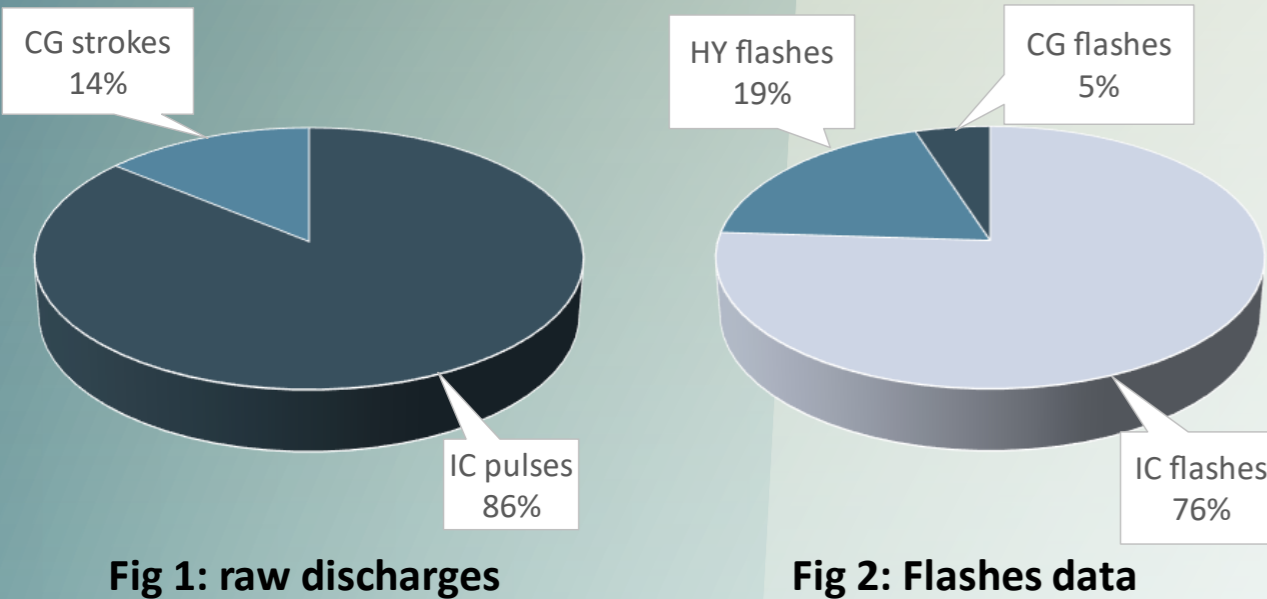


ANALYSIS OF THE INTRA-CLOUD LIGHTNING ACTIVITY DETECTED WITH LOW FREQUENCY LIGHTNING LOCATING SYSTEMS

Stéphane Pédeboy¹; Paul Barnéoud¹; Eric Defier²; Sylvain Coquillat²
¹Météorage (France), ²Laboratoire d'Aérodologie (France)

Context

In 2017, **Météorage**¹ detected about 4.3 million discharges out of which **86% are IC pulses**. After grouping these data in 1.3 million flashes, **94% exhibit at least one IC pulse**.



IC pulse: individual Intra-Cloud (IC) discharge
CG stroke: individual Cloud-to-Ground (CG) return stroke
IC flash: group of only IC pulses
CG flash: group of only CG strokes
HY flash: group of both IC pulses and CG strokes
 (1) see "Instruments and Data" section

Objectives

The tremendous set of IC lightning data detected by Météorage need to be analyzed to determine the :

- Origin** of the IC pulses
 - Initial and Preliminary Breakdown (IP/PB)
 - K-changes
- Occurrence** of IC pulses in flashes (statistics)
- Detection Efficiency** (DE_{ICF}) of IC flashes
- Location Accuracy** (LA_{ICP}) of IC pulses

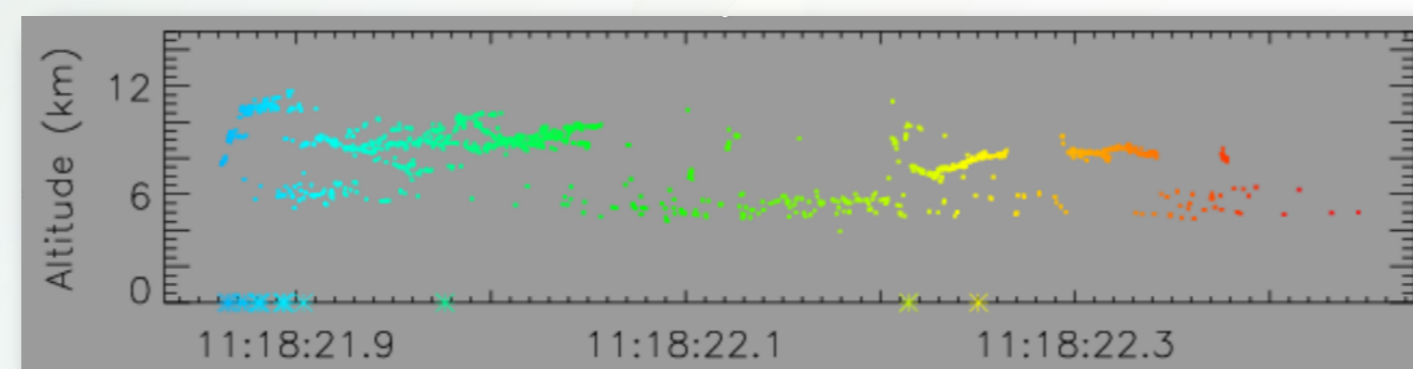


Fig 3: Example of Total Lightning Flash data

It shows the altitude of the VHF sources (Y axis) as a function of the time (X axis). The crosses on the X axis are the LF data in 2D. This flash is a single stroke +CG flash of 21 kA exhibiting 14 +IC pulses, 3 prior the return stroke and 11 after.

Instruments and Data

Météorage is the French national Lightning Locating System (LLS) operating Vaisala's Low Frequency (LF) lightning detection technology. Individual IC pulses and CG return strokes are grouped in flashes according to spatial-temporal criteria leading to :
 - **LF IC** and **LF CG flashes**, respectively made of IC pulses or CG strokes only,
 - **LF Hybrid (HY) flashes** resulting from a combination of IC pulses or CG strokes.

SAETTA is a Lightning Mapping Array (LMA) made of 12 stations deployed across Corsica and operated by the Laboratoire d'Aérodologie. The VHF and LF data are combined in **Total Lightning Flashes (TLF)** according to spatial-temporal criteria resulting in 4 types of events :

- TLF IC flashes without CG stroke
- TLF CG flashes without IC pulse
- TLF HY flashes with both IC pulse and CG stroke
- Flashes free from any located LF IC or CG data (FICG).

Results

Rate of the different type of flashes

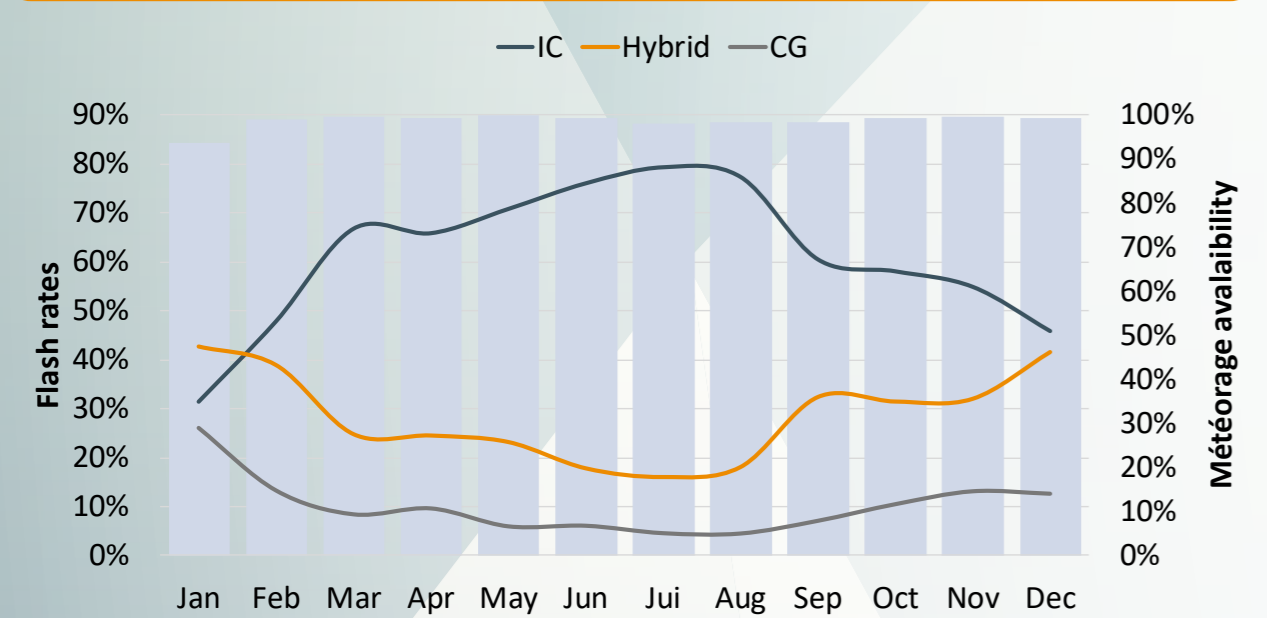


Fig 4: Monthly distributions of the percentages of IC, CG and Hybrid flashes in respect to the total amount of flashes detected by Météorage in France in 2017. The blue bars show the monthly Météorage availability (right vertical axis).

The curves show a clear seasonal effect related to the different type of thunderstorms occurring between winter and summer.

Evolution of the DE_{ICF} in time

The DE_{ICF} is computed based on the assumption that Météorage detects 100% of CG/HY flashes. All these flashes are removed from the TLF dataset in order to keep only the IC and the FICG flashes. The ratio $IC/(IC+FICG)$ gives the DE_{ICF} .

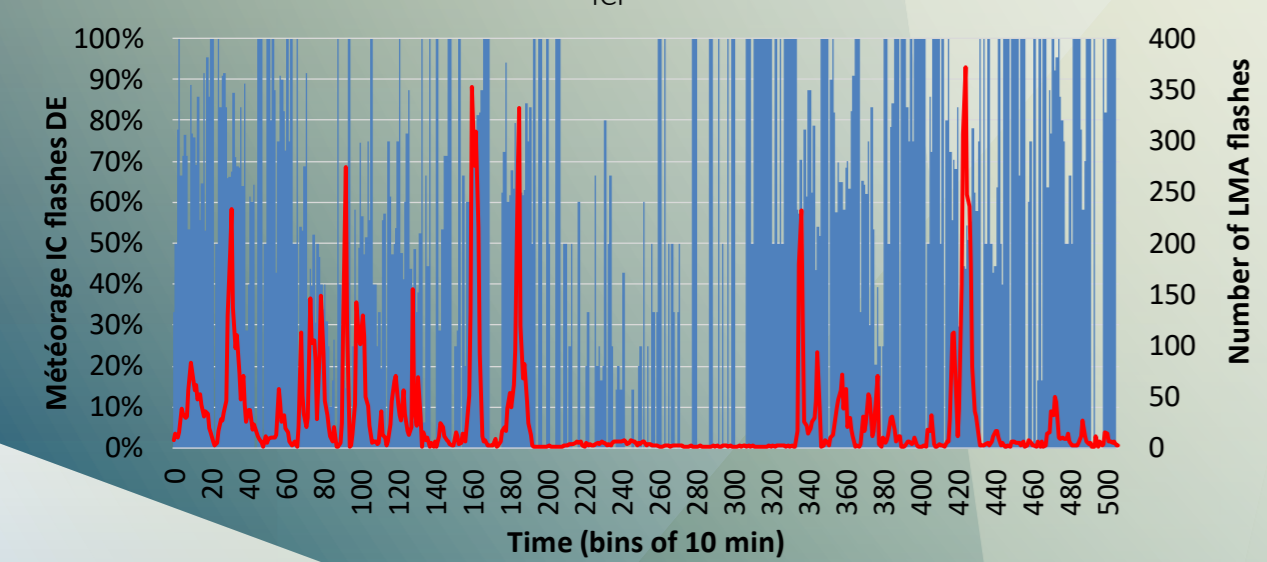


Fig 5: Evolution of the IC flashes DE for Météorage on the total period of SAETTA observations. The blue bars represent the IC DE per 10 minutes bins representing 19 thunderstorm days and refer to the left axis.

DE_{ICF} ranges between 7% to 100% with a mean value of **56%**. The vertical extent of IC flashes is crucial for the detection. A limit is estimated around **2.7 km**.

Statistics on IC pulses

Table 1 – Statistics on IC pulses

	IC pulses PRIOR first return stroke		IC pulses BETWEEN return strokes		IC pulses AFTER last return stroke	
	+HY flashes	-HY flashes	+HY flashes	-HY flashes	+HY flashes	-HY flashes
Nb of IC pulses	2.9	2.4	2.7	2.1	3.5	2.4
Inter IC pulses delay (ms)						
Mean/Stdev	60541/45/180	214583/59/192	2727/20/43	31955/38/60	11844/46/80	45962/60/91
Median	7	14	5	13	11	17
Separation delay (ms)						
Number of data	9565	69583	1519	24560	NA	NA
Mean/Stdev	99/116	122/124	38/62	77/91	NA	NA
Median	54	82	13	43	NA	NA
Duration (ms)						
Number of data	4709	38005	5700	88633	NA	NA
Mean/Stdev	157/164	194/177	32/66	55/80	NA	NA
Median	102	147	6	23	NA	NA

Inter IC pulse delay: time between subsequent IC pulses

Separation delay: time between last/first IC pulse and first/previous stroke

IC pulses Location accuracy (LA_{ICP})

LA is computed as the horizontal distance between a given IC pulse and its closest time correlated VHF source (1 ms max). The median delay is 0.3 ms.

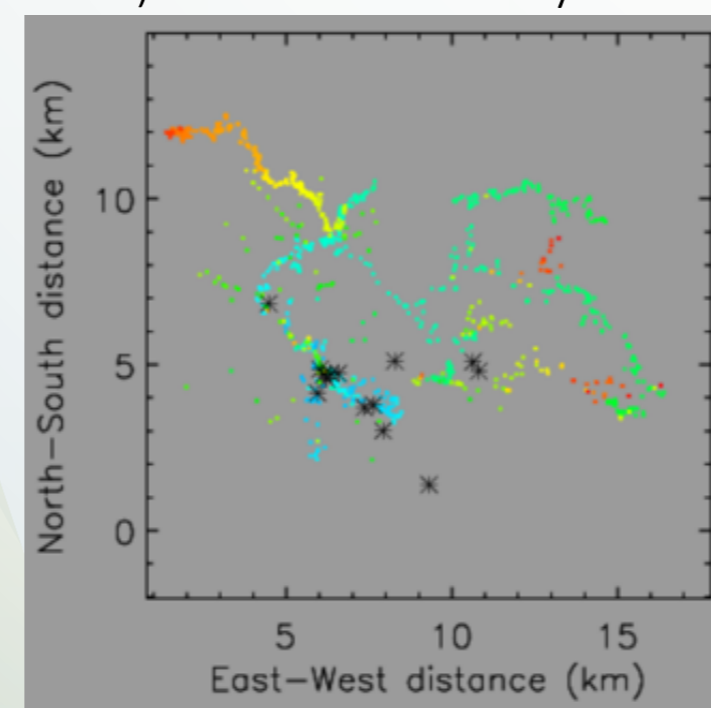


Fig 6: Horizontal plan view showing the location of LF data (black stars) in respect with the lightning horizontal projected path as detected by SAETTA (in colors).

LA_{ICP} is 1.64 km (median) and 3.0 km (mean). The number of sensors detecting IC pulses is crucial for a good LA . However some events detected by a large number of sensors exhibit big errors...

Discussion

Rate of CG flashes exhibiting a PB phase: 70% in our study to be compared to 60% [Wooi et al.] and 89% / 71% [Schulz and Diendorfer].

Flash starting with IC pulse of the same polarity as the first return stroke: 70%-HY / 66% +HY to be compared to 80%-95% from [Ushio; Gomes and Cooray; Zhang et al.; Schuman et al.; Nag and Rakov].

Delay between PBP/1st return stroke: 99 ms (+HY) and 122 ms (-HY) in our study to be compared to 99 ms from [Zhang] positive flashes.

Inter stroke IC pulses delay: 14 ms in our study to be compared to 18 ms from [Miranda] and 12 ms from [Thottappillil].

Our results are comparable to those from other authors using different measuring systems. We suspect Météorage is likely to have a DEICP issue related for weak IC pulses.

Conclusion

About **94%** of the total flashes observed by Météorage exhibit in average :

2.6 IC pulses in IC flashes

3.0 IC pulses in HY flashes with a maximum of 6.1 and 4.1 for respectively +HY and -HY flashes.

Most of the IC pulses detected by Météorage in HY flashes occur **prior the first (47%)** and **after last (40%)** strokes.

Our statistics are in good agreement with results found in literature demonstrating the capability of LLS like Météorage to deliver **reliable IC lightning data**, despite some limitation in IC pulse DE.

The performances of Météorage for IC detection are:

LA_{ICP} is 1.64 km (median) and 3 km (mean).

DE_{ICF} is 56% (mean) strongly affected by the vertical extent of the flash (e.g. 2.7 km in Corsica)

Acknowledgement

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