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Global ground strike point characteristics in negative downward lightning flashes

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Introduction

- High-speed video recordings are gathered from Austria (2012, 2015, 2017, 2018), Brazil (2008), South Africa (2017-2019) & USA (2015)
  - frame rates vary from 200 – 16 000 fps
  - minimum recording length of 1.6 s
- Only flashes where a clear channel to ground is observed for all associated strokes are included
- Each stroke is classified as creating a new ground strike point (GSP) or as following a pre-existing channel (PEC)
- Location and peak current estimation is retrieved by linking the ground-truth data to the observations made by a local LLS, i.e., ALDIS (Austria), RINDAT (Brazil), SALDN (South Africa) and NLDN (USA)
- Focus is on flash multiplicity, duration, and GSP characteristics
- Results based on two publications:
  - Poelman, D. R., Schulz, W., Pedeboy, S., Hill, D., Saba, M., Hunt, H., Schwalt, L., Vergeiner, C., Mata, C., Schumann, C., and Warner, T.: Global ground strike point characteristics in negative downward lightning flashes – part 1: Observations, *Nat. Hazards Earth Syst. Sci.*, 21, 1909-1919, 2021
  - Poelman, D. R., Schulz, W., Pedeboy, S., Campos, L. Z. S., Matsui, M., Hill, D., Saba, M., Hunt, H.: Global ground strike point characteristics in negative downward lightning flashes – part 2: Algorithm validation, *Nat. Hazards Earth Syst. Sci.*, 21, 1921-1933, 2021

Courtesy of H. Hunt, the Johannesburg Lightning Research Laboratory, Univ. of Witwatersrand, Johannesburg, South Africa

Flash properties: data sets

Parameter	Location ground-truth observations				
	AT	BR	SA	US	ALL
N(flashes)	490	122	484	78	1174
N(strokes)	1539	619	1839	305	4302
Mean multiplicity	3.14	5.07	3.8	3.90	3.67
Max multiplicity	14	17	26	14	26
Percentage of single stroke flashes	29.2	23.0	38.4	25.6	32.1

- Largest data set in terms of flashes: Austria
- Largest data in terms of strokes: South Africa

Flash properties: multiplicity

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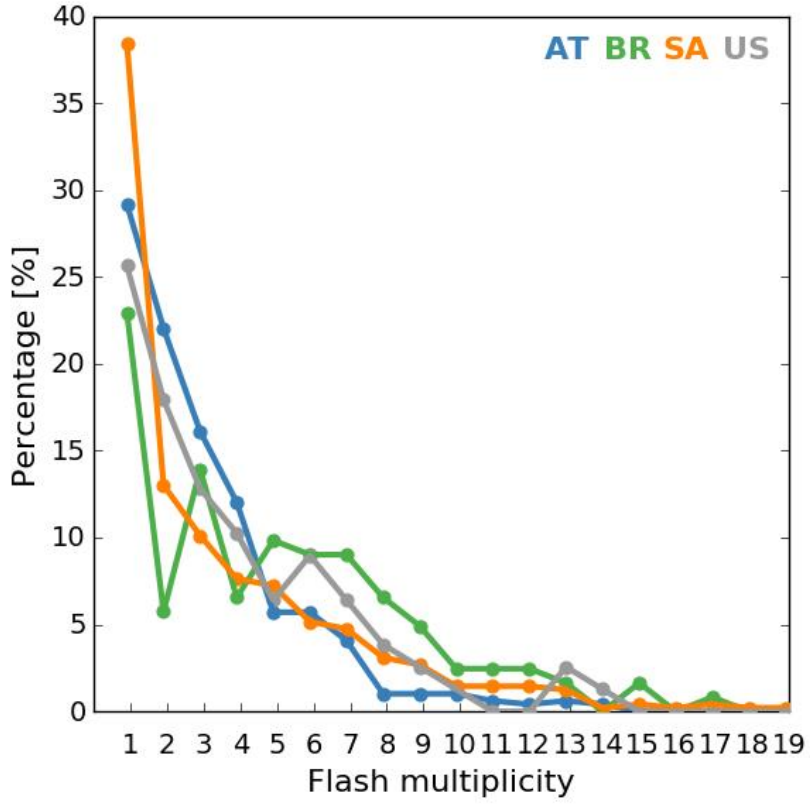
- Mean multiplicity ranges from 3.14 (AT) to 5.07 (BR)
- 1 flash in SA observed with multiplicity of 26 (lasting 1.06 s)
- Percentage single-stroke flashes varies between 23% (BR) and 38.4 (SA)



Flash properties: continuing current

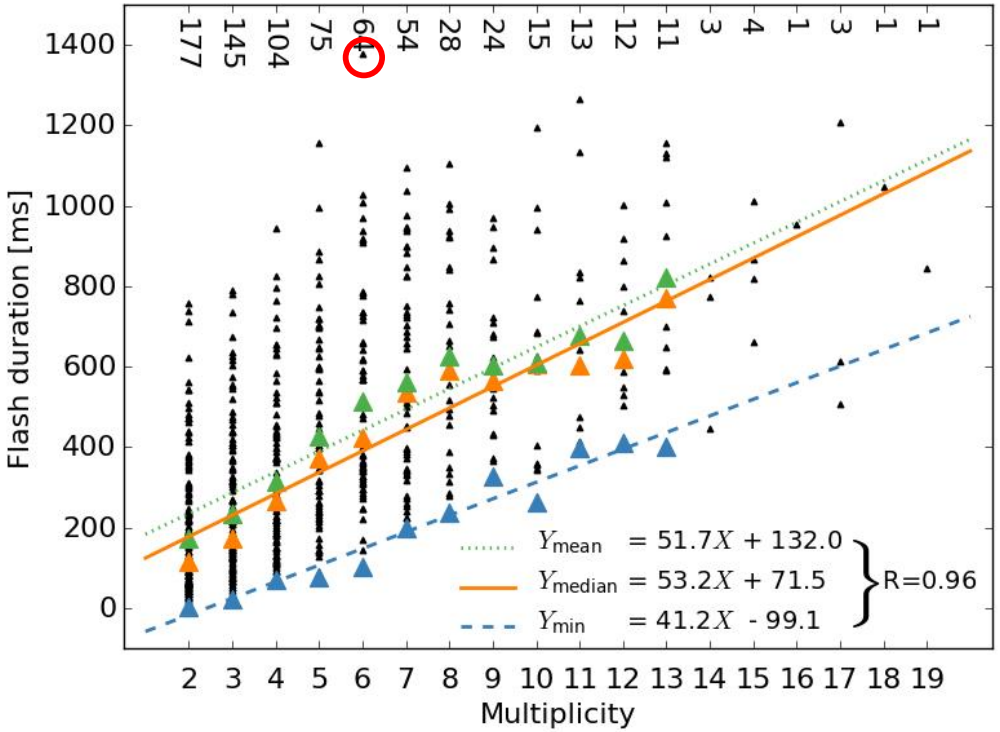
Parameter	Location ground-truth observations				
	AT	BR	SA	US	ALL
Continuing Current (CC)					
Mean (ms)	67.1	36.5	38.5	/	44.5
Median (ms)	15.0	8.0	9.0	/	10.0
Max (ms)	540	705	929	/	929
Percentage of strokes followed by CC ≥ 3 ms	33.7	71.7	73.0	/	57.7
Percentage of strokes followed by CC ≥ 500 ms	0.26	0.32	0.38	/	0.33
Percentage of flashes containing CC ≥ 10 ms	37.8	61.5	61.8	/	51.0

- minimum CC duration of 3 ms is applied in order to eliminate return-stroke pulse tails
- Mean CC duration ranges from 38.5 ms (SA) up to 67.1 ms (AT)
- Maximum value of 929 ms observed in SA
- 57.7% of all strokes are followed by a CC greater than 3 ms
- Only a small portion of strokes are followed by CC longer than 500 ms
- 51% of flashes contain CC with duration ≥ 10ms

Flash properties: duration

Parameter	Location ground-truth observations				
	AT	BR	SA	US	ALL
Average flash duration[1,2] (ms)					
Multiple-stroke flashes	306	538	394	328	371

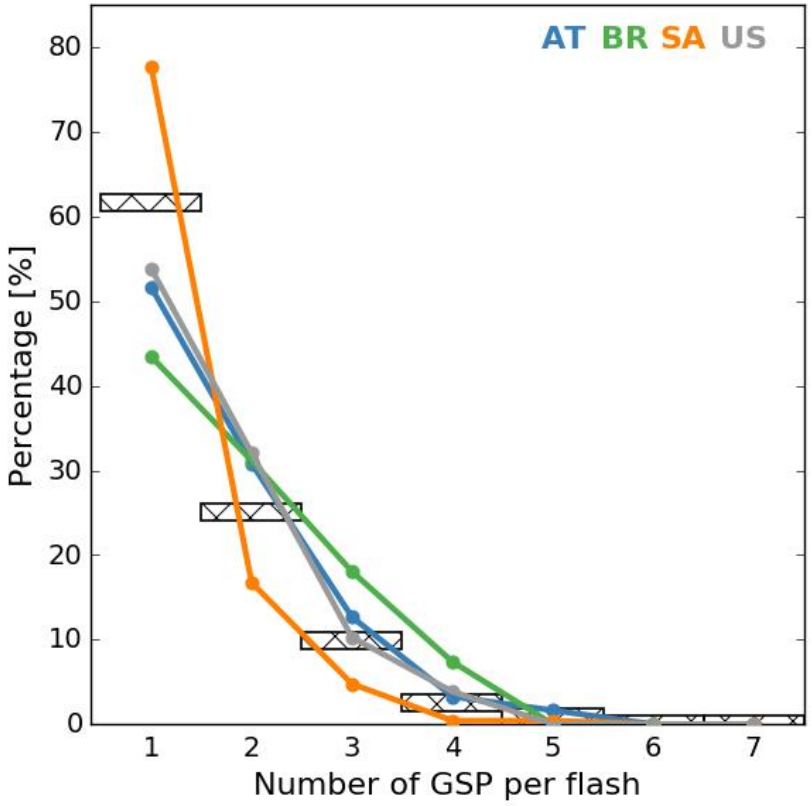
- Mean duration of multiple-stroke flashes is found to be 371 ms
- 95% of flashes have a duration below 926 ms
- Flash duration increases with increasing multiplicity, but large spread present
- Flash with longest duration of 1379 ms is observed in SA for a six-stroke flash



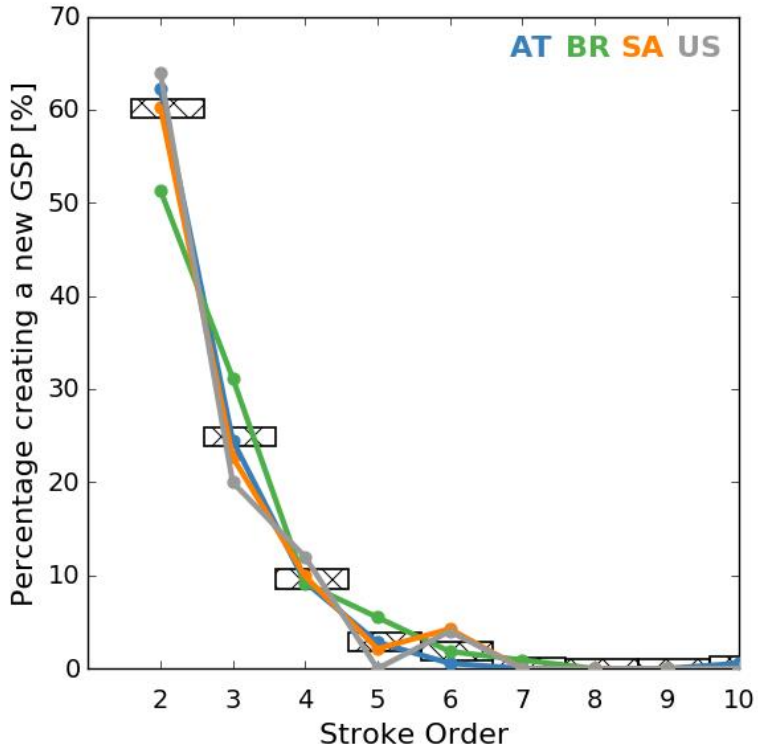
Flash properties: ground strike points

Parameter	Location ground-truth observations				
	AT	BR	SA	US	ALL
N(GSP)	845	232	626	129	1832
Average *N*(GSP/flash)	1.72	1.90	1.29	1.65	1.56
Max *N*(GSP/flash)	5	4	5	4	5
Average *N*(strokes/GSP)	1.82	2.67	2.94	2.36	2.35

- 62% of flashes strike ground in 1 point. This value drops to 44% when single-stroke flashes are excluded.
- On average 1.56 GSPs/flash; thus the number of GSPs is 56% higher compared to number of flashes
- Maximum number of GSP is found to be 5
- A ground contact point is struck 2.35 times on average

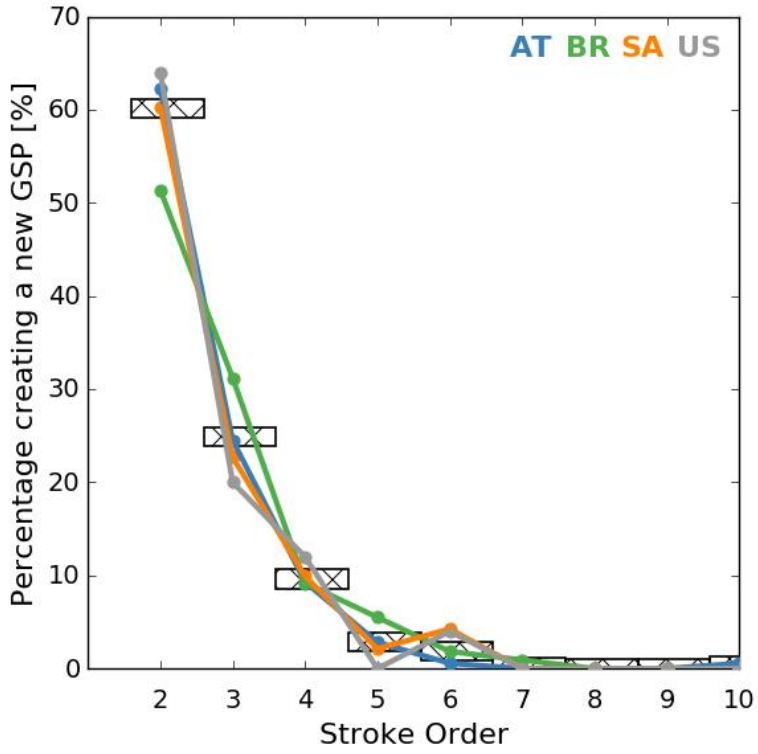


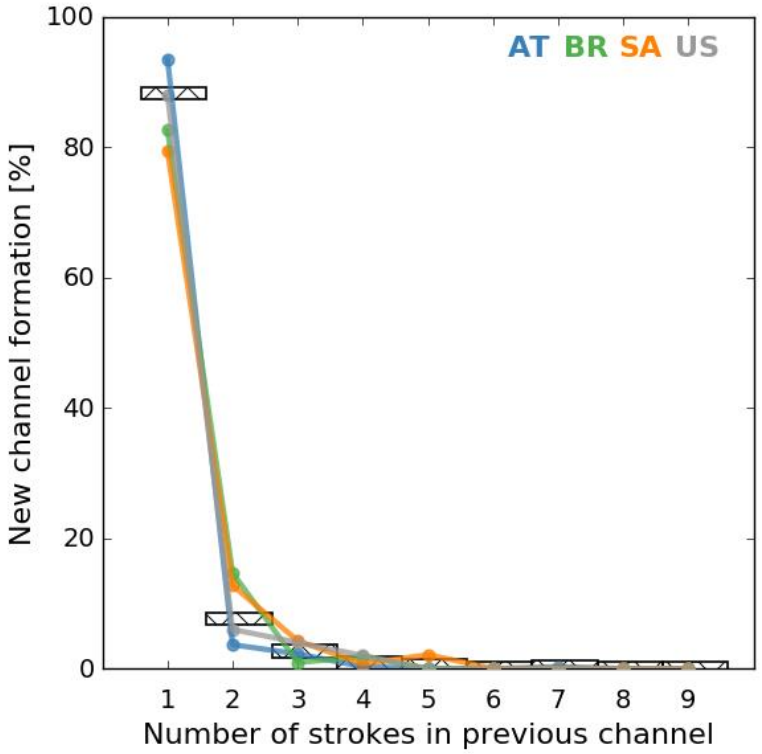
Flash properties: ground strike points



- The first subsequent stroke in a flash, i.e., stroke order of 2, creates a new GSP in 60% of the cases
- Percentage quickly drops for higher stroke orders

Flash properties: ground strike points





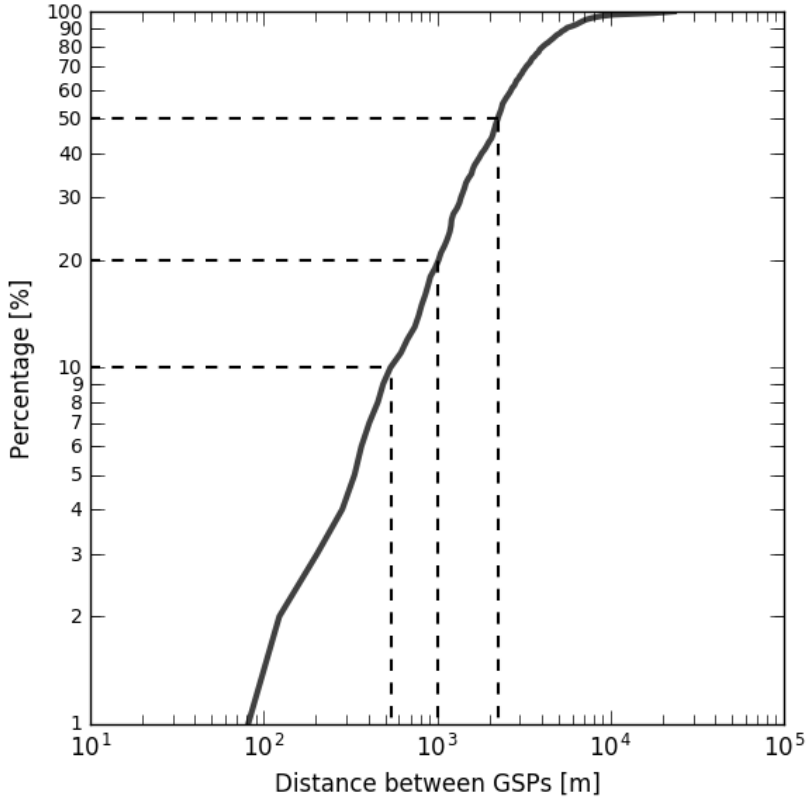
- The first subsequent stroke in a flash, i.e., stroke order of 2, creates a new GSP in 60% of the cases
- Percentage quickly drops for higher stroke orders

- 88.2% of new channels developed after the occurrence of only 1 stroke in previous channel
- Percentage quickly drops in case of 2 and 3 observed consecutive strokes

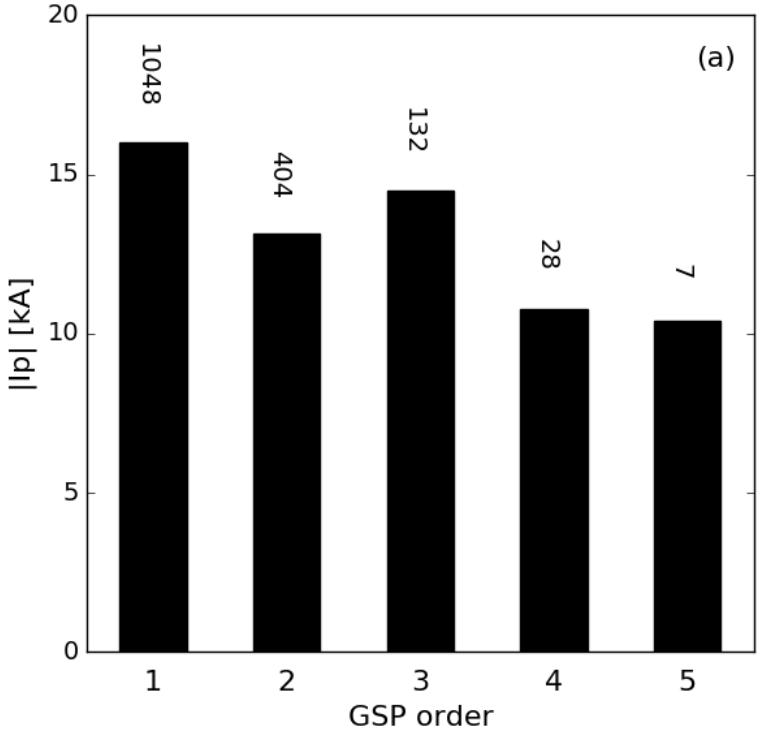
Flash properties: distance among GSPs

Parameter	Location ground-truth observations				
	AT	BR	SA	US	ALL
Distance between GSPs					
Sample size	473	104	148	53	778
Mean (km)	2.53	3.15	4.31	1.72	2.89
Median (km)	2.15	2.82	2.72	1.57	2.23
99th percentile (km)	9.82	8.09	20.87	5.65	17.69
Maximum (km)	23.16	9.93	21.6	5.89	23.16

- Location GSP is calculated as the mean location of the strokes
- Mean/median value of the separation distance is 2.89/2.23 km
- Cumulative distribution indicates that, e.g., only 10% of the distances between GSPs fall below 540 m, 20% below 1 km, …

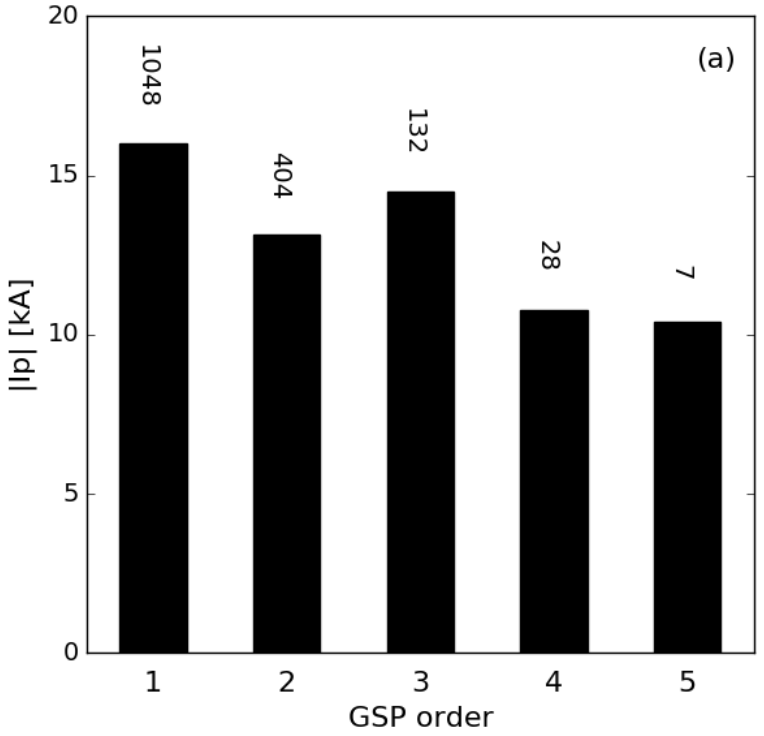


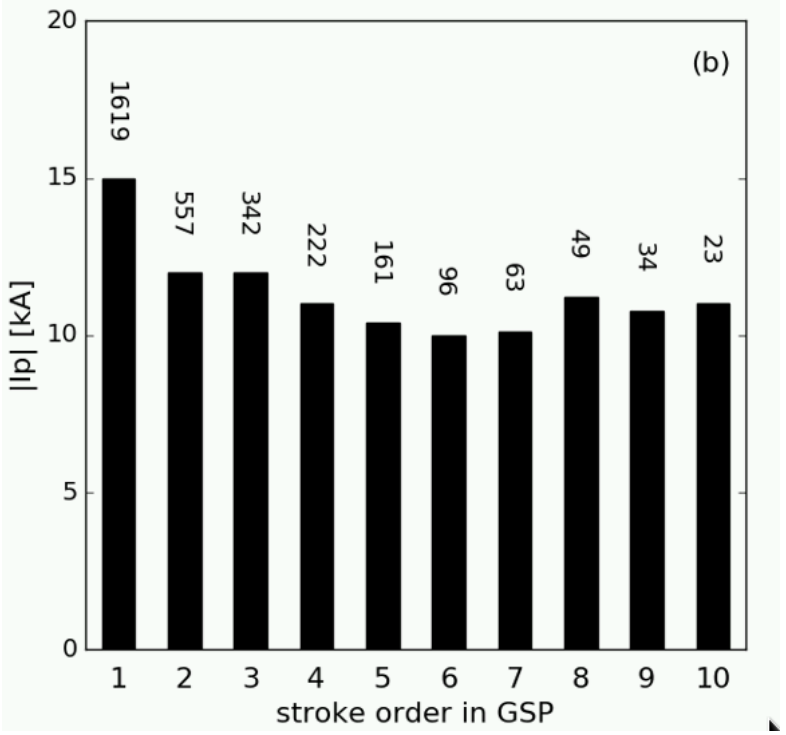
Flash properties: peak current



- Peak current, I_p, of GSP is I_p of 1st stroke in GSP
- Median peak current of 1st GSP is highest and drops slightly for GSP occurring later in flash

Flash properties: peak current





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- Median peak current of 1st GSP is highest and drops slightly for GSP occurring later in flash

- 1st stroke in GSP has highest $|I_p|$ of 15 kA
- $|I_p|$ drops for subsequent strokes within the same GSP

Conclusions

- On average more than 1 GSP is observed per flash, hence the use of N_G in risk calculation of lightning protection leads to an underestimation of the hazard.
- Ground strike point algorithms exist grouping individual strokes into ground strike points. Ingesting LLS observations in GSP algorithms would provide a means to study GSP characteristics on a larger temporal and spatial scale.
- The use of N_{SG} will improve risk estimation for lightning protection.