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Meteosat Third Generation Lightning Imager Level 2 expected performances

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LI MAG meeting on RfDs, June 24, 2020

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Outline

- Introduction
- LI Reference Processor
- Analysis assumptions and inputs
- Results
- Conclusions and future work

Introduction

- EUMETSAT is responsible for the design and development of the Level 2 processing

- The assessment of the pre-flight (expected) lightning detection performances of LI is a key topic:
  1. For the communication to the users (LI MAG forum)
  2. For the testing and tuning of the Level 2 processor
  3. For the development of the Detection Efficiency map aimed at facilitating the future use of LI Level 2 products
  4. To understand where LI will stand performance-wise against GLM and LIS

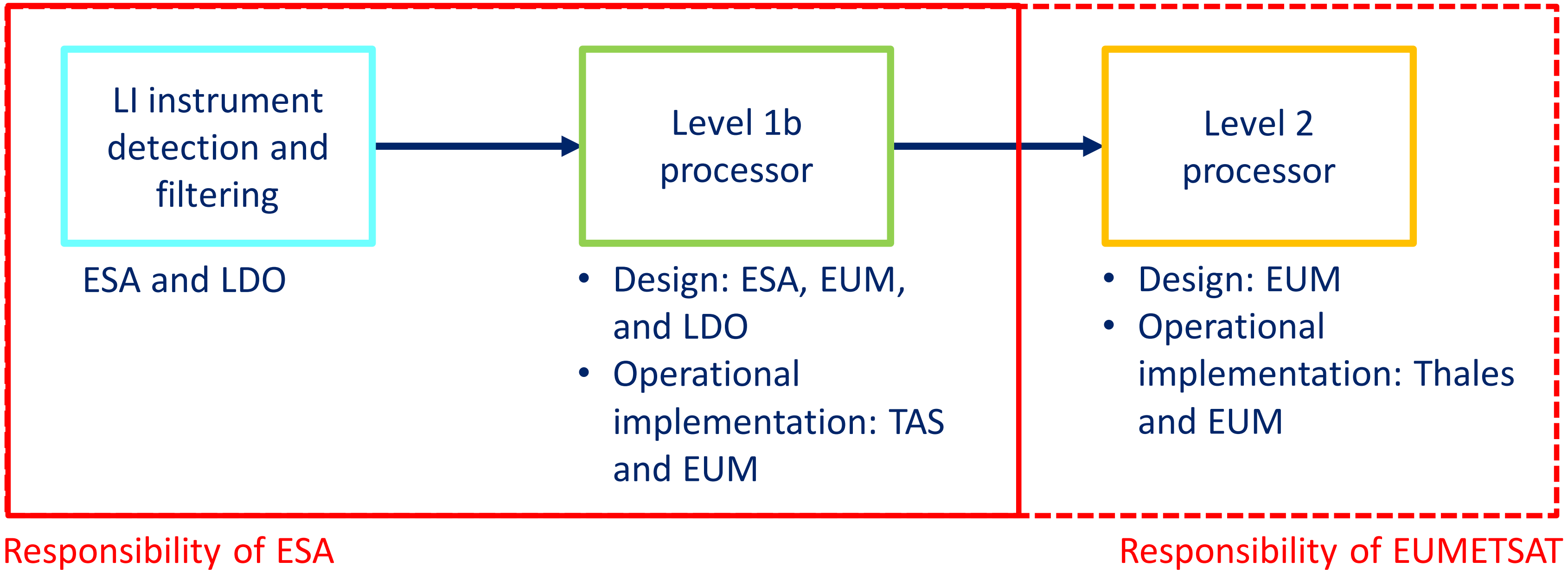
- EUM: EUMETSAT
- ESA: European Space Agency
- LDO: Leonardo
- TAS: Thales Alenia Space

LI instrument detection and filtering: ESA and LDO

Level 1b processor:
- Design: ESA, EUM, and LDO
- Operational implementation: TAS and EUM

Level 2 processor:
- Design: EUM
- Operational implementation: Thales and EUM

Introduction



- Level 1b performances have an impact on Level 2 performances

- Presentation from ESA (up to Level 1b):
  1. RfD on the IADP will be withdrawn, however the assessment of the Level 2 performance must be done
  2. RfD on the ASPKE will evolve (improvements are expected)
  3. RfD on the Sun-exclusion zone will evolve → impact on Radiometric Performances and Level 1b IADP

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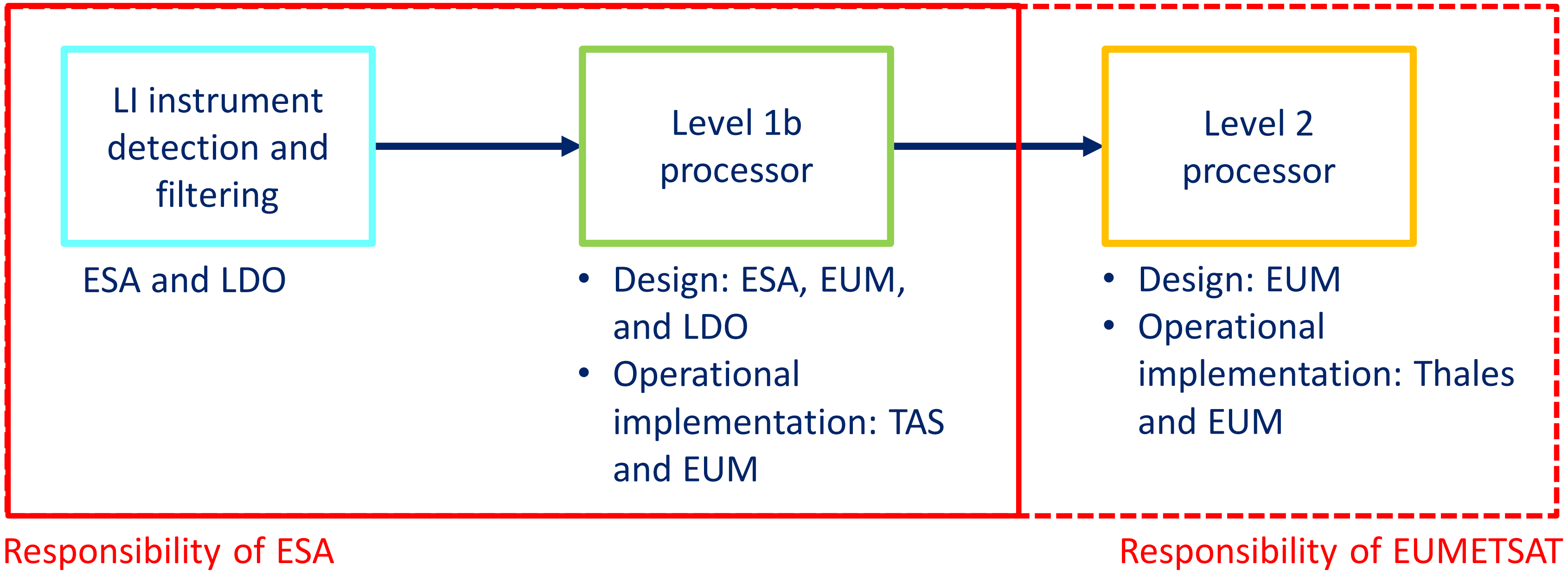
Introduction



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LI Reference Processor

LI instrument detection and filtering → Level 1b processor → Level 2 processor

LI instrument detection and filtering

ESA and LDO

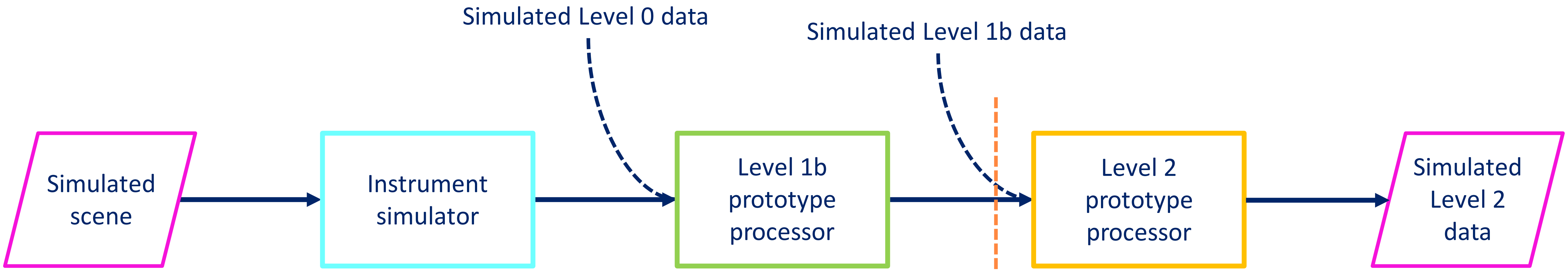
Level 1b processor

- Design: ESA, EUM, and LDO
- Operational implementation: TAS and EUM

Level 2 processor

- Design: EUM
- Operational implementation: Thales and EUM

LI Reference Processor



Inputs:
- Modified SEVIRI VIS0.8 background
- Simulated optical pulses

- Observation geometry
- Micro-Vibration
- Radiometric detection including noise
- Real Time Pixel Processor (RTPP) detection
- Single detection filter (SDT)
- Micro-Vibration filter (MVF)

- Level 1b background radiometric processing
- Level 1b DT radiometric processing
- Level 1b DT on-ground filtering:
  I. pre-processor (sanity checks)
  II. jitter reconstruction filter
  III. spatio-temporal coherency filter
  IV. hybrid filter

- DT acceptance for Level2 processing
- Group computation
- Group filtering
- Flash computation
- Flash filtering
- Definition of the Level 2 products

from this step on DTs are organized in **groups** and **flashes**

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LI Reference Processor

1.

Simulated scene

EUMETSAT developed a brand new approach for defining the input pulses following the guidelines from LI MAG meeting #9, and with great help of Dr B. Koshak, Dr M. Quick and Prof K. Cummins

Simulated Level 0 data

Simulated Level 1b data

Instrument simulator

- Observation geometry
- Micro-Vibration
- Radiometric detection including noise
- Real Time Pixel Processor (RTPP) detection
- Single detection filter (SDT)
- Micro-Vibration filter (MVF)

Level 1b prototype processor

- Level 1b background radiometric processing
- Level 1b DT radiometric processing
- Level 1b DT on-ground filtering:
  I. pre-processor (sanity checks)
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Level 2 prototype processor

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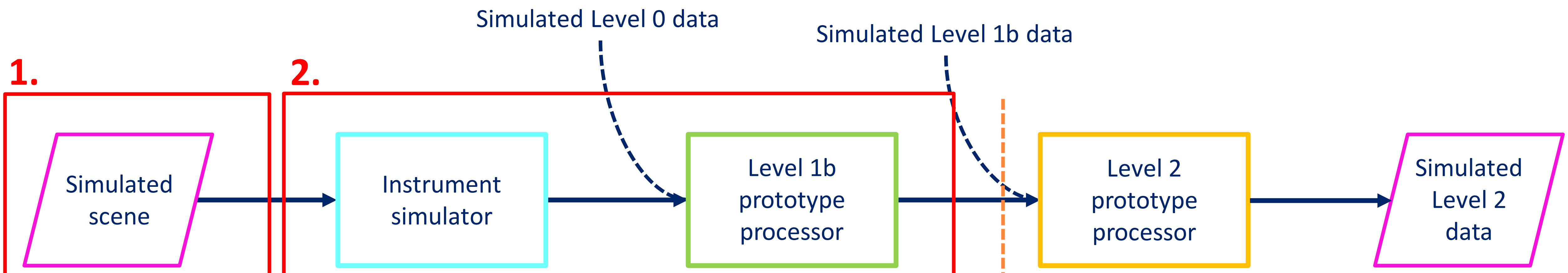
Simulated Level 2 data

LI Reference Processor



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2.

ESA provided EUMETSAT with the latest Level 0 + Level 1b simulator from industry (v2.27). Key features:

- Up-to-date QE maps for each OC
- Up-to-date micro-vibration spectrum
- Up-to-date stray light modelling
- Possibility to switch between BOL and EOL
- Up-to-date on-board detection and filtering settings

EUMETSAT performed the validation of the computation of the IADP against the industry approach.

EUMETSAT is familiarizing with the new functionalities

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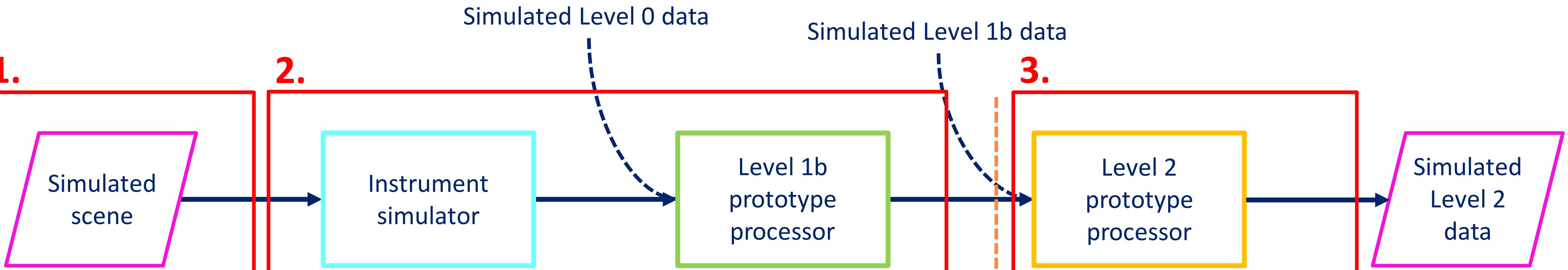
LI Reference Processor



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3.

EUMETSAT performed the integration with the L2 prototype processor (end of May)

Implementation of the performance computation:

1. Level 2 Flash DE
2. Level 2 Flash FAR
3. Level 2 ADP
4. Level 2 detection threshold

Analysis assumptions and inputs

- January 2020, LI MAG meeting #9: session on the review of the input settings for pulse and flash modelling → guidelines on how to improve the modelling towards realistic scenarios (MoM)

- April – May 2020:
  - Meeting with Prof K. Cummins (UA) on the properties of flashes and the role of such properties on the GLM flash DE
  - Meeting with Dr B. Koshak (NASA/MSFC) on the use of LIS data for modelling optical pulses and flashes
  - Multiple meetings with Dr M. Quick (CICS-MD) on the use of FEGS data for modelling optical pulses

The goal of this analysis is to complement the one undertaken by ESA and industry

ESA has shown the compliance of LI when observing engineering pulses, i.e., the pulses that drove the design

EUMETSAT is interested in assessing the Level 2 performances of LI when observing real pulses

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Analysis assumptions and inputs

Pulse property	Settings
Spatial variation	Uniform-radiance disk with size set by the radius. The pulse is “seen” at the focal plane with a smoothed spatial variation due to the convolution with the instrument spatial response and pixel response.
Temporal variation	Maxwell function with normalized integral over the pulse duration and peak reached at 1/3 of the duration → $R = k \cdot P / D$ where R is the pulse Radiance, P is the pulse Peak Radiance, and D is the pulse Duration.
Radiance (R)	From a 2D distribution derived from FEGS observations relating R; also the associated P is derived from the random draws
Duration (D)	Stems from the relation $R = k \cdot P / D$, i.e., D is consistent with the properties of the pulse
Radius	Derived from the LIS distribution of the group size as $r = (16 \cdot \#_{DT} / \pi)^{1/2}$
Location in space and time	Stem from the flash properties

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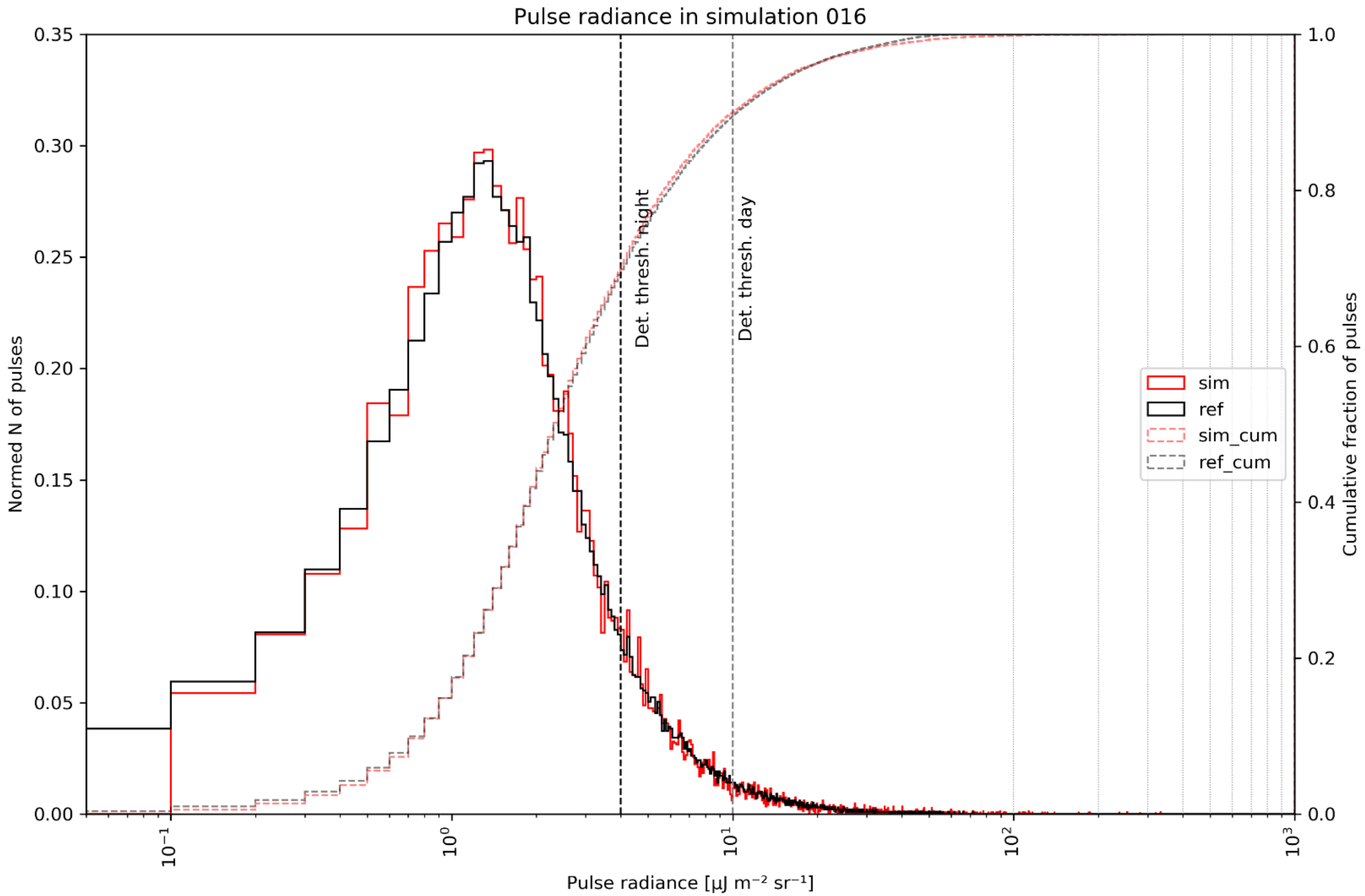
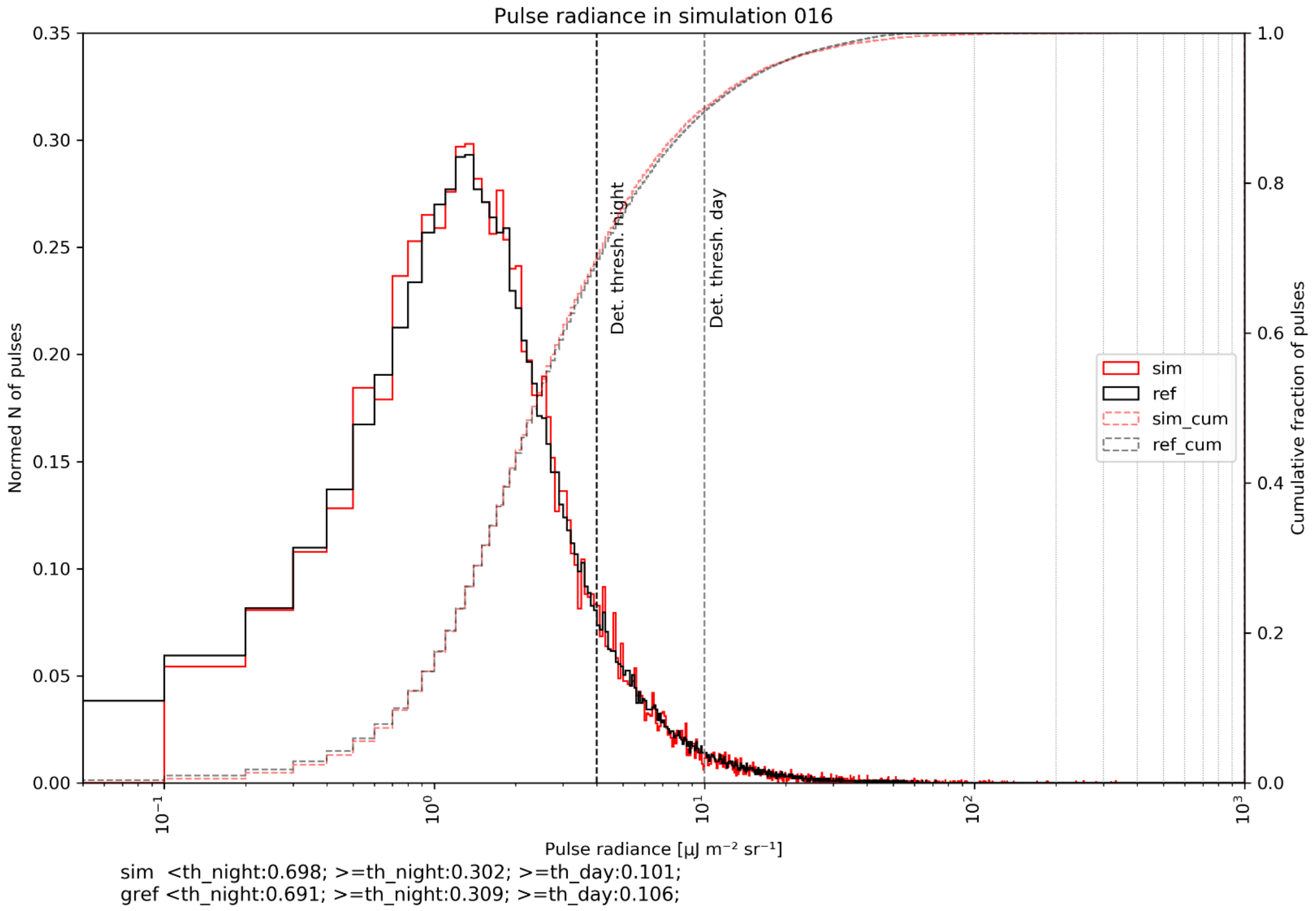
Analysis assumptions and inputs



sim <th_night:0.698; >=th_night:0.302; >=th_day:0.101;
gref <th_night:0.691; >=th_night:0.309; >=th_day:0.106;

The pulse radiance distribution from FEGS

Analysis assumptions and inputs



The pulse radiance distribution from FEGS was compared against the one from LIS:

1. Forced match at the peak of the LIS distribution to check the high-end behaviour
2. Evaluated the mismatch at the low end

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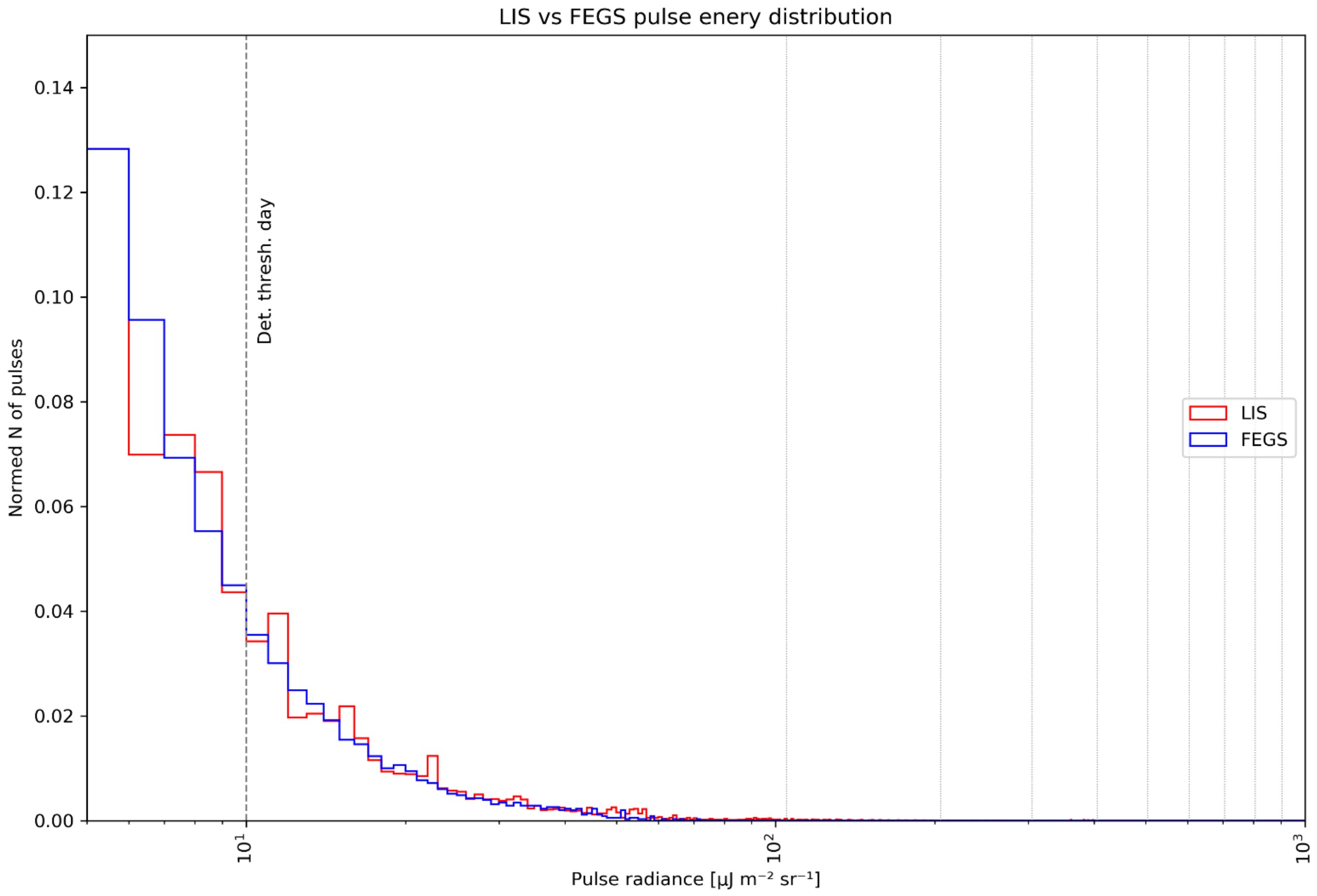
Analysis assumptions and inputs



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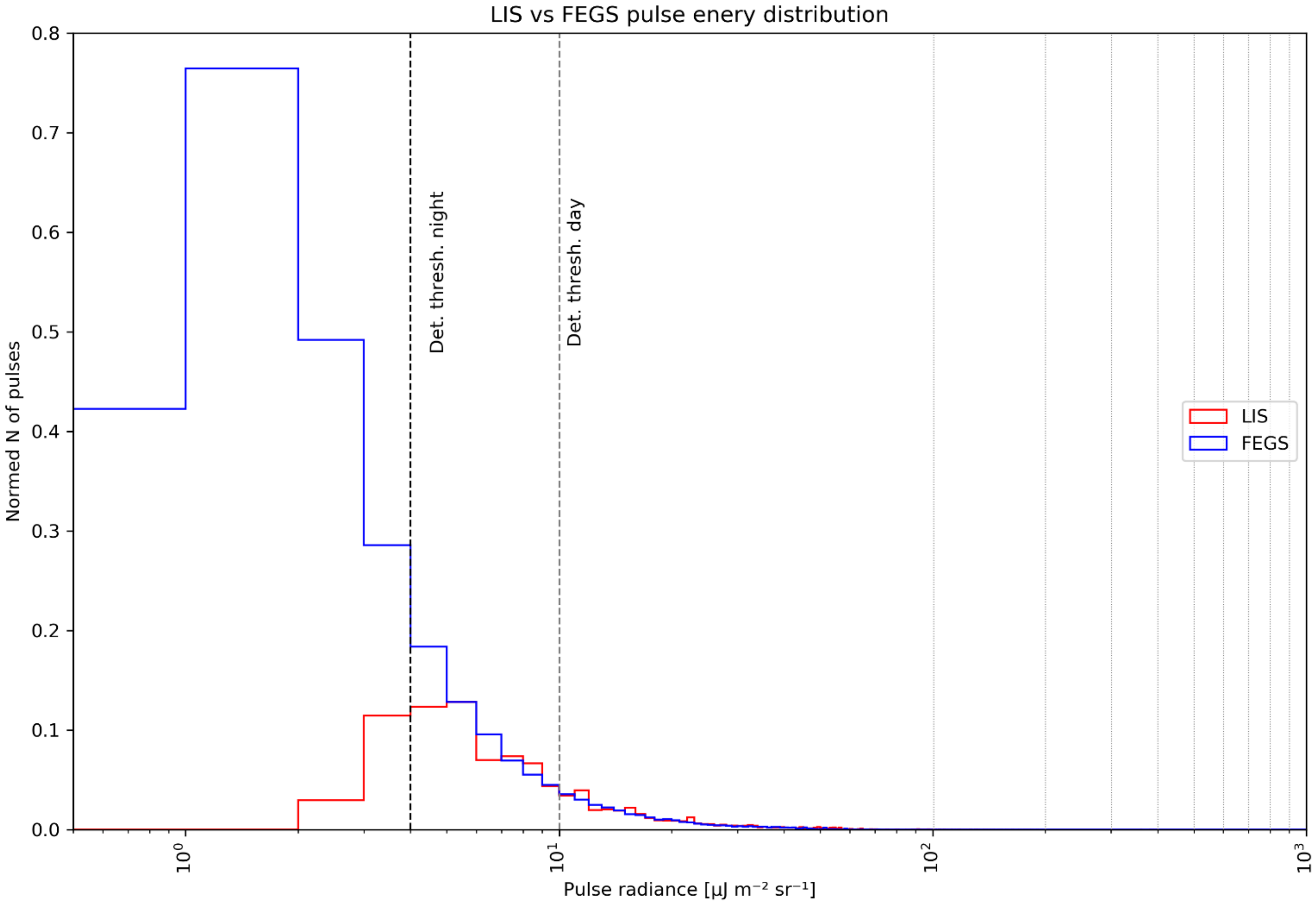

The pulse radiance distribution from FEGS was compared against the one from LIS:

1. Forced match at the peak of the LIS distribution to check the high-end behaviour → **very good match**
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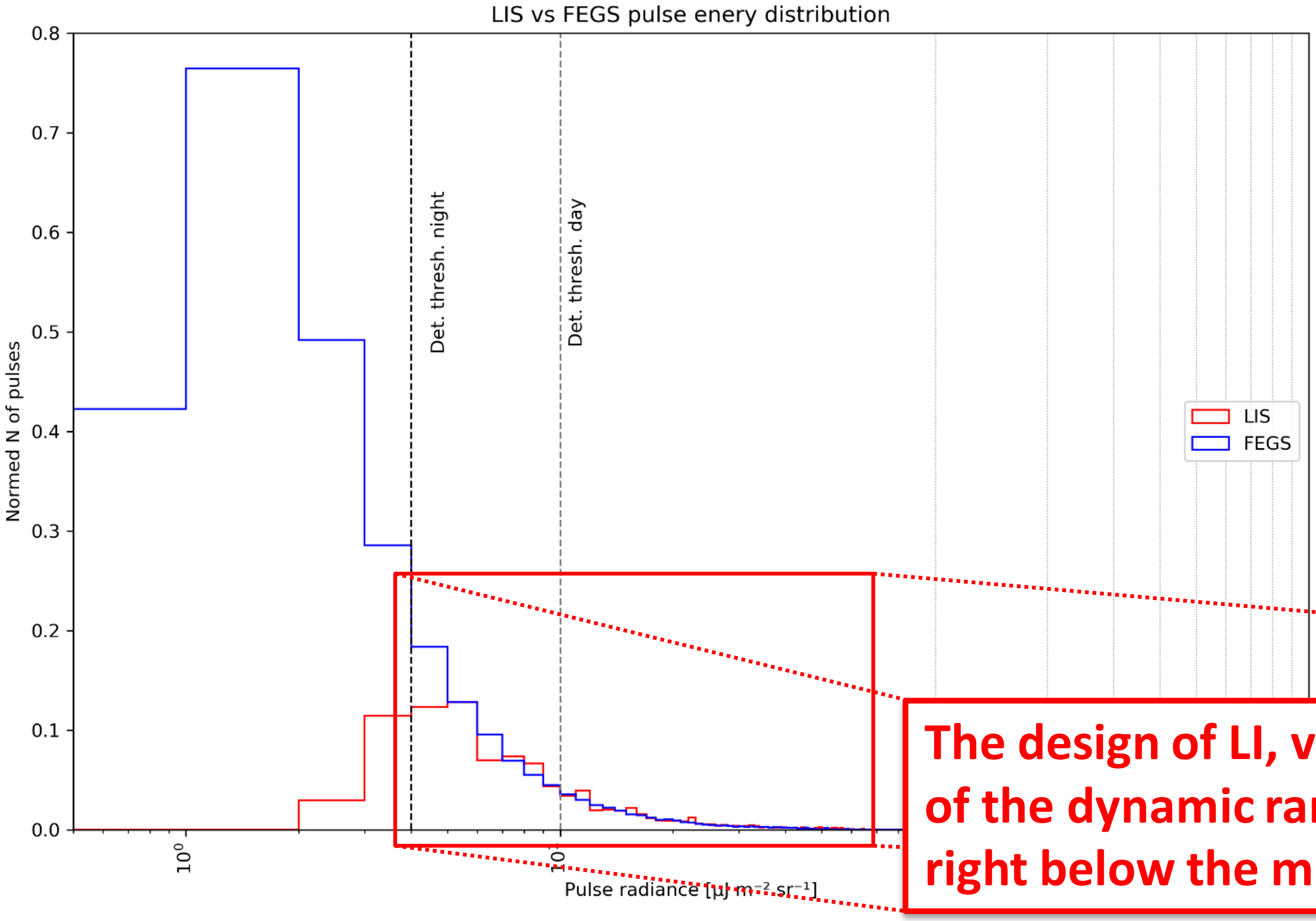
Analysis assumptions and inputs



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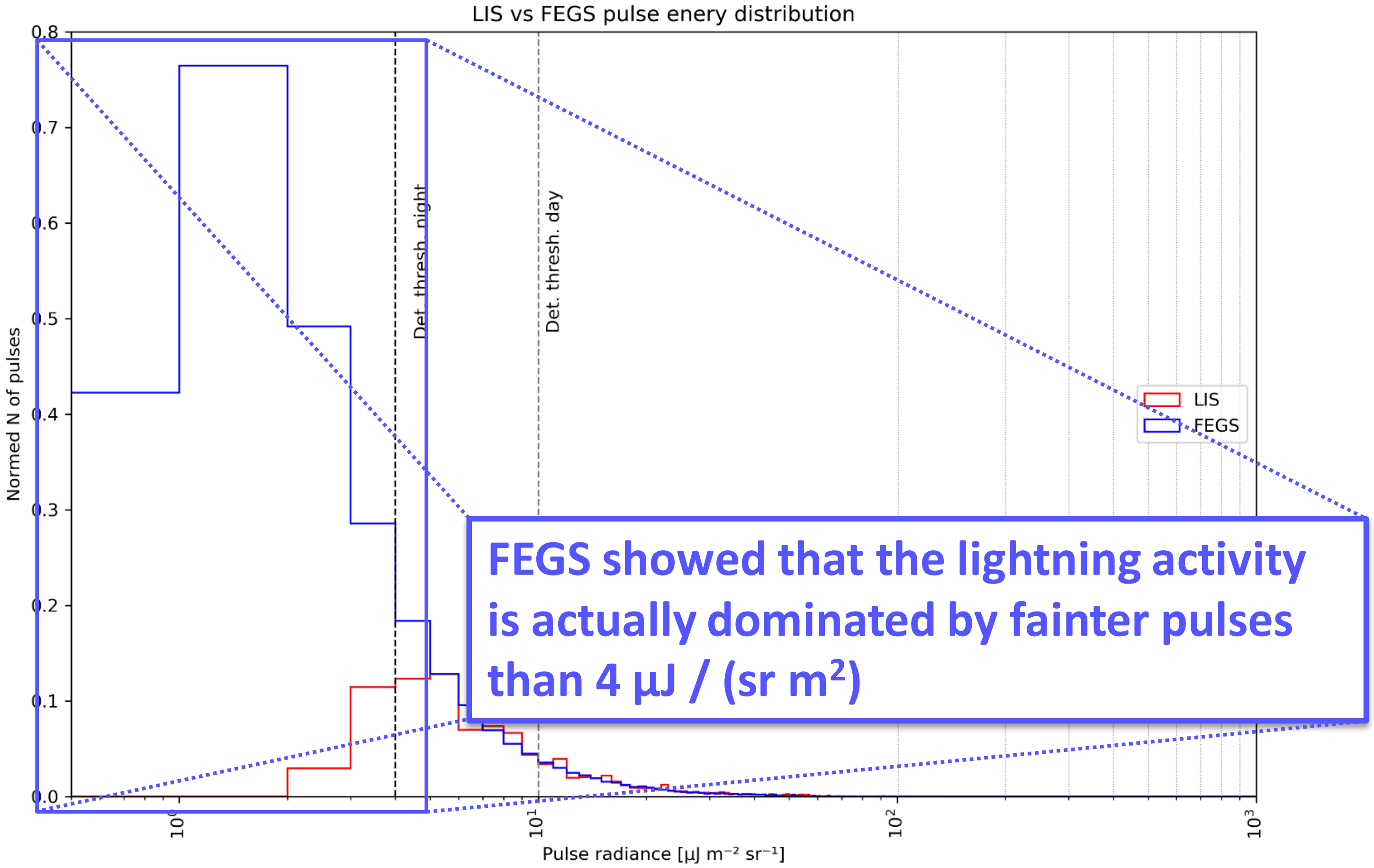
The design of LI, very much inspired by LIS, focuses on this part of the dynamic range → the minimum detectable energy is right below the most probable detected radiance of LIS

Analysis assumptions and inputs



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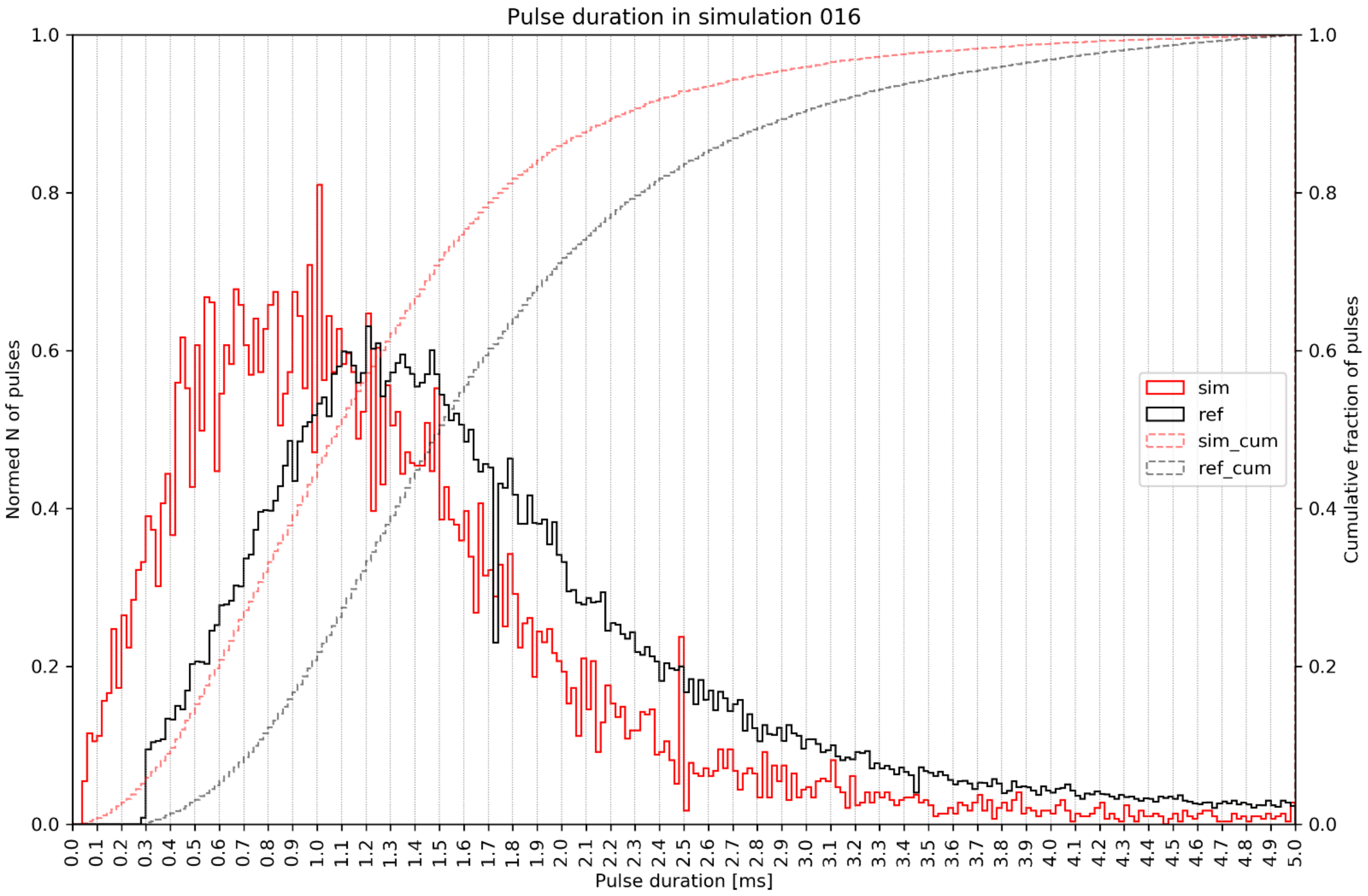

max: 4.980 ms
min: 0.040 ms

The pulse duration distribution is peaked at lower values than the pulse duration distribution derived from the analysis of FEGS pulse profiles

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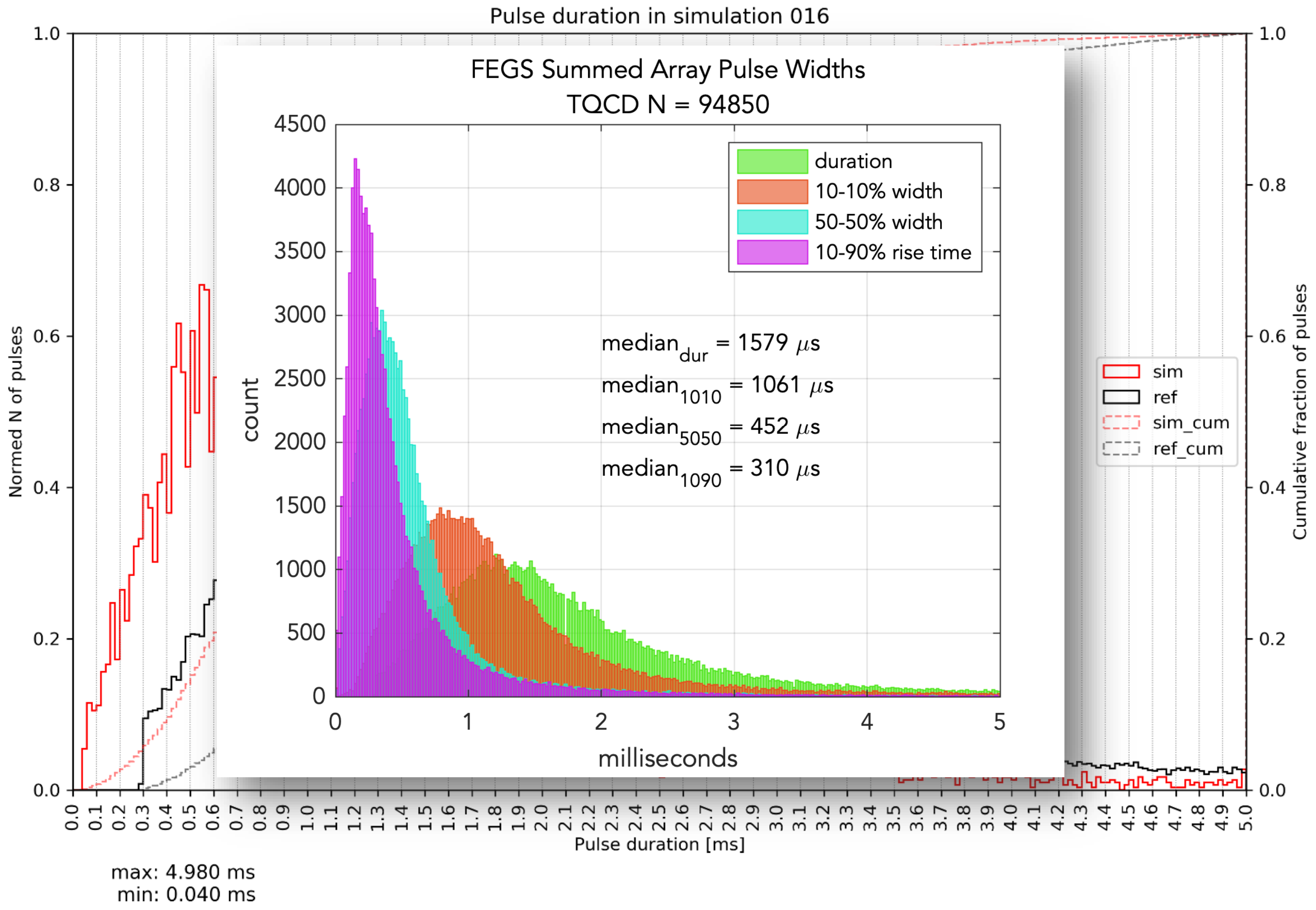
Analysis assumptions and inputs



The pulse duration distribution is peaked at lower values than the pulse duration distribution derived from the analysis of FEGS pulse profiles

Well within the families of pulse duration distributions derived from FEGS (e.g., very close to the 1010 case; Dr M. Quick private communication)

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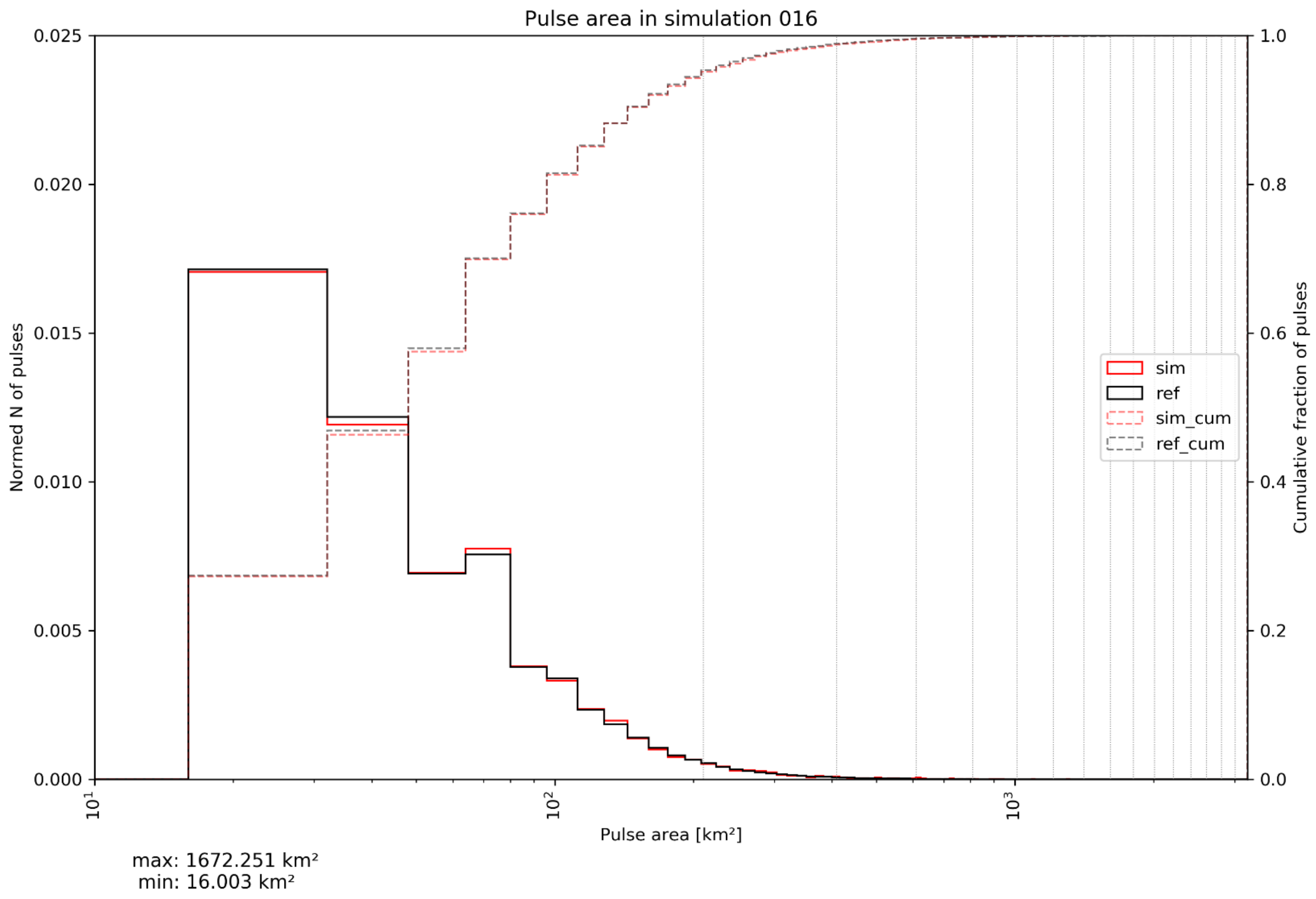
Analysis assumptions and inputs



The pulse area distribution from the distribution of number of events in groups from LIS

Open issue:

1. Most of the pulses smaller than the LIS pixel (link)
2. The typical pulses missed by GLM as derived from FEGS are faint, but not smaller than LIS pixel (link)

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Analysis assumptions and inputs

Flash property	Settings
Location in space	Random within two types of masks: 1. Multi-sensor precipitation rate estimate product 2. Cloud mask product (only for totally dark scenes)
Location in time	All flashes start at the same time, i.e., at frame 1 of the simulation
Number of pulses	From the distribution of number of groups per flash **boosted by a factor 3**
Time difference between pulses	From the distribution of time differences between groups in flashes from LIS data
Location of pulses within the flash	Randomly located around the flash location within the distance from the flash area derived with the Ebro LMA by adopting the convex-hull method; the flash is assumed to be round in shape
Flash duration	Stems from the number of pulses and time difference between pulses; the maximum flash duration is 2 sec

Analysis assumptions and inputs

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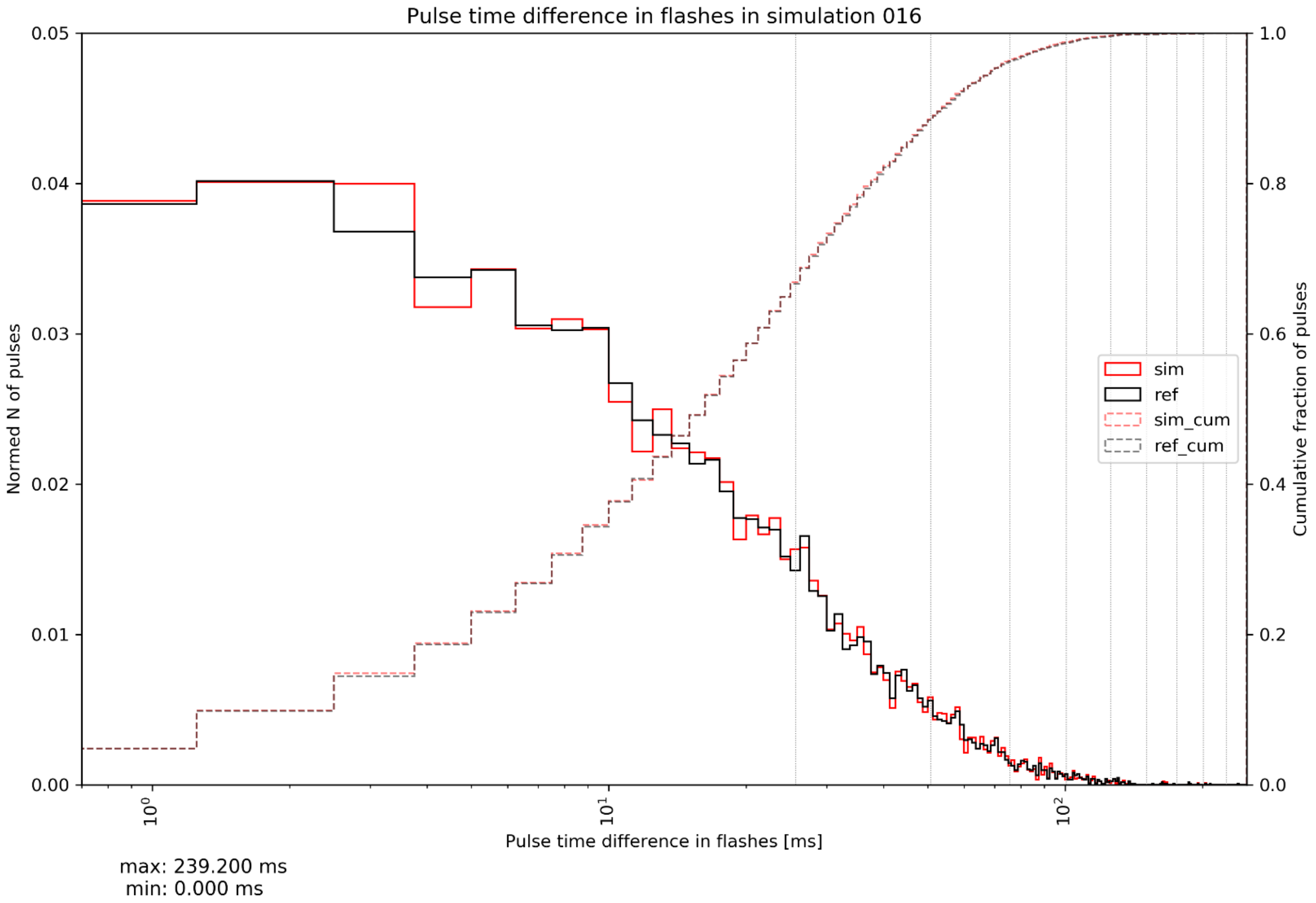
About 30% of the information in LIS statistics is below 5 μJ / (sr m^2)

The boosting factor to the number of pulses is computed as $8 \times 0.3 + 0.7 = 3.1$

Analysis assumptions and inputs



The distribution of the time difference between pulses in flashes is not modified since it is anyway dominated by short intervals

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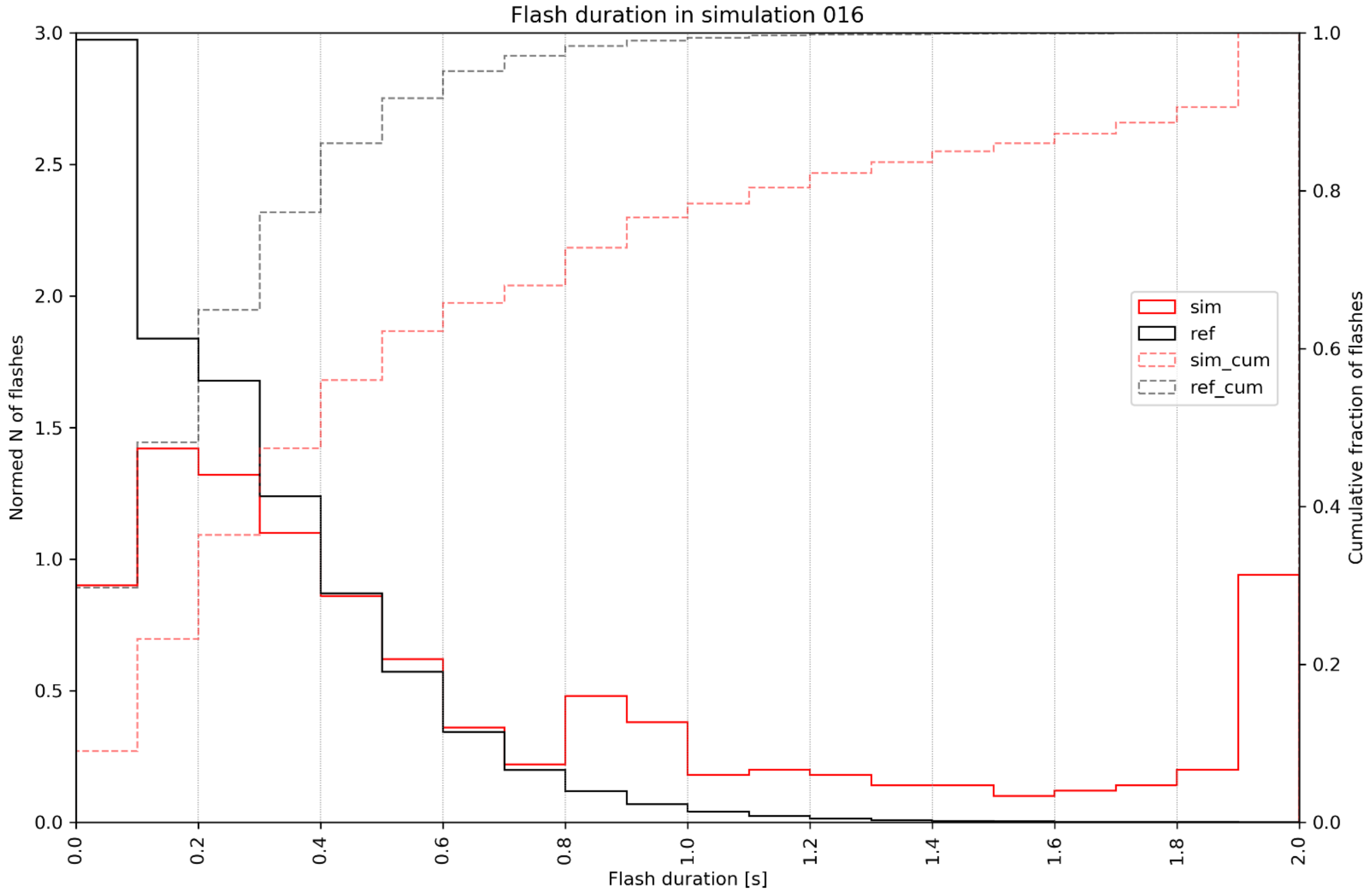
Analysis assumptions and inputs



max: 1.999 s
min: 0.011 s

The distribution of the flash duration is characterized by longer flashes than in the LIS distribution (here ref) with an artificial peak at 2 millisecond

It is known that LIS is underestimating the flash duration as a consequence of its limited sensitivity (see link1 and link2)

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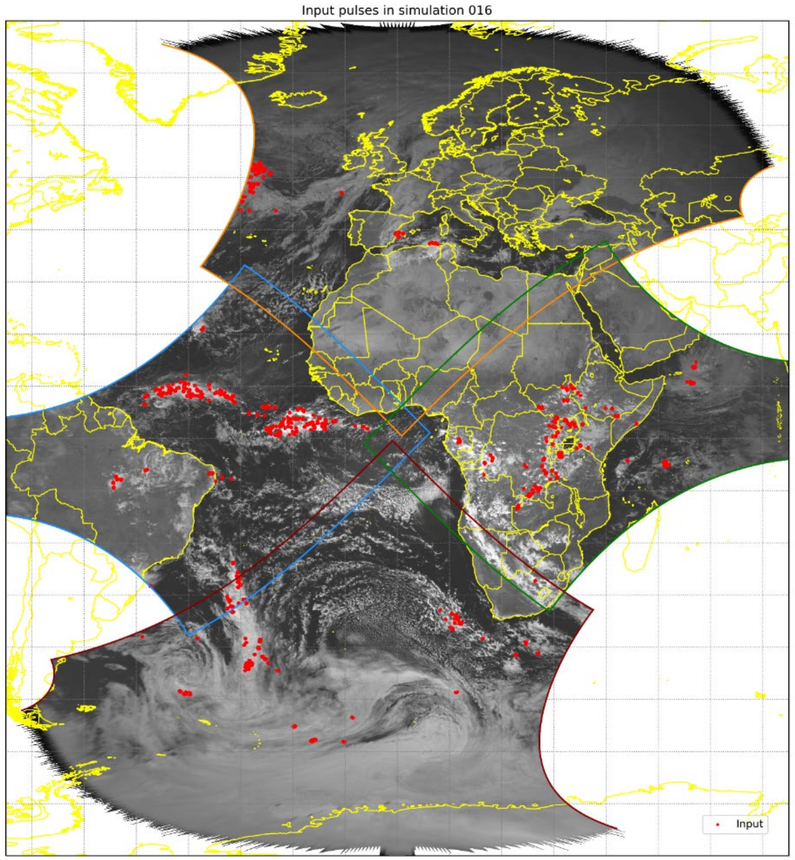
Analysis assumptions and inputs

Session	Settings
ID016 day	201110291212 Flashes located on multi-sensor precipitation rate estimate mask 10 simulation runs Maximum duration 2 sec Total number of flashes: 500 Total number of pulses: about 15000 Standard Level 0 and Level 1b settings for BOL and micro-vibration without the COM component Level 2 settings for the day
ID017 night	201303200012 Flashes located on cloud mask Level 2 settings for the night
ID018 half	201303201812 Flashes located on multi-sensor precipitation rate estimate mask Different Level 2 settings for the different OCs

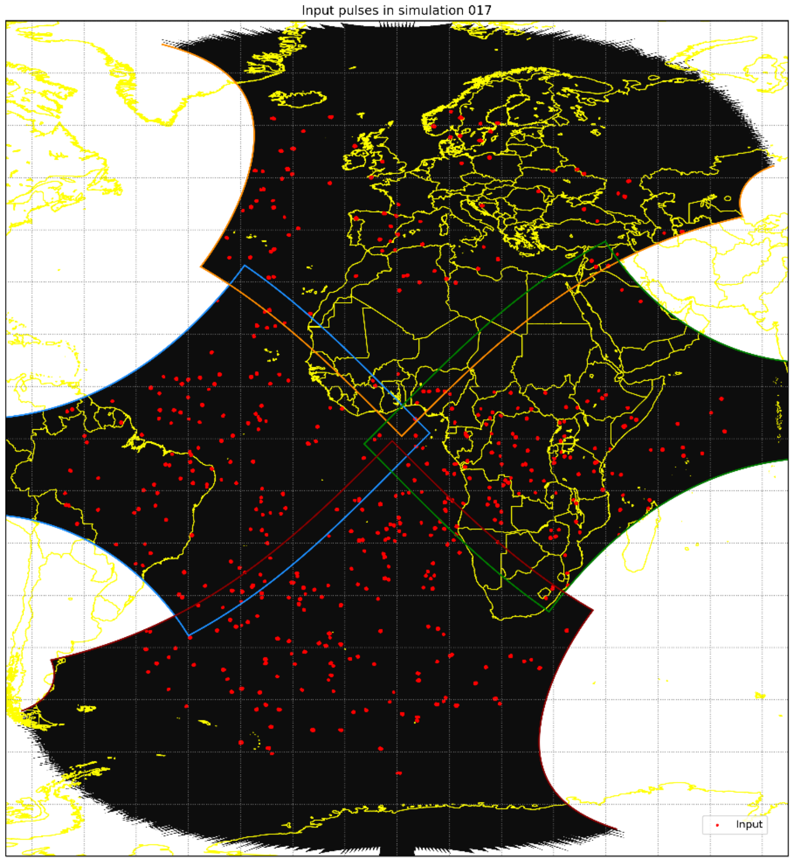
in green the variable settings

Analysis assumptions and inputs



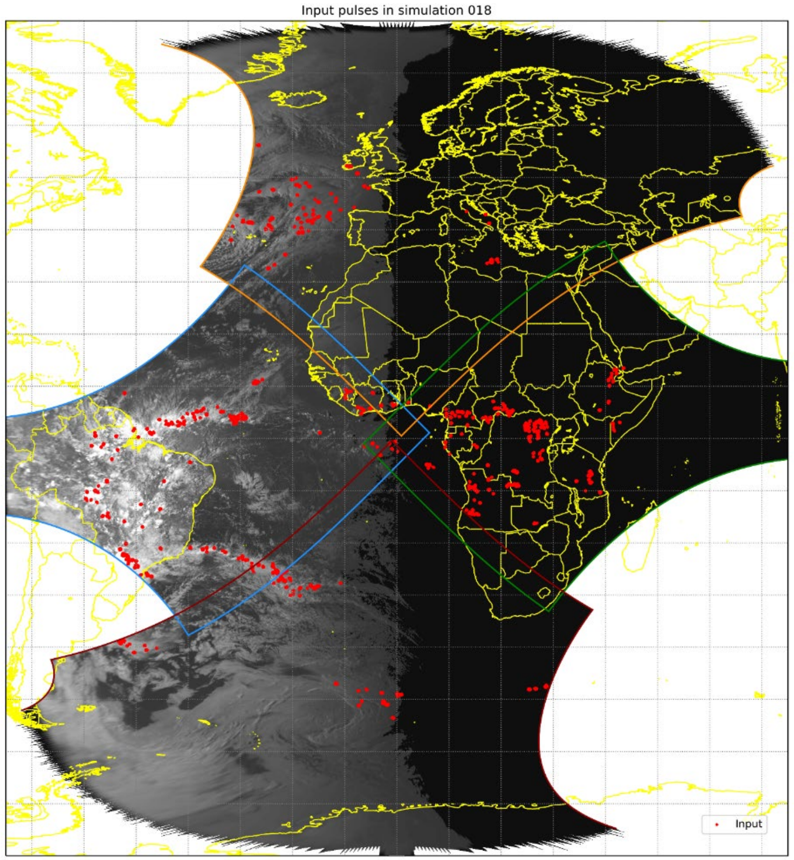
7am 12pm 5:30pm

201110291212



7pm 12am 5:30am

201303200012



1pm 6pm 11:30pm

201303201812

Red dots are input pulses

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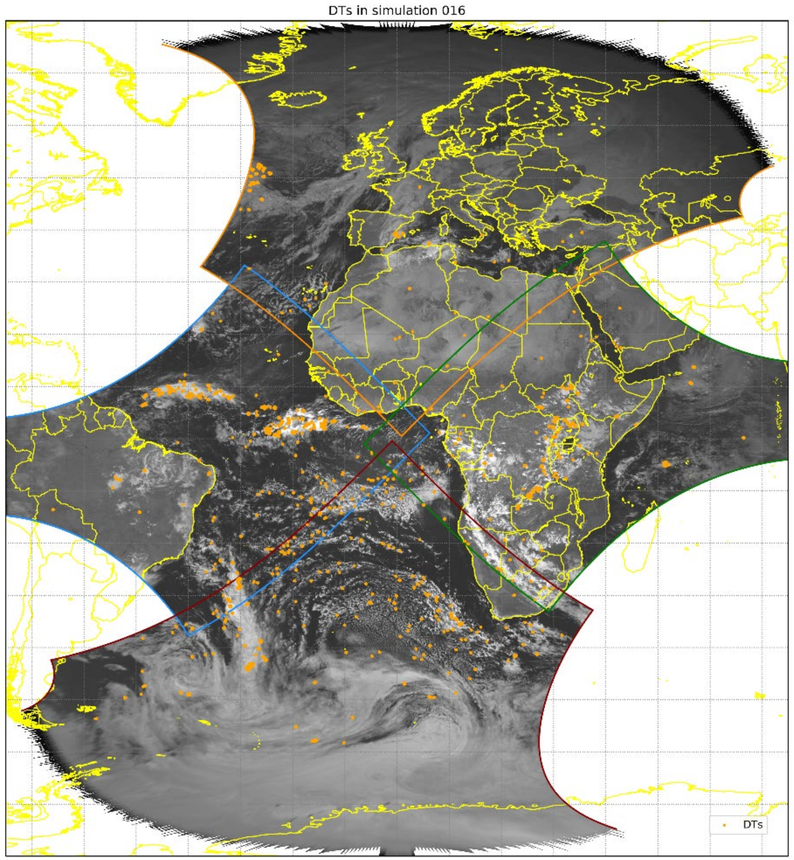
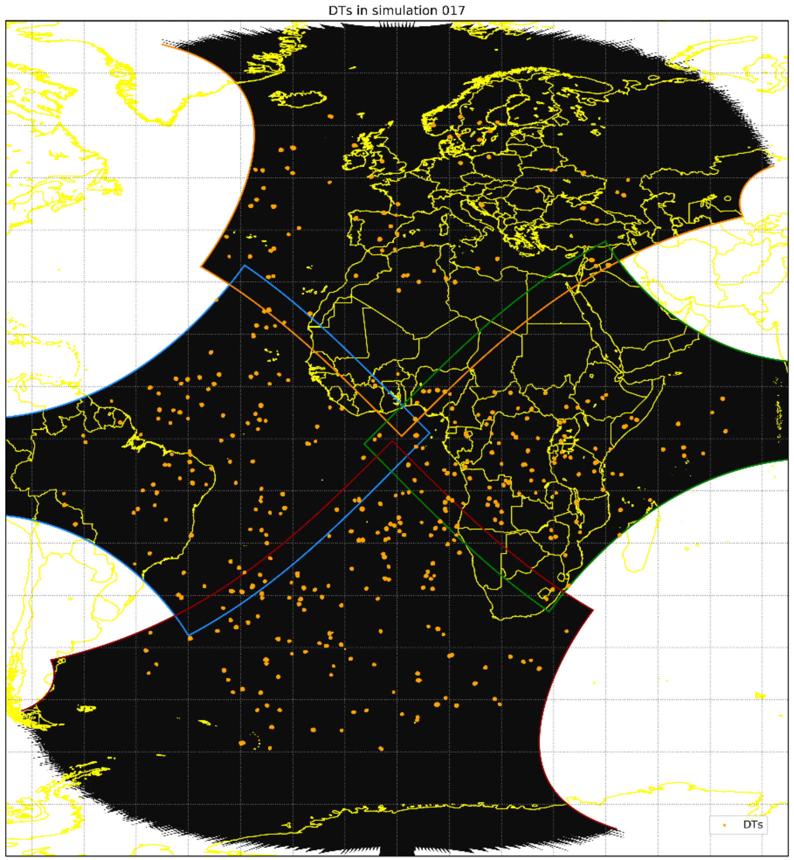
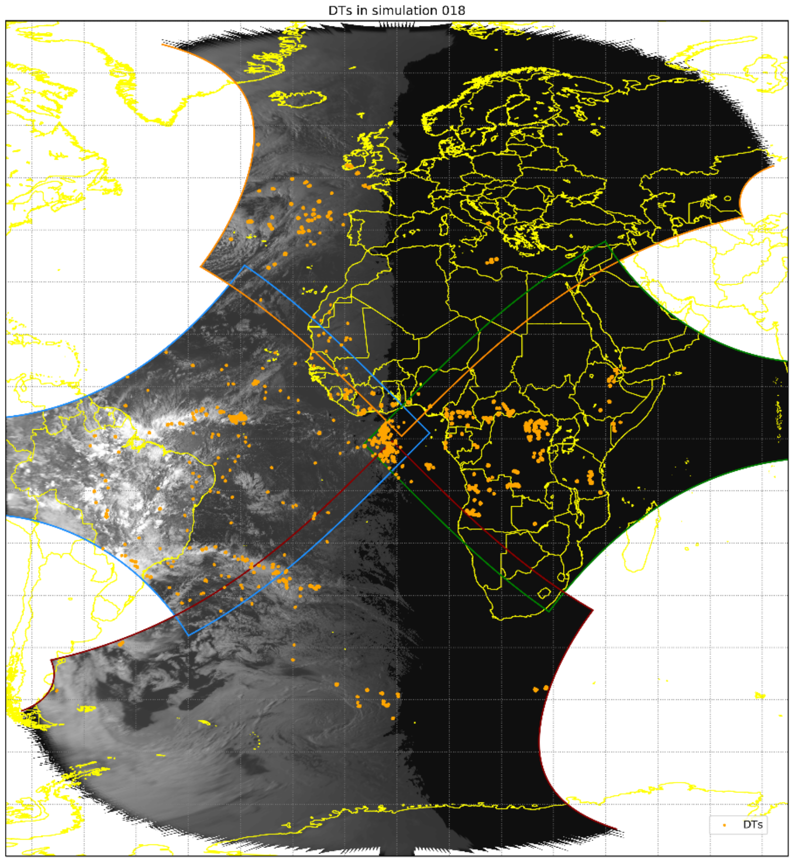
Results

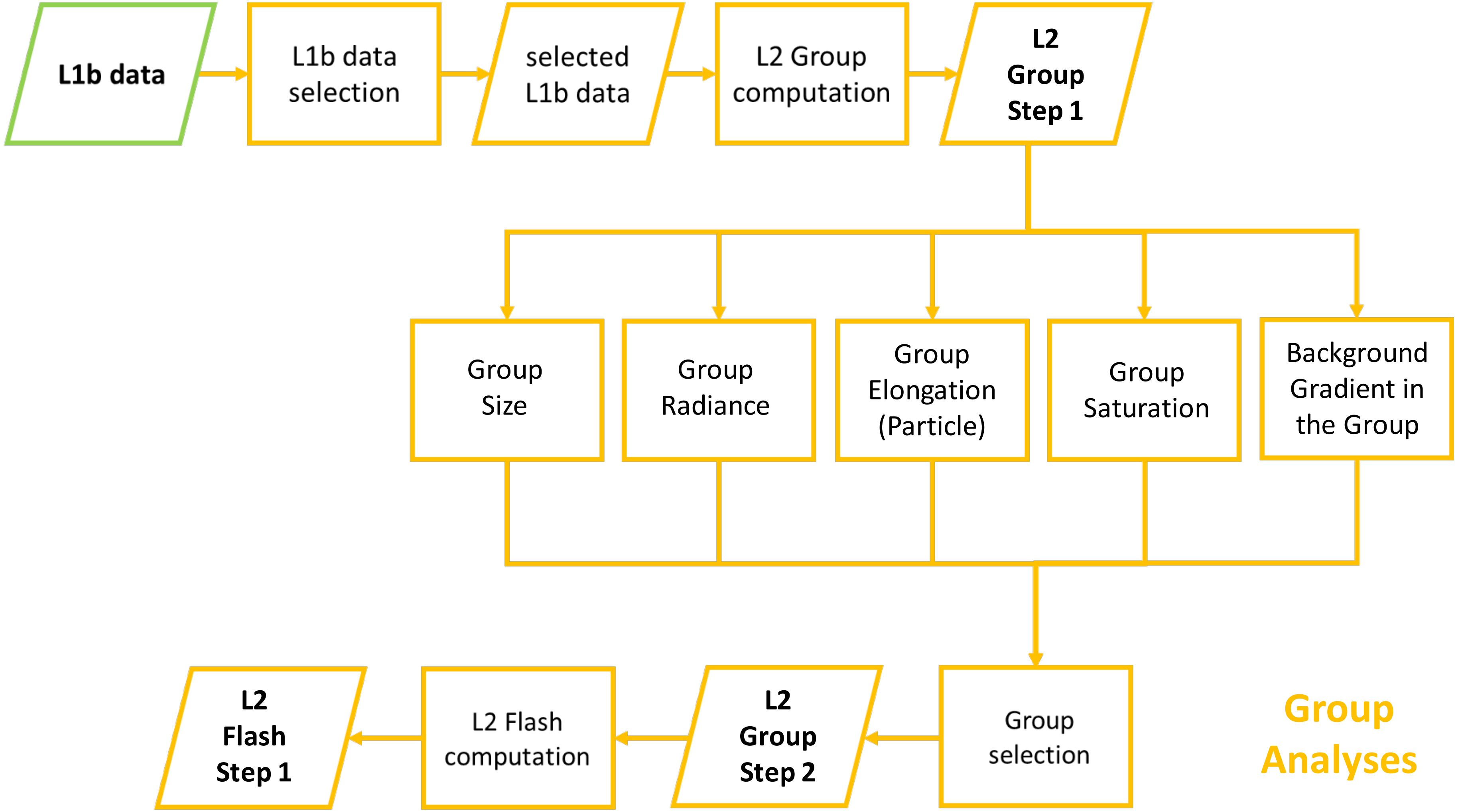






Orange dots are Level 2 DTs

Results - day



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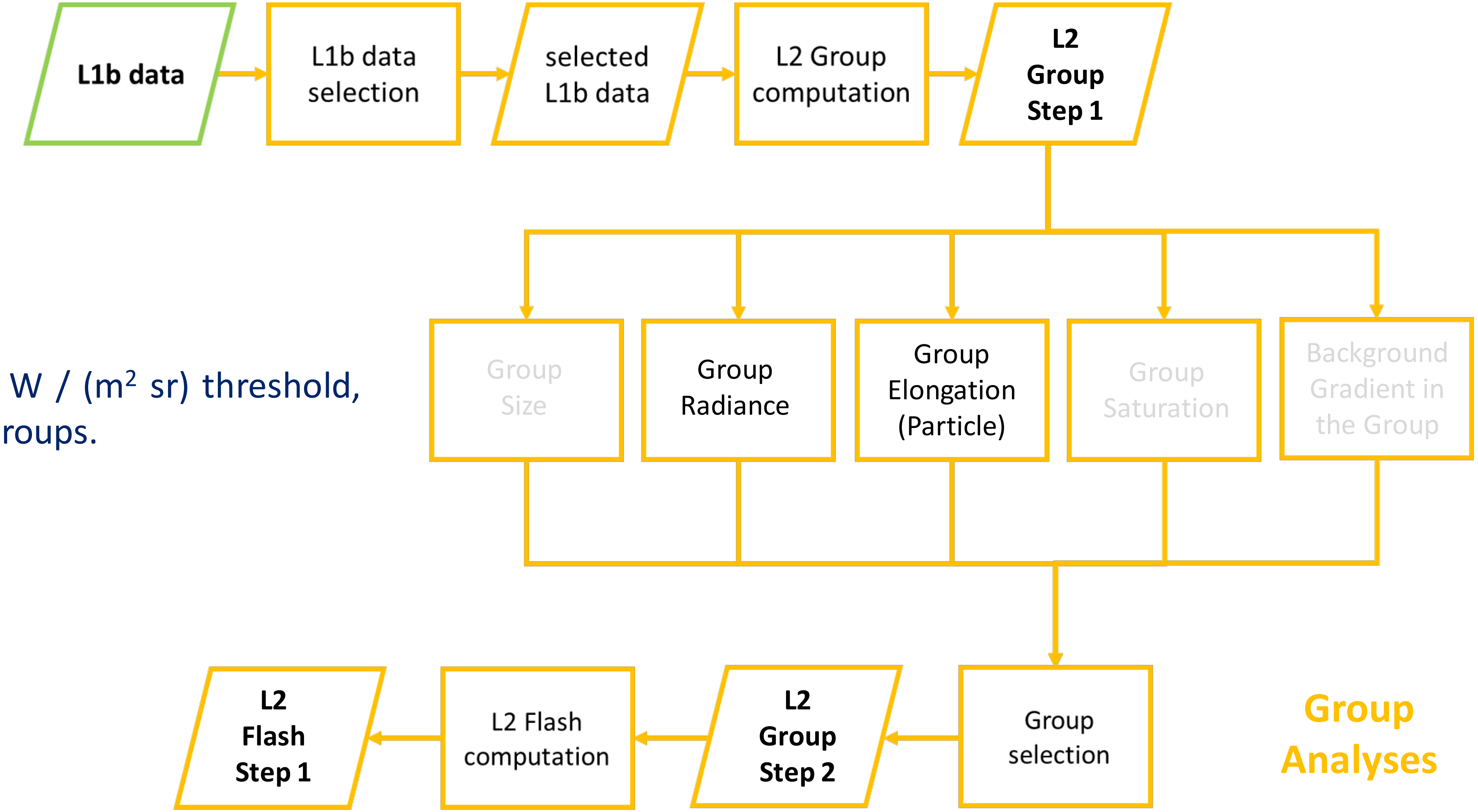
Results - day



1. Particle filter on Groups
2. Radiance filter, with 0.006 W / (m^2 sr) threshold, for at least half of DTs on Groups.

Group Analyses

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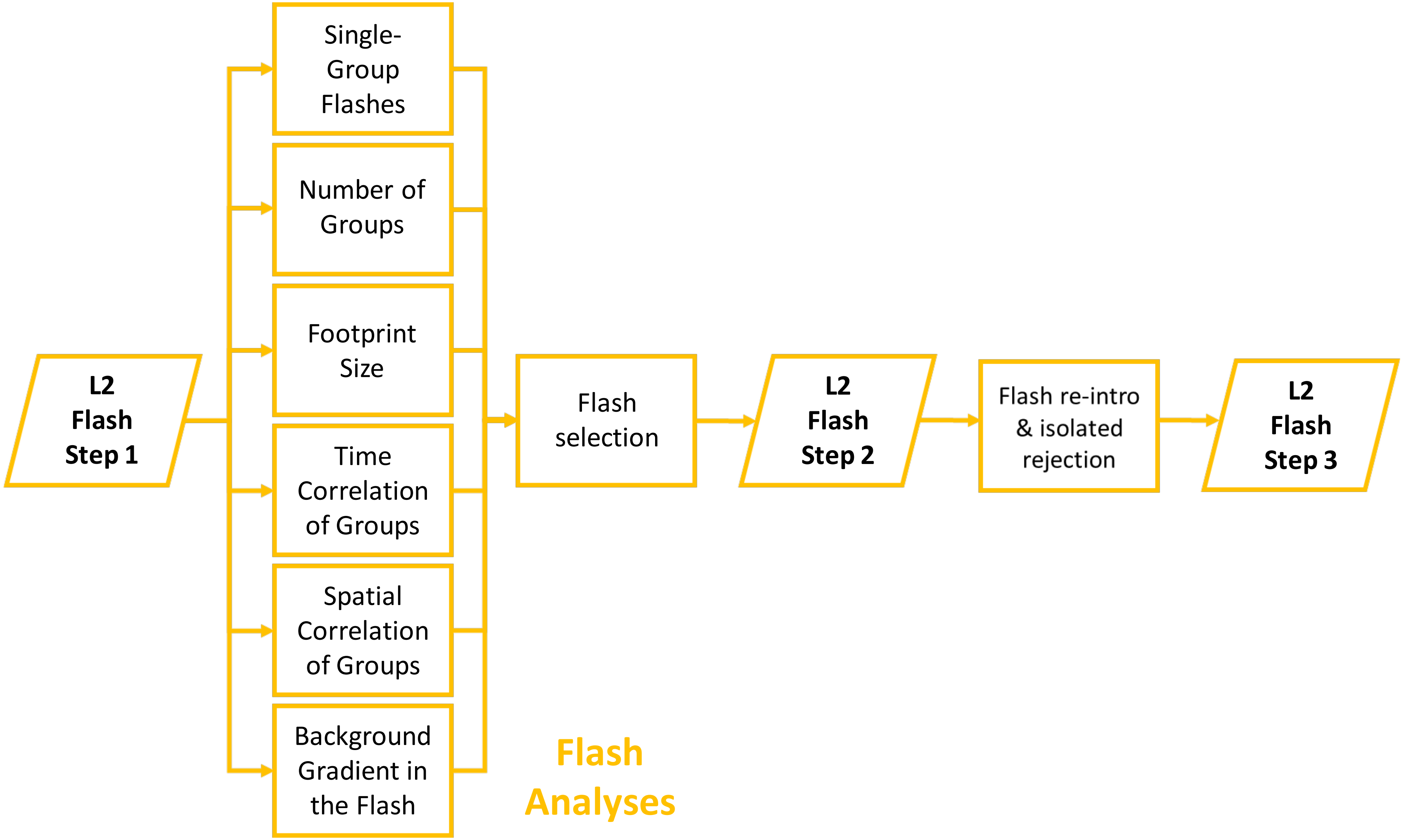
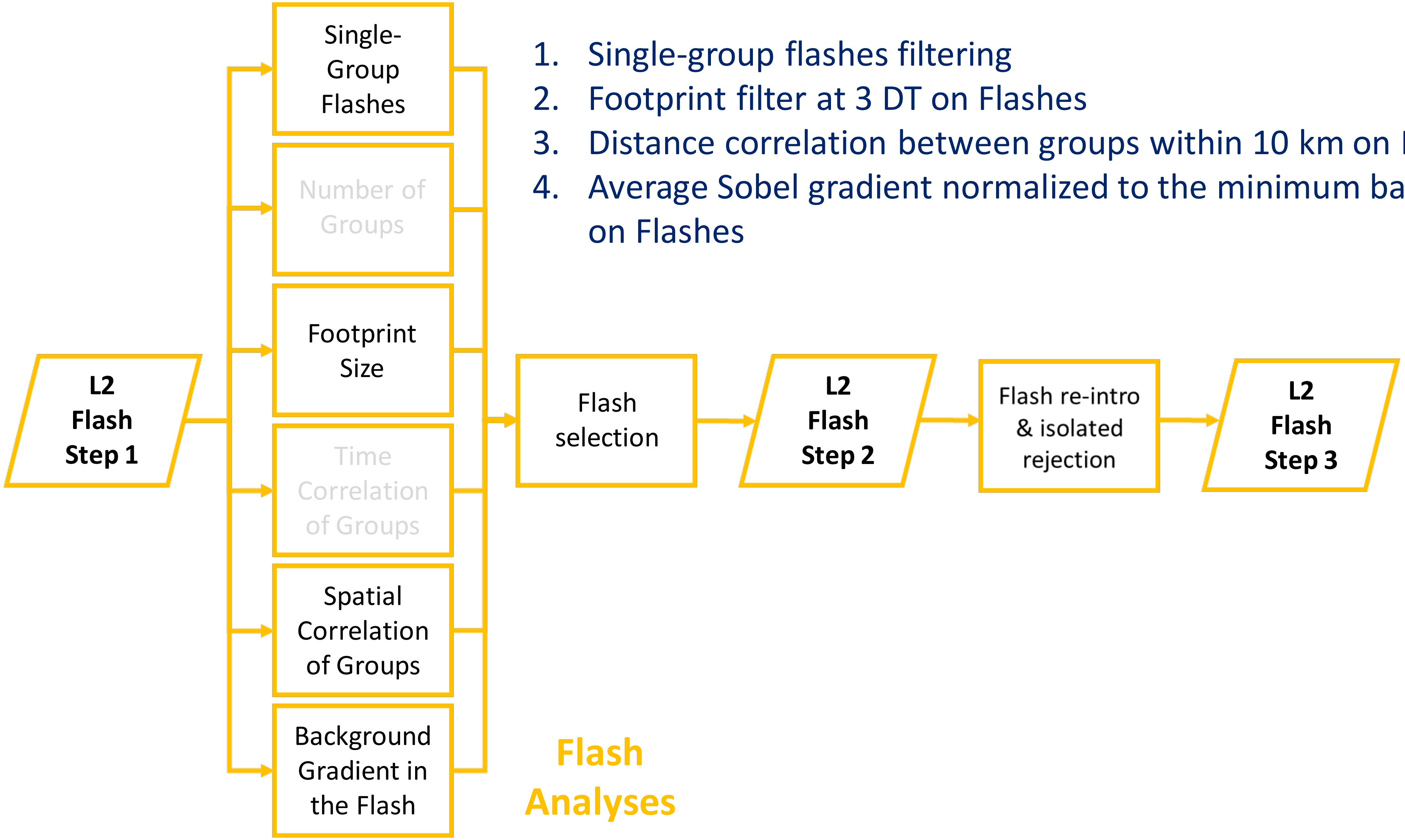
Results - day

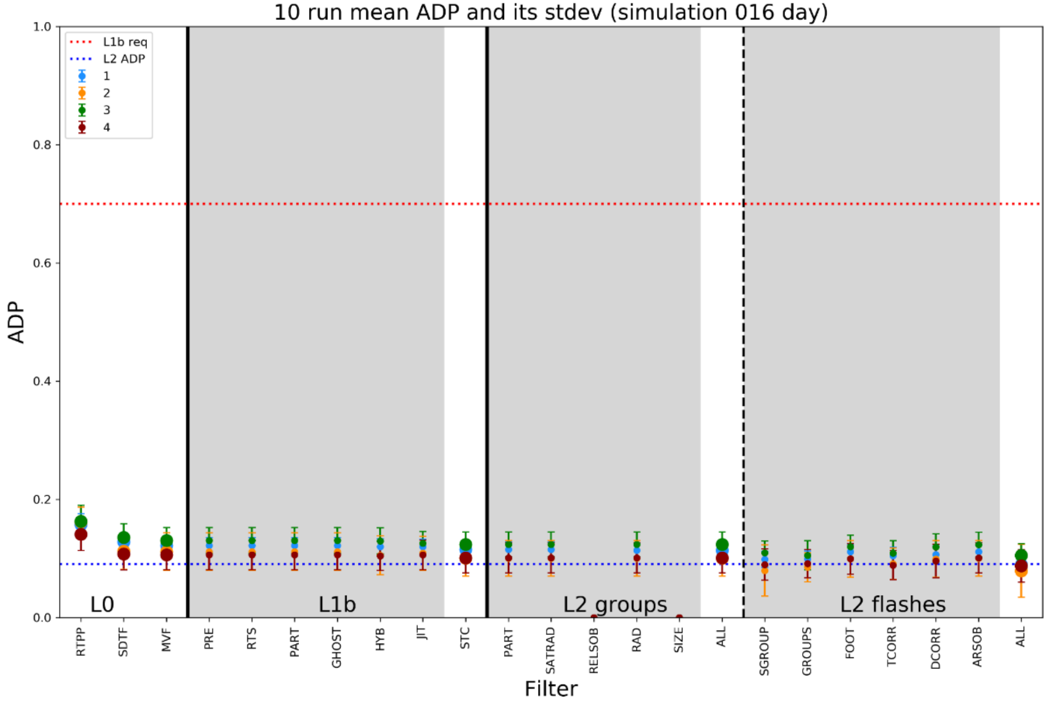

Single-Group Flashes
Number of Groups
Footprint Size
Time Correlation of Groups
Spatial Correlation of Groups
Background Gradient in the Flash
L2 Flash Step 1
Flash selection
L2 Flash Step 2
Flash re-intro & isolated rejection
L2 Flash Step 3
Flash Analyses

Results - day

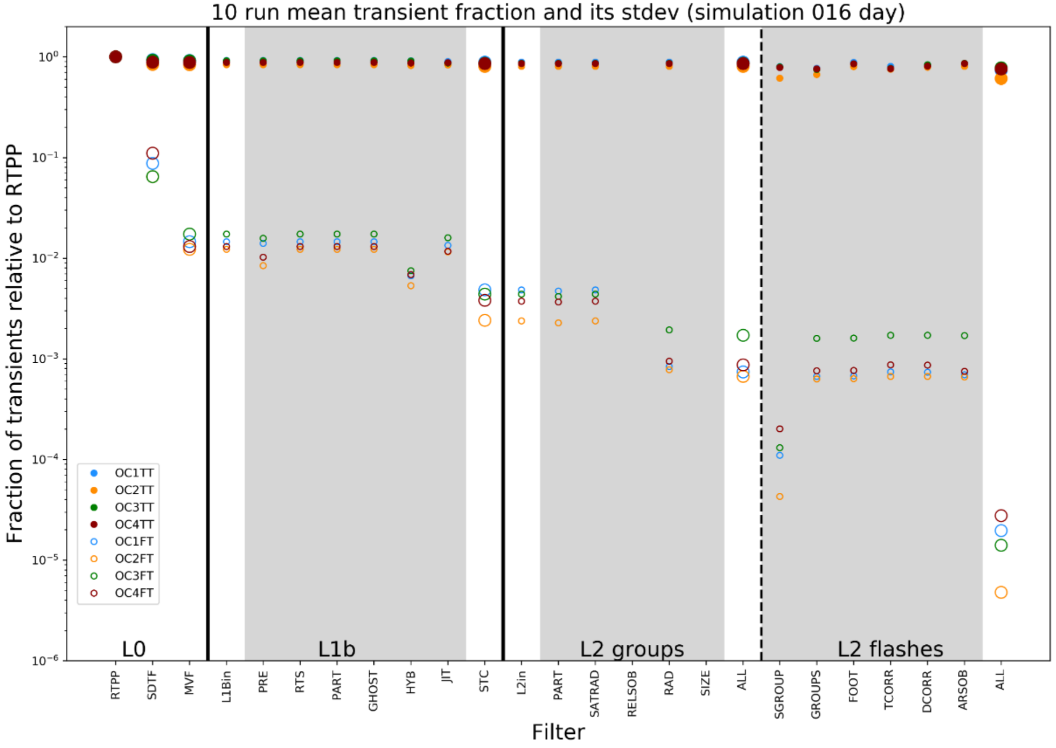
1. Single-group flashes filtering
2. Footprint filter at 3 DT on Flashes
3. Distance correlation between groups within 10 km on Flashes
4. Average Sobel gradient normalized to the minimum background with threshold at 10 on Flashes



Results - day



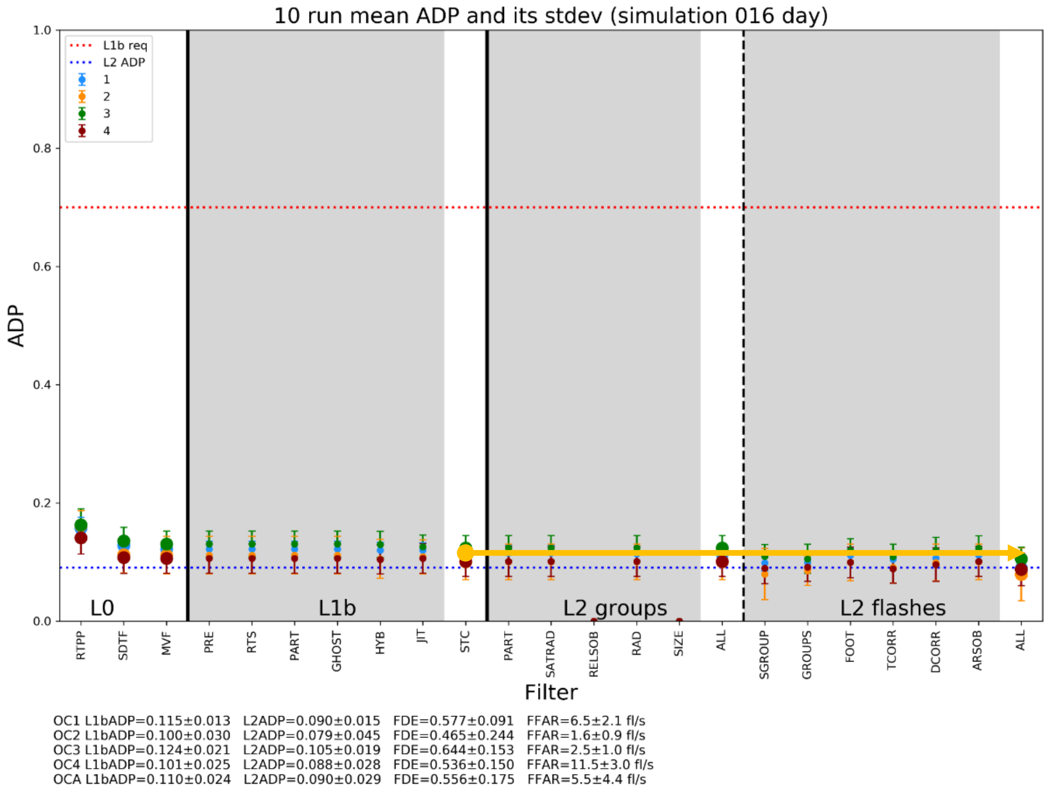
OC1 L1bADP=0.115±0.013 L2ADP=0.090±0.015 FDE=0.577±0.091 FFAR=6.5±2.1 fl/s
OC2 L1bADP=0.100±0.030 L2ADP=0.079±0.045 FDE=0.465±0.244 FFAR=1.6±0.9 fl/s
OC3 L1bADP=0.124±0.021 L2ADP=0.105±0.019 FDE=0.644±0.153 FFAR=2.5±1.0 fl/s
OC4 L1bADP=0.101±0.025 L2ADP=0.088±0.028 FDE=0.536±0.150 FFAR=11.5±3.0 fl/s
OCA L1bADP=0.110±0.024 L2ADP=0.090±0.029 FDE=0.556±0.175 FFAR=5.5±4.4 fl/s

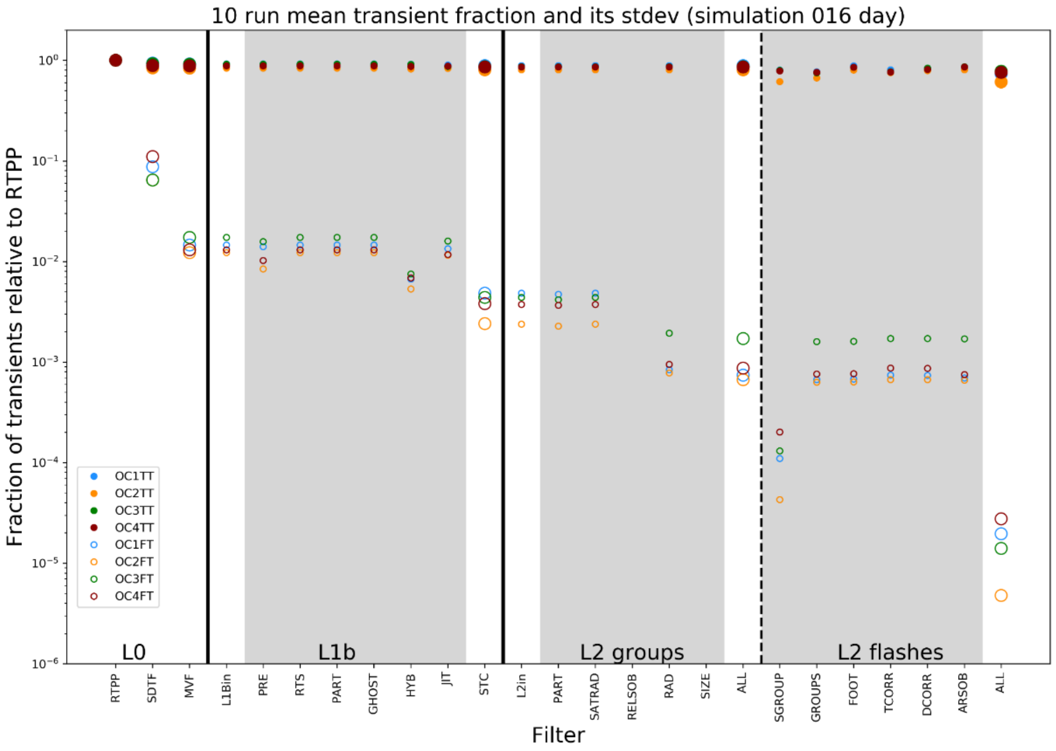


Key principles:

1. smallest possible reduction of the ADP between Level 1b and Level 2
2. FDE – FFAR balance

Results - day





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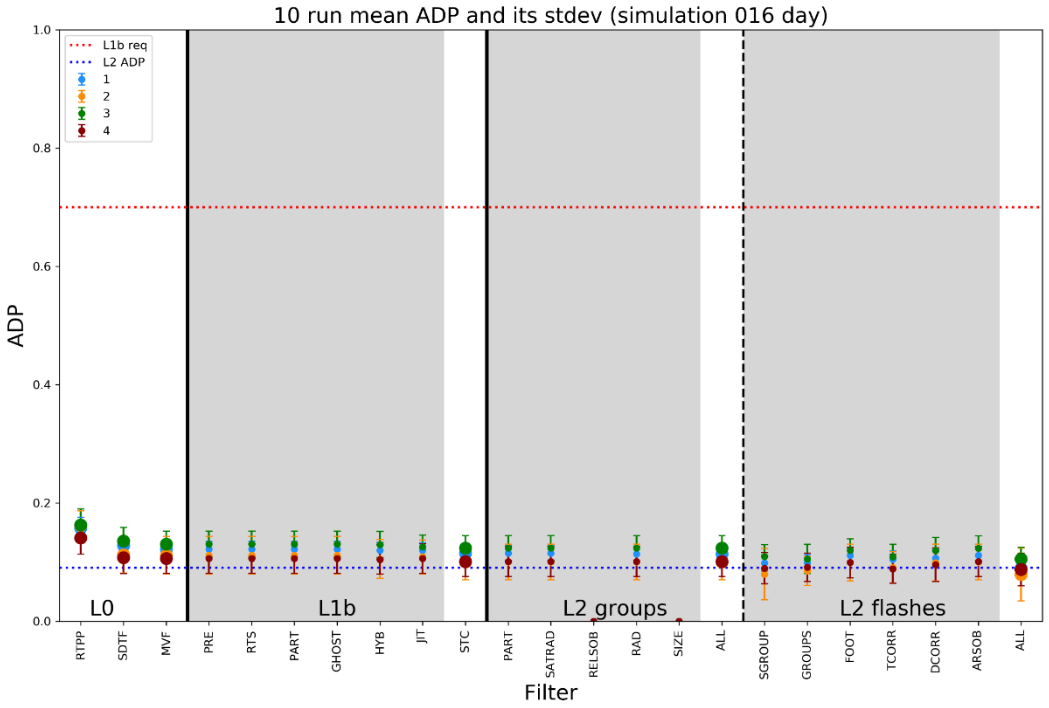

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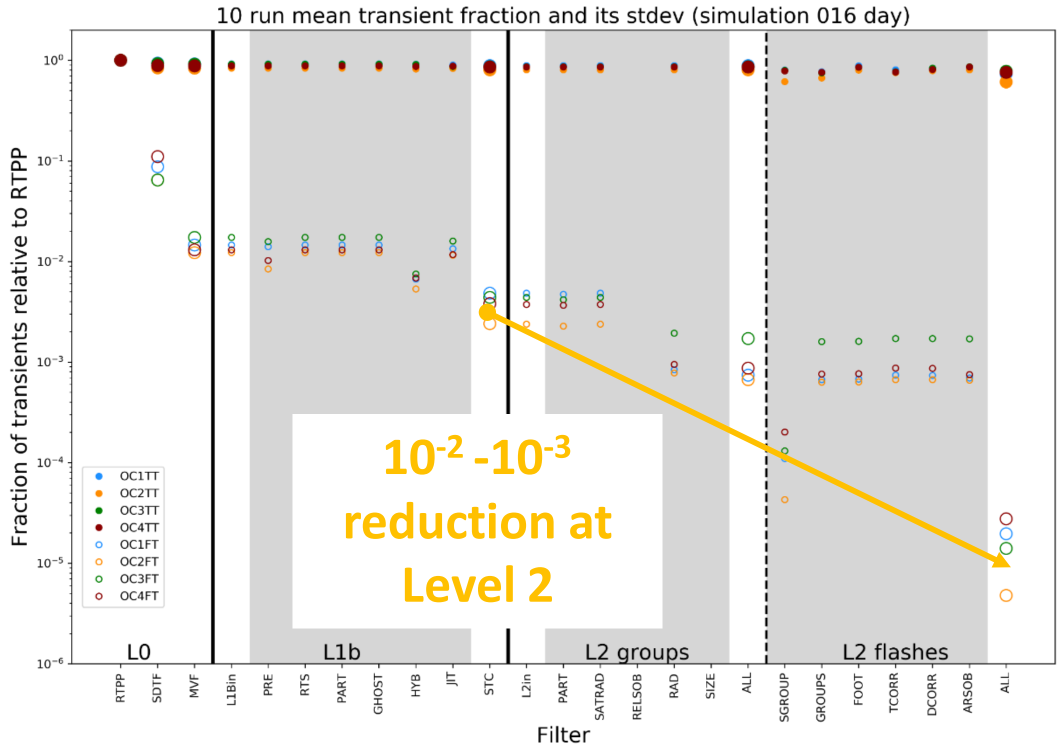

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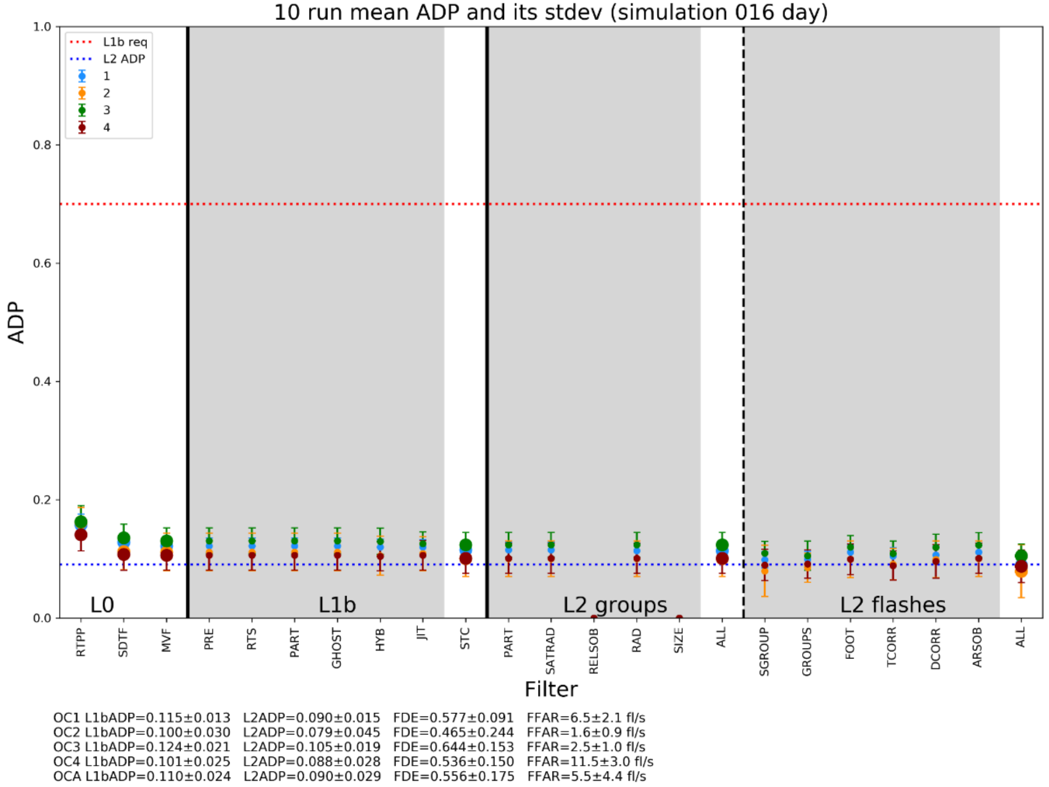

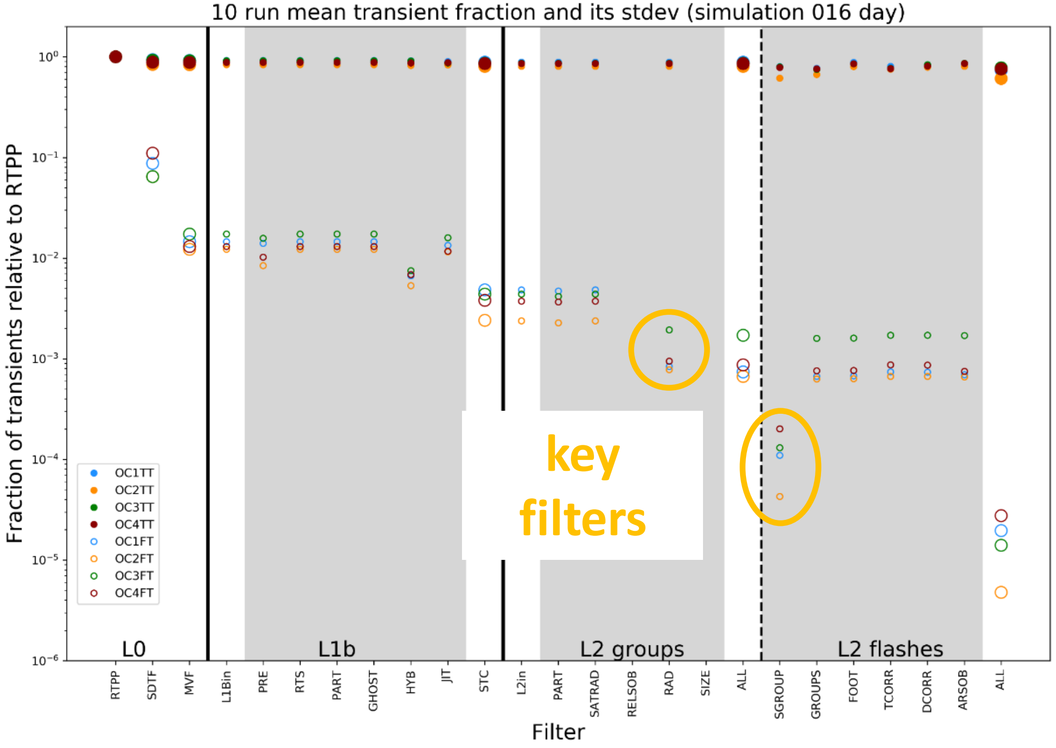

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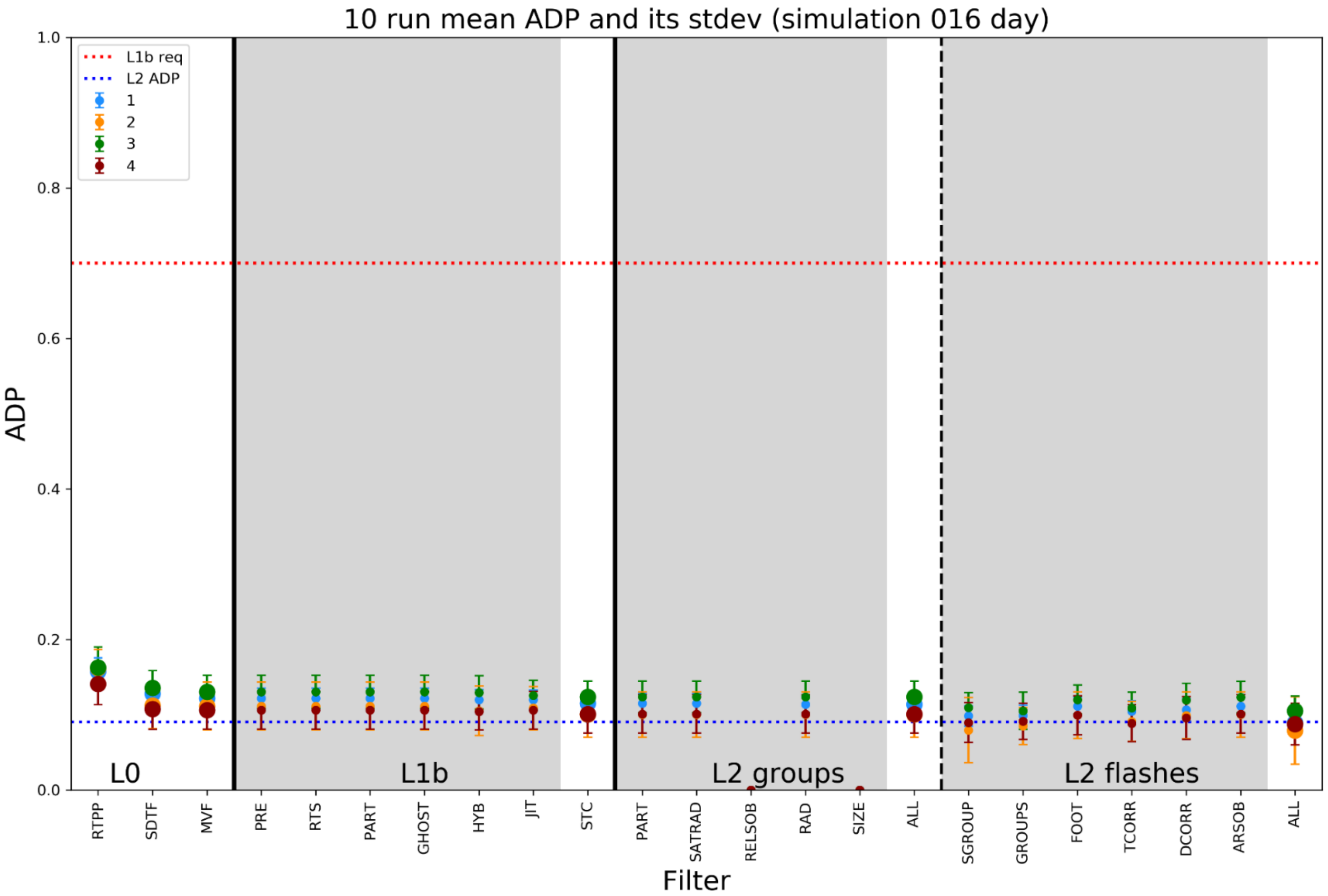
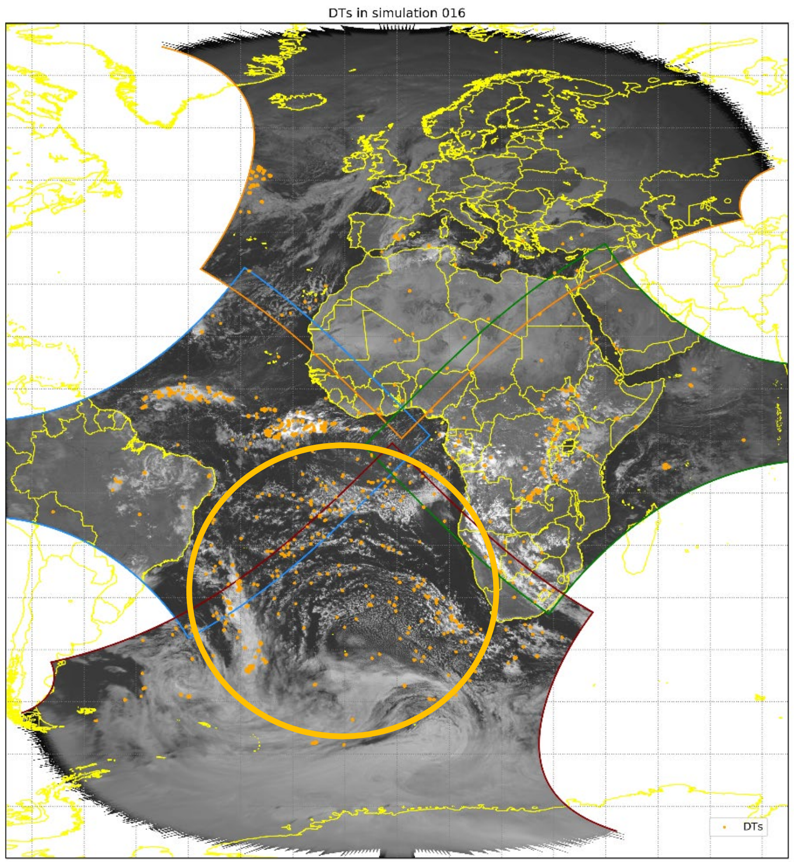
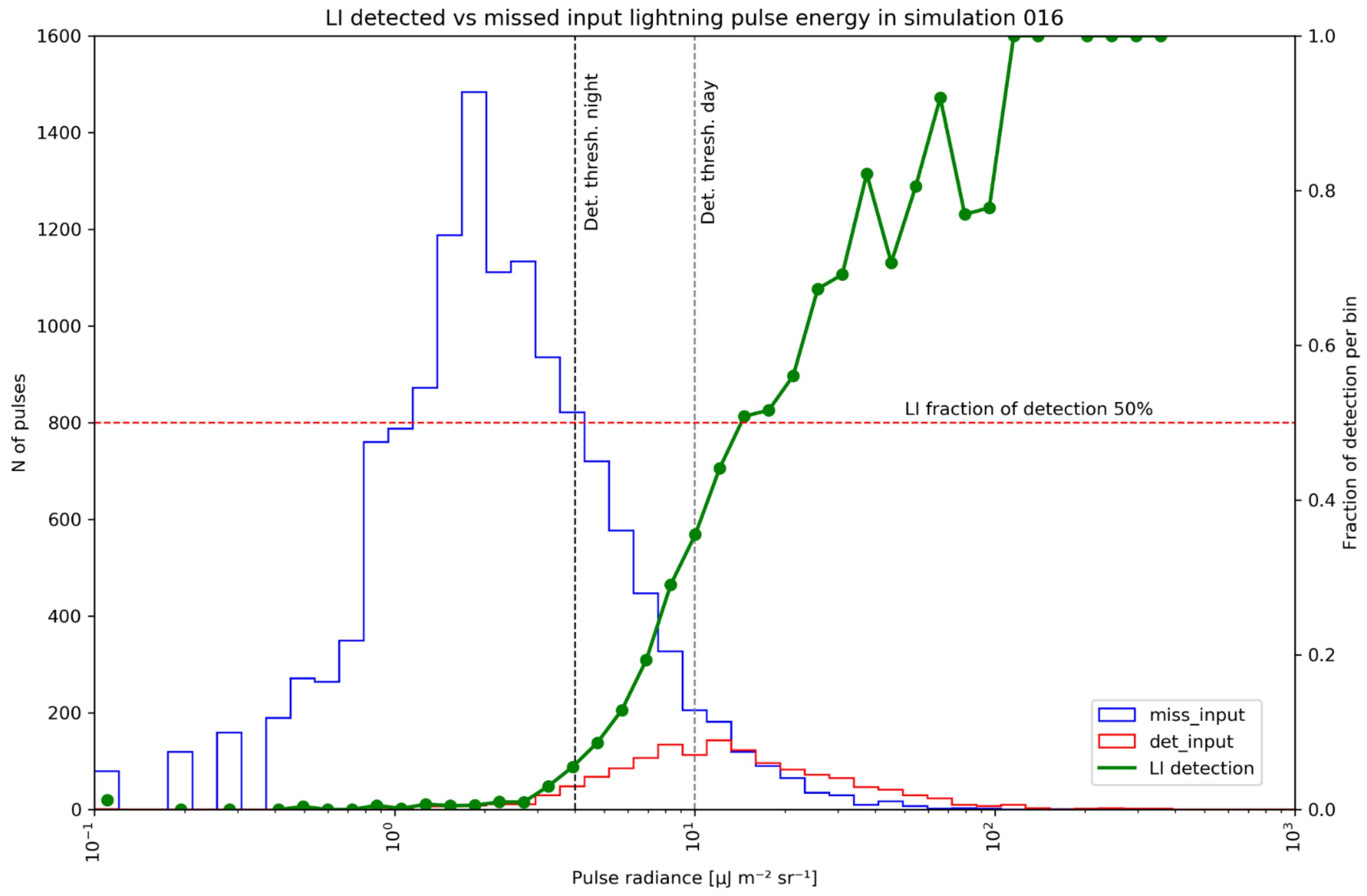


OC1 L1bADP=0.115±0.013 L2ADP=0.090±0.015 FDE=0.577±0.091 FFAR=6.5±2.1 fl/s
OC2 L1bADP=0.100±0.030 L2ADP=0.079±0.045 FDE=0.465±0.244 FFAR=1.6±0.9 fl/s
OC3 L1bADP=0.124±0.021 L2ADP=0.105±0.019 FDE=0.644±0.153 FFAR=2.5±1.0 fl/s
OC4 L1bADP=0.101±0.025 L2ADP=0.088±0.028 FDE=0.536±0.150 FFAR=11.5±3.0 fl/s
OCA L1bADP=0.110±0.024 L2ADP=0.090±0.029 FDE=0.556±0.175 FFAR=5.5±4.4 fl/s



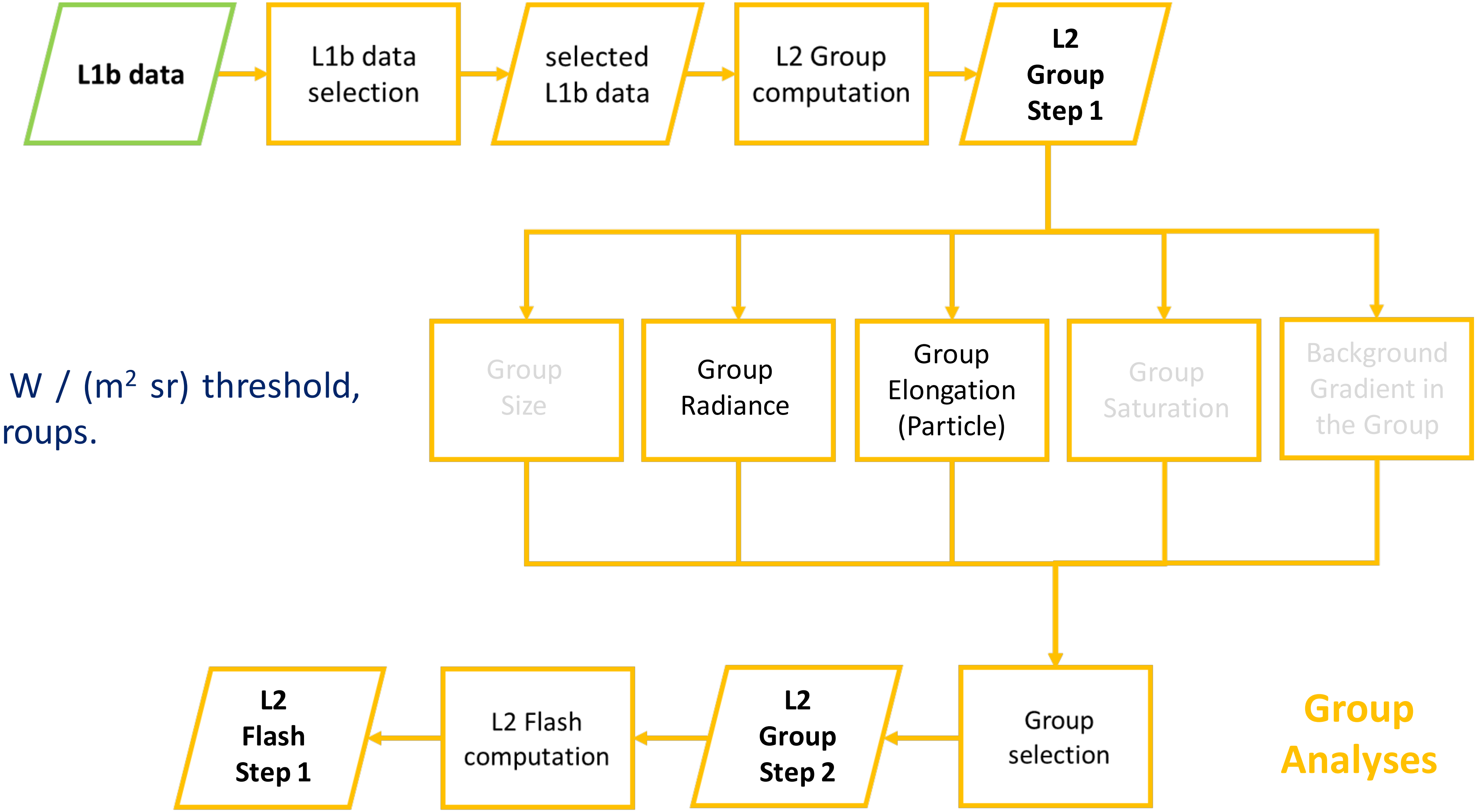
Results - day



The detection threshold, defined as for GLM when compared against FEGS is about 15 μJ / (sr m^2)

Note: such a threshold is derived for the brightest illumination condition by placing flashes over the brightest clouds

Results - night



1. Particle filter on Groups
2. Radiance filter, with 0.002 W / (m^2 sr) threshold, for at least half of DTs on Groups.

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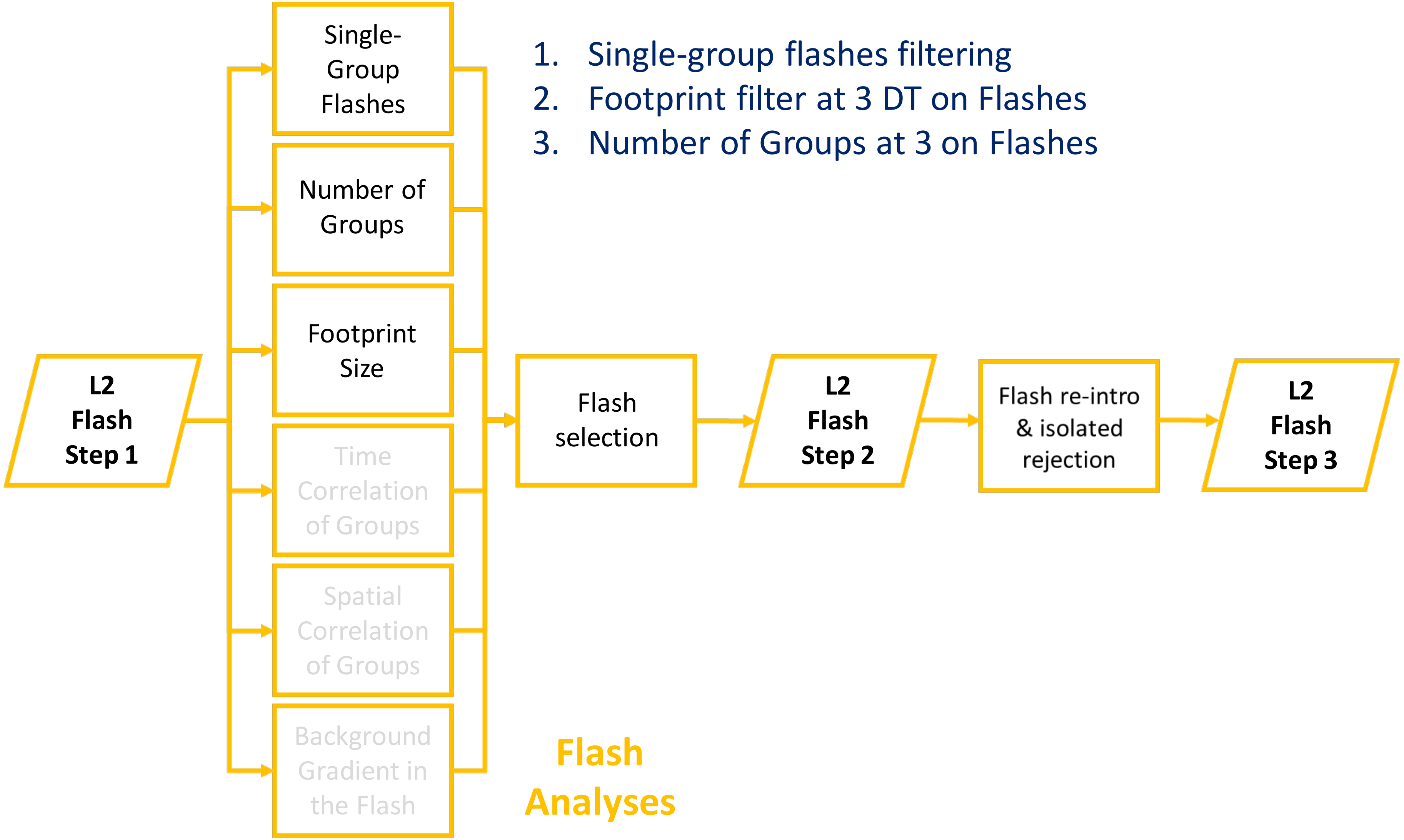
Results - night



1. Single-group flashes filtering
2. Footprint filter at 3 DT on Flashes
3. Number of Groups at 3 on Flashes

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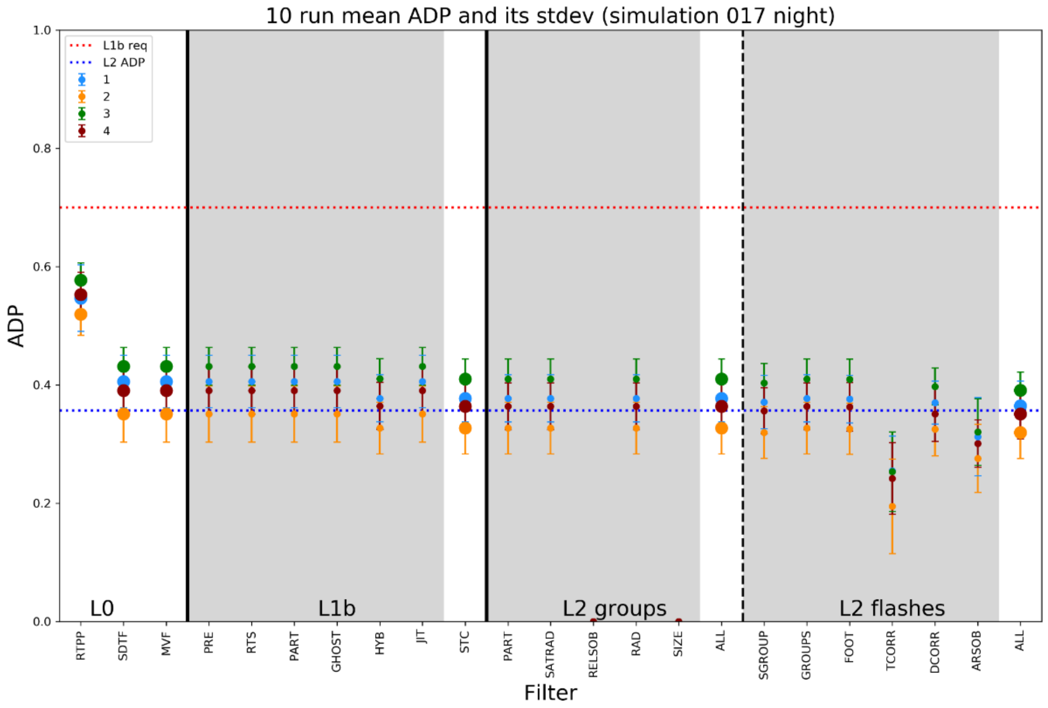
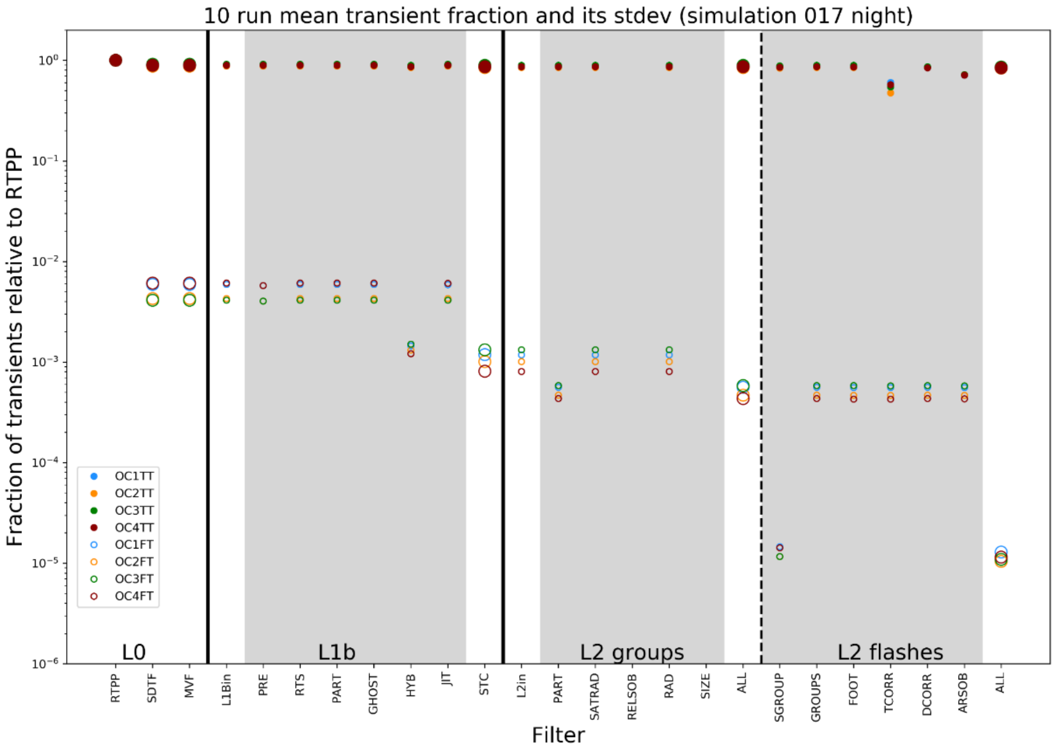
Results - night



OC1 L1bADP=0.377±0.040 L2ADP=0.365±0.041 FDE=0.895±0.083 FFAR=0.0±0.0 fl/s
OC2 L1bADP=0.327±0.044 L2ADP=0.319±0.044 FDE=0.883±0.105 FFAR=0.1±0.2 fl/s
OC3 L1bADP=0.410±0.034 L2ADP=0.391±0.030 FDE=0.858±0.110 FFAR=0.0±0.0 fl/s
OC4 L1bADP=0.364±0.040 L2ADP=0.351±0.043 FDE=0.864±0.117 FFAR=0.1±0.2 fl/s
OCA L1bADP=0.369±0.048 L2ADP=0.357±0.047 FDE=0.875±0.102 FFAR=0.0±0.1 fl/s



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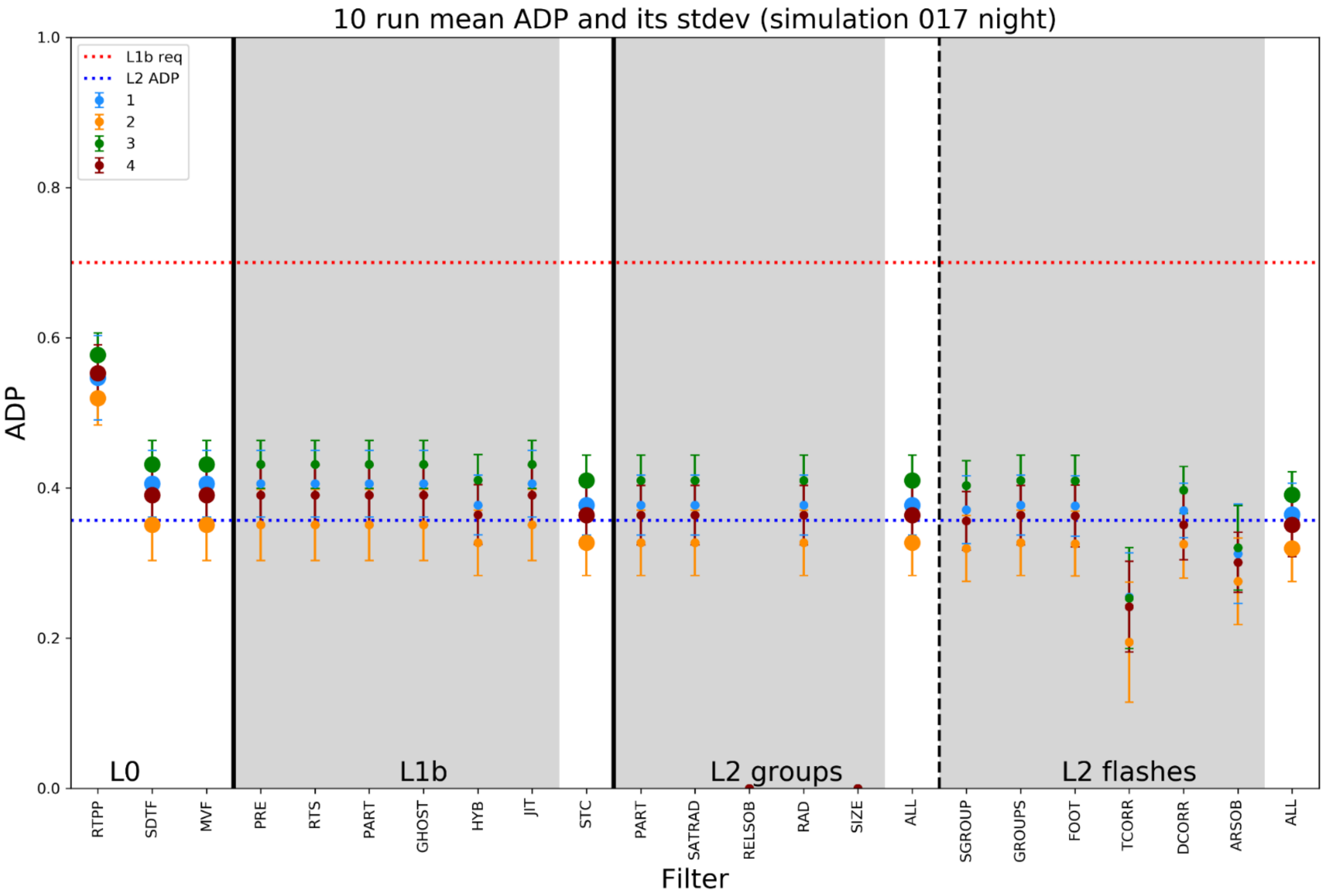
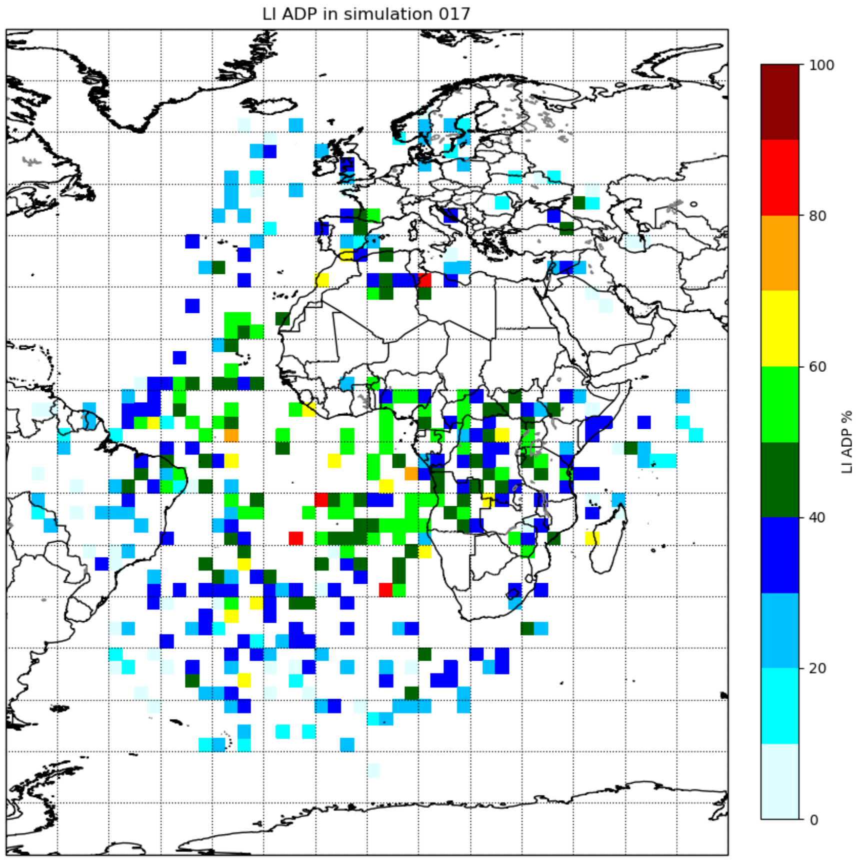
Results - night



OC1 L1bADP=0.377±0.040 L2ADP=0.365±0.041 FDE=0.895±0.083 FFAR=0.0±0.0 fl/s
OC2 L1bADP=0.327±0.044 L2ADP=0.319±0.044 FDE=0.883±0.105 FFAR=0.1±0.2 fl/s
OC3 L1bADP=0.410±0.034 L2ADP=0.391±0.030 FDE=0.858±0.110 FFAR=0.0±0.0 fl/s
OC4 L1bADP=0.364±0.040 L2ADP=0.351±0.043 FDE=0.864±0.117 FFAR=0.1±0.2 fl/s
OCA L1bADP=0.369±0.048 L2ADP=0.357±0.047 FDE=0.875±0.102 FFAR=0.0±0.1 fl/s



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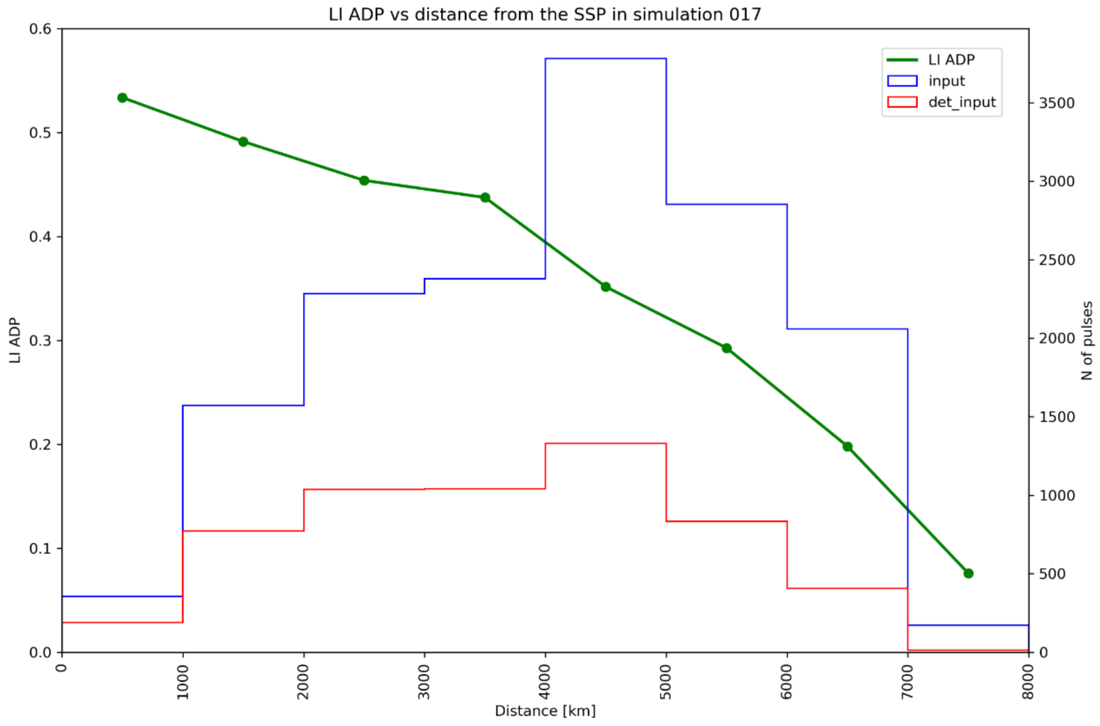
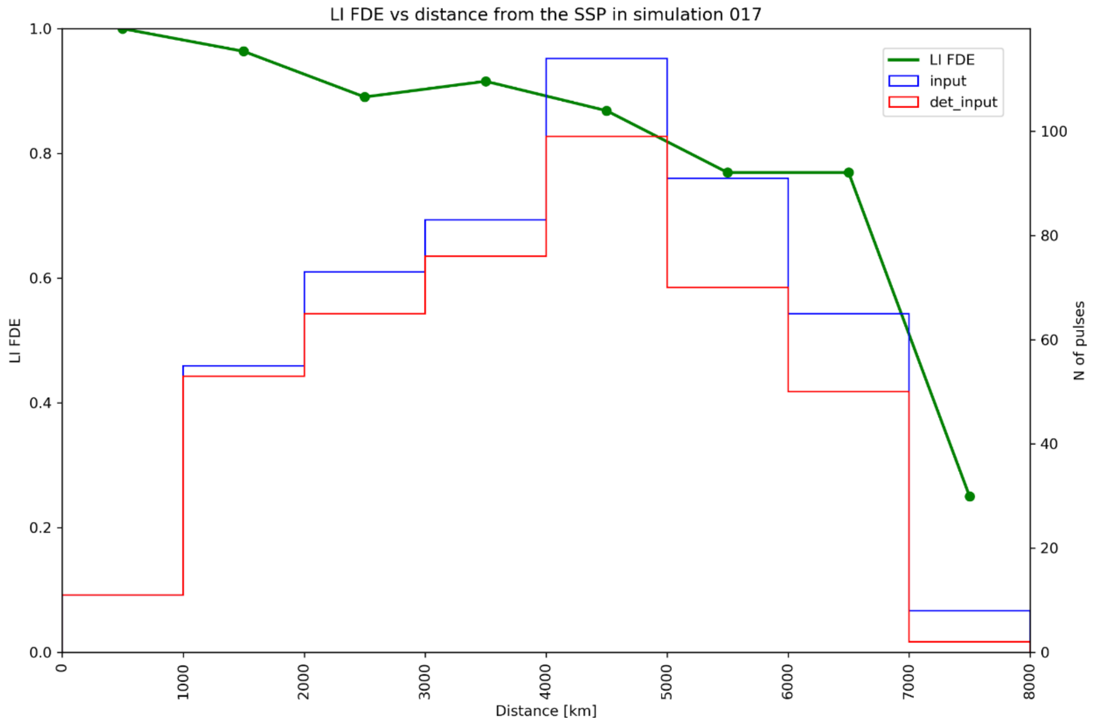
Results - night





Despite the reduction of the ADP with the distance from the SSP, the FDE drops only at the very end of the FOV

Such result can be computed thanks to the uniform distributions of flashes in the FOV

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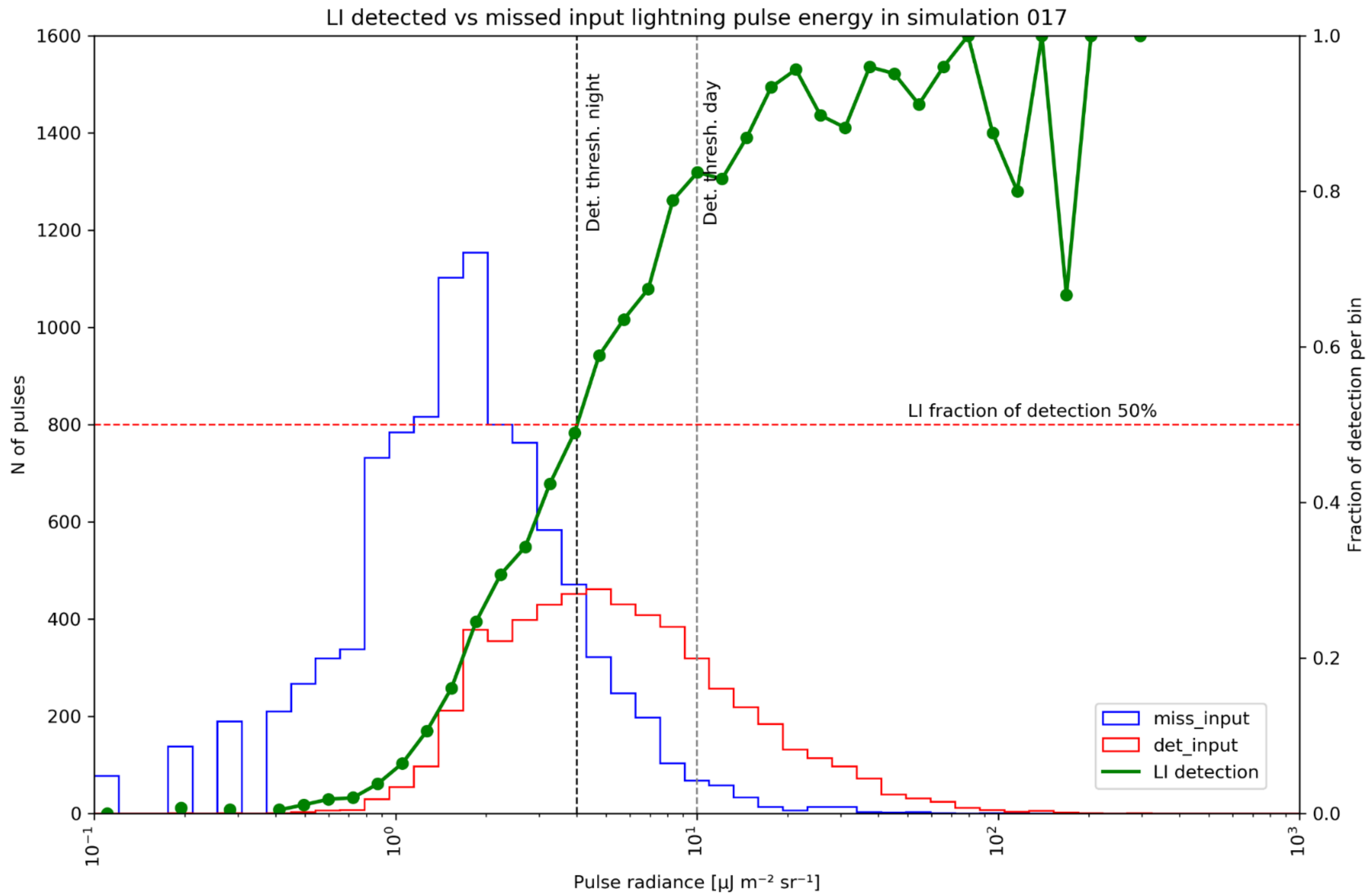
Results - night



The detection threshold, defined as for GLM when compared against FEGS is about 4 μJ / (sr m^2)

Results - half

OC1 (day)

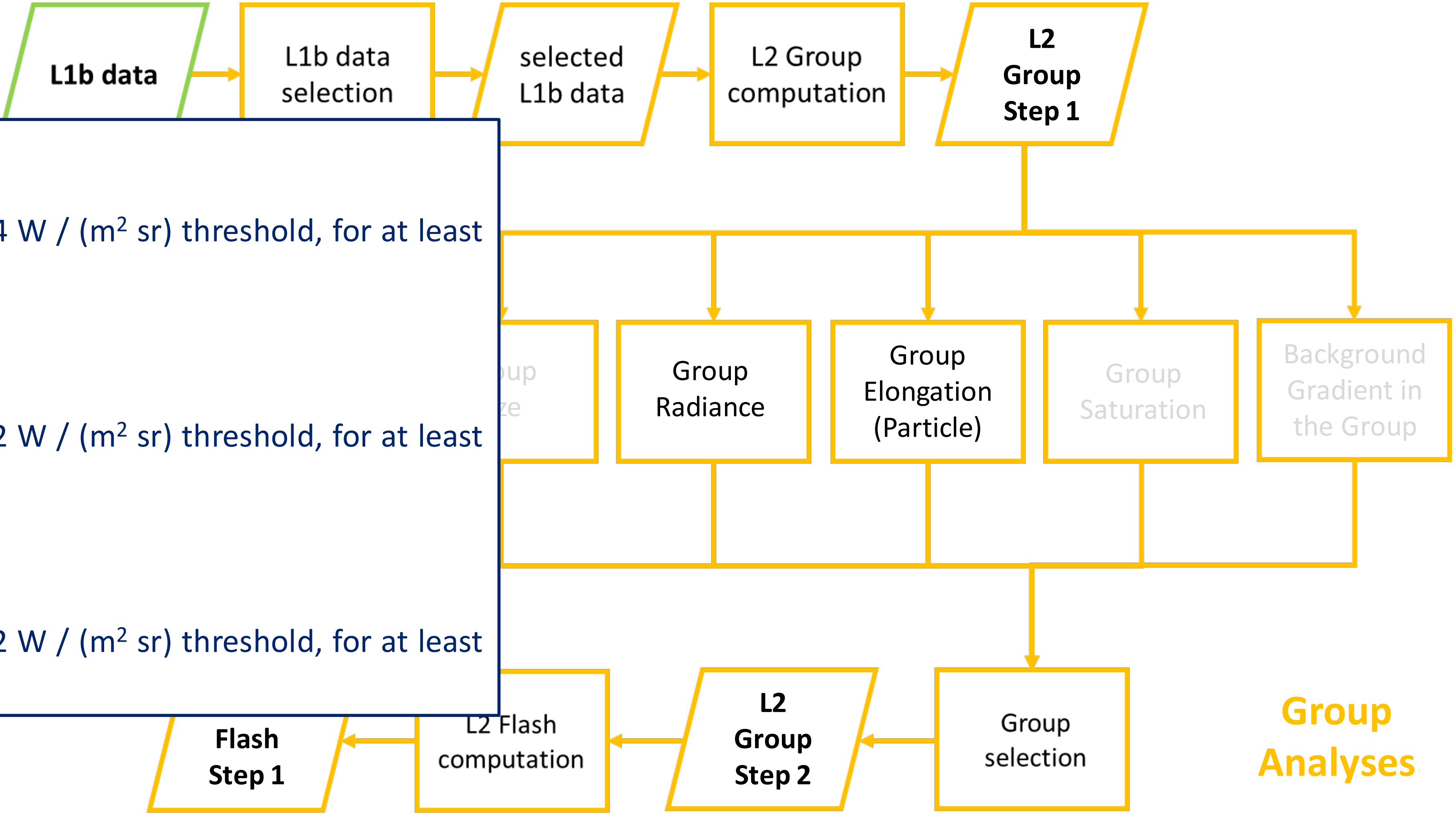
1. Particle filter on Groups
2. Radiance filter, with 0.004 W / (m^2 sr) threshold, for at least half of DTs on Groups

OC2 and OC4 (terminator)

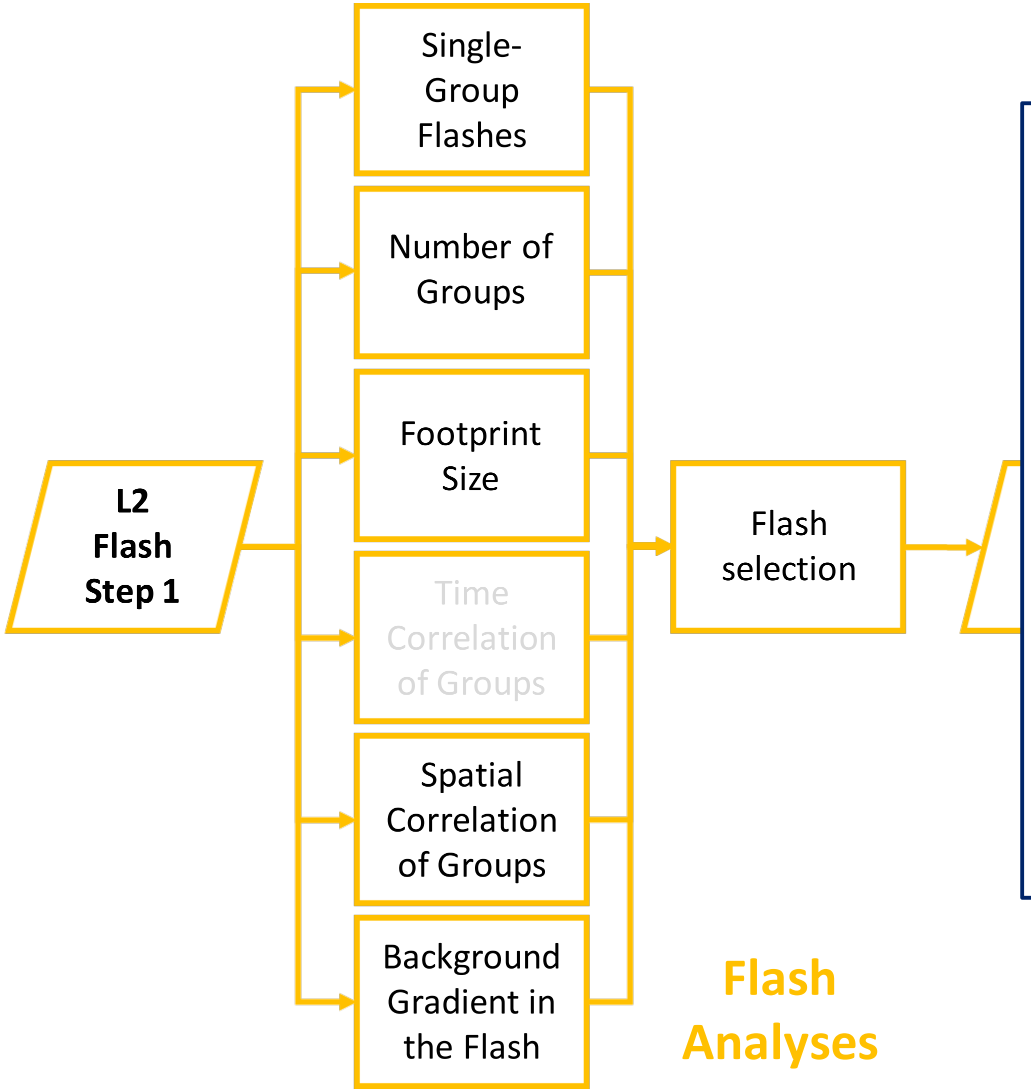
1. Particle filter on Groups
2. Radiance filter, with 0.002 W / (m^2 sr) threshold, for at least half of DTs on Groups

OC3 (dark)

1. Particle filter on Groups
2. Radiance filter, with 0.002 W / (m^2 sr) threshold, for at least half of DTs on Groups



Results - half



OC1 (day)

1. Footprint filter at 3 DT on Flashes
2. Distance correlation between groups within 10 km on Flashes
3. Average Sobel gradient normalized to the minimum background with threshold at 10 on Flashes

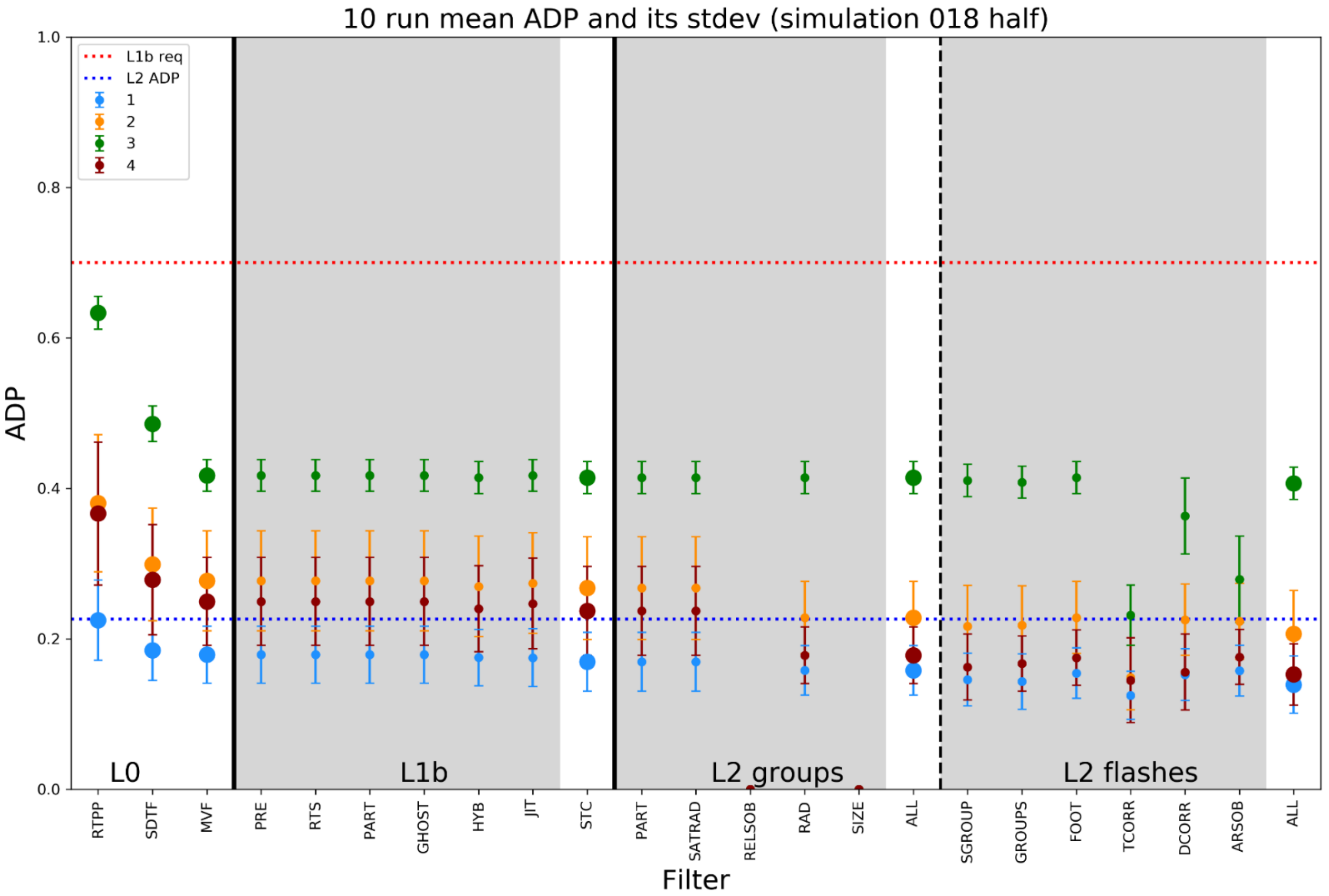
OC2 and OC4 (terminator)

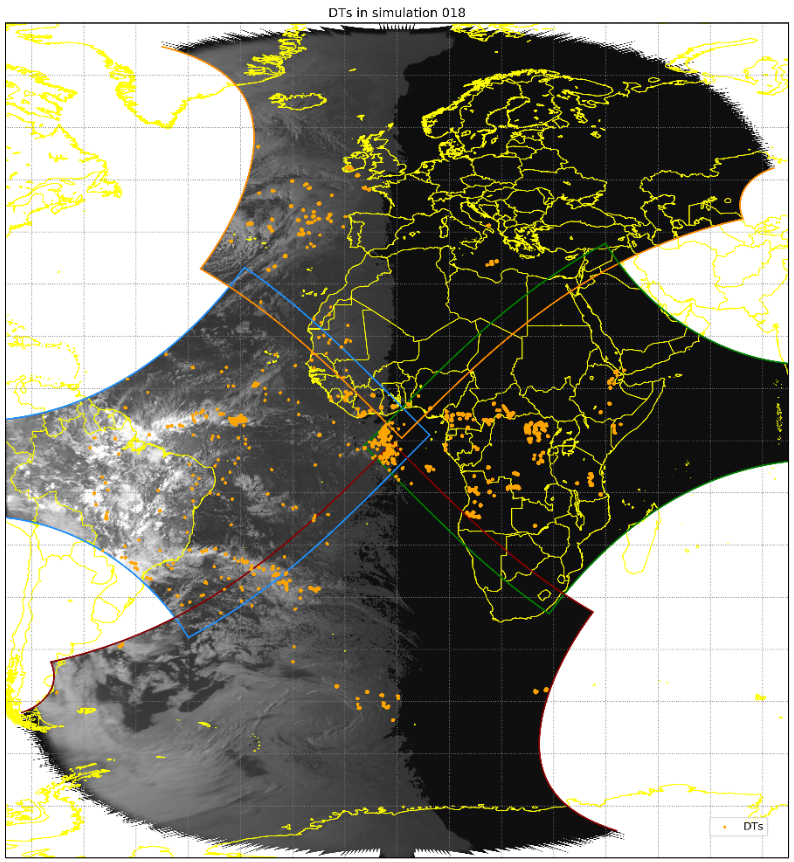
1. Footprint filter at 3 DT on Flashes
2. Distance correlation between groups within 10 km on Flashes
3. Average Sobel gradient normalized to the minimum background with threshold at 10 on Flashes

OC3 (dark)

1. Number of Groups at 3 on Flashes
2. Footprint filter at 3 DT on Flashes

Results - half





OC1 L1bADP=0.169±0.039 L2ADP=0.139±0.038 FDE=0.614±0.129 FFAR=6.0±1.3 fl/s
OC2 L1bADP=0.267±0.068 L2ADP=0.207±0.057 FDE=0.700±0.180 FFAR=0.8±0.7 fl/s
OC3 L1bADP=0.414±0.021 L2ADP=0.407±0.022 FDE=0.896±0.057 FFAR=6.5±1.5 fl/s
OC4 L1bADP=0.237±0.059 L2ADP=0.153±0.041 FDE=0.530±0.170 FFAR=0.5±0.4 fl/s
OCA L1bADP=0.272±0.103 L2ADP=0.226±0.116 FDE=0.685±0.194 FFAR=3.5±3.0 fl/s

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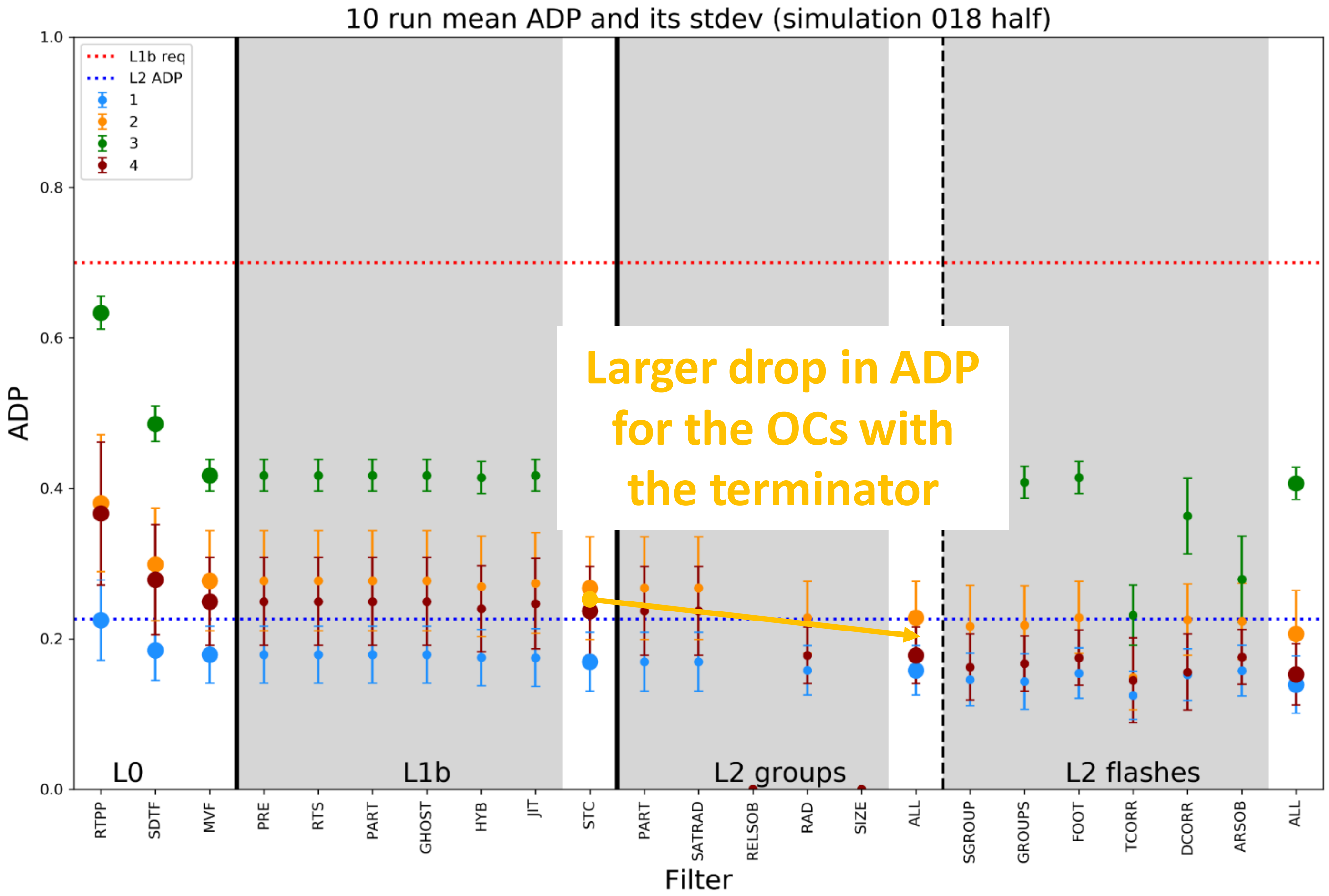
Results - half



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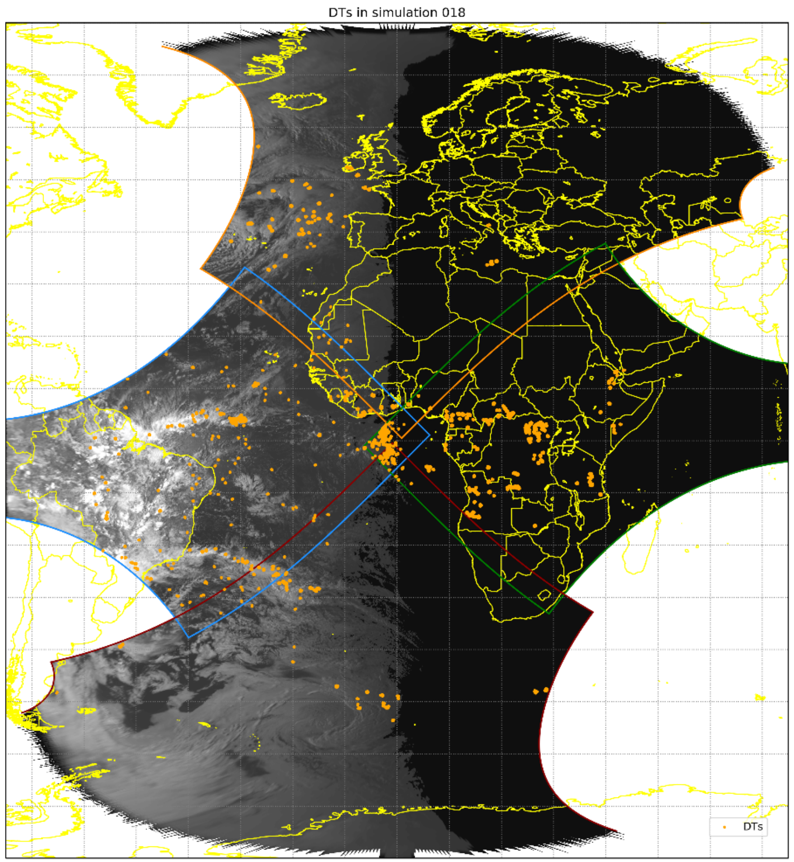
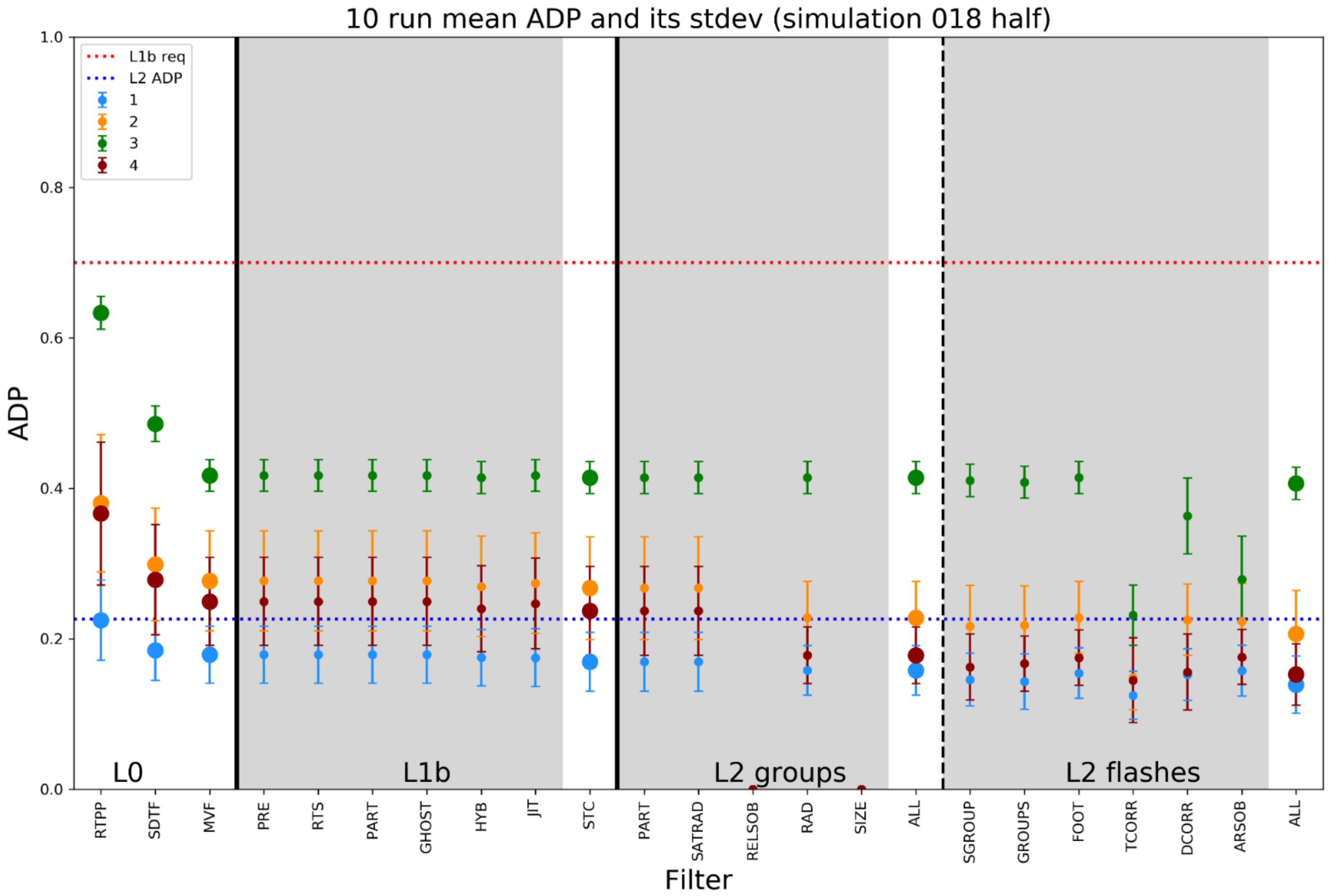
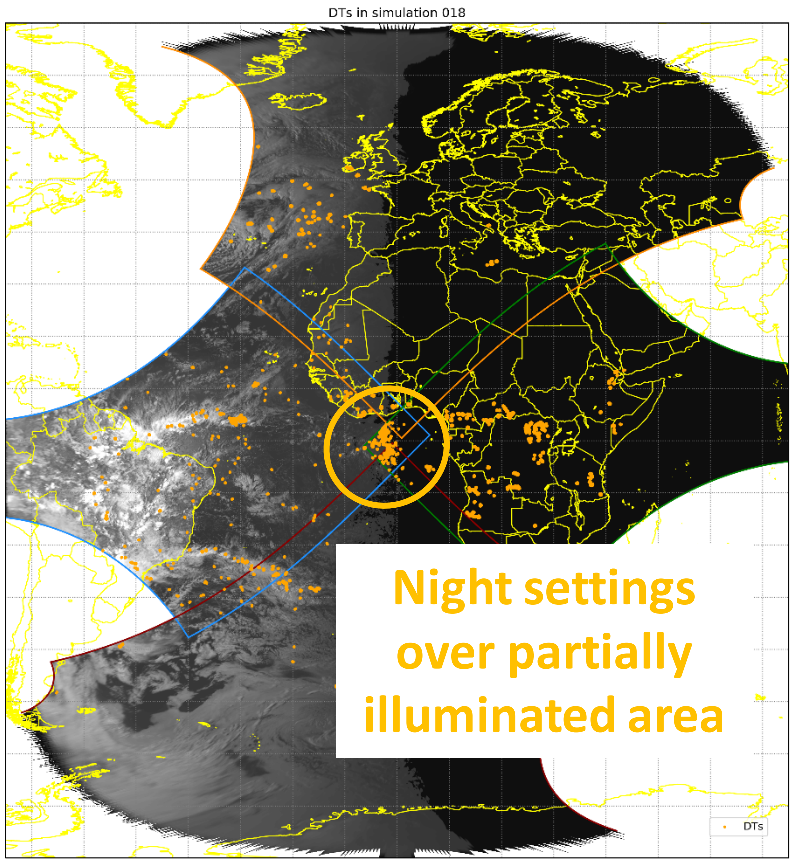


Results - half





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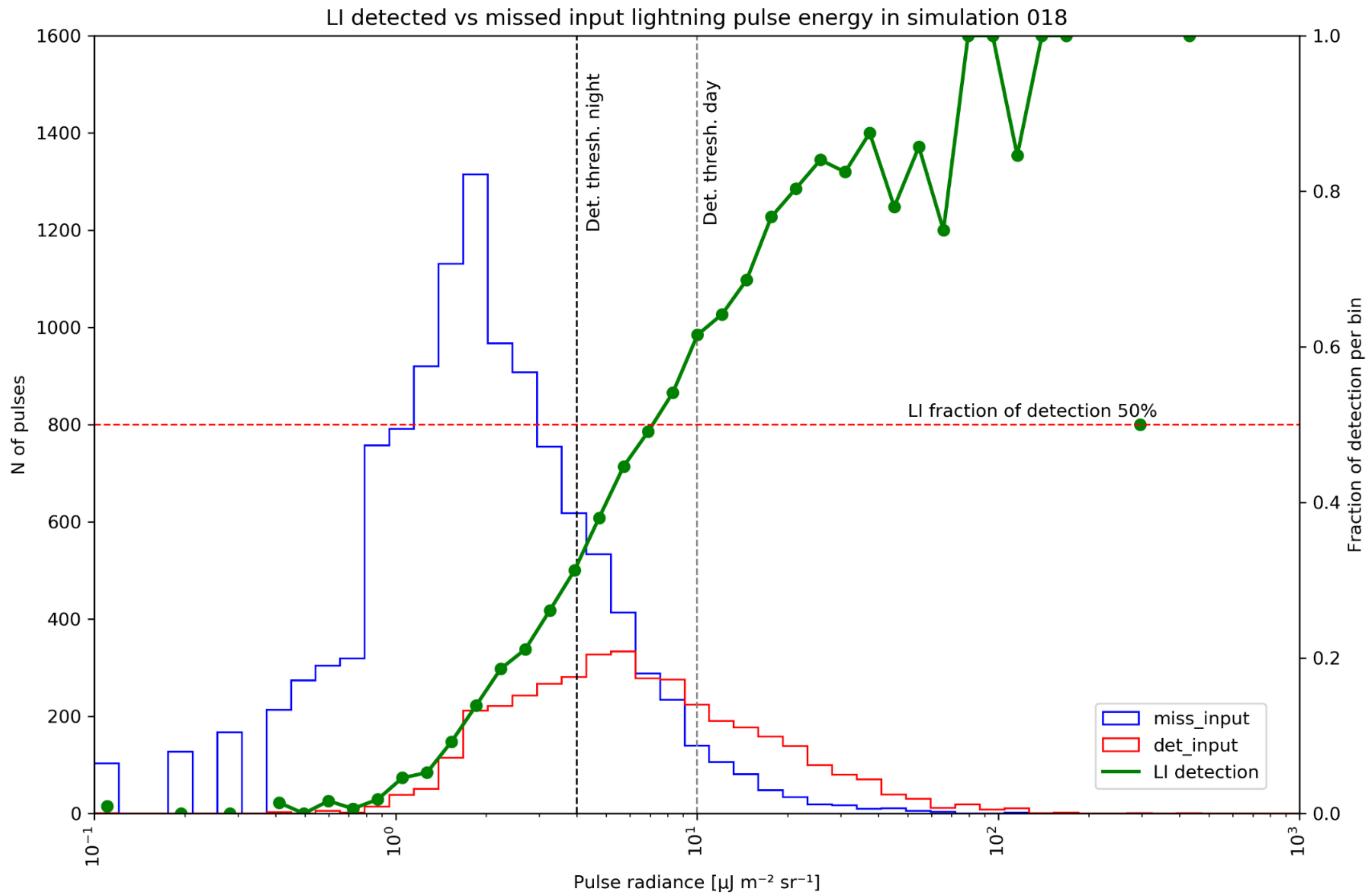
Results - half



The detection threshold, defined as for GLM when compared against FEGS is about 6.5 μJ / (sr m^2)

Results - summary

Session	Level 1b ADP	Level 2 ADP	Level 2 FDE	Level 2 FFAR	Level 2 det. thld.
016 day	0.11 ± 0.03	0.09 ± 0.03	0.56 ± 0.18	6 ± 4 1/(sec OC)	≈ 15 µJ / (sr m^2)
017 night	0.37 ± 0.05	0.36 ± 0.05	0.88 ± 0.10	0 ± 0 1/(sec OC)	≈ 4 µJ / (sr m^2)
018 half	0.27 ± 0.10	0.23 ± 0.12	0.69 ± 0.19	4 ± 3 1/(sec OC)	≈ 6.5 µJ / (sr m^2)

- The simulated lightning detection performances of LI are characterized by a strong variability
- The ADP at Level 1b and Level 2 for realistic pulses is always much lower than the ADP computed by industry. This is due to three main factors:
  1. Background scene and pulse radiance are not correlated in this analysis
  2. The pulse radiance distribution employed in this analysis is strongly dominated by radiances below 4 µJ / (sr m^2) (i.e., the detection threshold at night for LI)
  3. For illumination conditions different from total darkness, pulses have been placed on bright thick clouds, i.e., the brightest scene available in the FOV for any illumination condition
- The FDE varies from about 0.3 to 0.98, for a FFAR that can be as high as 24 flashes per second
- The detection threshold varies in [4, 15] µJ / (sr m^2)

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Results – comparison against GLM

Session	Level 1b ADP	Level 2 ADP	Level 2 FDE	Level 2 FFAR	Level 2 det. thld.
`016 day`	0.11 ± 0.03	0.09 ± 0.03	0.56 ± 0.18	6 ± 4 1/(sec OC)	≈ 15 µJ / (sr m^2)
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GLM performances **against FEGS over the US and for 6am – 6pm local times** (link to the reference):

- Strong storm-by-storm variability
- Difficult to compare LI ADP and GLM pulse DE due to the differences between the GLM storm sample and simulation settings
- Average **GLM FDE of 61%**; if one considers all the OCs from the day session and OC1, 2, and 4 from the `half` one, the average **LI FDE is 60% (over the whole FOV → fairly conservative assessment)**
- The **GLM detection threshold is 10 µJ / (sr m^2)** (Dr Mason Quick private communication, wrong plot in the link)

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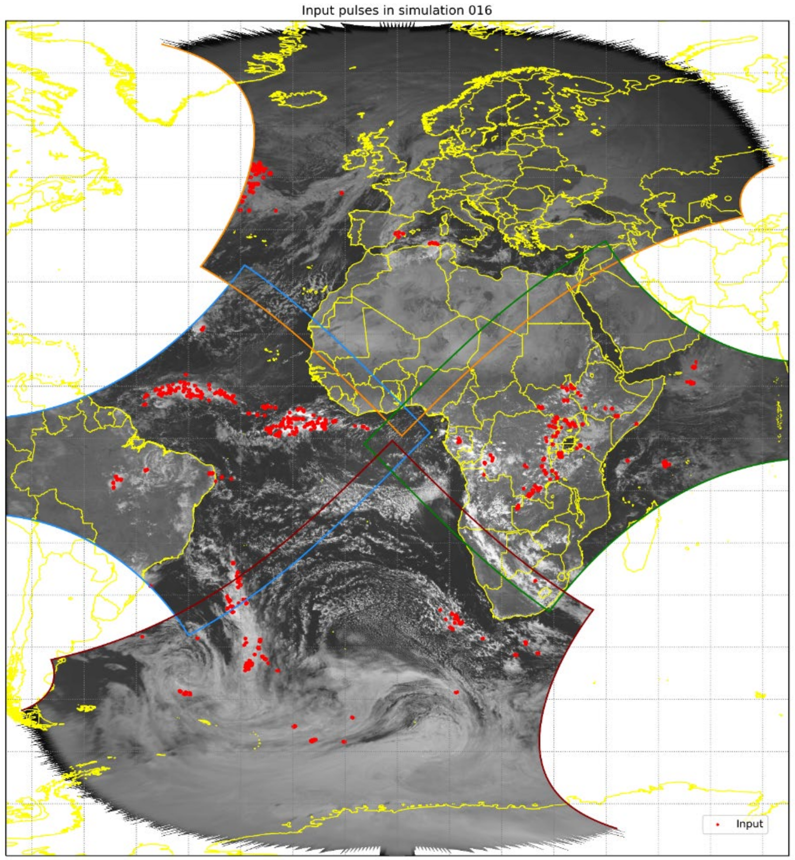
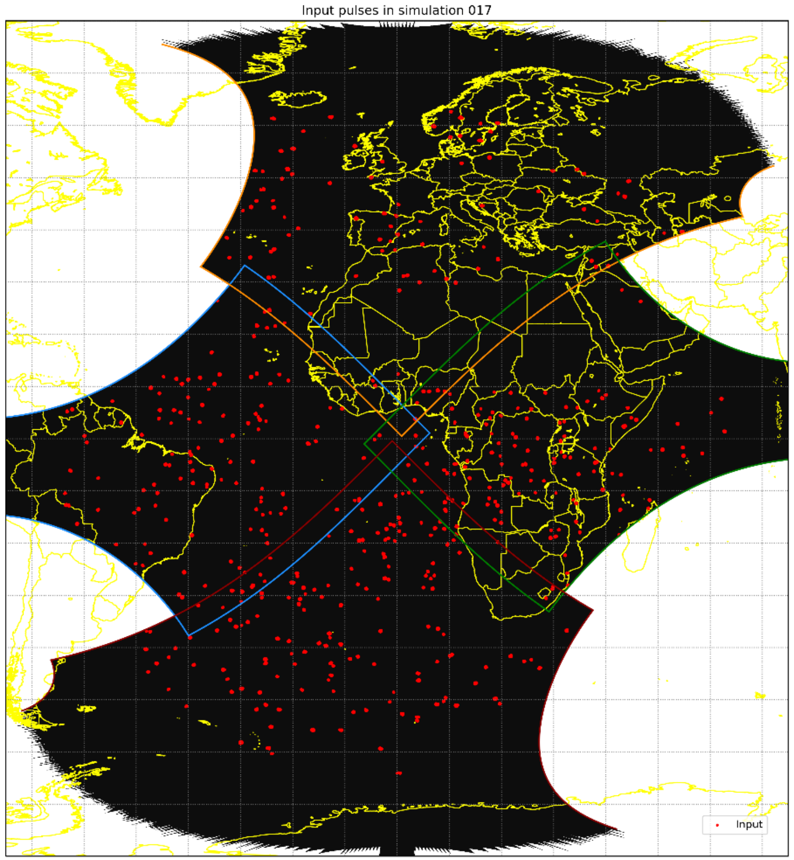
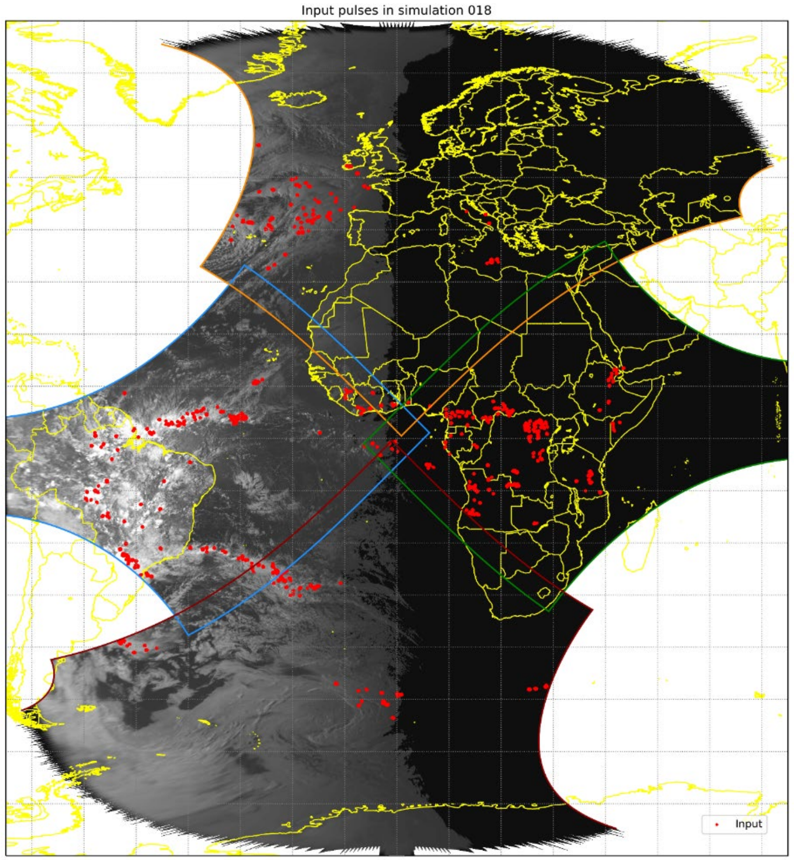
Analysis assumptions and inputs







7am 12pm 5:30pm

201110291212

7pm 12am 5:30am

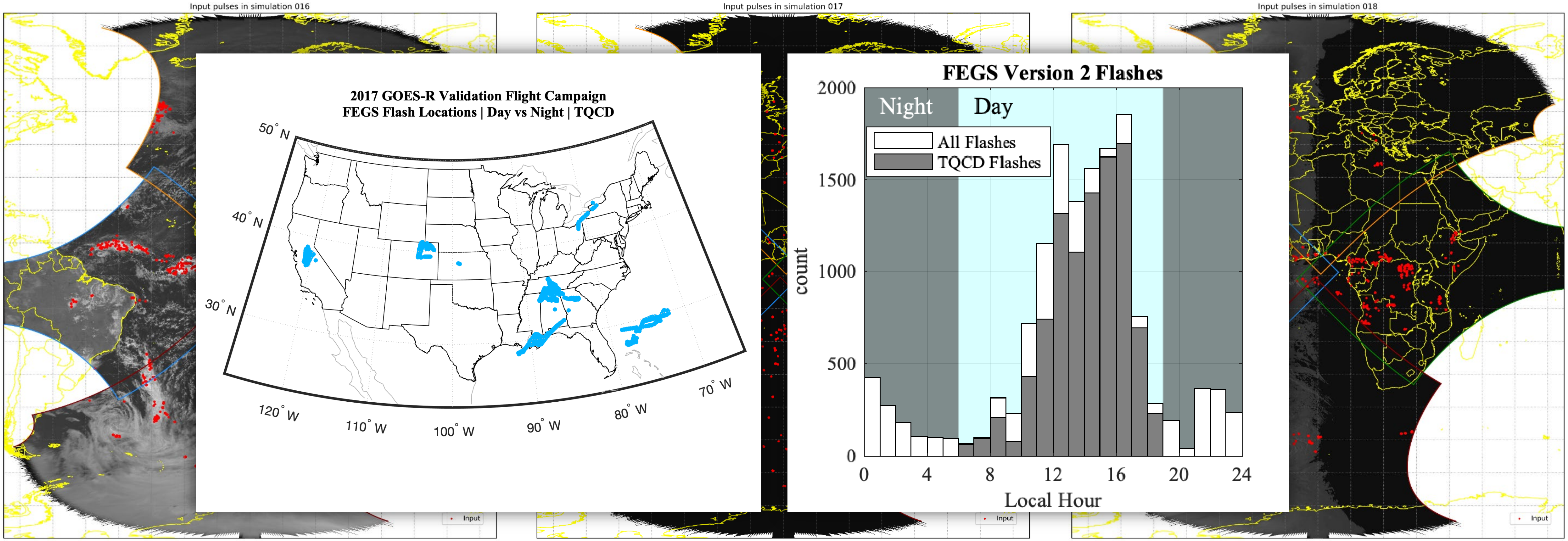
201303200012

1pm 6pm 11:30pm

201303201812

Red dots are input pulses

Analysis assumptions and inputs



7am 12pm 5:30pm | 7pm 12am 5:30am | 1pm 6pm 11:30pm

201110291212 | 201303200012 | 201303201812

Red dots are input pulses

EUMETSAT

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- The **GLM detection threshold is 10 µJ / (sr m^2)** (Dr Mason Quick private communication, wrong plot in the link)

GLM performances **against the Kennedy Space Flight Center (Florida) LMA** (link to the reference):

- Strong storm-by-storm variability
- Average **GLM FDE over 24h of 74%**; if one considers the results at a distance of about 3000 km from SSP one gets a day-night variation of the **LI FDE between 60% and 90% (average of 75%)**

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Discussion – 1/2

- Despite the good FDE, OC-based Level 2 filtering settings is too coarse and works well only in fully illuminated or dark conditions while it does not address the challenges arising from changing illuminations within the OC → **filtering settings in illumination-dependent LUTs could be employed for FDE improvement**

- Visible impact of the viewing geometry on ADP and FDE → **there is the need of producing complementary results that could lead to the computation of ADP and FDE maps, i.e., maps providing the expected performances as a function of the position in the FOV and scene brightness/reflectance**

- **There still margin for improvement in the modelling of the flashes**:
  - I. one could account for temporal evolution of flash properties whose impact on detection performances of lightning imagers has been presented in this publication link
  - II. one could try to model the elongation of flashes

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Discussion – 2/2

What about the expected in-flight performances?

- **The performance assessment against key reference ground networks for LI, i.e., GLD360 and EUCLID (key references over Europe) will provide us with much higher FDE**. In fact, both networks are expected to provide us with only part of the lightning activity and to favor the detection of CG lightning events. LI is expected to detect a large fraction of the IC + CG (complete) lightning activity.

Future work

- The LI Reference processor will allow EUMETSAT to assess the impact of typical stray-light patterns provided by industry on the Level 2 performances at night-time (July 2020)

- The LI Reference processor will be employed for the definition of the LI detection efficiency map that will be provided to users to have a qualitative idea of the expected Level 2 performances at different position in the FOV and for different illumination conditions

- The LI Reference processor will be employed to define SZA-dependent LUTs for the Level 2 filtering parameters

- Further improvement in the modelling of input flashes must be considered, this will enable the computation of additional/complementary results

Conclusions

- The assessment of the LI Level 2 expected performances has been performed by means of:
  I. The up-to-date EUMETSAT LI Reference Processor which is the most realistic representation currently available of the LI detection and filtering end-to-end chain
  II. The use of realistic modelling of pulses and flashes as input to the simulations. The inputs have been defined exploiting state-of-the-art data characterizing optical pulses from lightning detected from space by FEGS and LIS. In particular, the use of the pulse radiance from FEGS allowed us to account for the dominating component of lightning activity with pulse radiance below the minimum detectable energy of LI at night
  III. Three different illumination scenarios: full illumination conditions at noon, complete darkness at midnight, and transition from day to night. These are representative of the variation in illumination conditions over 24h
  IV. The up-to-date Level 2 filtering settings which account for the change of illumination conditions between the different OC for the three scenarios in III.

- A fairly conservative estimate of the LI Level 2 performances is in line with key GLM performance indicators measured over the US.

Acknowledgements

This work would not have been possible without the support of:

ESA
LI MAG forum
Dr Mason Quick
Dr Dennis Buechler
Prof Kenneth Cummins
Dr William (Bill) Koshak
Dr Phil Watts
Dr Kevin Barbieux
Dr Alessandro Burini