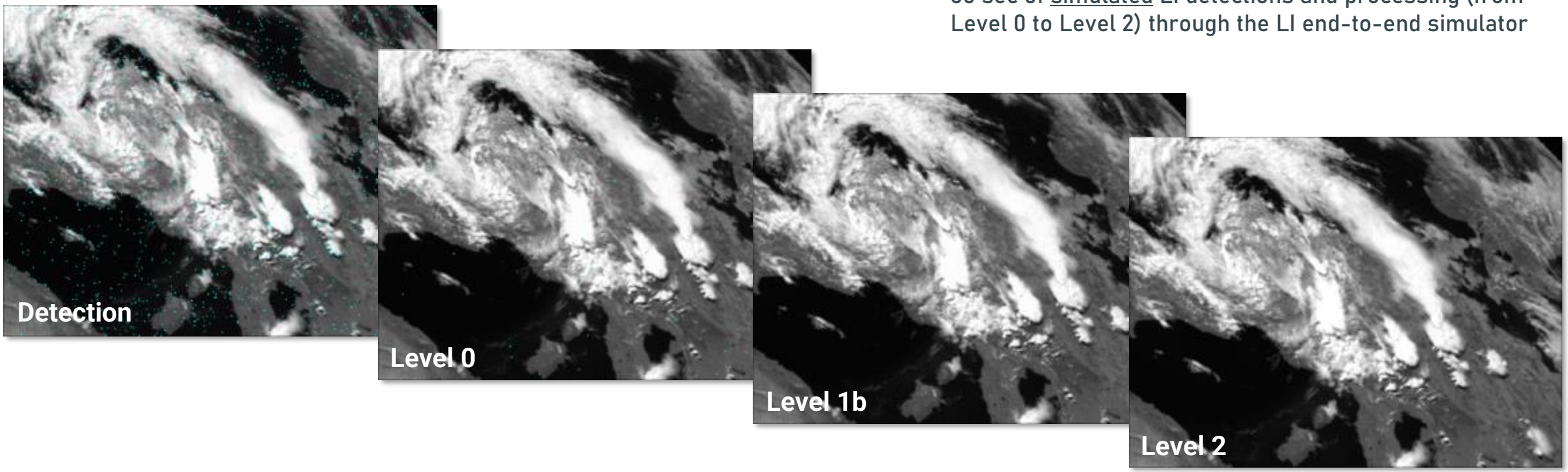
*LI is manufactured by Leonardo (Italy) under the industrial prime contractor Thales Alenia Space (France) as part of the ESA lead MTG space segment development



FOV of GLM on GOES-16 (blue) and FOV of the four cameras of LI (west in yellow, north in green, east in purple, and south in brown, respectively)

LI processing

30 sec of simulated LI detections and processing (from Level 0 to Level 2) through the LI end-to-end simulator



- LI will be operated to send to the ground as many Detected Transients (DTs) as possible (with limits imposed by the downlink-bandwidth). Two processing steps take place on-board: detection + Level 0 filtering (Single-Detection Filter + Micro-Vibration Filter)
- The ground processing (Level 1b+Level 2) will classify as false the remaining false DTs and define the disseminated products
- EUMETSAT will have the possibility of accessing and monitoring all levels of processing

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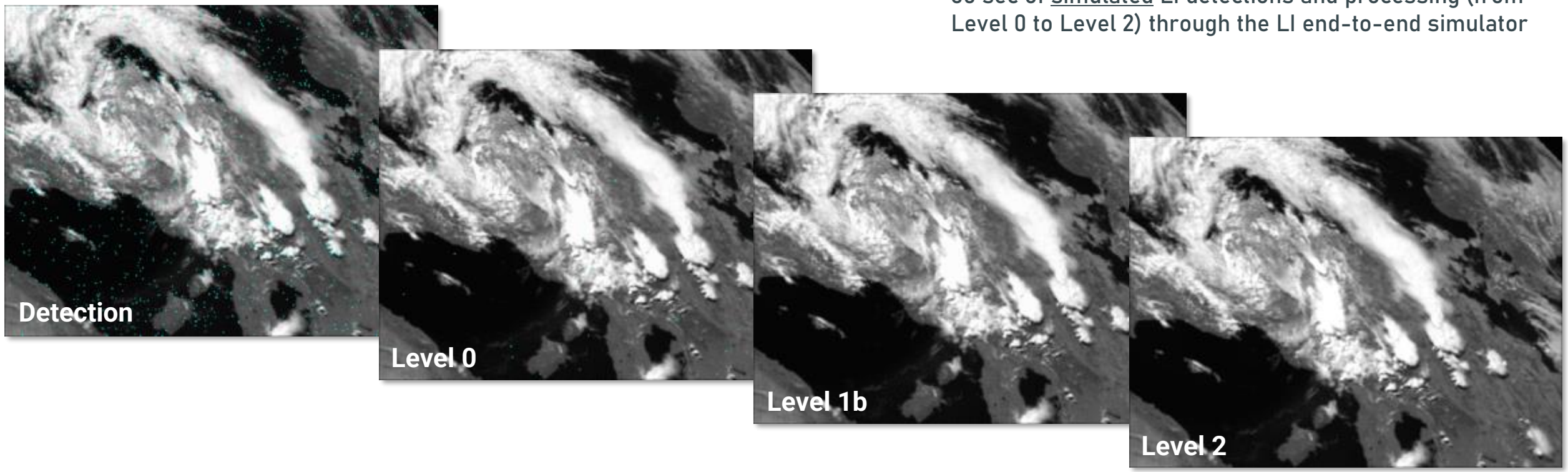
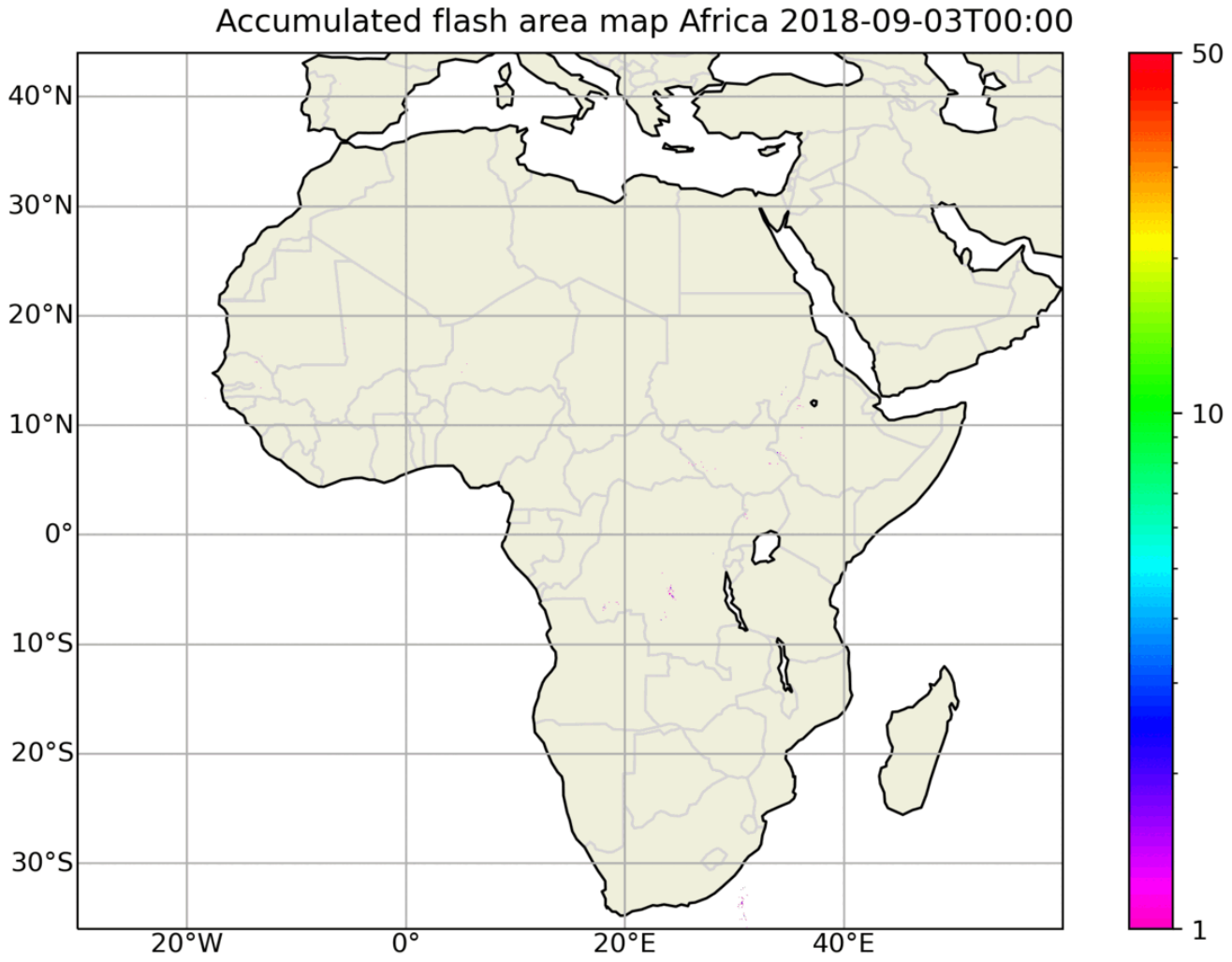


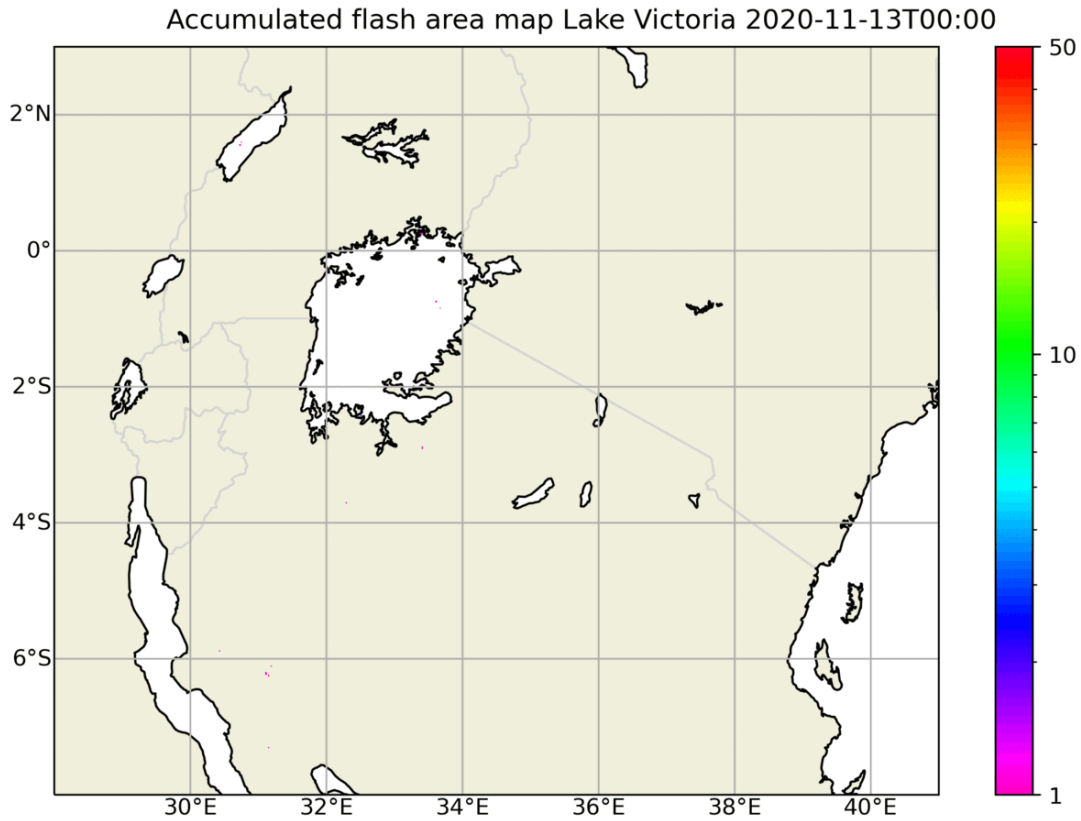
The balance between Detection Efficiency (DE) and False Alarm Rate (FAR) quantifies the performances of the LI System:

- The DE quantifies the capability of the system of detecting optical pulses (purple pixels) as DTs and retaining this information at the end-to-end processing (orange pixels).
- The FAR quantifies the amount of false detections through the LI end-to-end processing. FAR is high at Level 0 and low at Level 2.

The FAR represents the amount of false detections one can live with in order to have a high enough DE.

LI products for lightning monitoring





Example of LI Level 2 product simulated by means of GLD360 data:
about 24h of accumulated Level 2 flash area (LI-2-AFA) over Africa (left) with the detail over Lake Victoria (right)

LI processing

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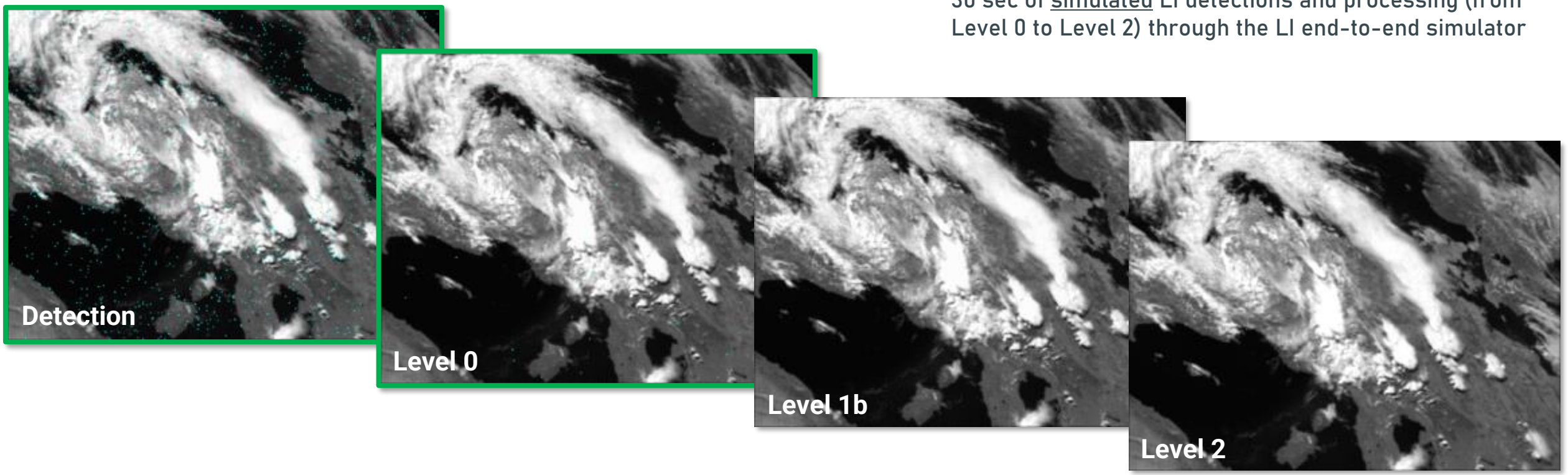

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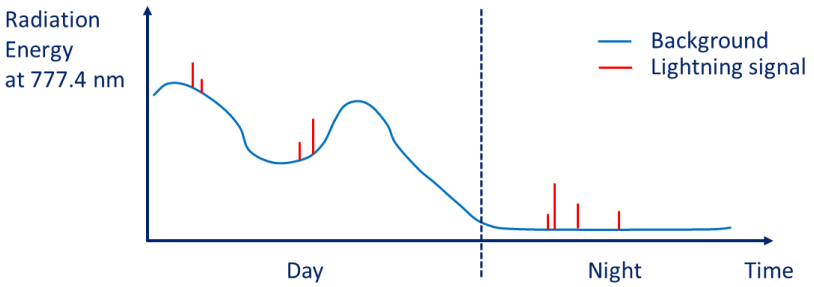
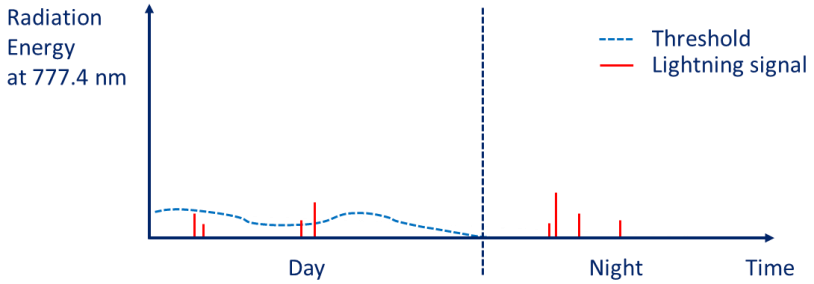
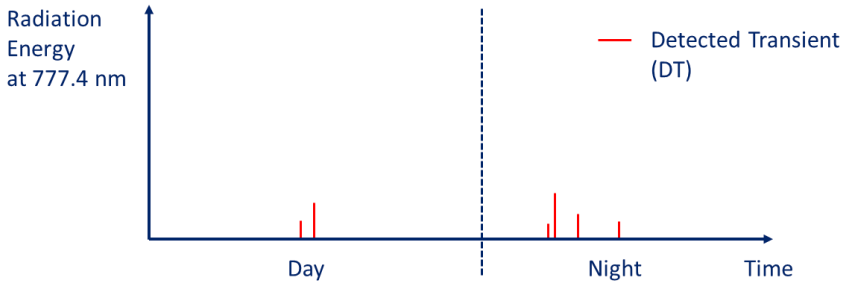
LI processing – detection



Typical pixel signal over 24h



Background removal and detection threshold computation over 24h



Detection (ideal case)

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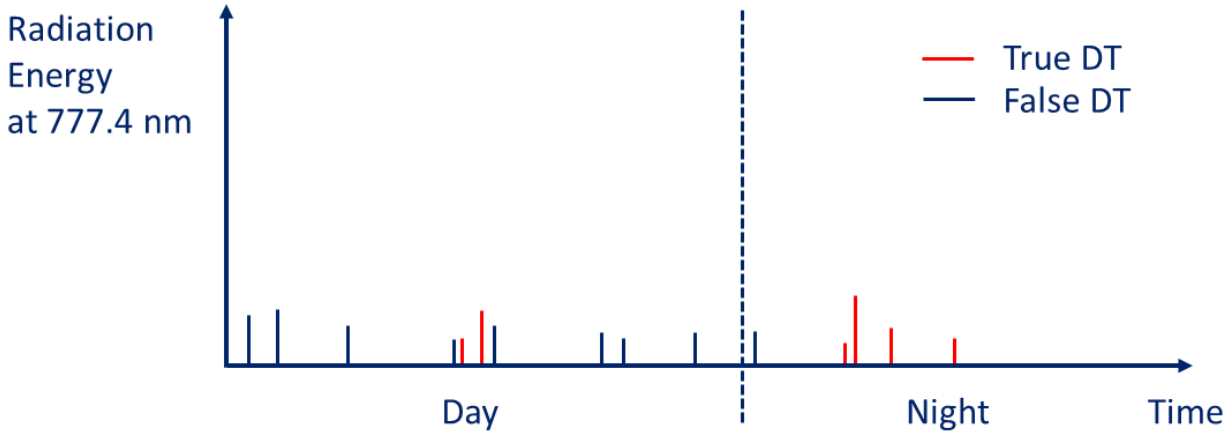
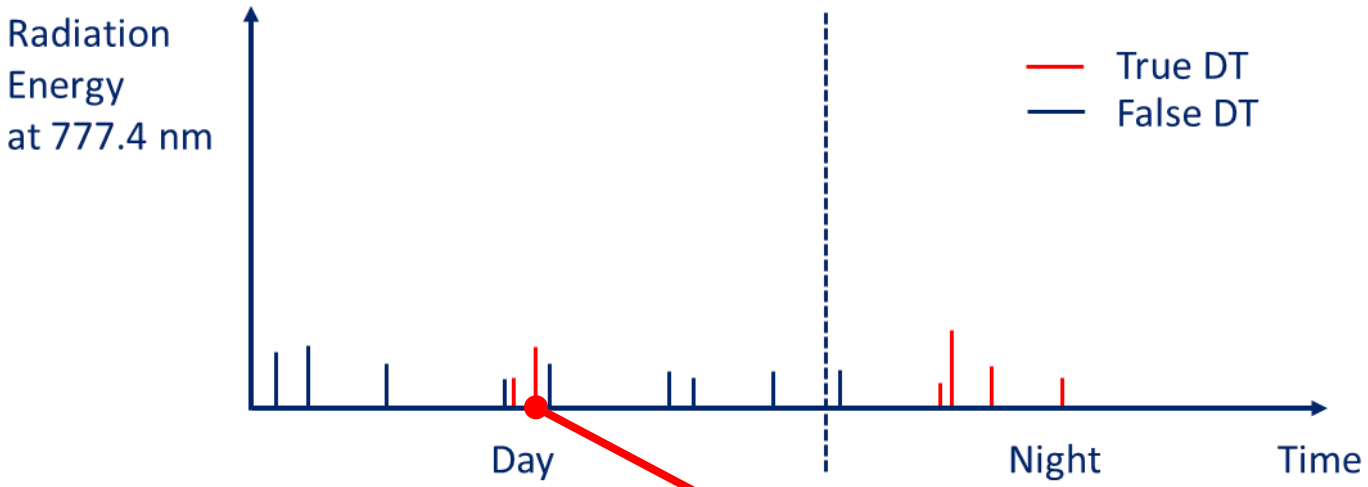


Detection (real case)

Sources of false DTs:

- radiometric noise;
- micro-vibration of the platform;
- particle impacts on the focal plane;
- Sun glint;
- …

LI processing – detection



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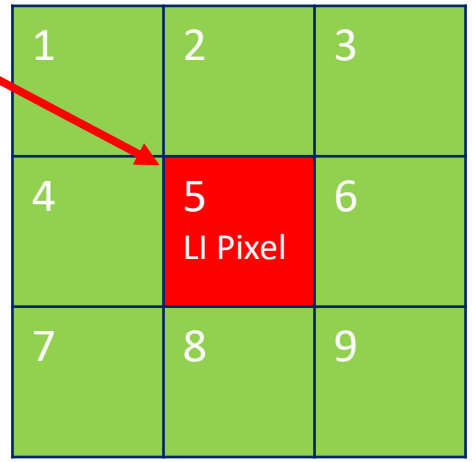
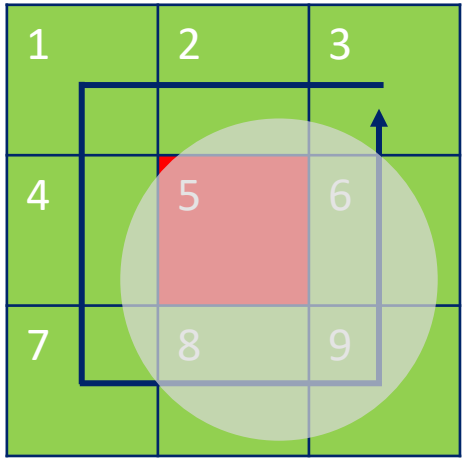


For each DT the following info is available:

1. 3x3 window with measurement
2. 3x3 window with the estimated background measurement
3. location in space (lat/lon) and time

LI processing – on-board processing

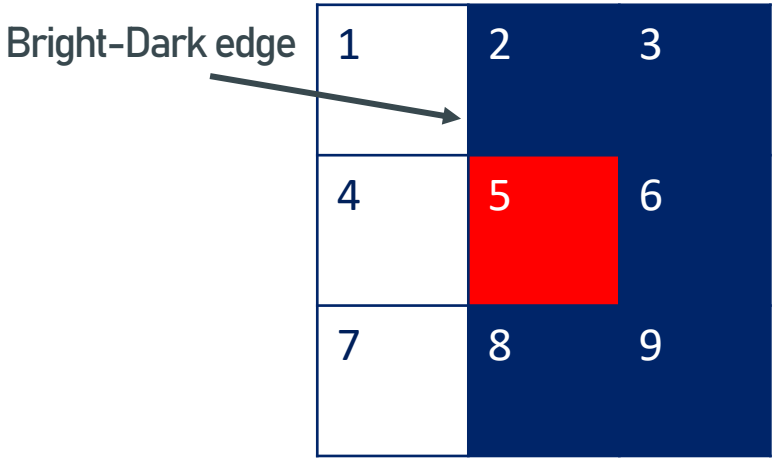
Single Detection (DT) Filter (SDTF)



Single Detection (DT) Filter (SDTF): checks the content of the 8 neighbors.

$$\sum_{p=1,9\ p\neq 5} (\mathrm{DT}_p - \mathrm{Bkg_p}) > \mathrm{LUT_{SDTF}}\left(\frac{\sum_{p=1,9\ p\neq 5} \mathrm{Bkg_p}}{8}\right)$$

Micro Vibration Filter (MVF)



Micro Vibration Filter (MVF): checks the background gradient.

$$\mathrm{Sobel_{Bkg}} = \sqrt{\mathrm{Sobel_x}^2 + \mathrm{Sobel_y}^2}$$

$$\mathrm{S_x} = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}, \quad \mathrm{S_y} = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

$$\mathrm{Sobel_{Bkg}} > \mathrm{Thld_{MVF}}\left[\sum_{p=1,9} (\mathrm{DT}_p - \mathrm{Bkg_p})\right]$$

LI products for fireball detection

The LI-1B-LE is the best product for the detection of fireballs in LI measurements

1. Despite being the Level 1b product, LI-1B-LE contains the complete set of Level 0 DTs. This stems from the fact that the LI Level 1b processing does not remove DTs when classified as false, it flags them. Fireballs are false DTs and the FAR is the highest at Level 0.

2. In LI-1B-LE, DTs are calibrated and navigated.

3. DTs in LI-1B-LE are characterized by a set of Level 1b filtering flags that can be employed as supplementary information in the process of spotting fireballs.

Possible processing approach

The LI Science Team is currently developing the LI STAtistical and Reporting (LI-STAR) tool which will be employed systematically for the monitoring of LI.

LI-STAR processes systematically LI-1B-LE products in an automated fashion.

Based on a similar approach, one could run an algorithm for the detection of fireballs that, for example, could extract continuously fireball candidates (in a dedicated "fireball product") to be examined off-line by more refined tools.

The detection could work by accumulating Level 0 measurements over a rolling time window to spot elongated features.

- Note: particle impacts on the focal plane are known to produce similar signature

On the expected detection capabilities

Slide on the outcome of the pre-flight performance assessment of LI in comparison to GLM

The LI detection threshold is expected to be in line with GLM's

Session	Level 2 FDE	Level 2 FFAR	Level 2 det. thld.
Day	0.56 ± 0.18	6 ± 4 1/(sec OC)	≈ 15 µJ / (sr m^2)
Night	0.88 ± 0.10	0 ± 0 1/(sec OC)	≈ 4 µJ / (sr m^2)
Terminator	0.69 ± 0.19	4 ± 3 1/(sec OC)	≈ 6.5 µJ / (sr m^2)

a. **The simulated lightning detection performances of LI are characterized by a strong variability**
b. **The FDE varies from about 0.3 to 0.98, for a FFAR that can be as high as 24 flashes per second (there is margin for improvement)**
c. **The detection threshold varies in [4, 15] µJ / (sr m^2)**

GLM performances against FEGS over the US and for 6am – 6pm local times (link to the reference):

- Strong storm-by-storm variability
- When selecting similar illumination conditions, the LI FDE over the whole LI FOV (59% average) is comparable with the GLM FDE over the US (61% average)
- The GLM detection threshold is 10 µJ / (sr m^2) (Dr Mason Quick private communication)

Conclusion

- LI will be launched in December 2022 on-board the MTG-I1 satellite.
- LI is expected to detect fireballs from bolides entering the atmosphere.
- LI expected lightning detection capabilities are in line with GLM's. From this, one can assume that fireball detection capabilities should be in line too.
- LI-1B-LE product is ideal for performing fireball detection since it contains Level 0 information that is also navigated and calibrated.
- The LI Science Team will consider the possibility of running an automatic fireball detection software.

Thank you!

Questions are welcome.