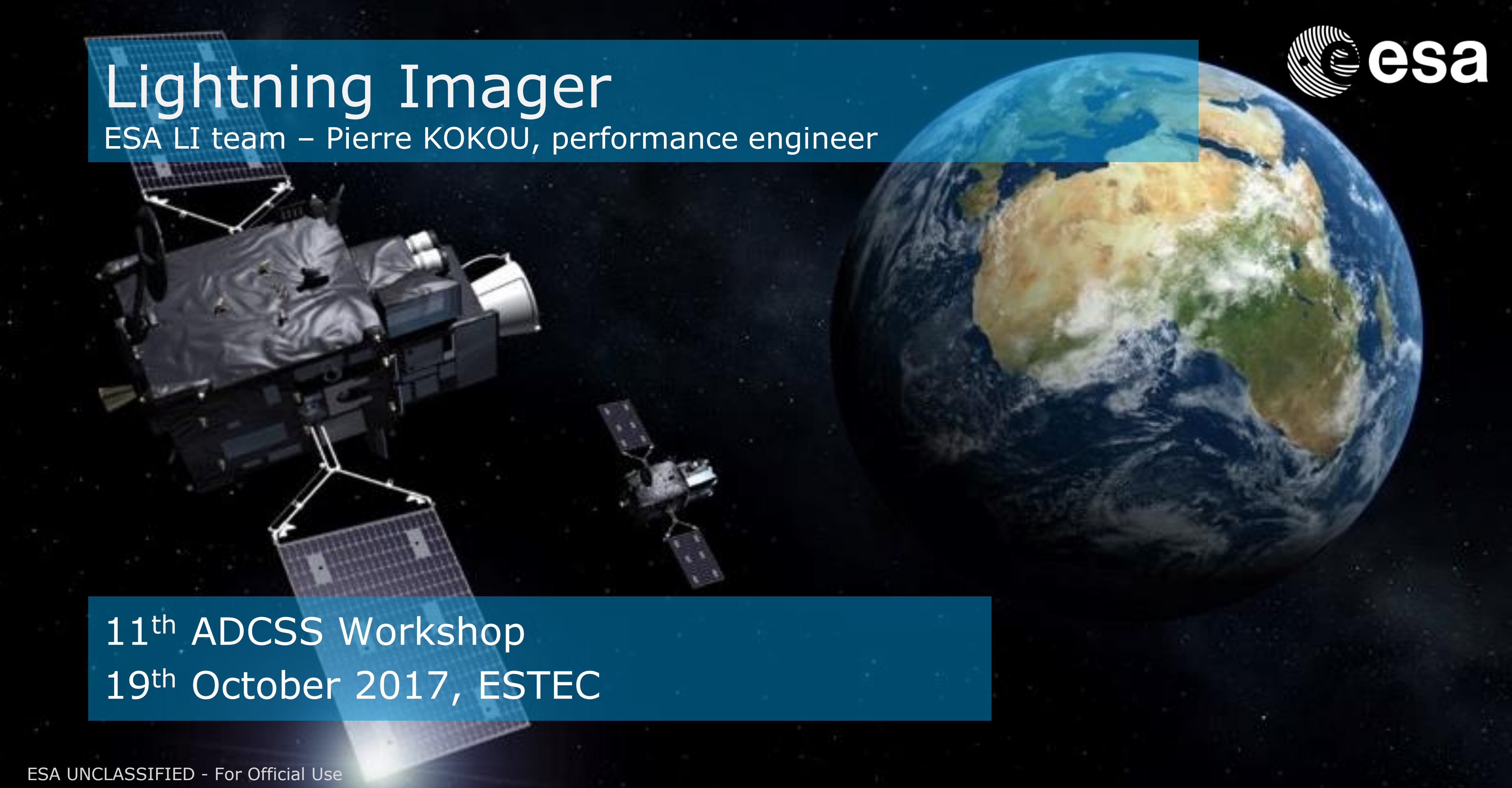
Lightning Imager

ESA LI team – Pierre KOKOU, performance engineer



11th ADCSS Workshop

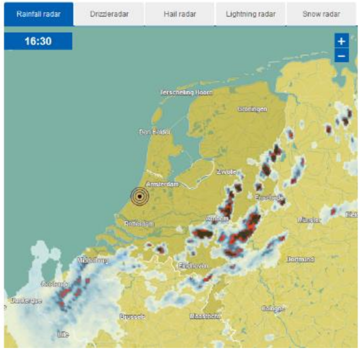
19th October 2017, ESTEC

Meteosat Third Generation (MTG) Lightning Imager (LI)

The Lightning Imager, aboard the MTG-I satellites, will bring full hemispheric near real-time lightning detection capabilities.

Applications

1. *Nowcasting* for lightning (*e.g.* for the aviation)
2. Early warning for severe weather events
3. Refine meteorological models
4. Other uses to be created by the user community…



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How to detect lightning from space?

1. Detection principle
2. Sources of false events

Why does on-board processing power matter?

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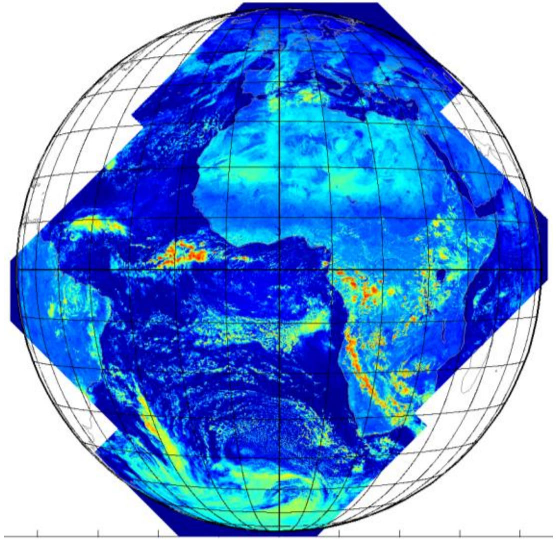
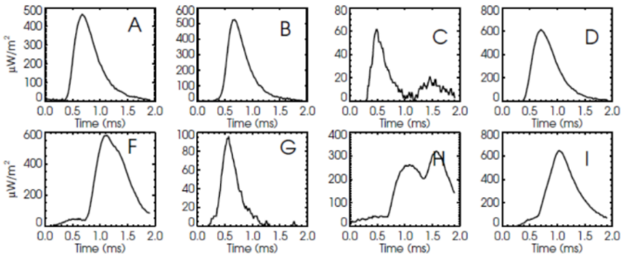
Detection principle: What does a lightning look like?

As seen from ground:

As seen from space:

Detection principle: main LI features





Constant observation of the same scene

- Satellite in GEO

Lightning have a specific spectrum

- Monochromatic observation in the 777.4 nm wavelength (neutral O)

Average footprint of lightning is ~90 km^2

- Size of pixel at SSP ~ 5 km
- 4.7 M pixels to cover the FOV

Lightning is short in time: ~1 ms

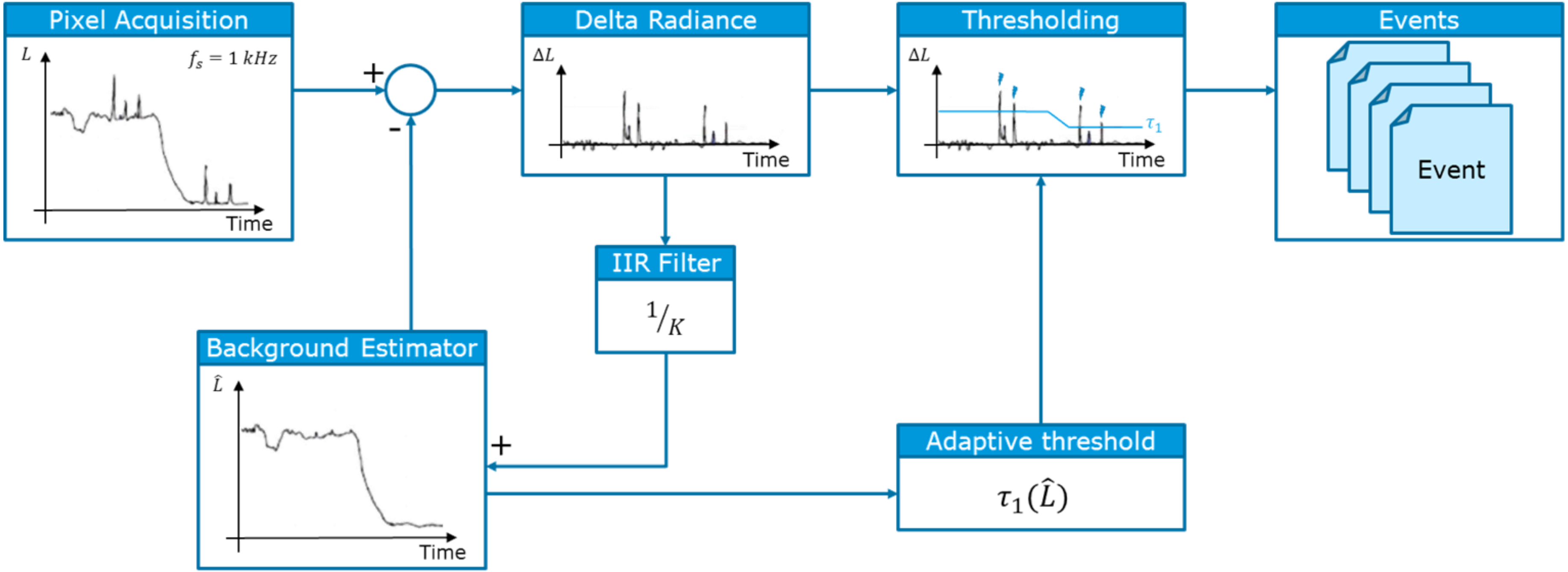
- Acquisition frequency = 1000 Hz

Lightning is a sudden peak of energy

- Need to detect a transient over a ~constant background

Detection principle: Real-Time Pixel Processor (RTPP)

For each pixel:



The 4.7 M pixels are processed every ms by 16 ASICs ATMEL 150 nm

Sources of false events

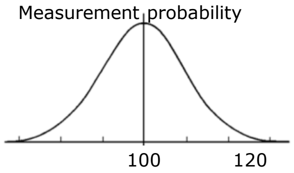
<u>Illustrative scenario:</u> *on pixel [x,y], the following radiances are measured:*

Time step	Radiance measured
T	100
T+1	120
T+2	100

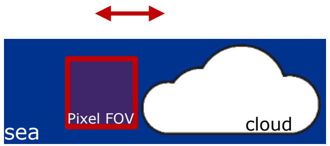
It's a true lightning event! → There was a pulse located on the pixel at time T+1

It's a false event, due to…

1) Acquisition noise: random noise in the radiance measured at time T+1 was very high and positive.



2) Micro-vibration (jitter): the vibrations of the satellite were such that, at time T+1, a brighter scene was observed by the pixel



T	100
T+1	120
T+2	100

3) Other sources: energetic particles, RTS, ghosts…

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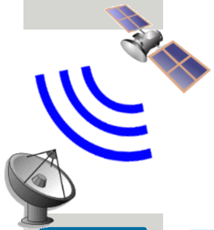
LI filters: long story short

	Name	Goal	Hardware
RTPP	Real Time Pixel Processor	Detection step – trigger events	ASIC
SDT	Single DT filter	Eliminate (noise) FEs	FPGA
MVF	Micro-Vibration filter	Eliminate (jitter) FEs	PowerPC
JR	Jitter Reconstruction	Reconstruct potential jitter to eliminate its contribution	On-ground processing centre
STC	Spatio-Temporal Coherency	Eliminate (noise) FEs that are alone in a [0.5s, 50km] radius	
…	Other filters	Eliminate FEs due to noise, particles, RTS, ghosts…	



Filtering algorithms purpose:

- reduce the number of false events (FEs);
- while keeping most of the true events (TEs).

LI filters: Single DT filter (SDT)

RTPP

SDT

MVF

JR

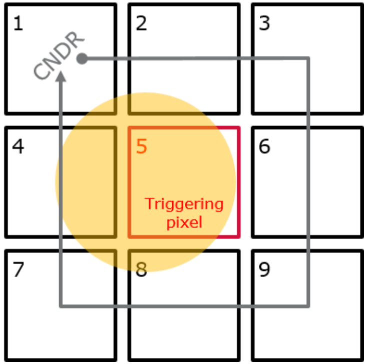
STC

...

Goal: eliminate "1-pixel" false events

A pulse is likely to illuminate multiple adjacent pixels.

If the pixels around the central pixel having generated the event do not have *enough* extra energy, then the event is discarded.

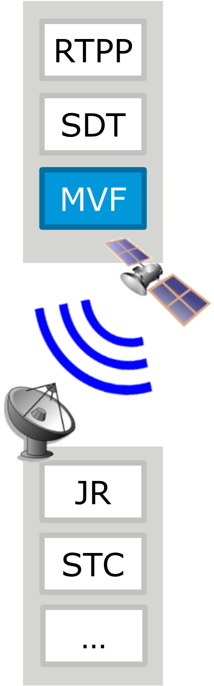


$$CNDR = \sum_{i=1,\, i\neq 5}^{9} \Delta L_i < \text{threshold} \Longrightarrow \text{event is discarded}$$

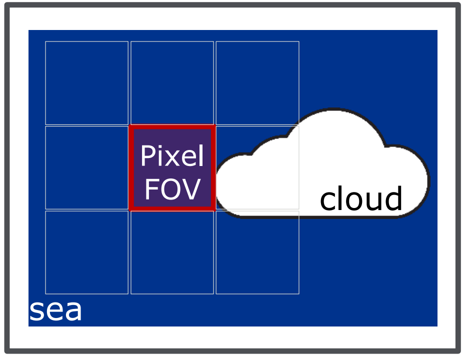
CNDR = Cumulative Neighbouring Delta Radiance

This algorithmic step is executed on FPGA RTAX 2000

LI filters: Micro-Vibration Filter (MVF) [1/2]

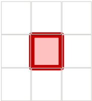


Goal: eliminate jitter false events with large gradient

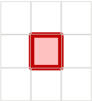


$\|\nabla L_{Bkg}\|$ ➔ Gradient ~ measure of variation around the central pixel

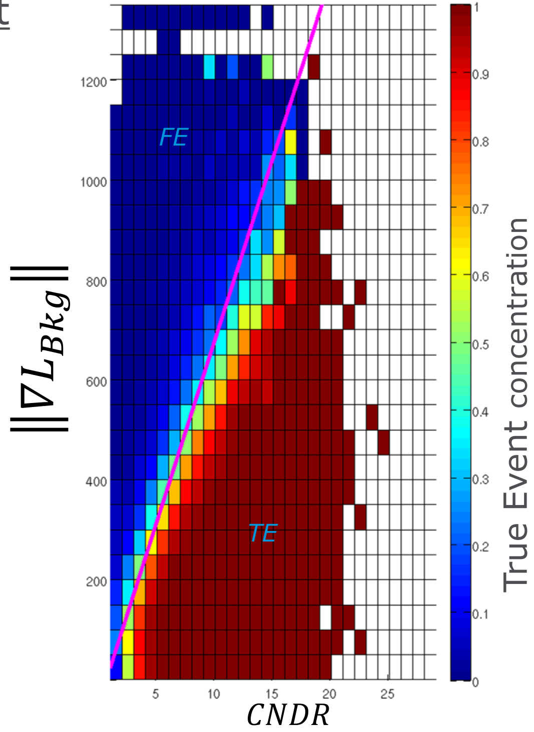
$$G_x = \begin{pmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{pmatrix} *$$



$$G_y = \begin{pmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix} *$$



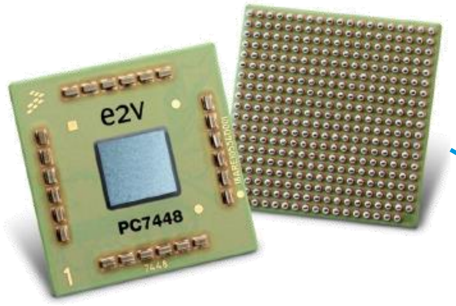
$$\|\nabla L_{Bkg}\| = \sqrt{(\boldsymbol{G}_x^2 + \boldsymbol{G}_y^2)}$$



LI filters: Micro-Vibration Filter (MVF) [2/2]

PowerPC 7448 [e2V] (Freescale 90nm SOI) @ 960 MHz

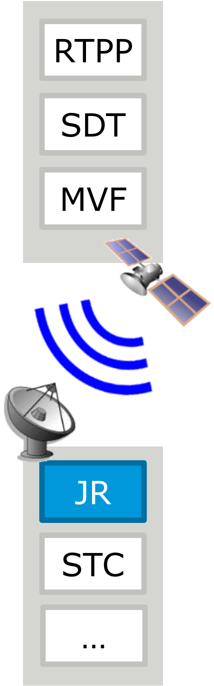
- Performance 2.3 MIPS / MHz (Dhrystone 2.1) 2300 MIPS @ 1 GHz- 32 KB L1 cache for
- Instructions: instruction parity protected
- 4 Integer Units (IUs) / A 5-stages Fully IEEE Compliant FPU (single/double precise ops)
- 32 KB L1 cache for Data / 1 MB L2 cache ECC protected
- 4 Vector units (SIMD machine) AltiVec™



Part of the Single Board Computer (SBC) developed by TAS-I

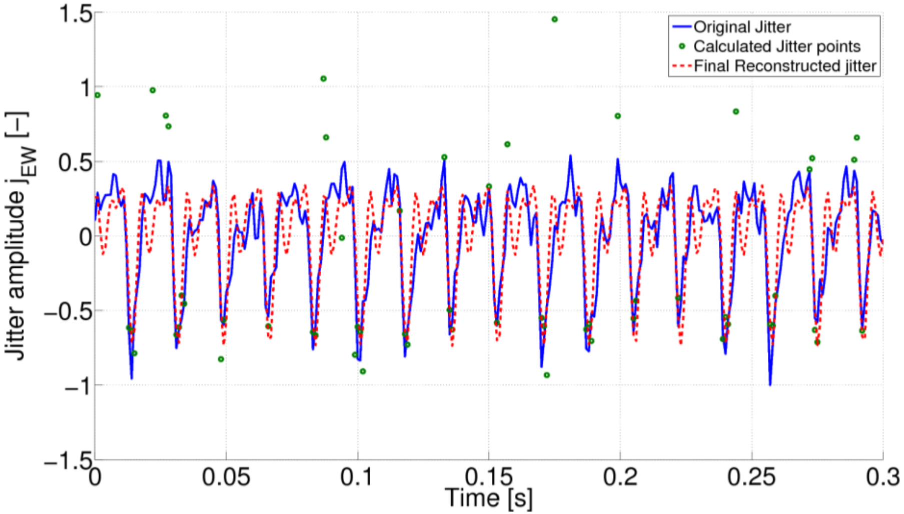
The SBC also executes other tasks: clustering, packetizing…

LI filters: Jitter Reconstruction (JR)



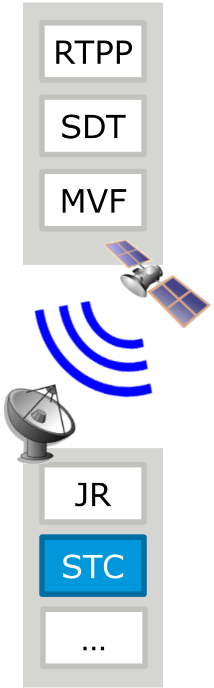
Goal: reconstruct the vibration to remove its contribution

The events can be analysed to estimate *a posteriori* what was the jitter of the satellite, and hence remove the potential contribution to the signal.



$$\Delta L(t) = \Delta L_{jitter} + \Delta L_{noise} + (\Delta L_{pulse})$$

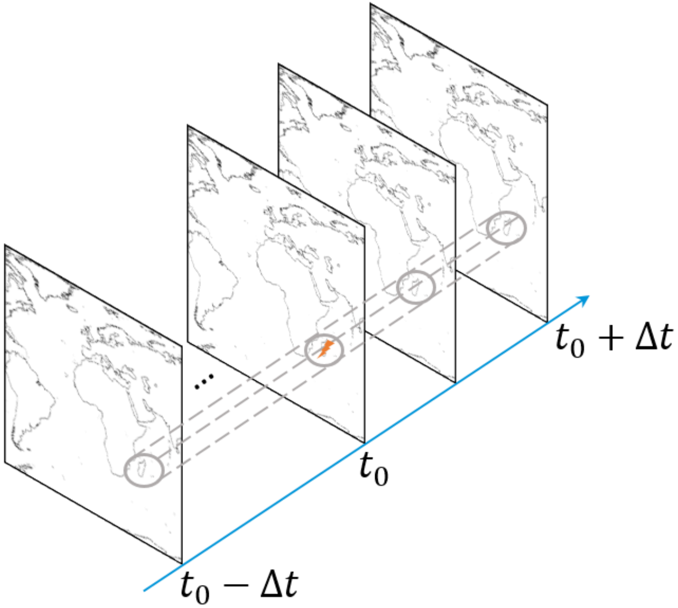
LI filters: Spatio-Temporal Coherency (STC)



Goal: eliminate isolated false events

Lightning occur in groups.

If an event is alone in time and space, it's probably a false event



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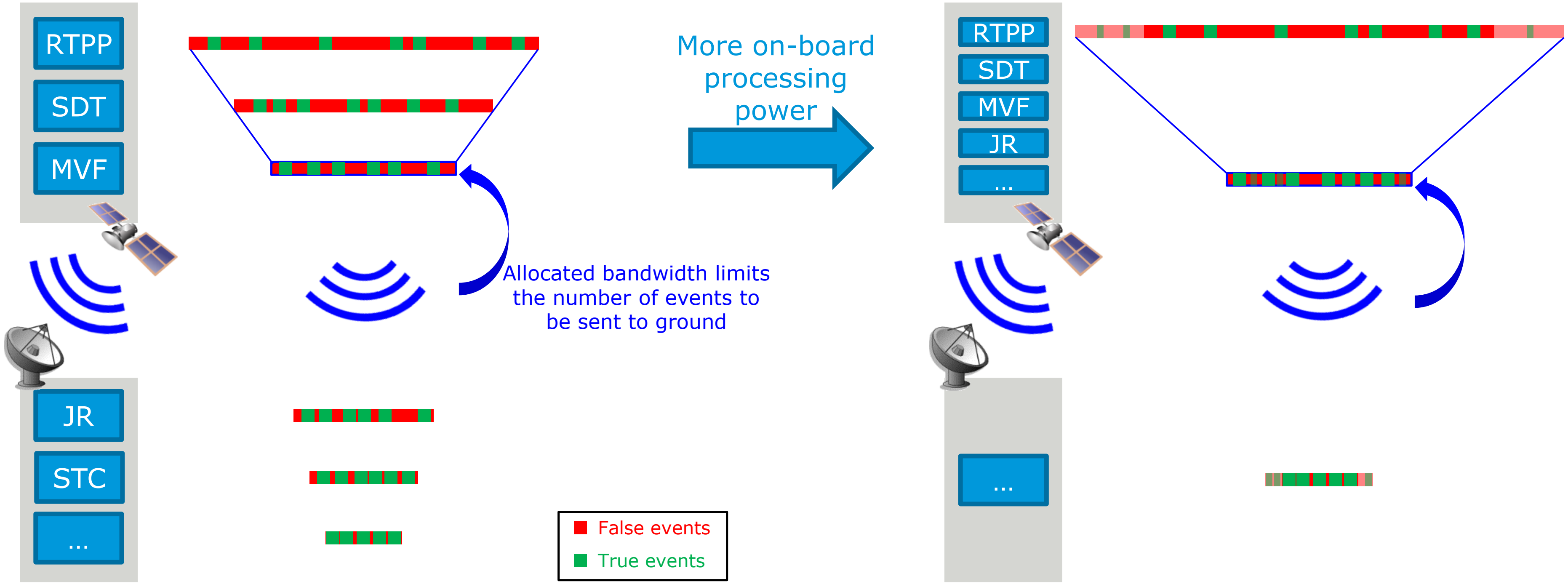
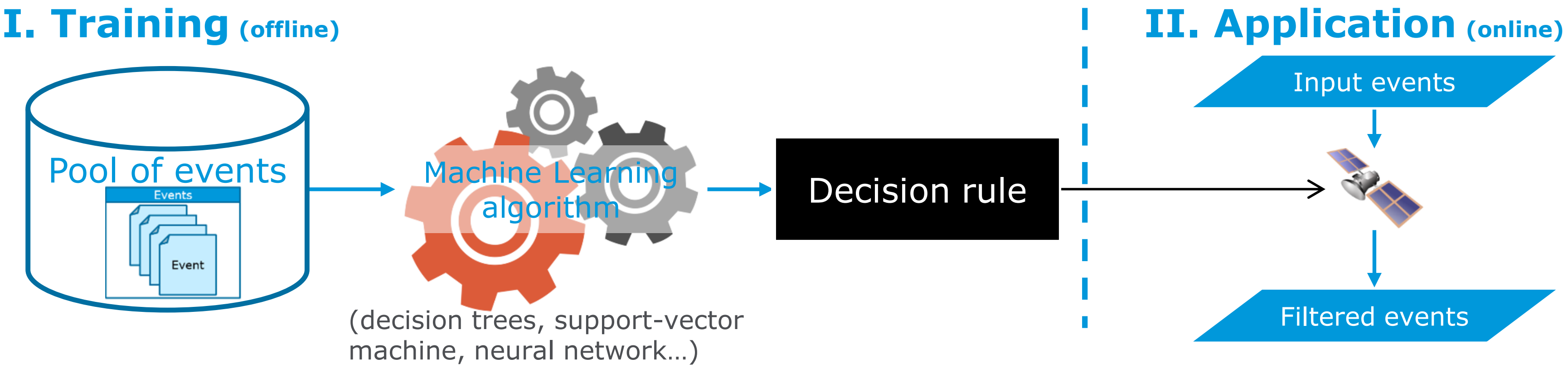
Trade-off on-board processing power



More processing power means more/better filtering on-board, so that more events can be processed on-board
➔ detection threshold can be lowered to try to detect weaker lightning pulses

A glimpse about potential future developments

- Once the first LI is flying, one could imagine use machine learning on a batch of cross-verified true events to find new & more effective ways to distinguish true events from false events.



- Once a new decision rule has been found, it has to be checked that on-board processing hardware capable of executing it is available.
  - ➢ Need for dedicated hardware architecture?
    (e.g. processing unit developed to specifically execute neural networks => check *TPU* and *AI accelerator* on wikipedia)

Thanks for your attention!

Questions? Now or at the coffee break?