

From Flash to Footprint: Mapping Ground Strike Points with Precision

Dieter Poelman

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From Flash to Footprint: Mapping Ground Strike Points with Precision

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|-------------------------------|----------------------|
| I. Setting the Stage | IV. GSP Algorithms |
| II. Why GSPs Matter | V. LLS-derived GSPs |
| III. GSPs in High-Speed Video | VI. Takeaway Message |

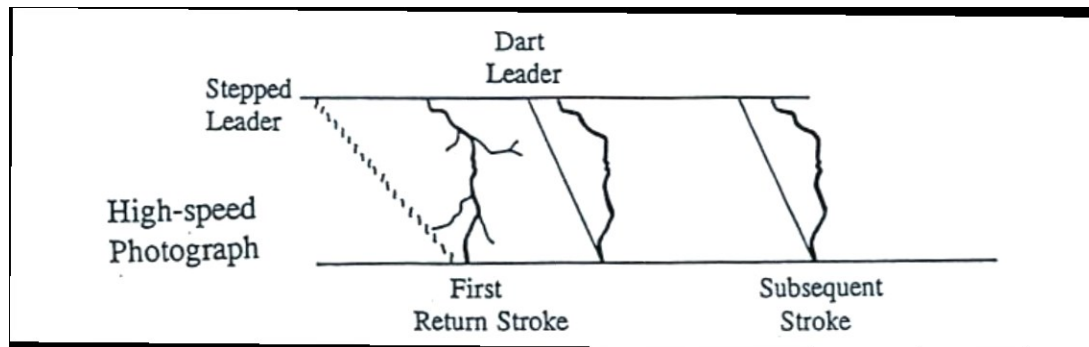
I. Setting the Stage

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(APL 2025)

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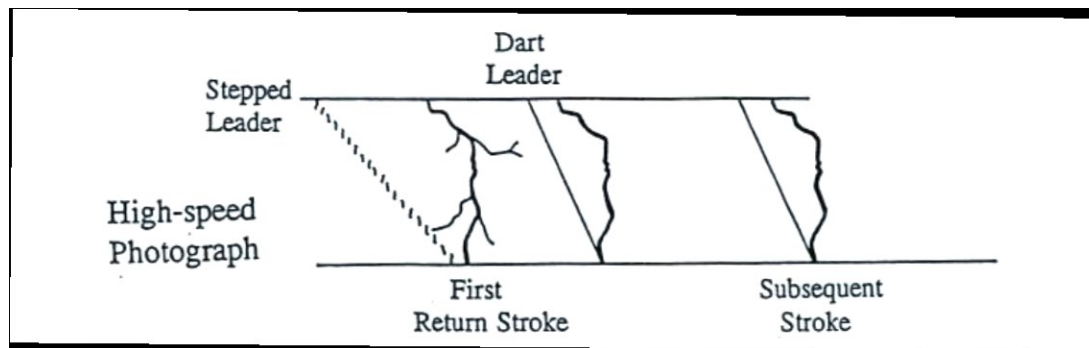
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Based on Krider lecture (www.atmo.arizona.edu)



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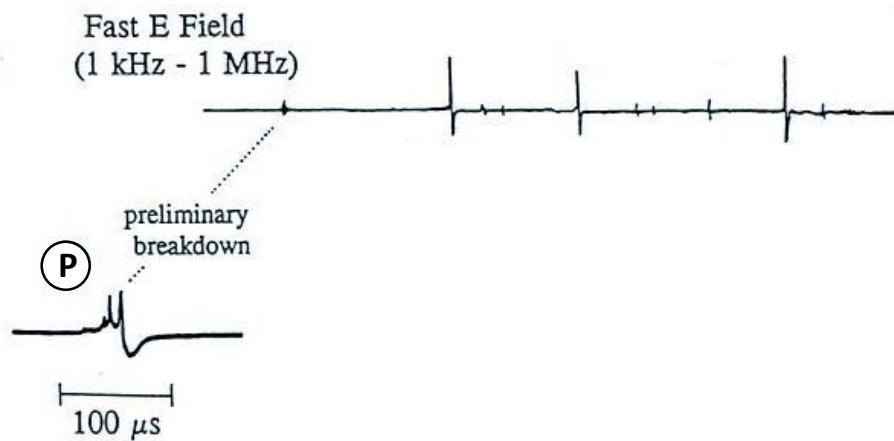
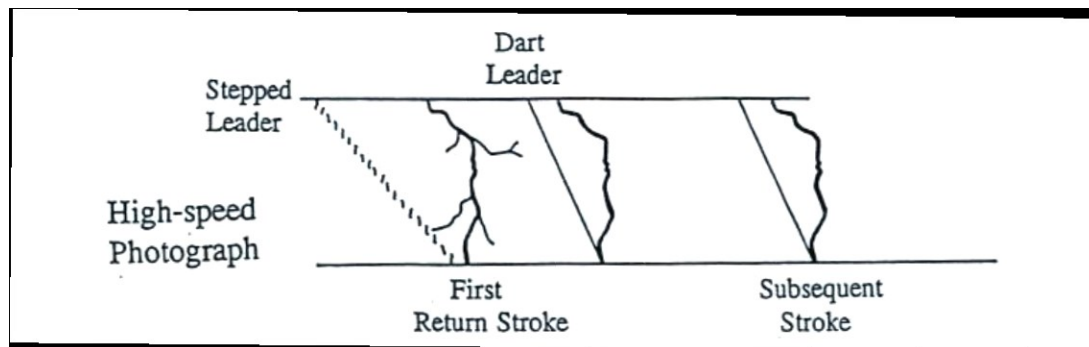
Fast E Field
(1 kHz - 1 MHz)



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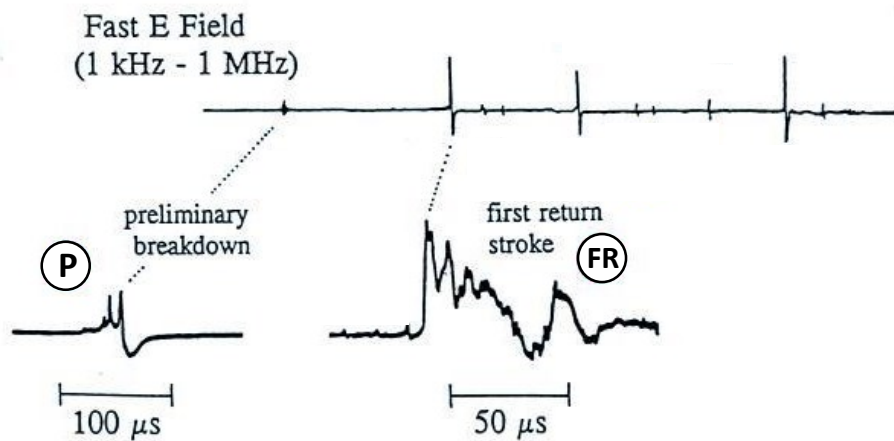
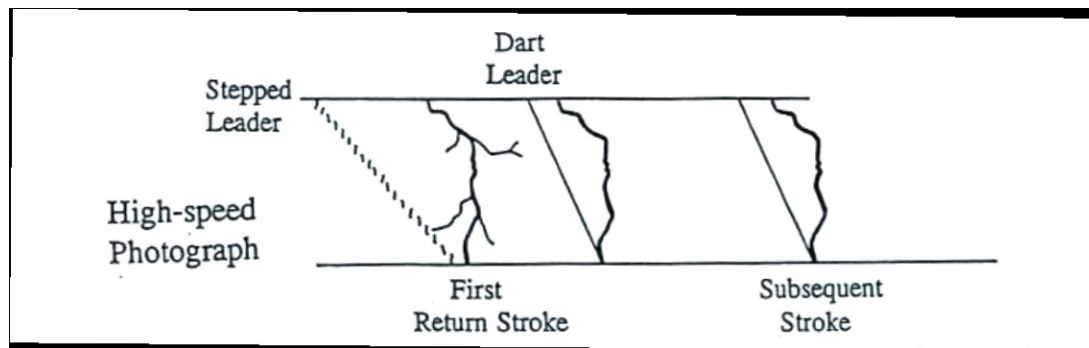
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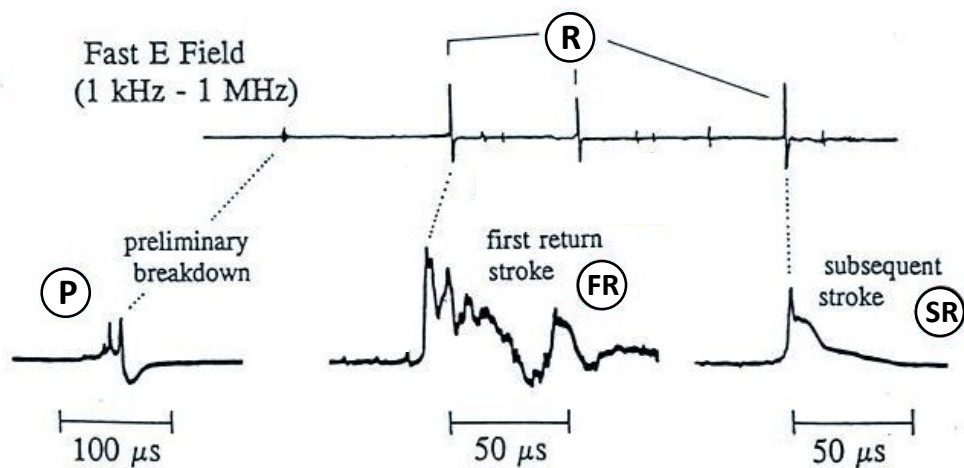
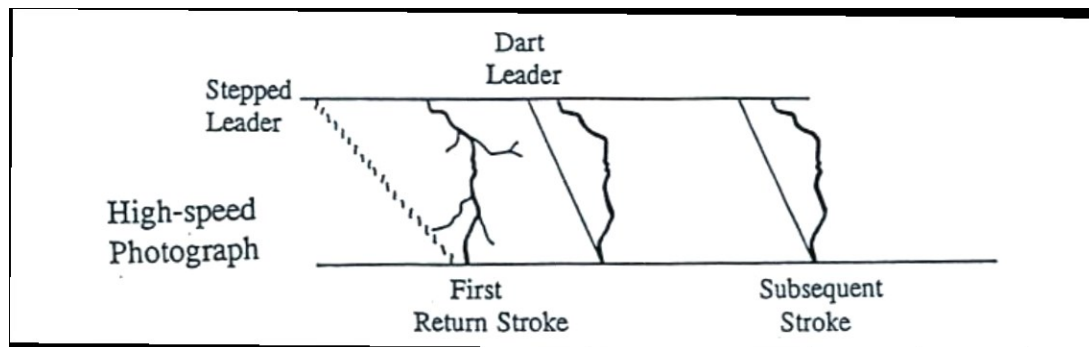
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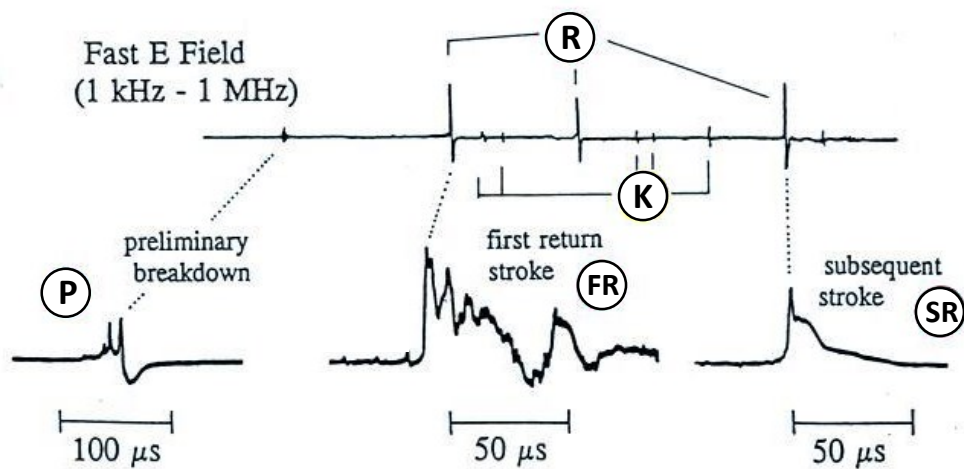
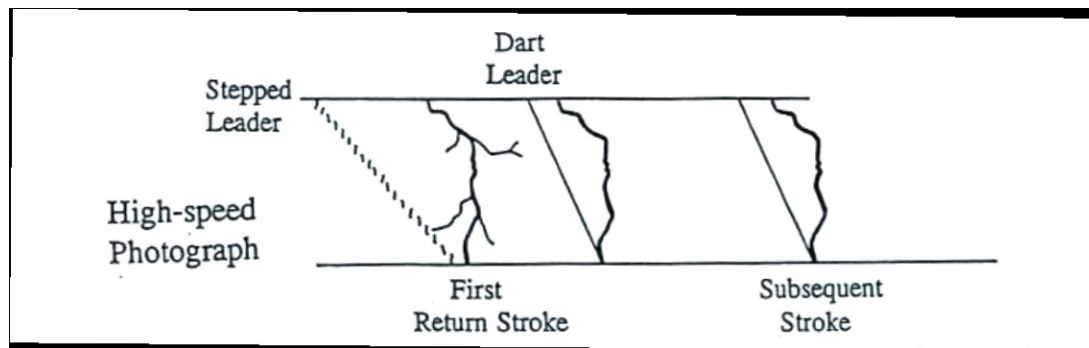
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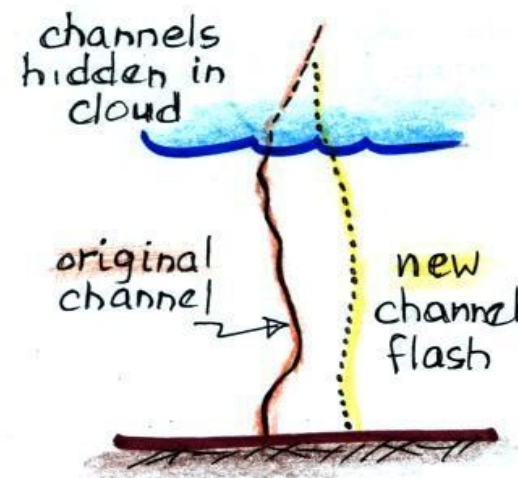
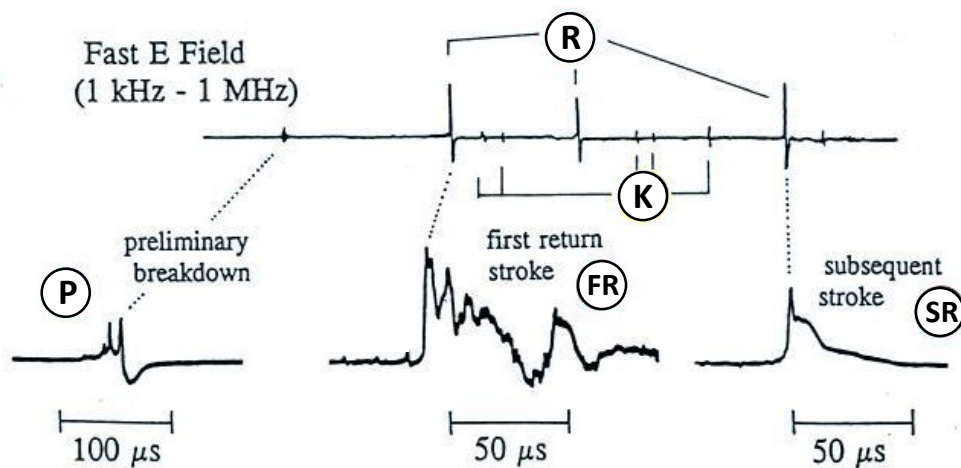
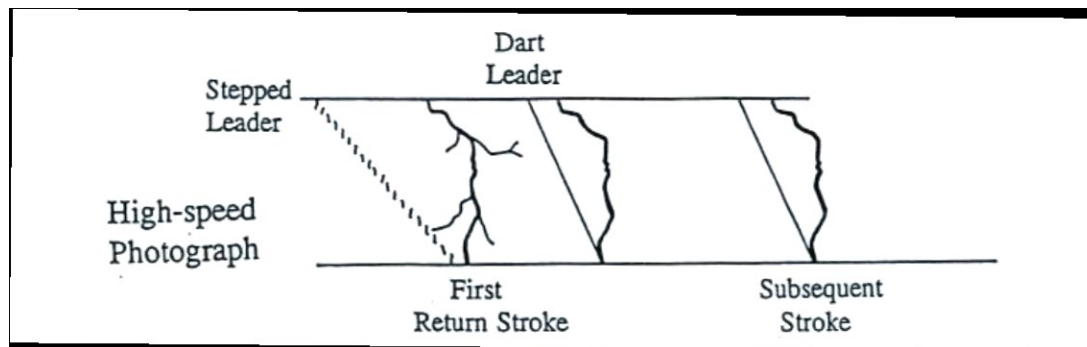
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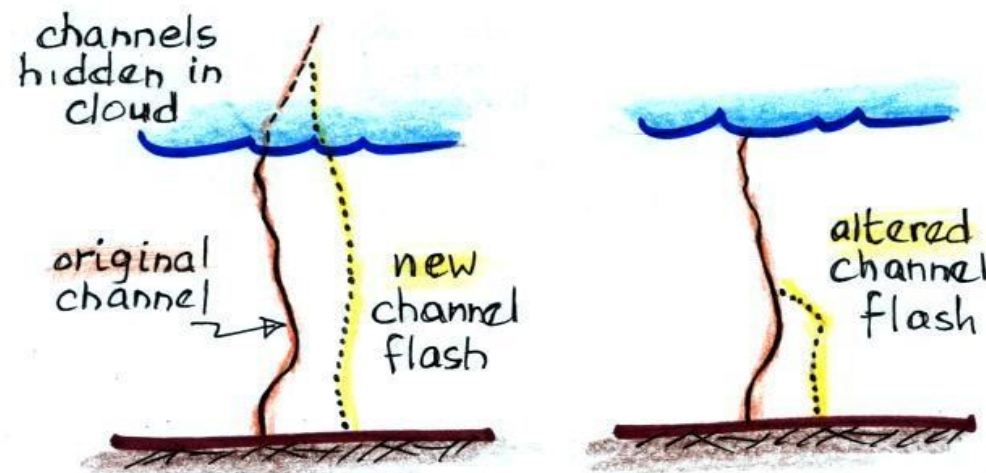
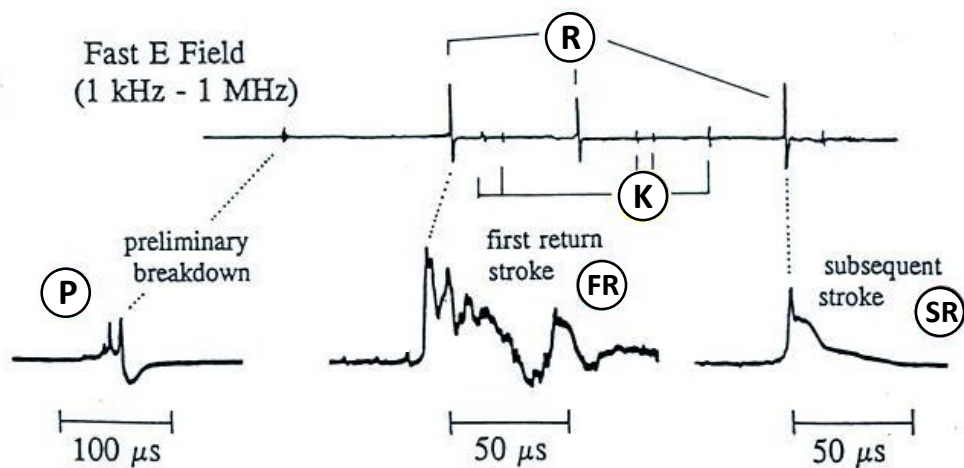
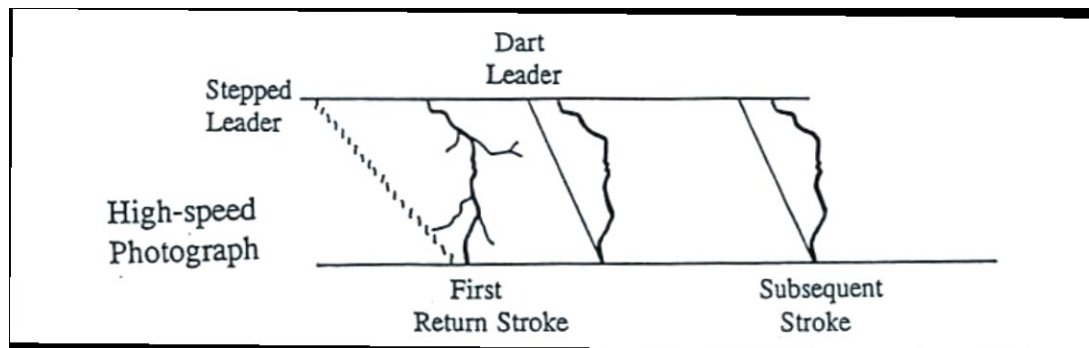
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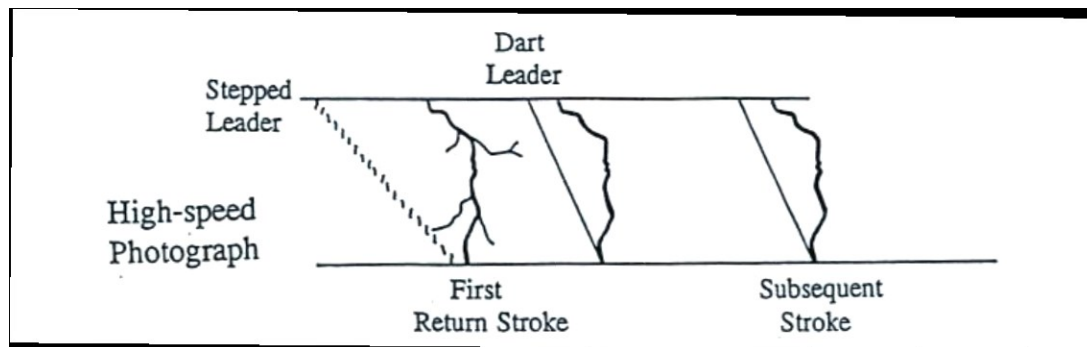
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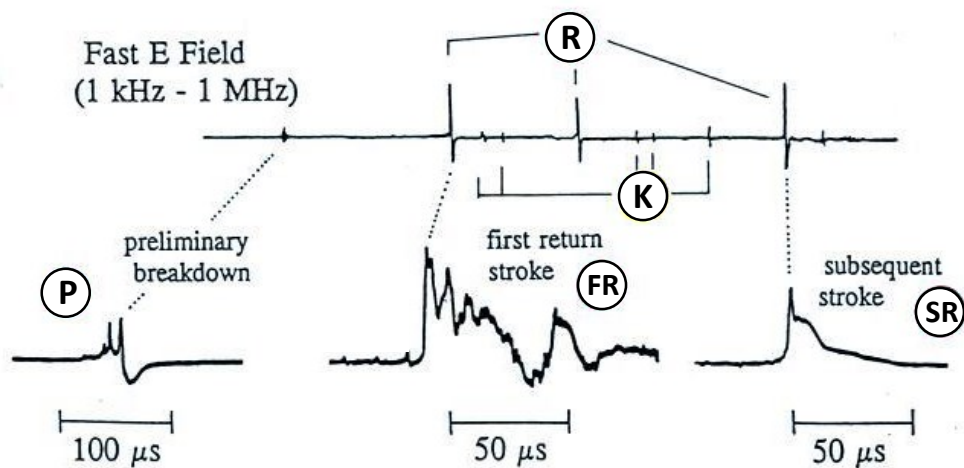


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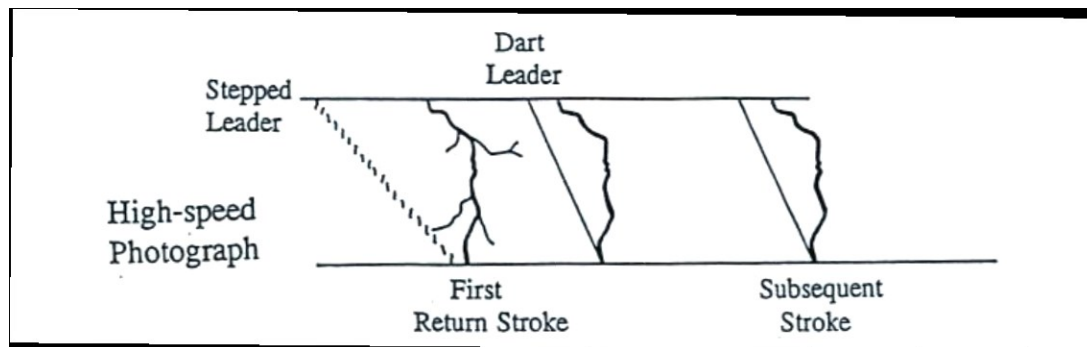


Hendry (1993)

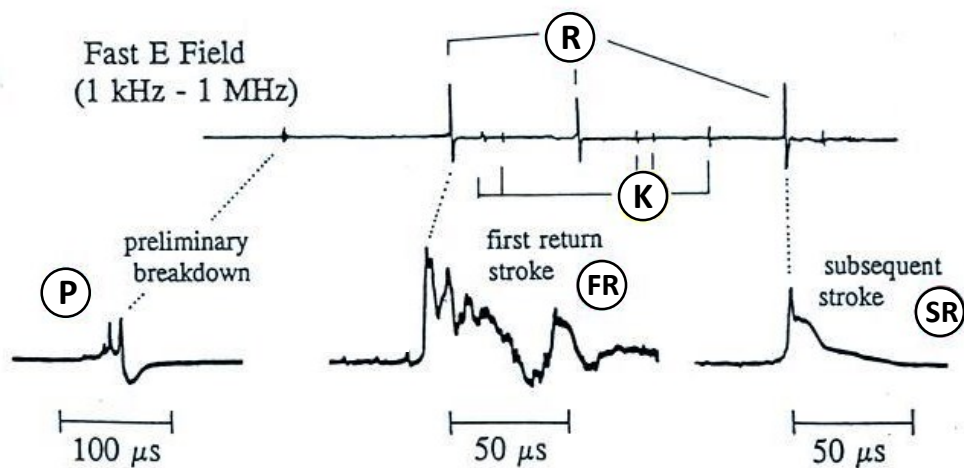


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Hendry (1993)



Courtesy of H. Hunt (Univ. Witwatersrand)



(GSP1 @ 561ms)



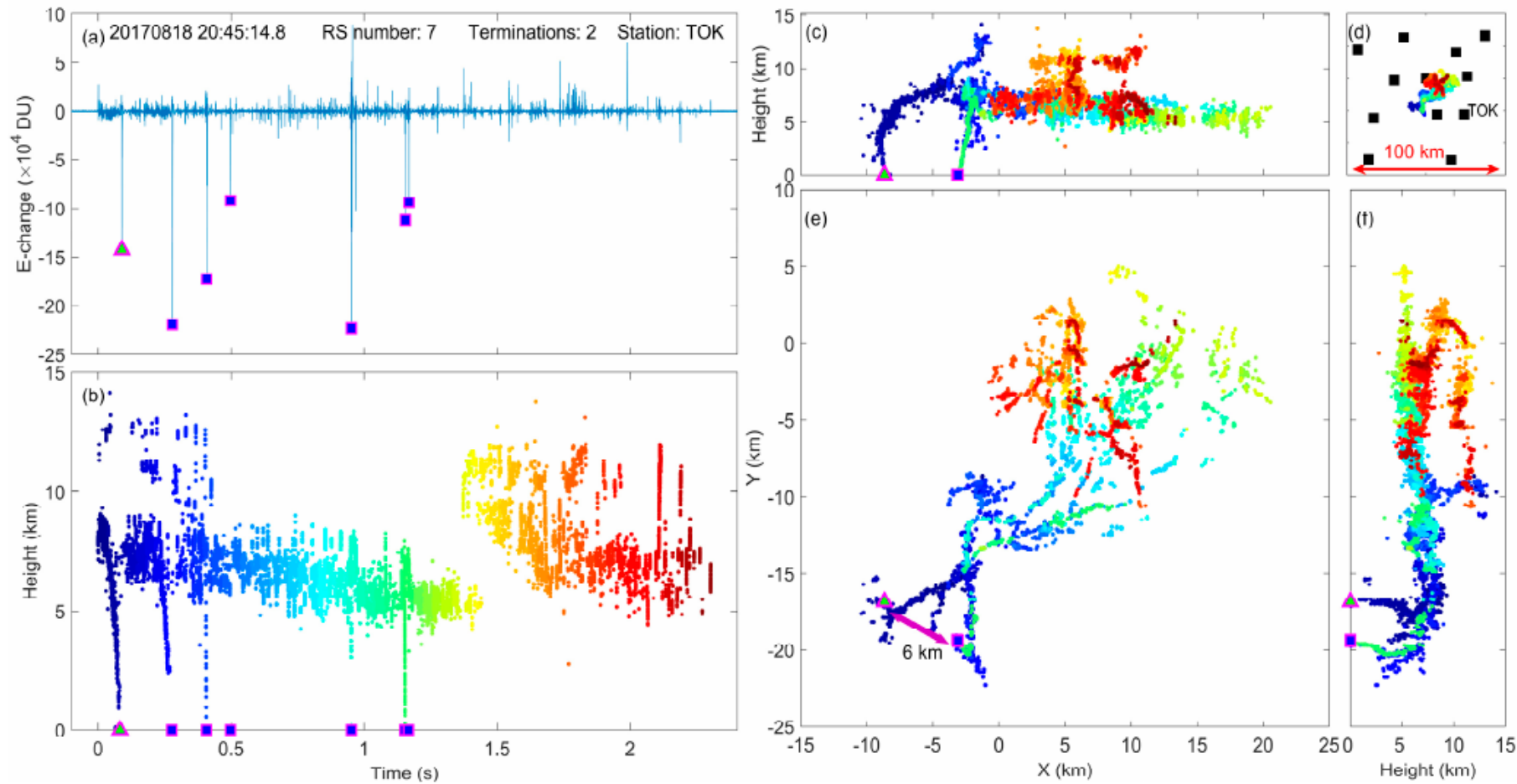
(GSP2 @ 654ms)



(GSP3 @ 744ms)

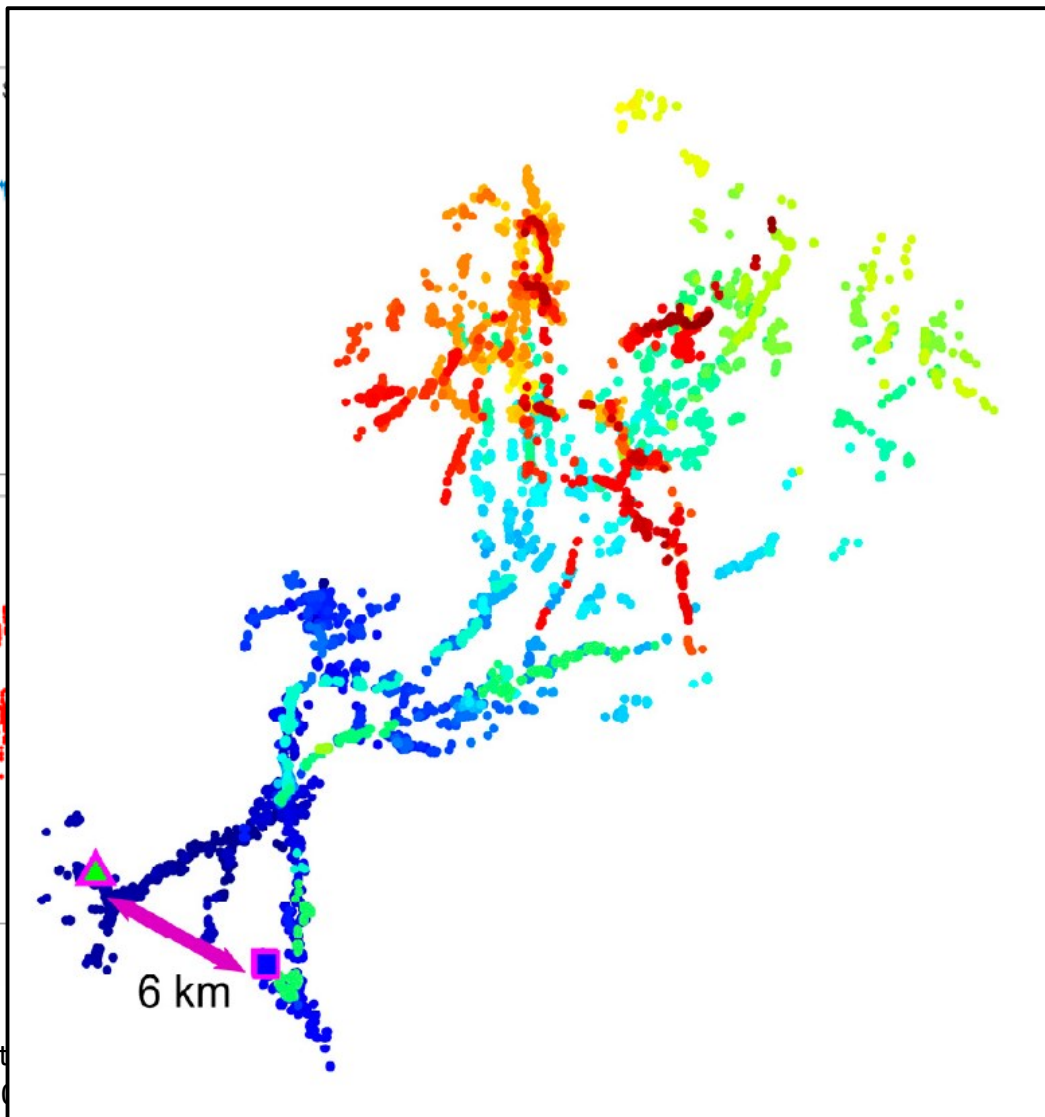
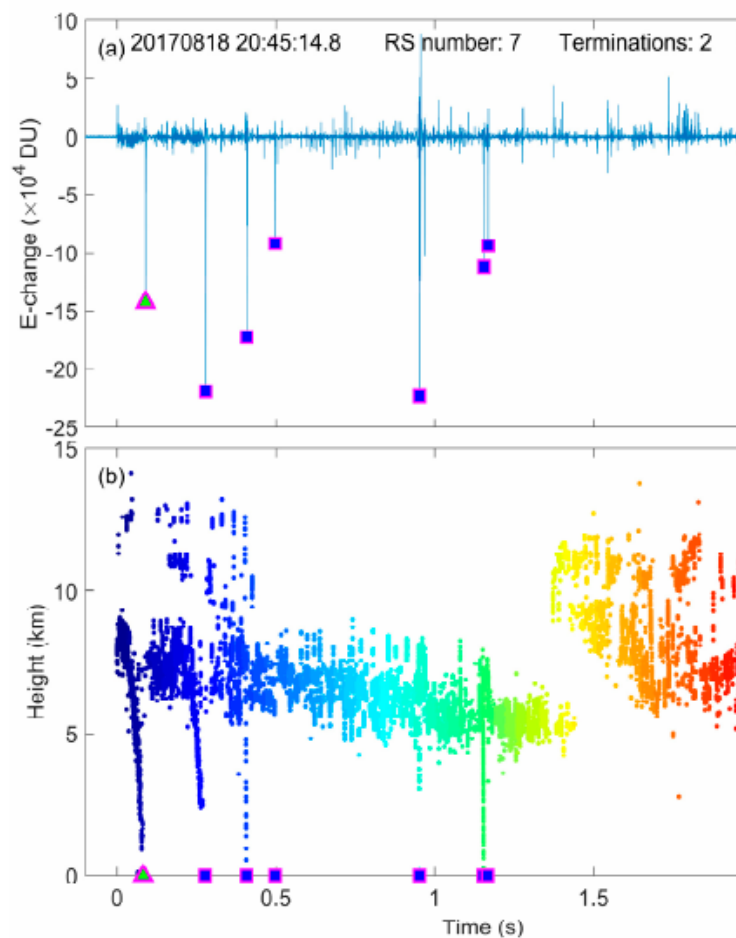
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Panliang Gao et al. (2019): Characterization of multitermination CG flashes using a 3D Lightning Mapping System (FALMA), *Atmosphere*, 10, 625, doi:10.3390/atmos10100625

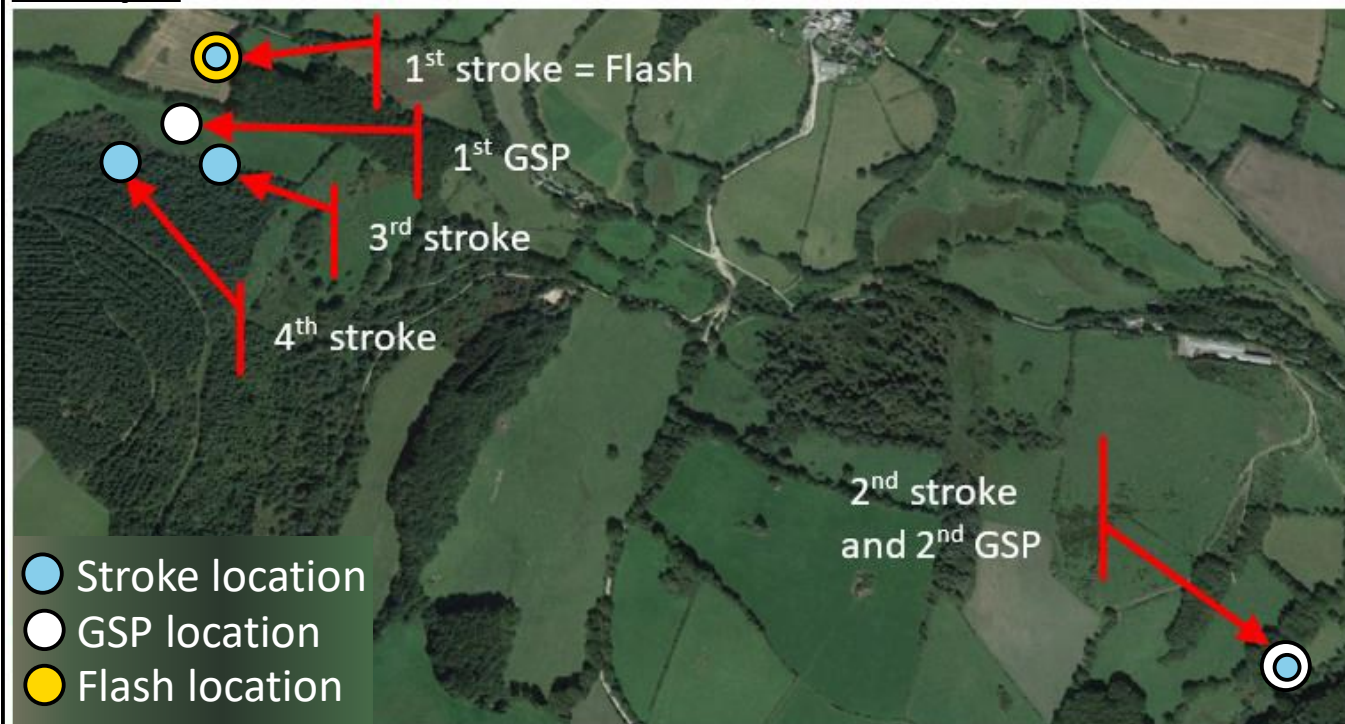
I. Setting the Stage



Panliang Gao et al. (2019): Characterization of multi-lobed lightning mapping system (FALMA), *Atmosphere*, 10

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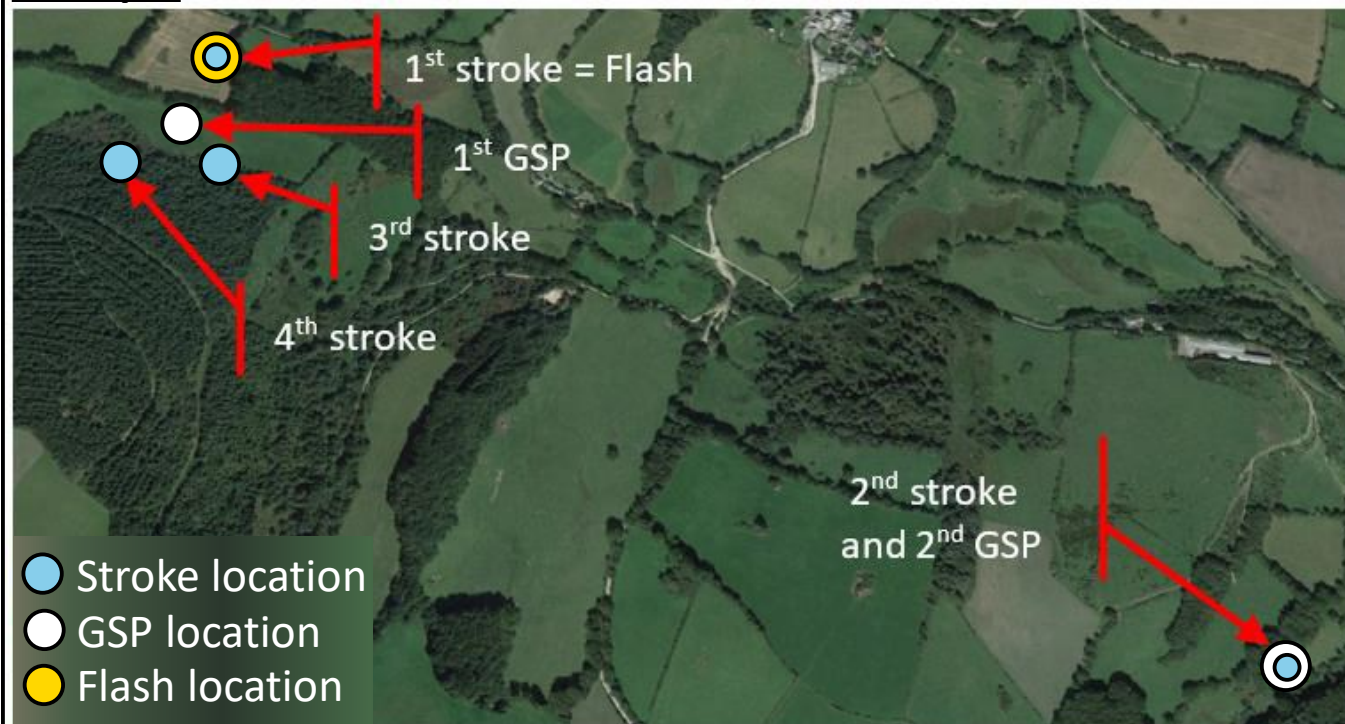
Example



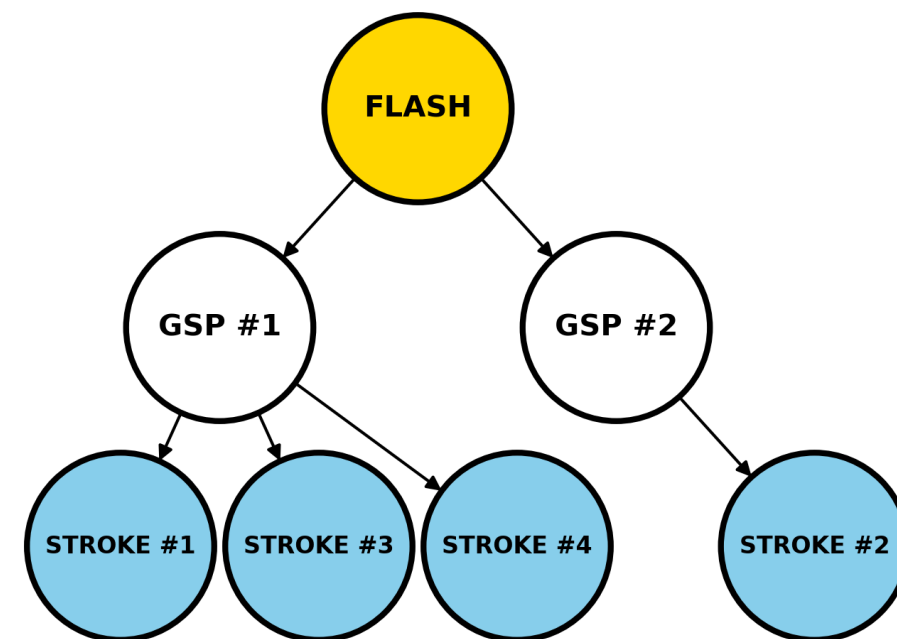
Courtesy of S. Pedebuy (Météorage)

I. Setting the Stage

Example



Courtesy of S. Pedebuy (Météorage)



II. Why GSPs Matter

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-  Scientific curiosity



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N = number of direct lightning strikes ($N_D = N_{(S)G} \cdot A_E \cdot C_D$)


P = probability of damage to a structure

L = economic loss

$R = \text{risk} = N \cdot P \cdot L$

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Example:

$$N_D = N_{(S)G} \cdot 0.01 \cdot 1; P = 10\%; L = 100.000\text{€}$$

$$\begin{aligned} R &= N_{(S)G} \cdot 0.01 \cdot 0.1 \cdot 100.000 \\ &= 100 \cdot N_{(S)G} \end{aligned}$$

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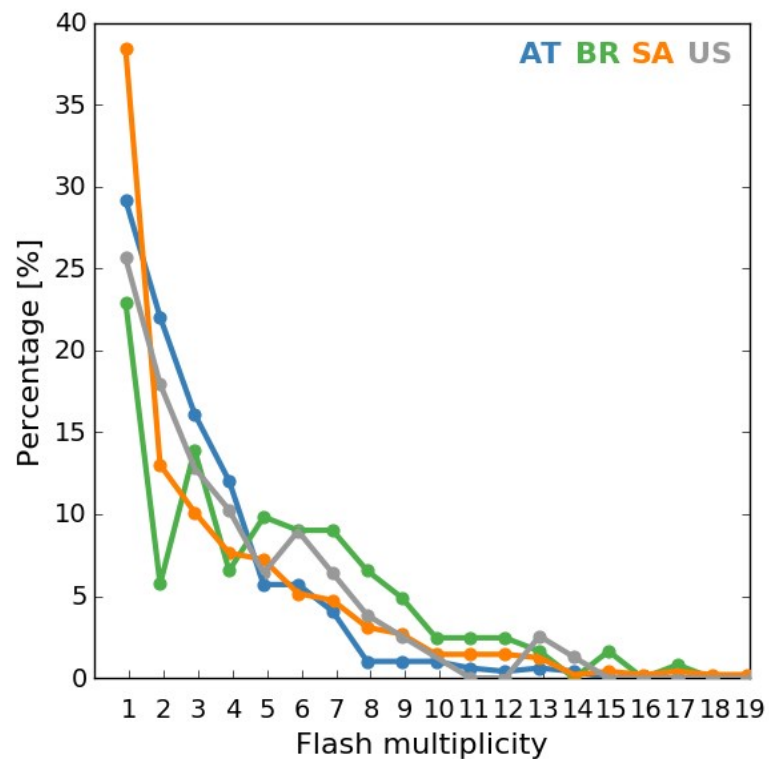
Take action if $R > R_T$

III. GSPs in High-speed Video

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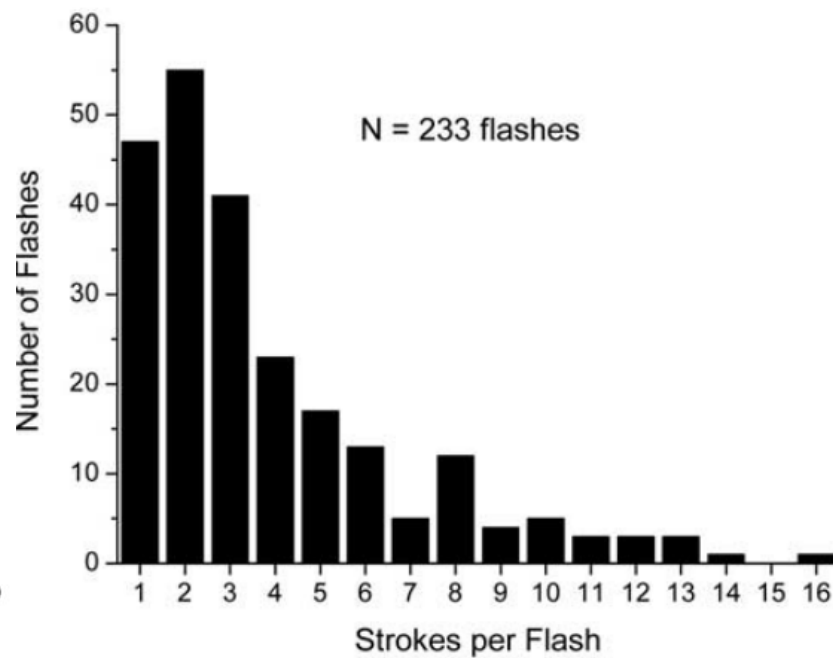
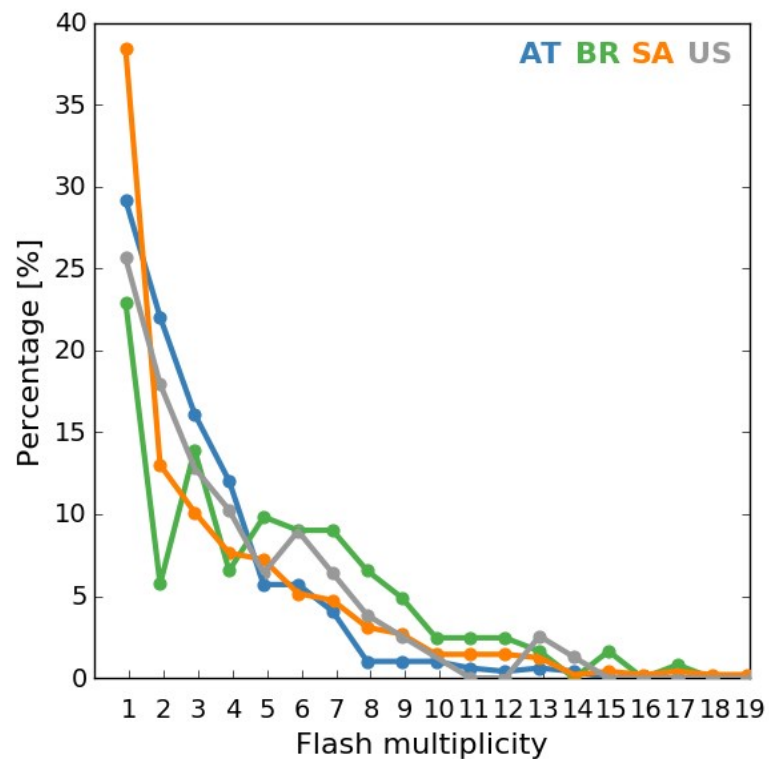
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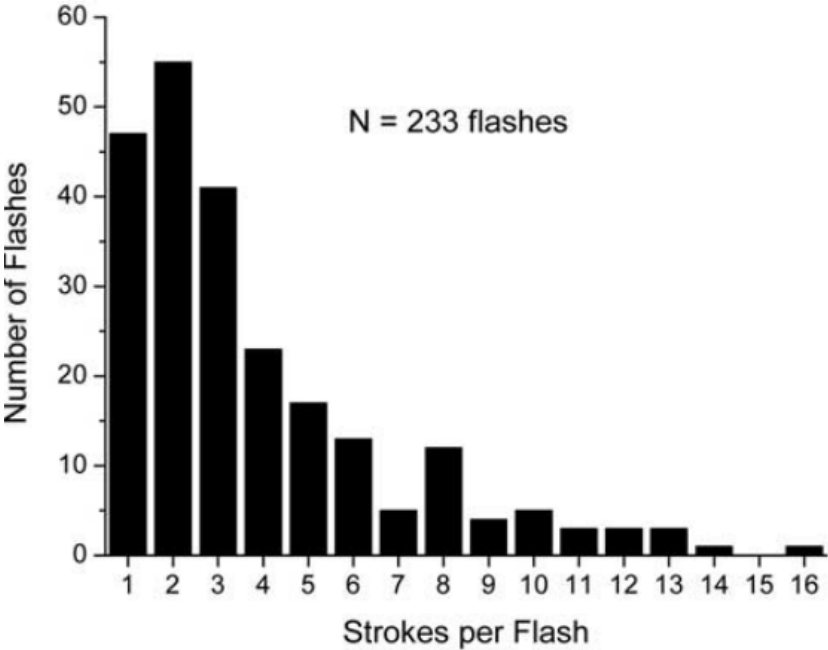
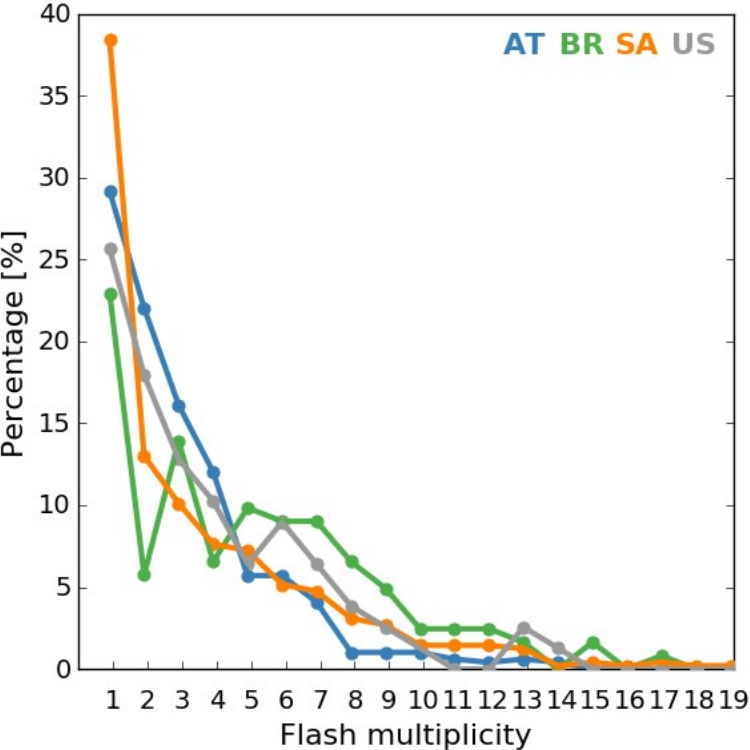
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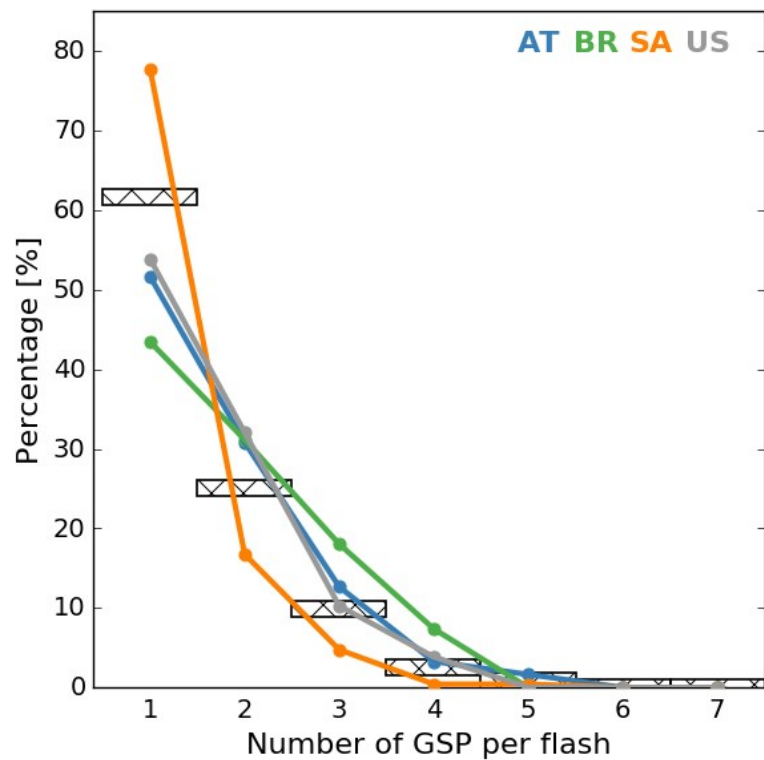


	Poelman et al. (2021)	Saba et al. (2006)
Mean multiplicity		
AT	3.14	
BR	5.07	3.8
SA	3.8	
US	3.9	
ALL	3.67	

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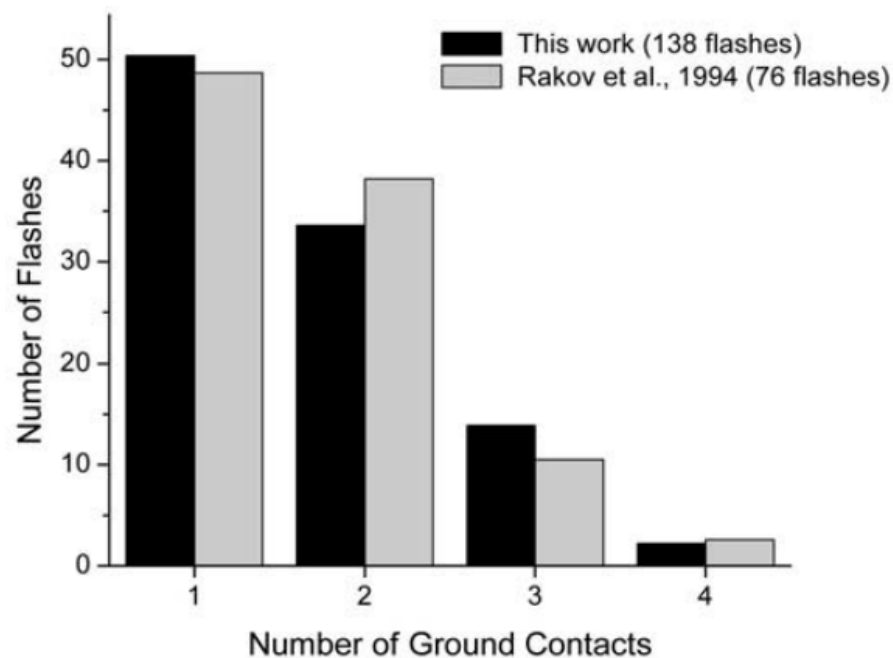
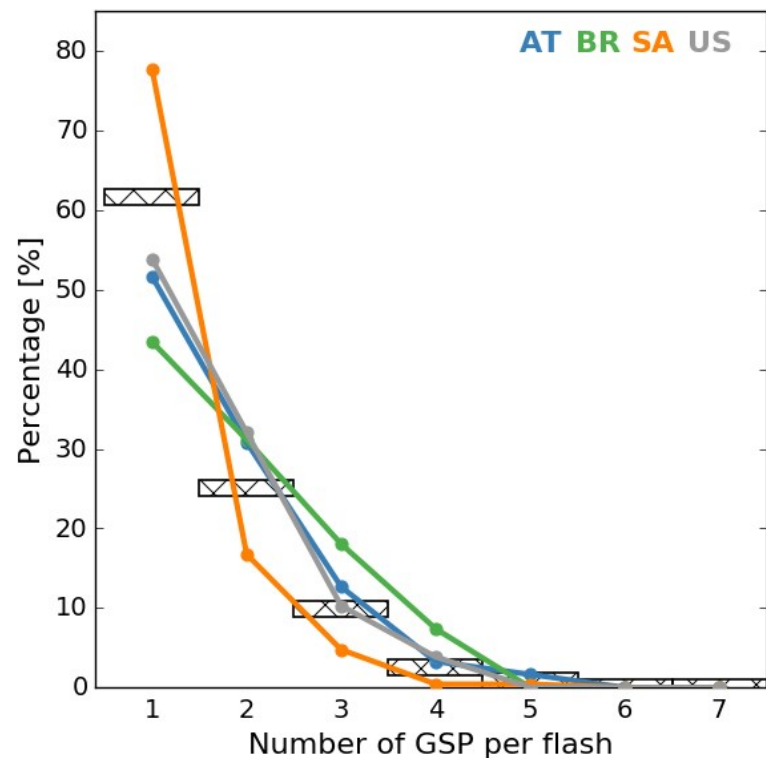
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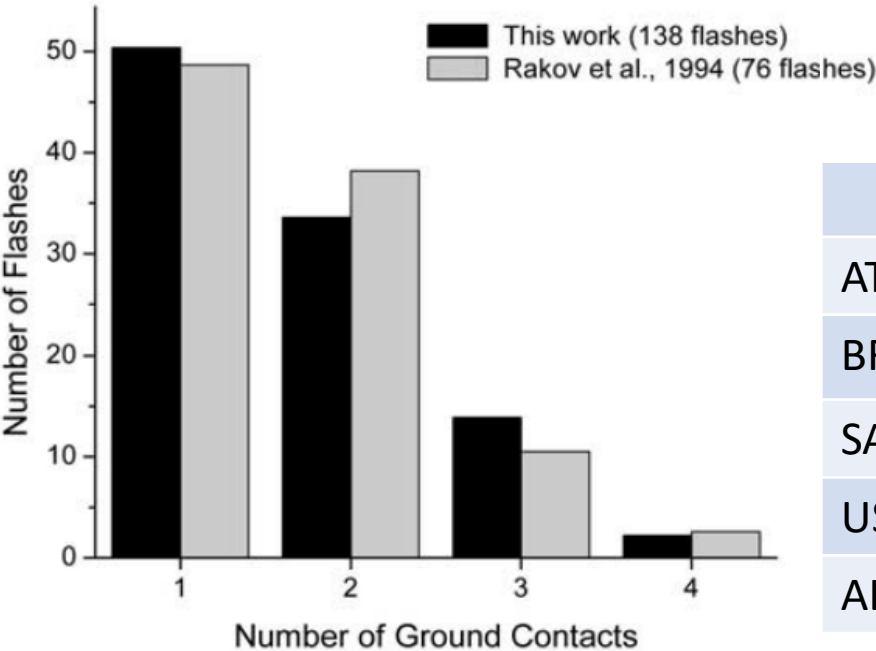
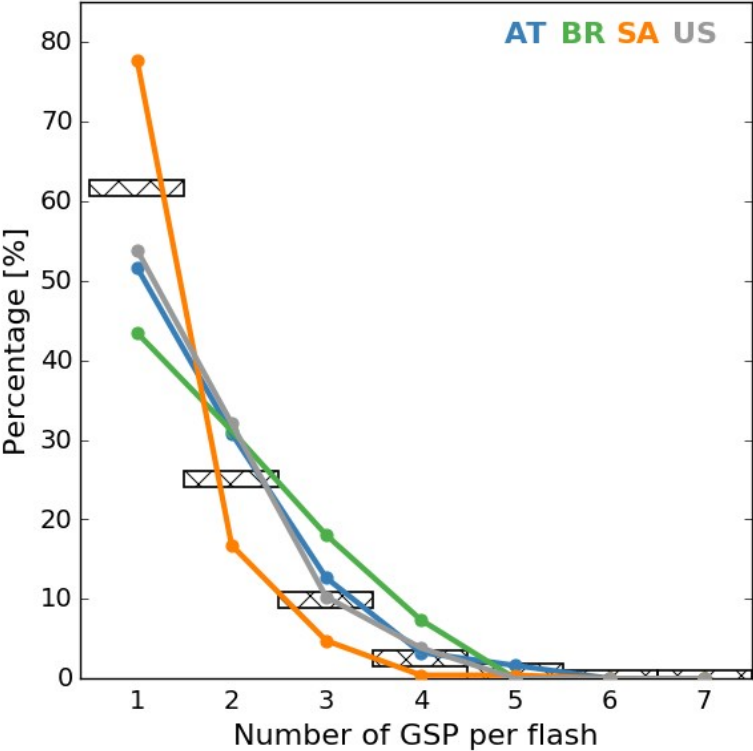
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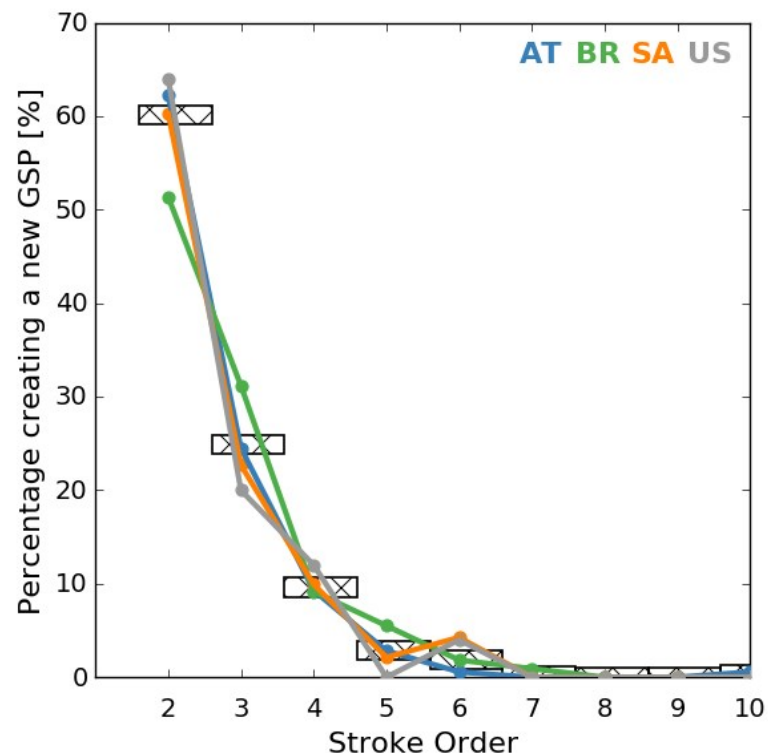
	Poelman et al. (2021)	Saba et al. (2006)
Average number of GSPs/flash		
AT	1.72	
BR	1.9	1.7
SA	1.29	
US	1.65	1.67
ALL	1.56	

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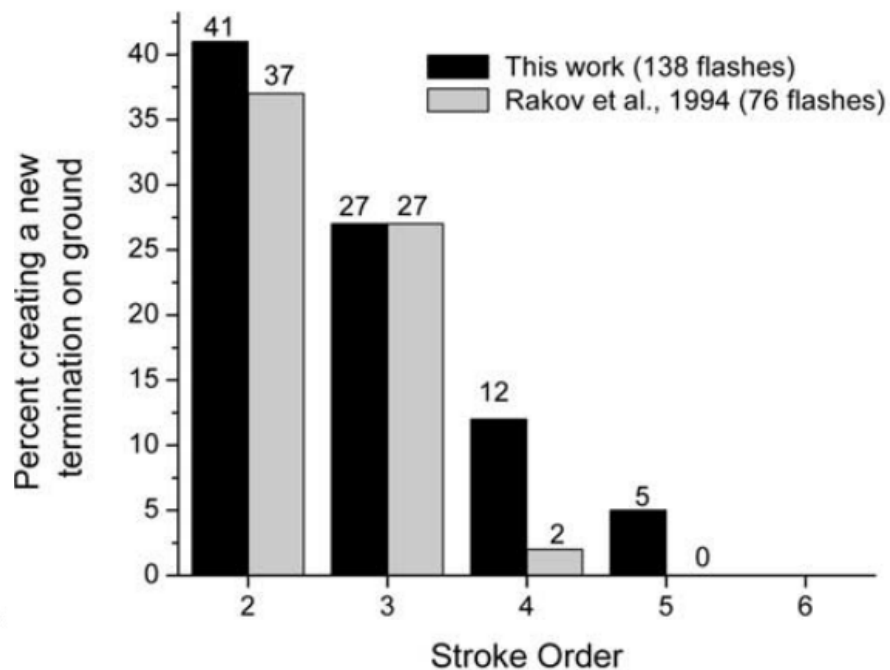
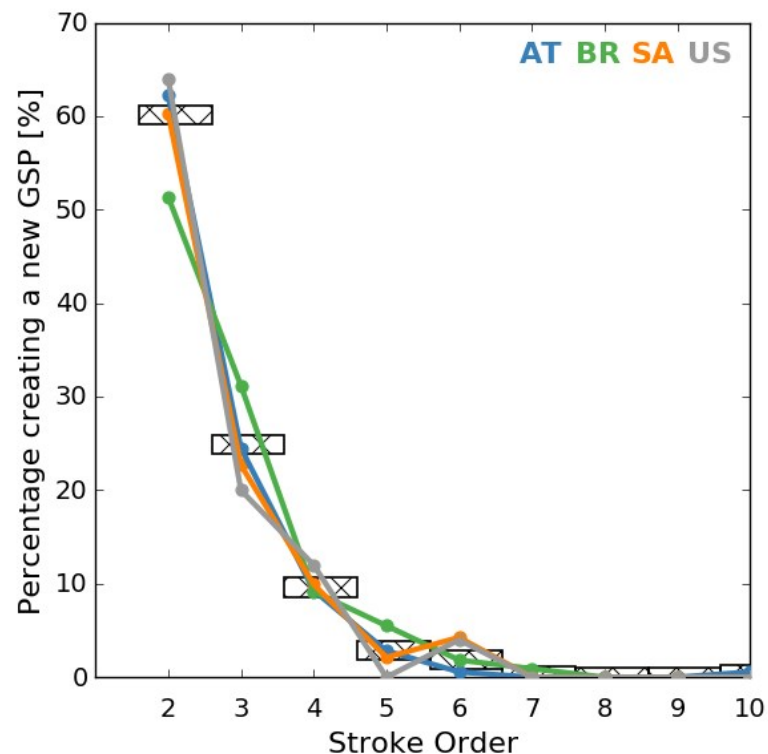
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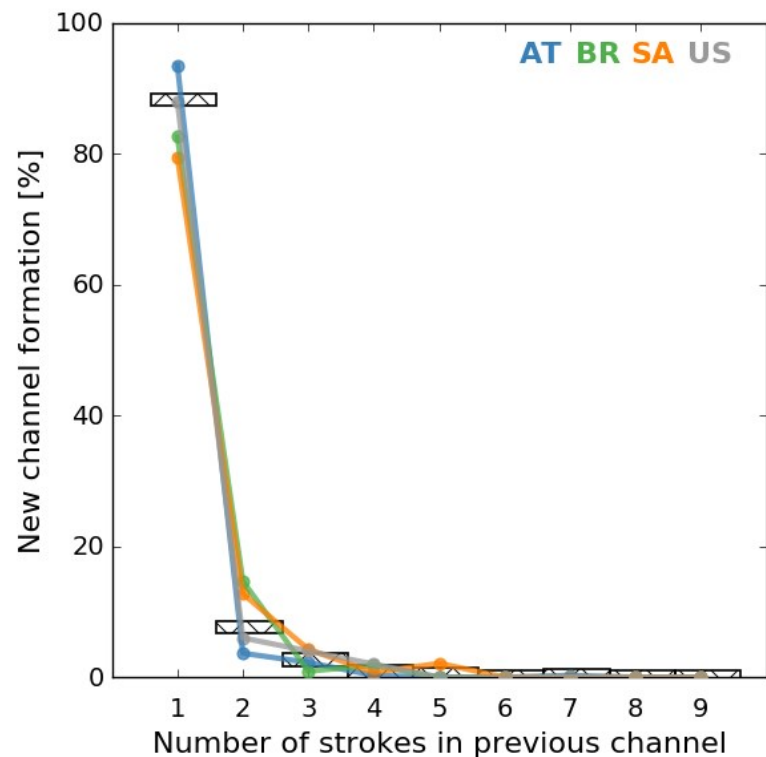


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IV. GSP Algorithms

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Purpose:

- Group different strokes of a flash into one or more GSPs.
- Aims to mimic the exact distribution of GSPs as observed in high-speed camera images.
- Allows determination of GSP density on a predefined geographical and periodical scale.
- Enables high-certainty estimation of GSP density using a large set of actual LLS observations.

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Two Main Types:

- Distance-based grouping

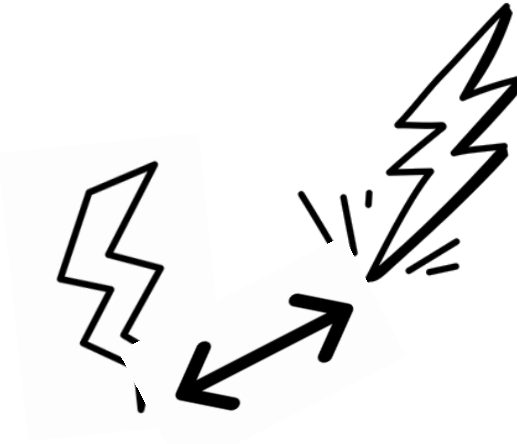
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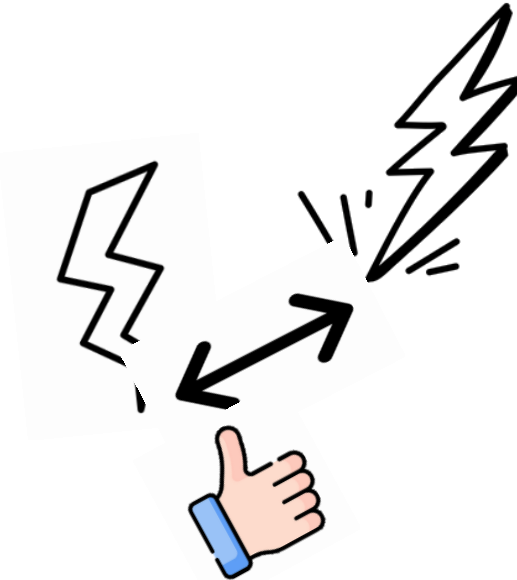
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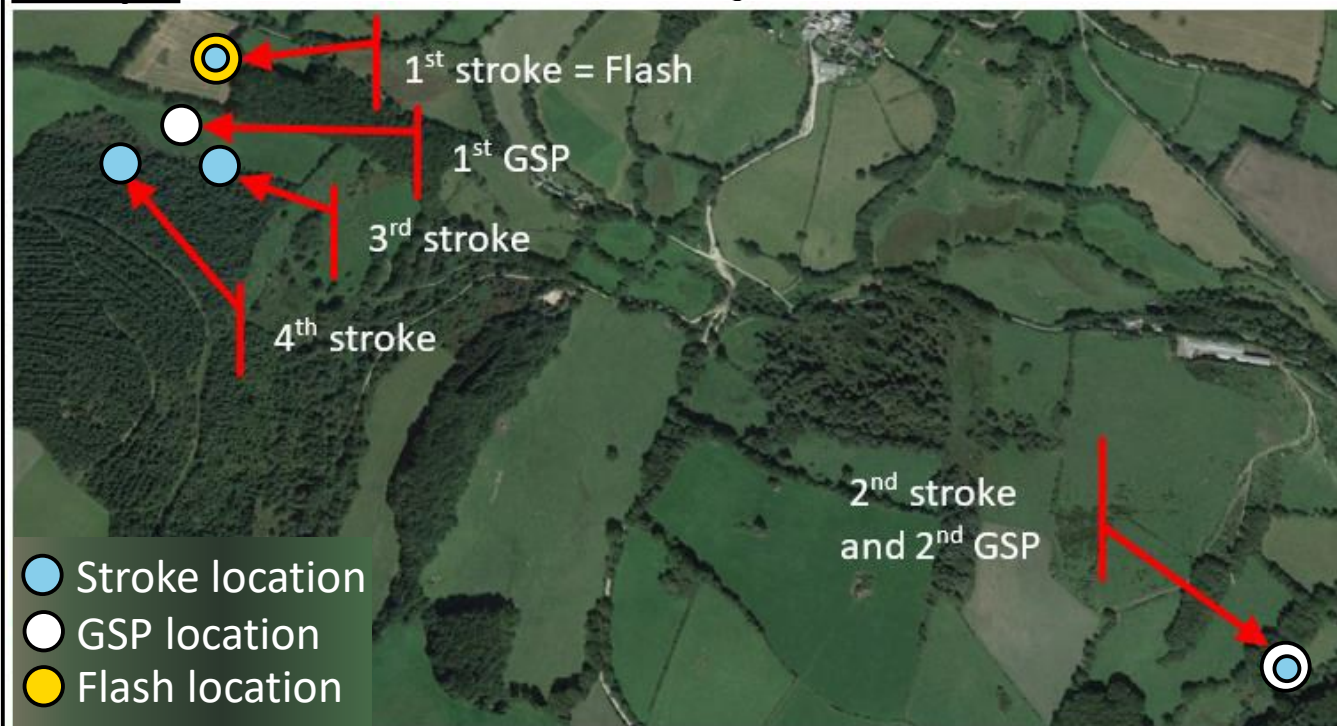
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Example



Courtesy of S. Pedebay (Météorage)

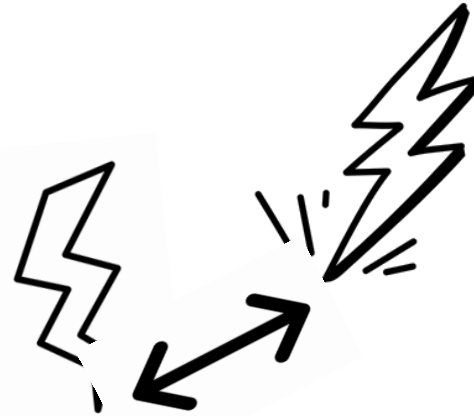
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Two Main Types:

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- Distance + uncertainty ellipse combination



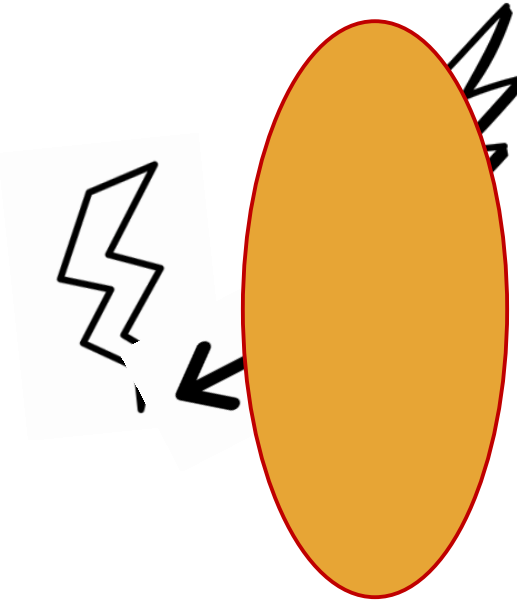
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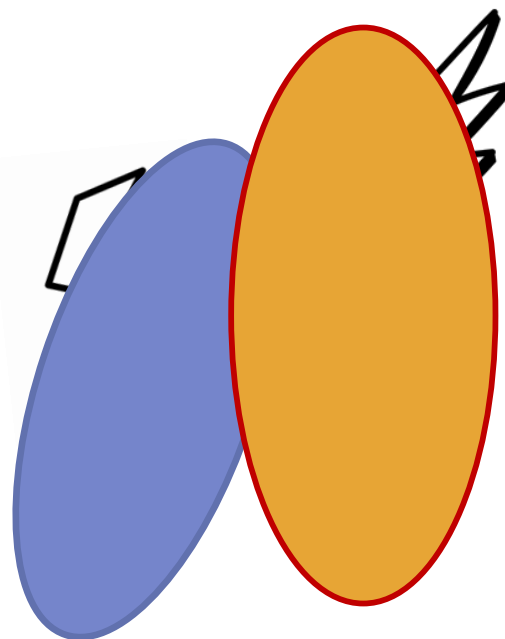
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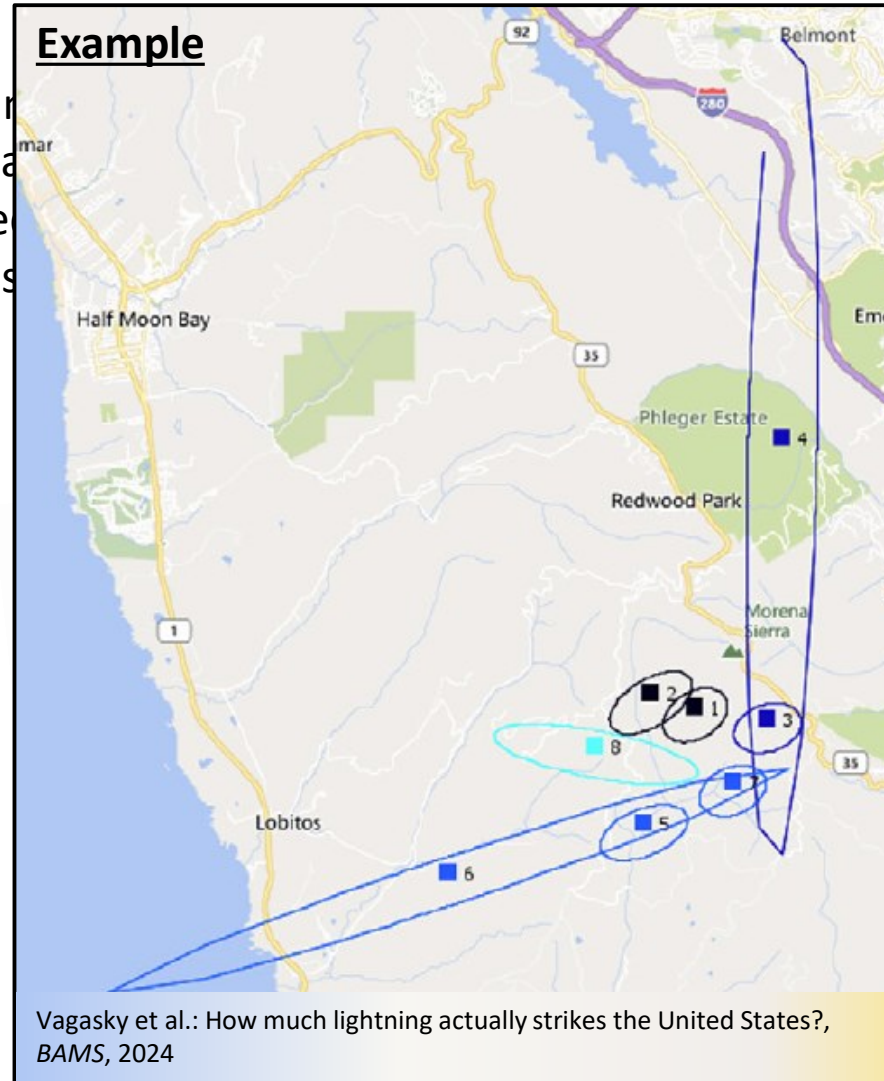
IV. GSP Algorithms

Purpose:

- Group different strokes of a flash into one or more GSPs
- Aims to mimic the exact distribution of GSPs as observed
- Allows determination of GSP density on a pre-defined area
- Enables high-certainty estimation of GSP density

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Limitation:

- Quality of the local LLS
- Adopting a distance threshold proportional to 3 – 5 times that of the mean LA leads to best results (Poelman et al., 2021b: Global ground strike point characteristics in negative downward lightning flashes – Part 2: Algorithm Validation, Nat. Hazards Earth Syst. Sci., 21, 1921-1933)

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Performance:

- Poelman et al. (2021b) tested 3 different algorithms against a large set of ground-truth observations taken in different regions in the world. Success rates of up to 90% to retrieve the correct type of the strokes in the flash.

V. LLS-derived GSPs

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I. IEC 62858 TC81: Lightning Protection

“Lightning density based on lightning location systems – General Principles”

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LLS Data for Risk Evaluation

- No common standard for performance requirements
- Ensures reliable & homogeneous N_G and N_{SG} values

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IEC 62305-2 & Risk Assessment

- Only N_G or N_{SG} can be used in evaluation

I. IEC 62858 TC81: Lightning Protection

“Lightning density based on lightning location systems – General Principles”



LLS Data for Risk Evaluation

- No common standard for performance requirements
- Ensures reliable & homogeneous N_G and N_{SG} values



IEC 62305-2 & Risk Assessment

- Only N_G or N_{SG} can be used in evaluation



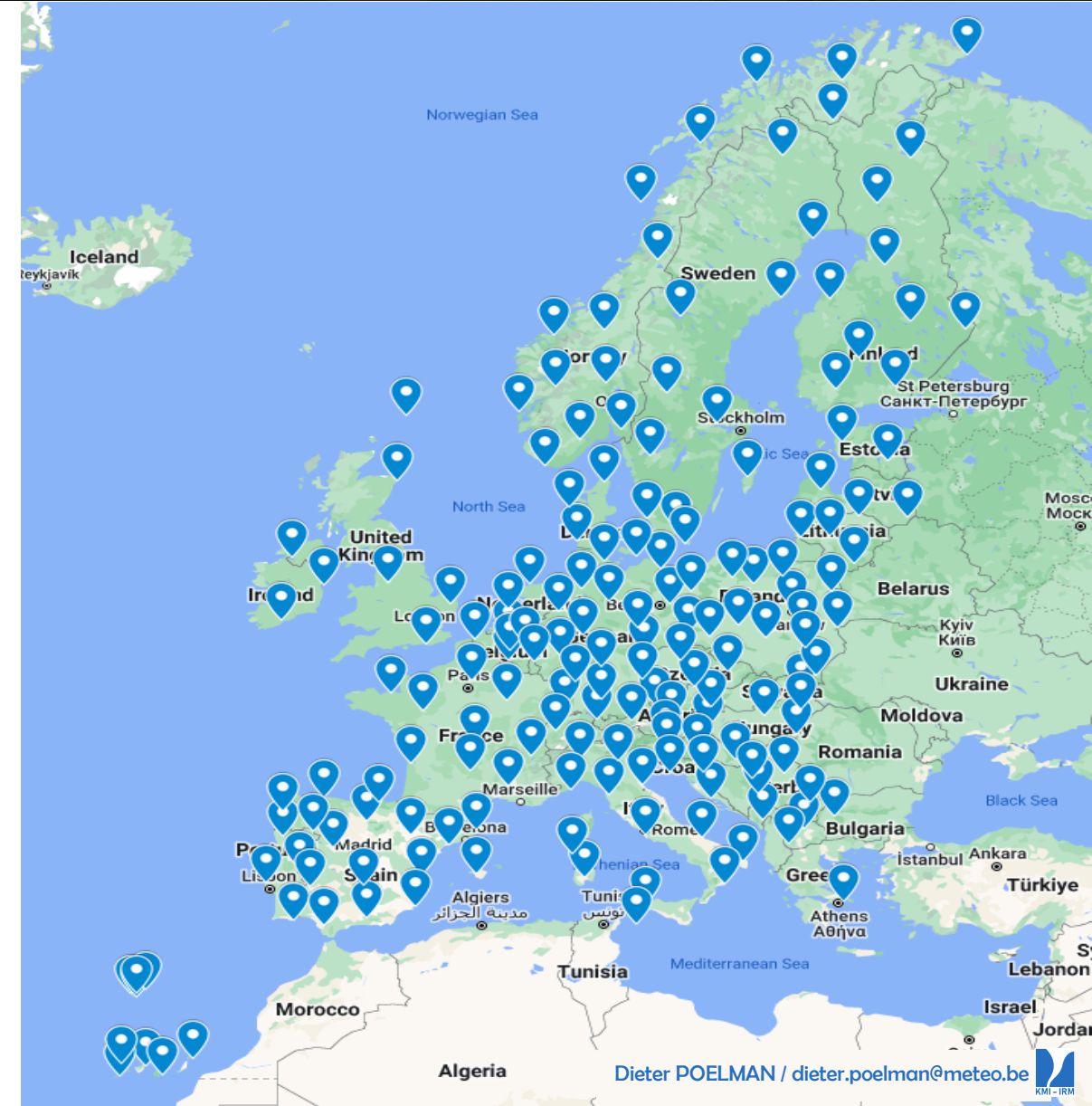
LLS Performance Characteristics

- Flash Detection Efficiency (DE) $\geq 80\%$
- Median Location Accuracy (LA) $\leq 500\text{m}$
- 90th percentile LA $\leq 1\text{km}$

V. LLS-derived GSPs

II. EUCLID

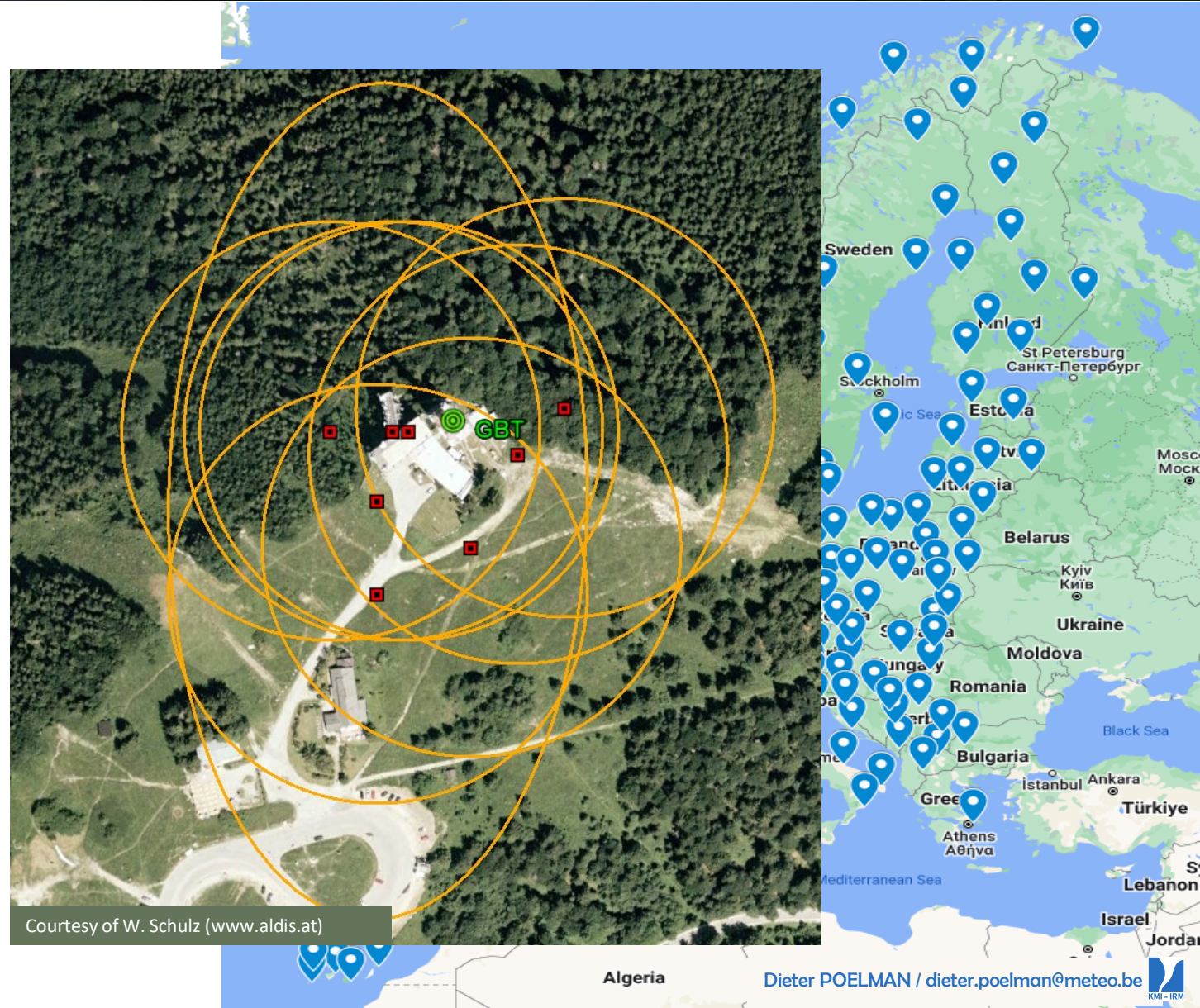
- EUCLID operates ~170 sensors
- Network evolves, consistently upgrading from older sensor models to newer ones and optimizing sensor placement by adding or relocating sensors
- Median LA ~100m (Gaisberg)
- Stroke/flash DE of 84%/98% based on video & E-field records
- $\text{EUCLID} \propto \text{NLDN} \rightarrow \text{CA}(\text{CG}) = 92\%$
 $\rightarrow \text{CA}(\text{IC}) = 86\%$



V. LLS-derived GSPs

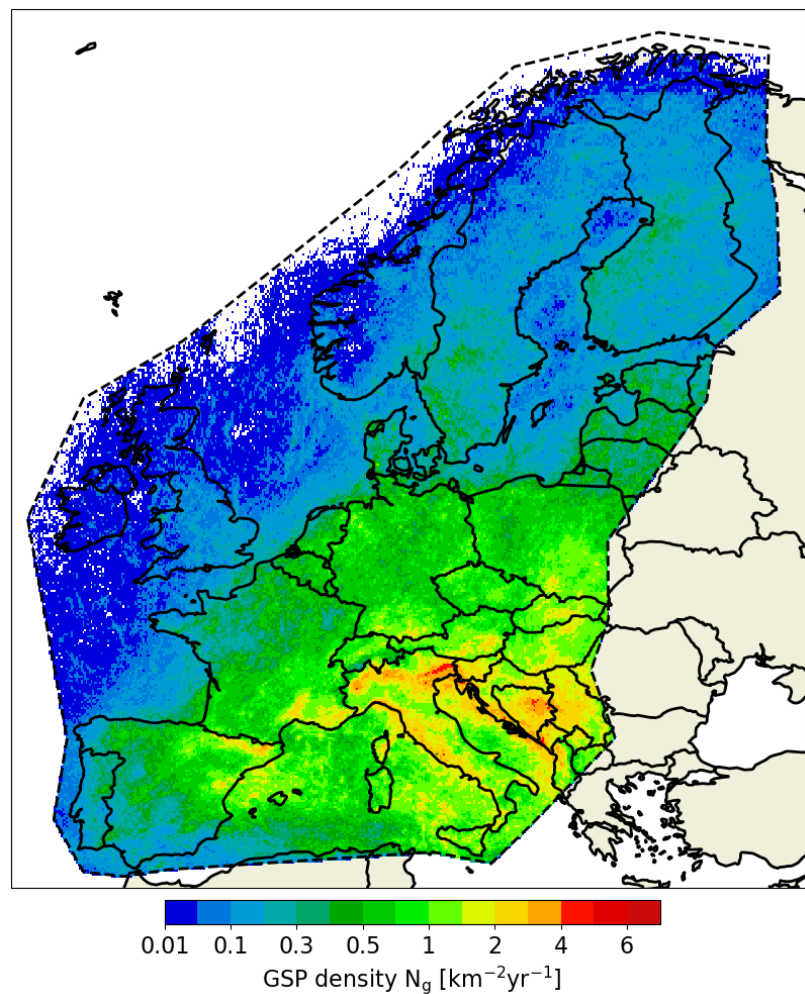
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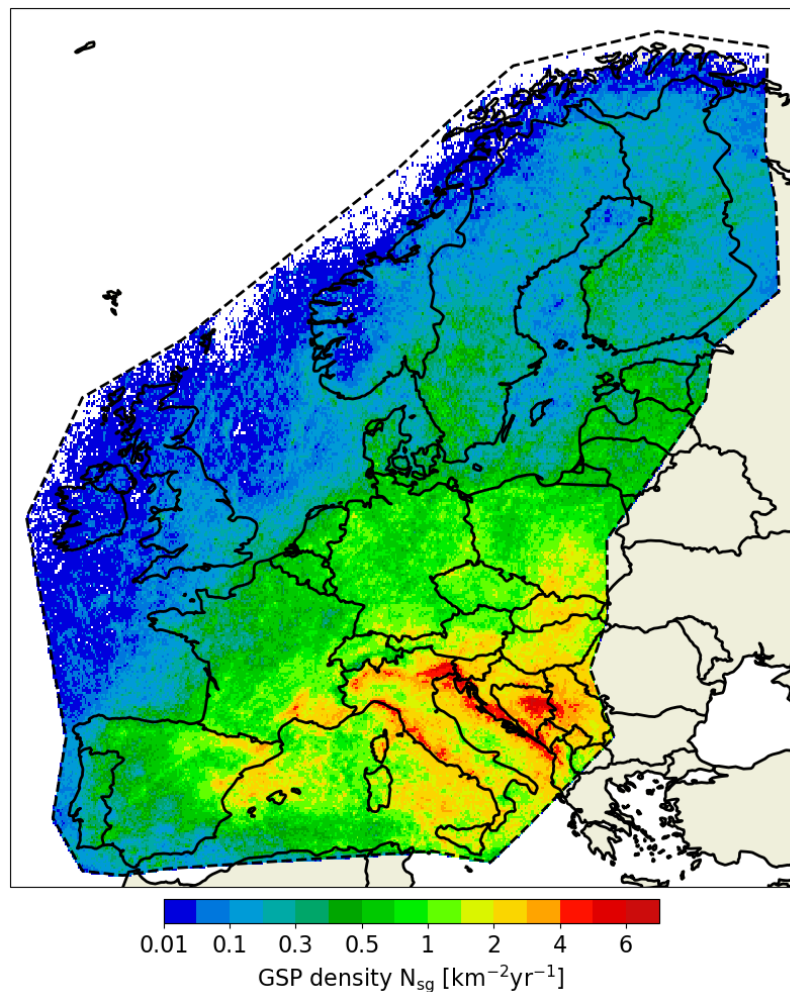
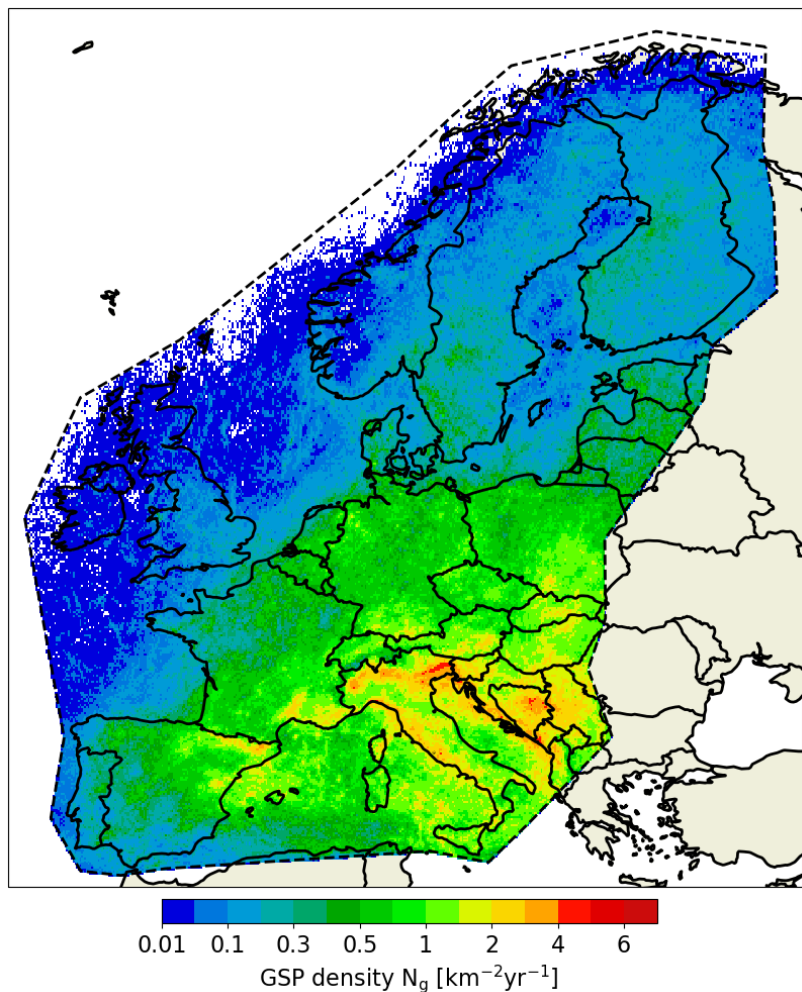
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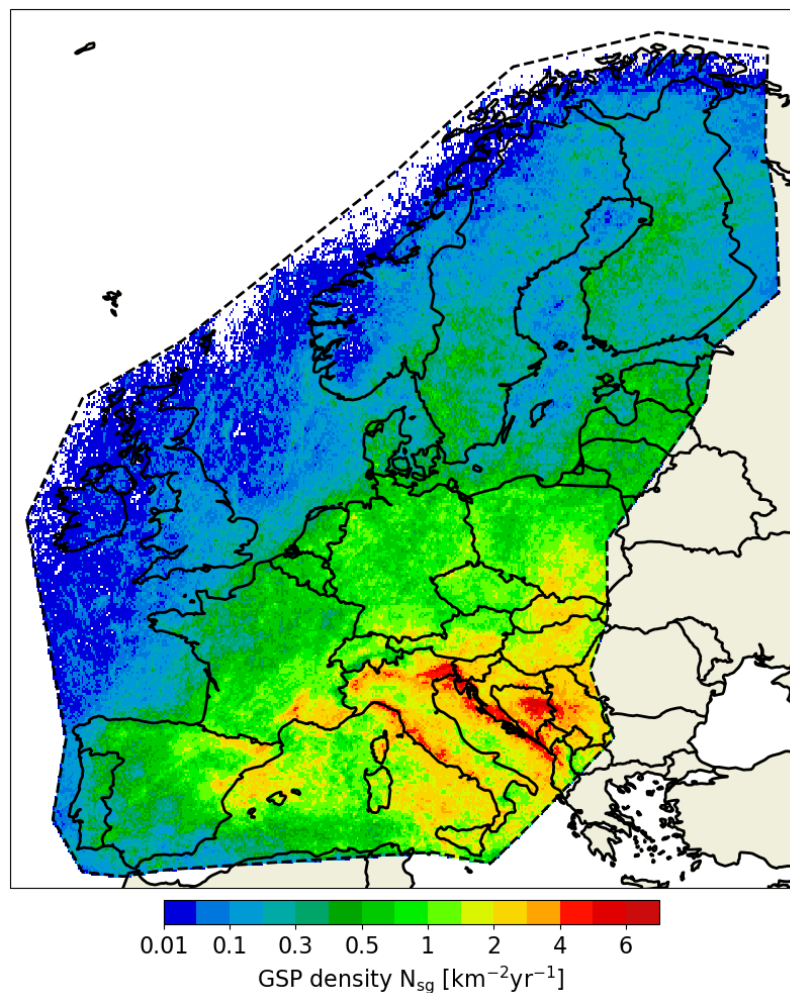
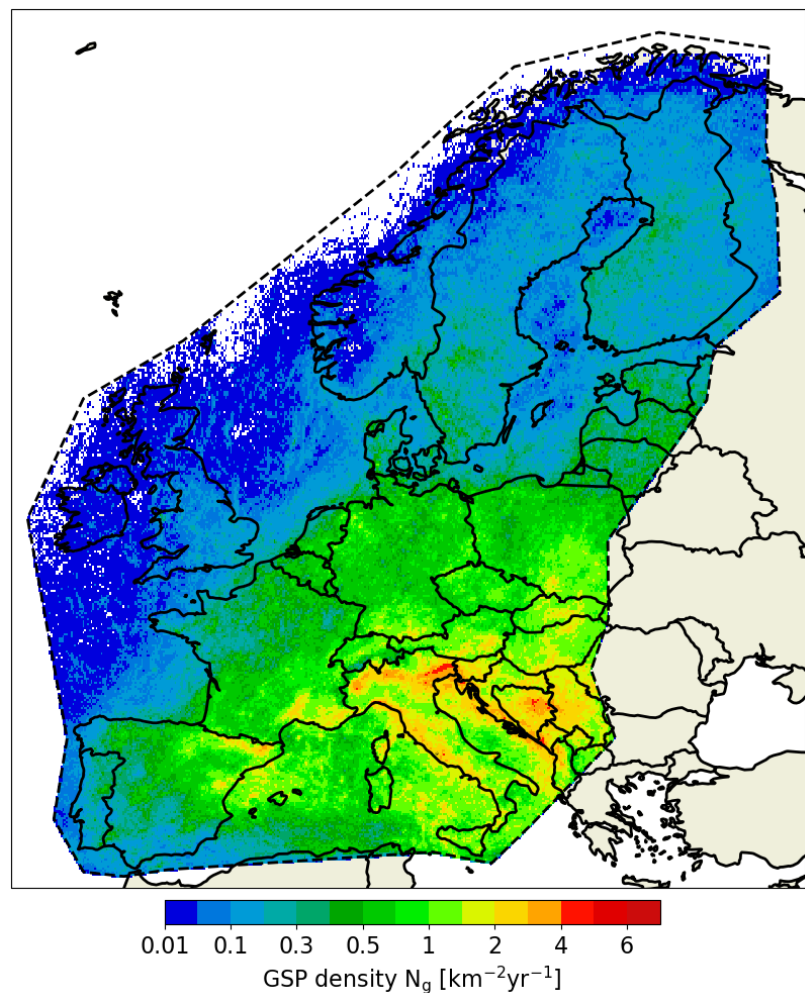
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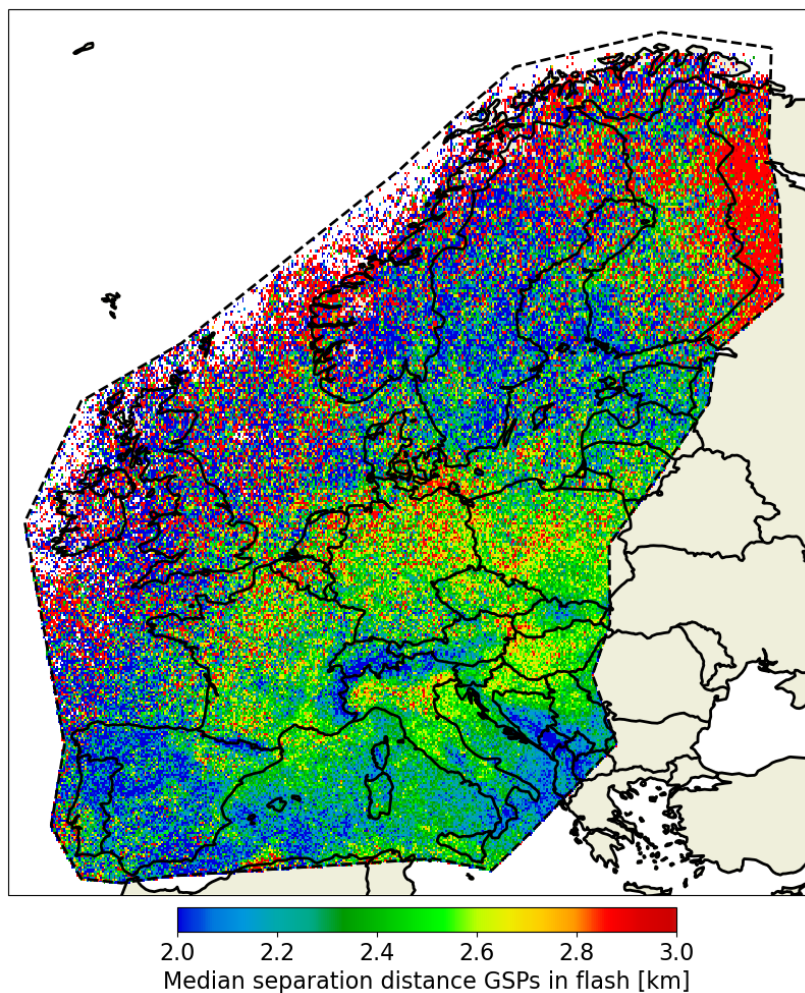


	N_G	N_{SG}
Median [$\text{km}^{-2}\text{yr}^{-1}$]	1.3	1.8
Max [$\text{km}^{-2}\text{yr}^{-1}$]	6	8.5

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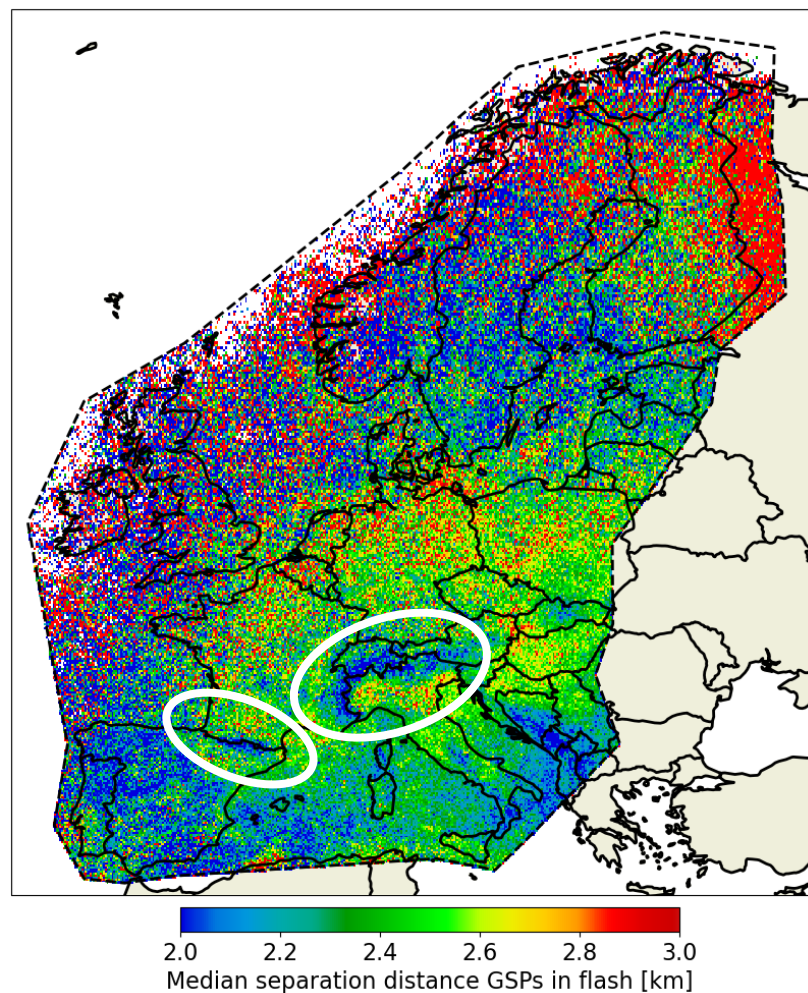
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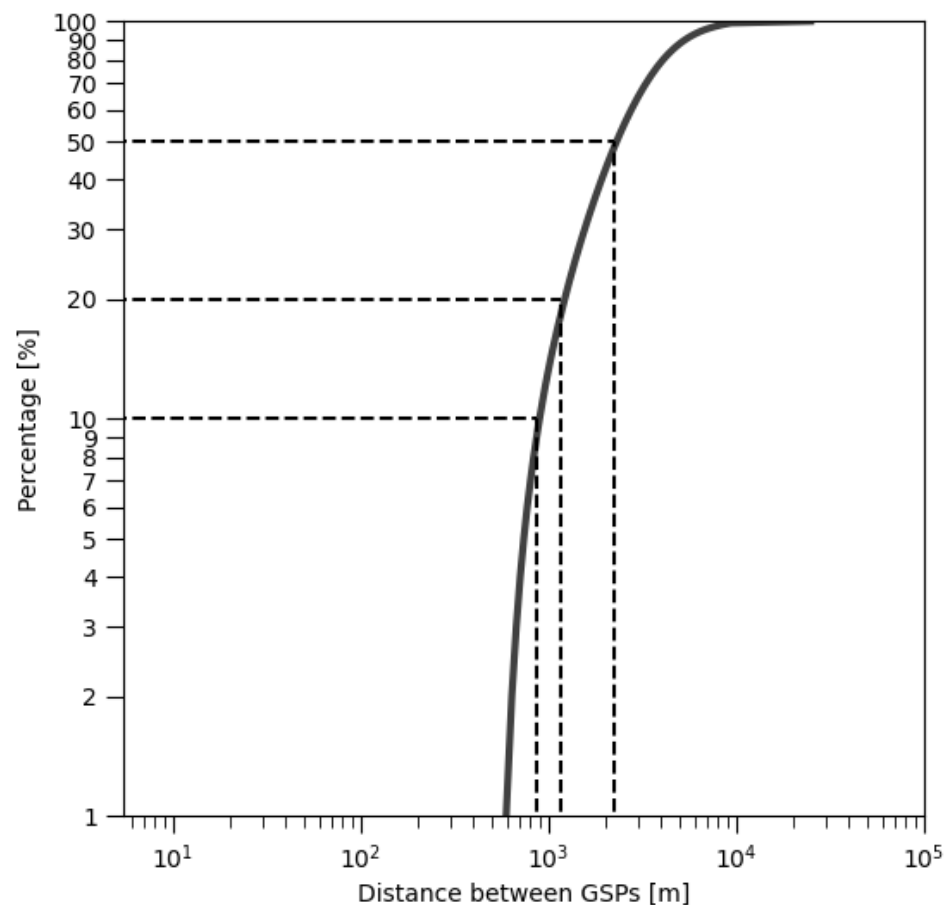
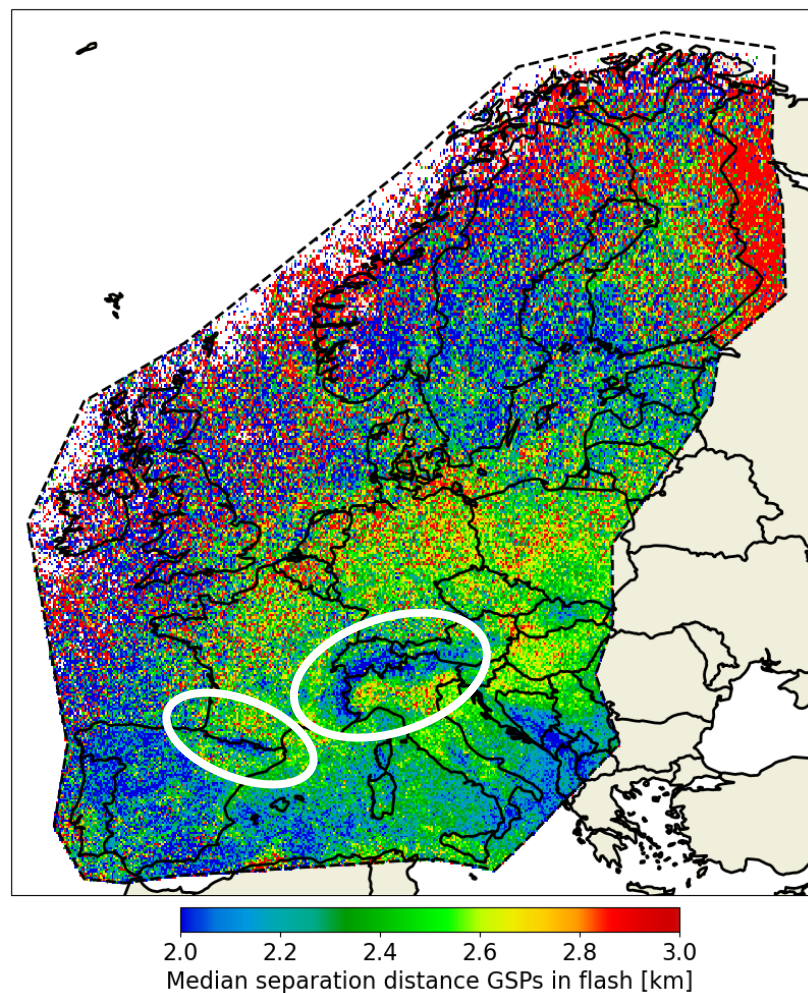
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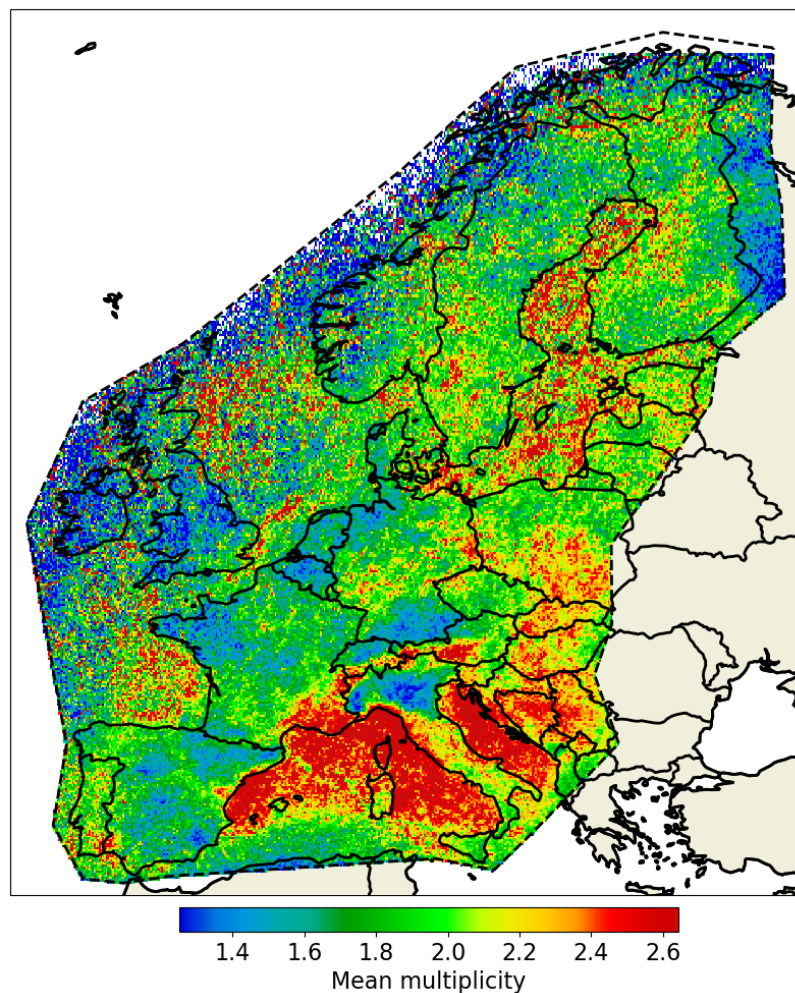
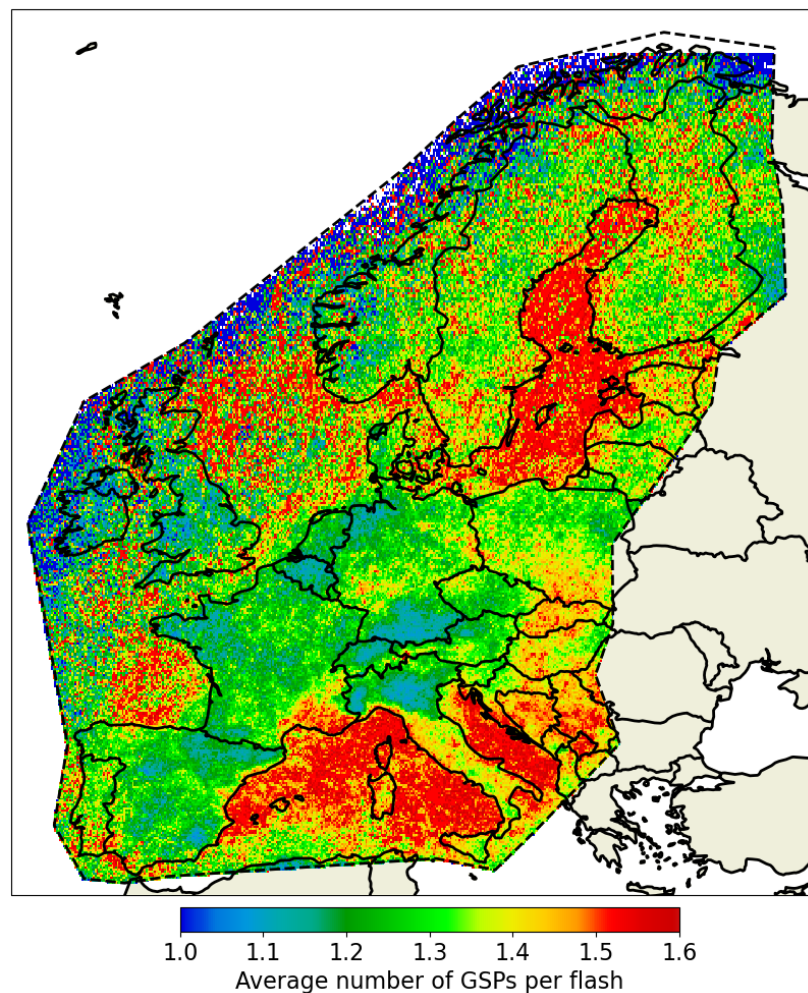


	Separation Distance [km]
Median	2.3
10 th percentile	0.9
90 th percentile	5.5

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Mean GSPF

Sea: ≥ 1.5
Land: 1.3

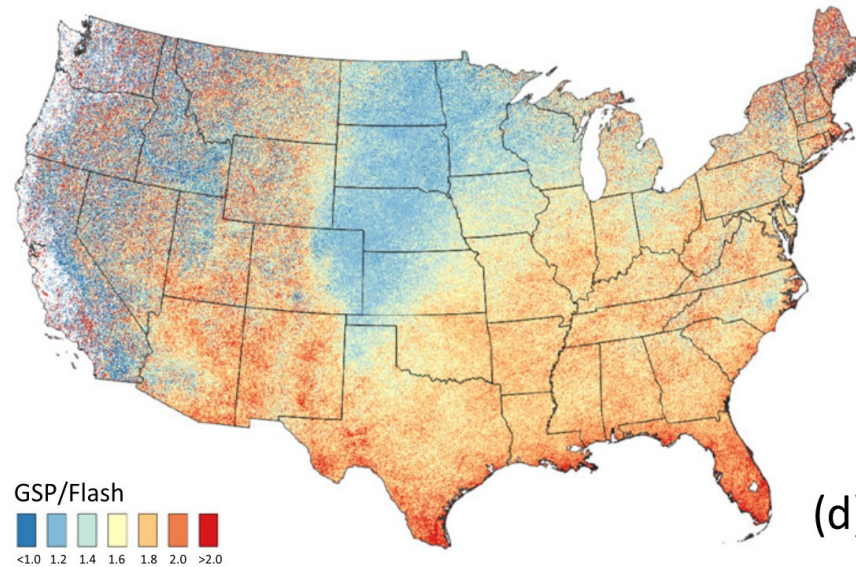
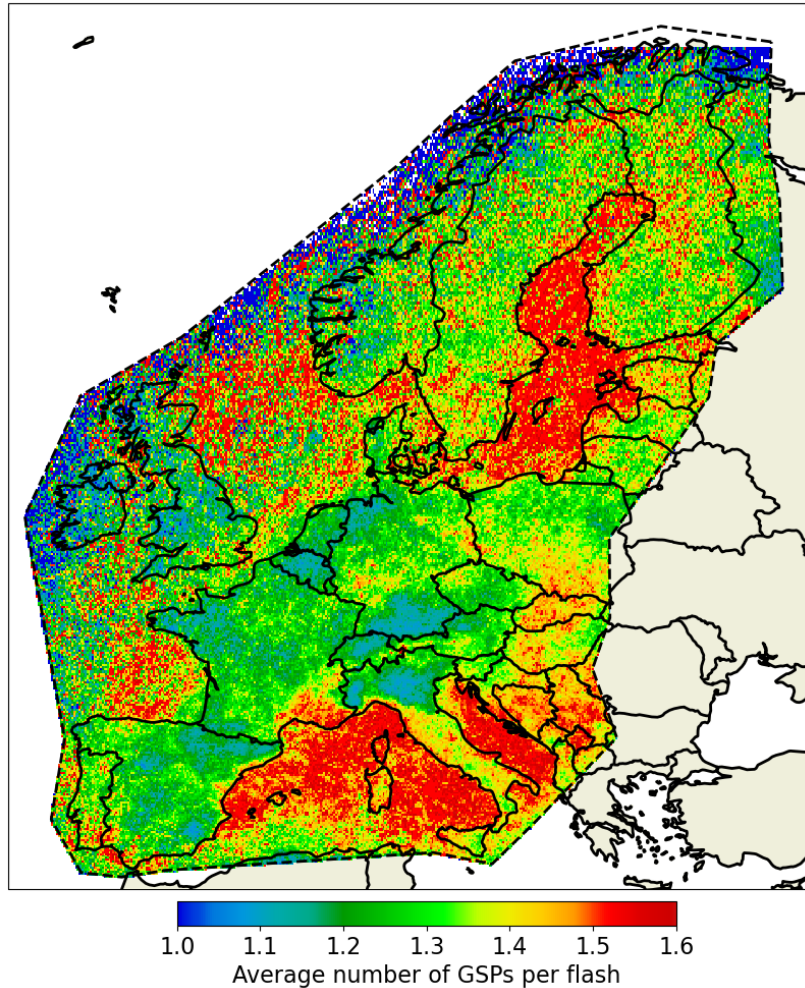
Mean
multiplicity

2.1
(95% of flashes
 ≤ 6 strokes)

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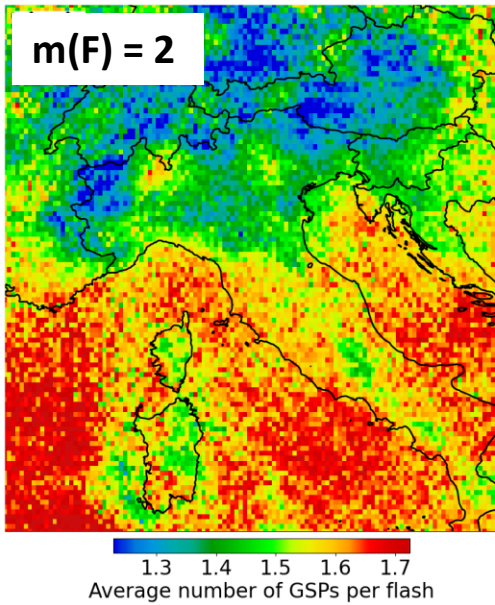
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Vagasky et al. (2024): How much lightning actually strikes the United States, *Bull. Amer. Meteor. Soc.*, 105, E749-E759

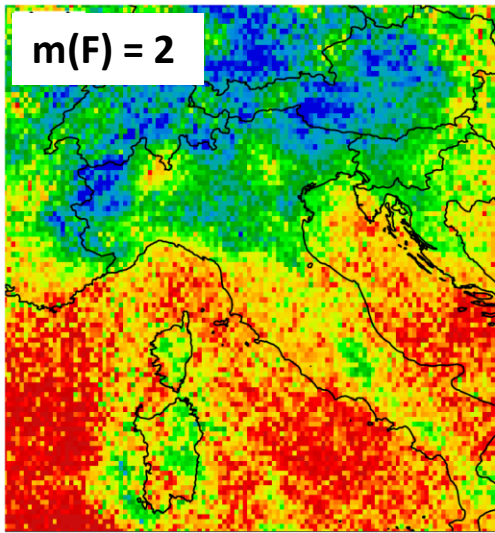
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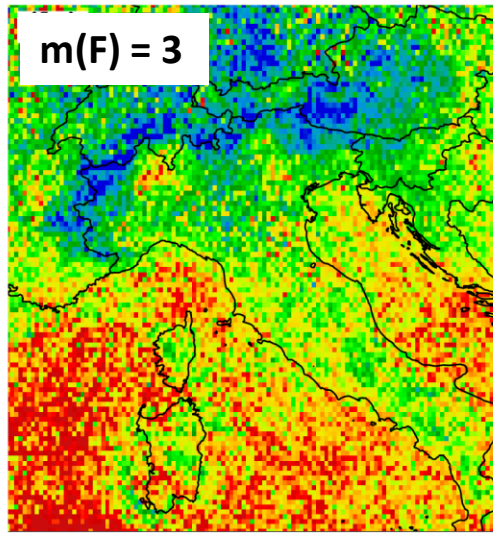


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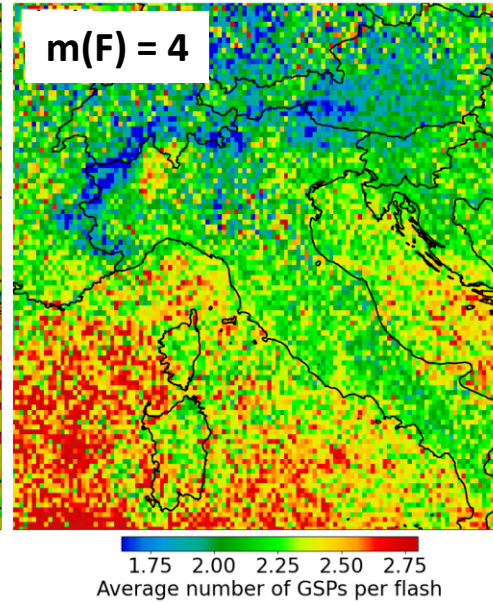
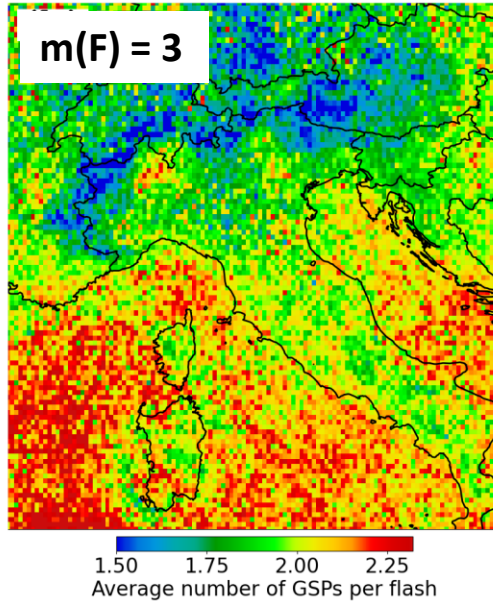
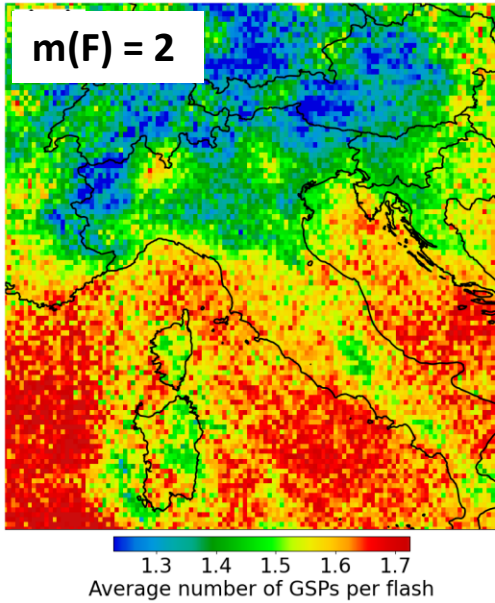
1.3 1.4 1.5 1.6 1.7
Average number of GSPs per flash



1.50 1.75 2.00 2.25
Average number of GSPs per flash

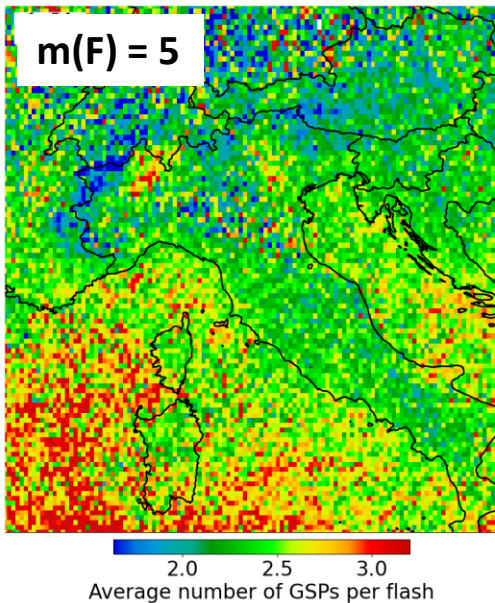
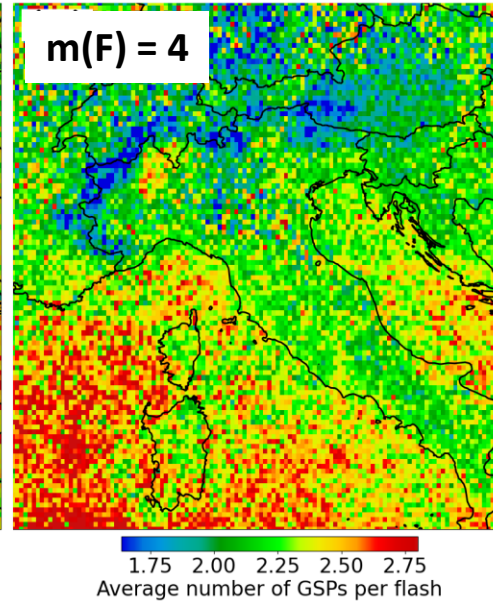
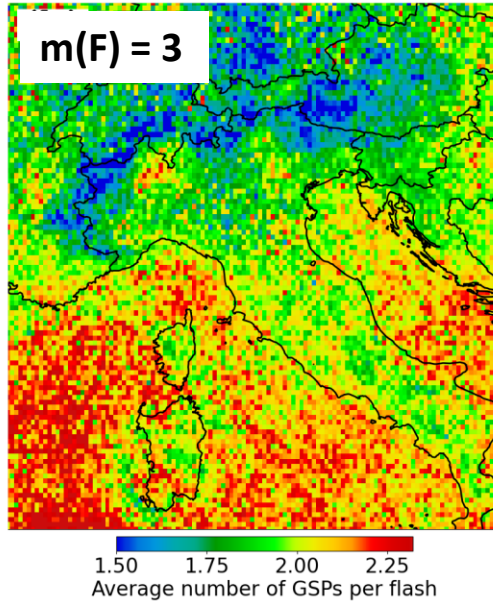
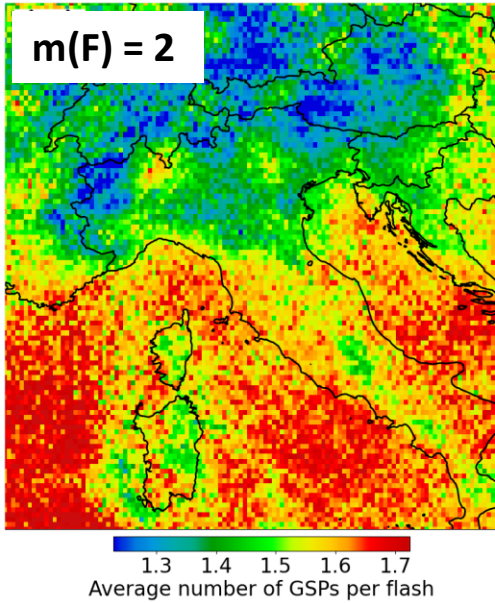
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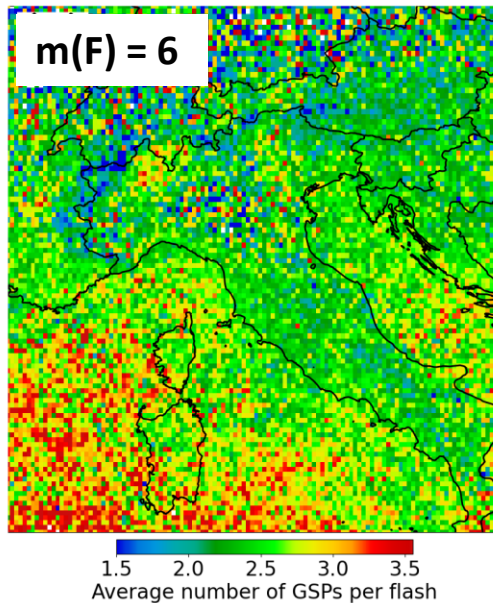
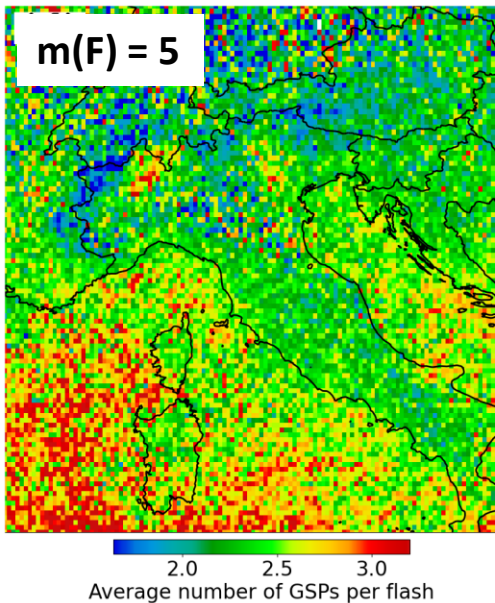
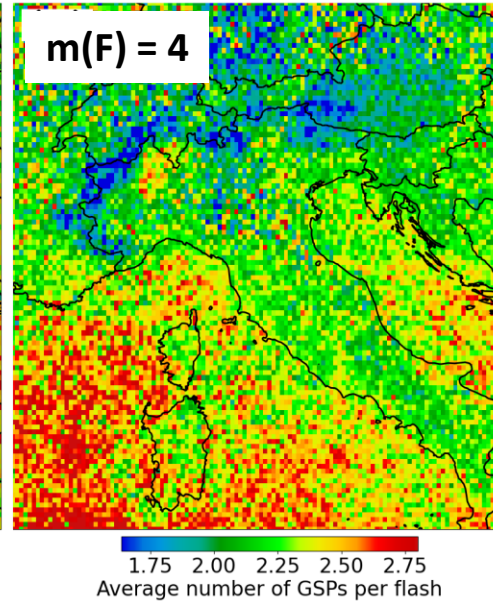
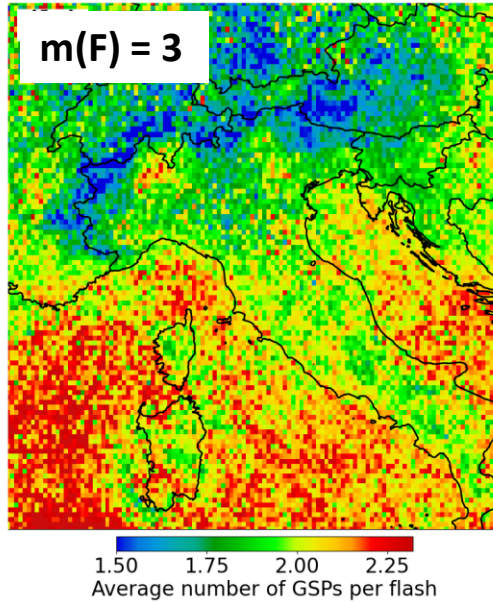
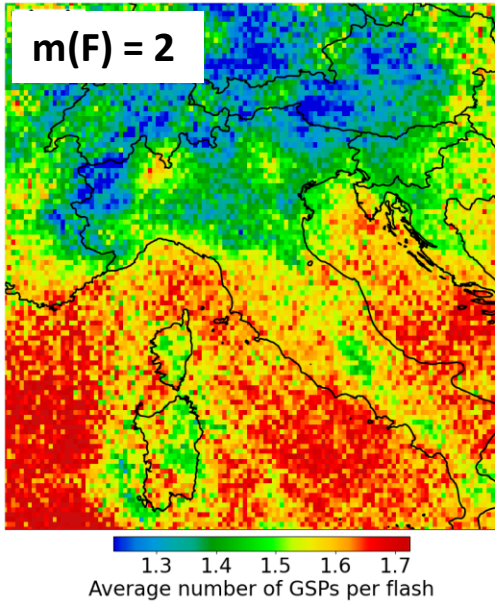
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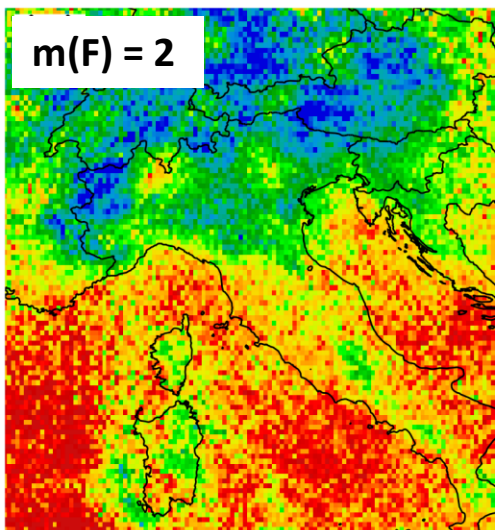
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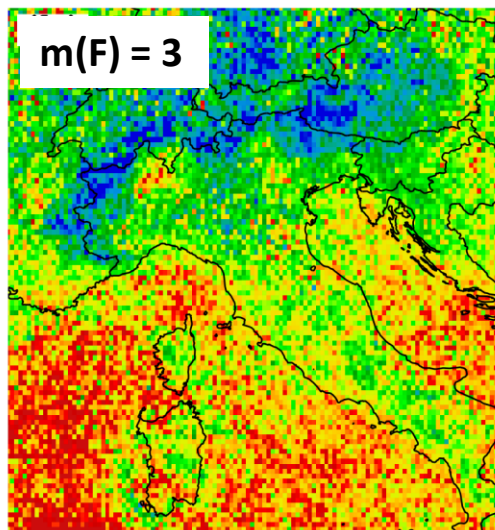


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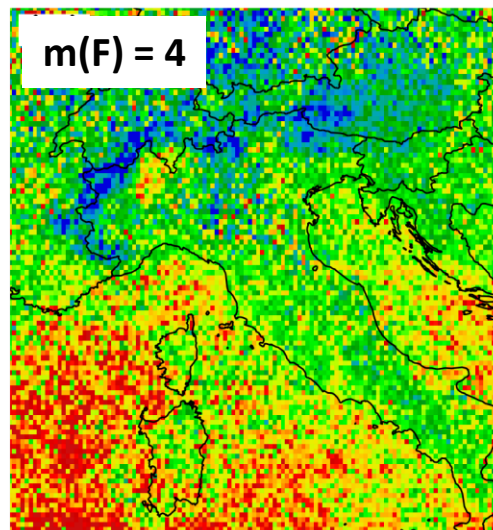
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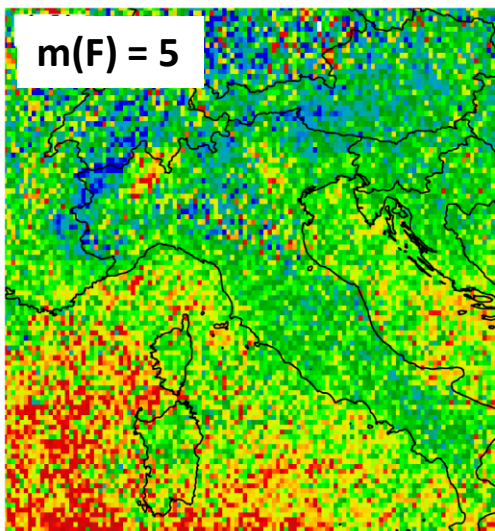
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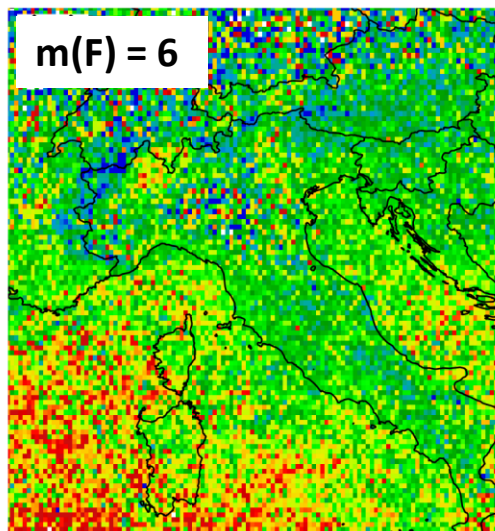
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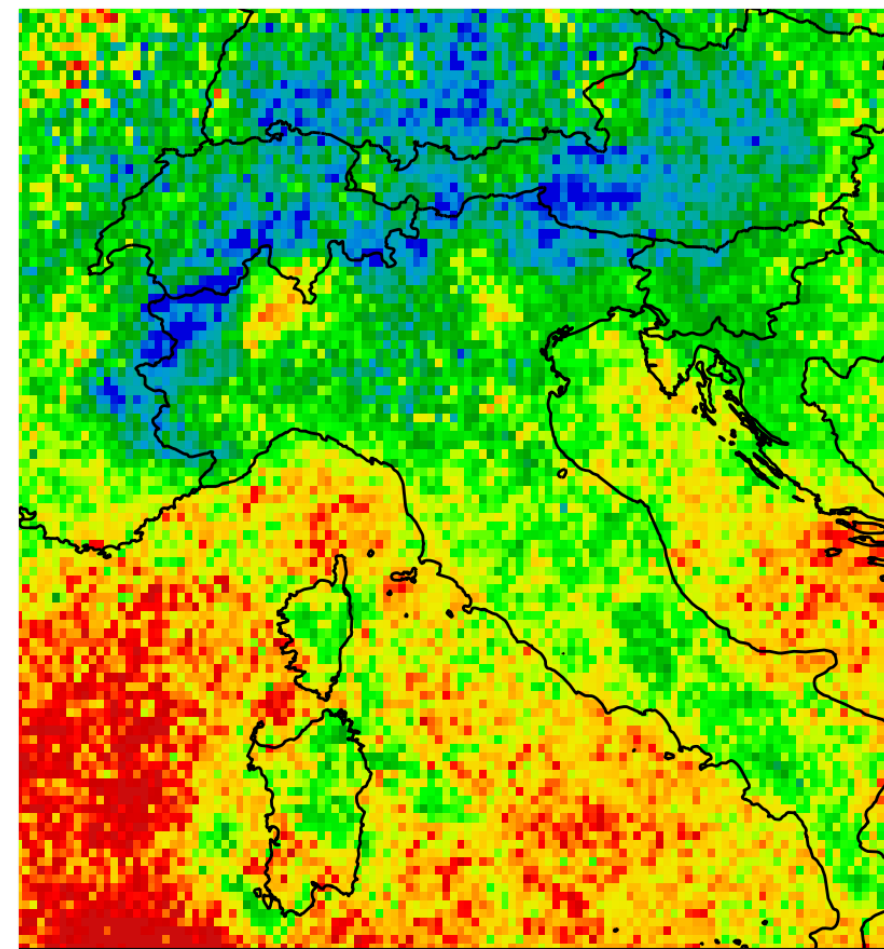
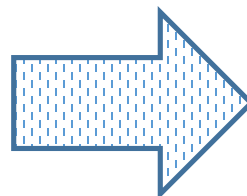
1.75 2.00 2.25 2.50 2.75
Average number of GSPs per flash



2.0 2.5 3.0
Average number of GSPs per flash



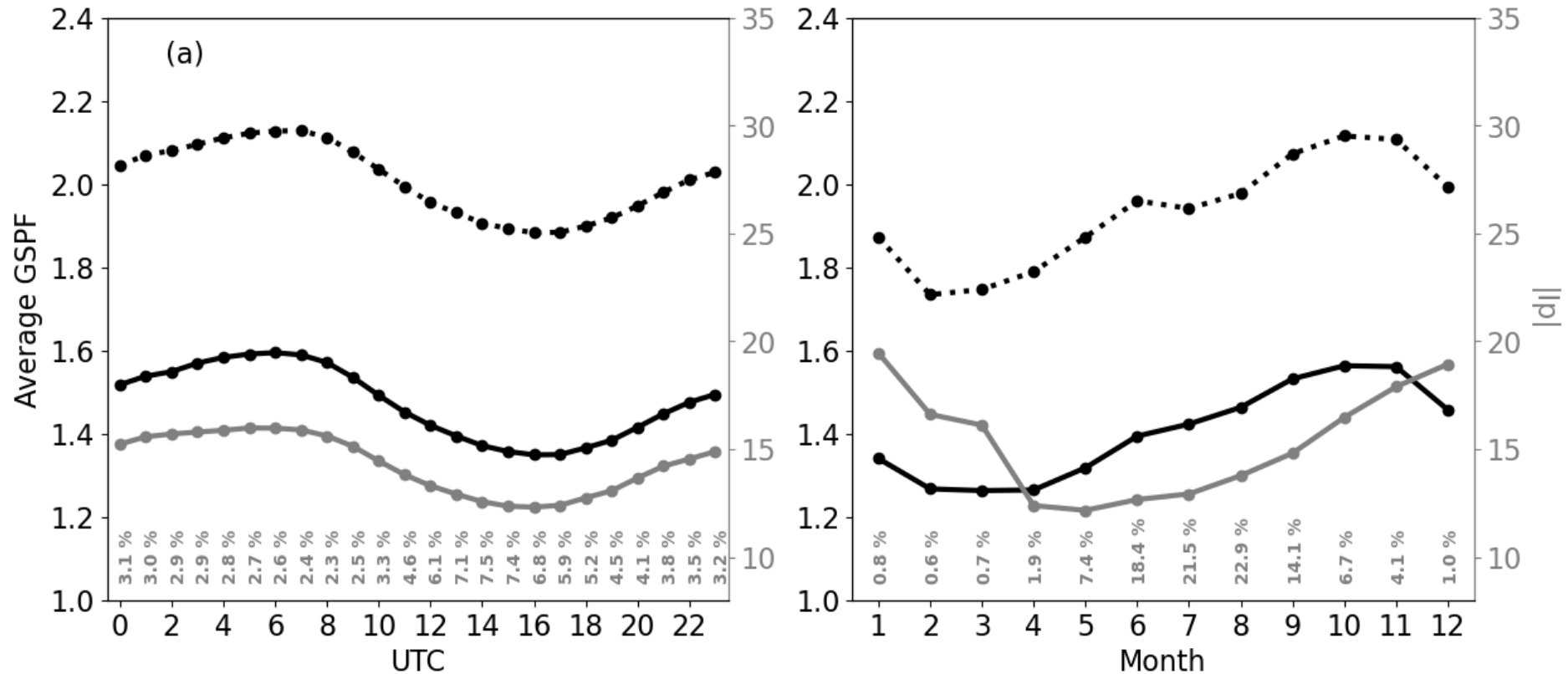
1.5 2.0 2.5 3.0 3.5
Average number of GSPs per flash



0.0 0.2 0.4 0.6 0.8 1.0
Normalized number of GSPs per flash

V. LLS-derived GSPs

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VI. Takeaway Message

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VI. Takeaway Message

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- Risk models that use flash density N_G may underestimate the true threat.
- Ground strike point density N_{SG} is a more precise metric for risk assessment.
- High-speed video provides the benchmark for realistic GSP behavior.
- GSP algorithms can reliably cluster strokes into meaningful GSPs only when the LLS has high location accuracy and undergoes continuous validation.

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THANK YOU!
&
Special thanks to



Wolfgang Schulz



Hannes Kohlmann



Stephane Pedeboy