

**Answer to RC2 (Martin Murphy), nhess-2021-12**

**General comments:**

The authors provide a nice, concise summary of high-speed video observations of negative CG flashes from four locations around the world. My only pre-publication suggestions would be perhaps to consider augmenting the paper with some additional information that apparently should be in the data sets. This includes:

- lines 90-92: statistics on the occurrence of forked strokes, and on the occurrence of and duration of continuing currents (at locations other than the US site, as noted)

**=> Investigating the characteristics of forked strokes is indeed interesting. Unfortunately, the indication of forked strokes was only properly documented for the Austrian 2018 data set, and (almost) not for the others. It would require a considerable effort to add information about forked strokes for all the data sets. Hence, we believe this is more appropriate for a potential follow-up study.**

Anyhow, based on AT 2018 it is found that 9.4% of the observed flashes comprise of at least one forked stroke (18/191). This is in line with the 12.4% found in Valine and Krider (2002)\* whereby 48 (37 + 11) out of a total of 386 cloud-to-ground lightning flashes contained forked strokes or produced channels “that struck the ground in two or more places and shared a common channel at higher altitudes”. Examining those latter flashes that contain forked stroke(s) in AT 2018, 34.4% of the strokes within those flashes are forked (21/61), whereas overall this is only the case in 3.75% of all observed strokes (21/560). If one would apply a similar amount of ~3-4% of the observed strokes being forked in the other data sets, this results in an increase of the average amount of ground strike points per flash,  $N(\text{GSP}/\text{flash})$ , as indicated in Table 1 by this same factor.

This will be included in the new version of the manuscript.

**=> Investigating the presence of continuing current (CC) leads to following findings:**

	Continuing Current (CC)				
	AT	BR	SA	US	ALL
Mean (ms)	67.1	41.2	38.5	/	45.8
Median (ms)	15.0	10.0	9.0	/	10.0
Max (ms)	540	540	929	/	929
% strokes followed by CC $\geq 3\text{ms}$	33.7	48.1	73.0	/	54.0
% strokes followed by CC $> 500\text{ms}$	0.26	0.49	0.38	/	0.35
% flashes containing CC $> 10\text{ms}$	37.8	52.8	61.8	/	50.1

Following the approach as in Ballarotti et al. (2012)\*, a 3 ms minimum CC duration is applied in order to eliminate what could just be return-stroke pulse tails in the high-speed camera records. Considering all ranges of CC ( $\geq 3$  ms), the mean CC duration ranges from 38.5 ms in SA up to 67.1 ms as observed in AT, with an overall average of 45.8 ms. Median values are considerably lower with an overall median of 10 ms. The maximum value of 929 ms was measured in South Africa, which is about 200 ms longer than the maximum value found in Ballarotti et al. (2012).

Out of 1096 flashes recorded with CC information, 50.1% contained continuing currents with duration greater than 10 ms and 54% of all strokes were followed by any CC greater than 3 ms. Only a small portion, i.e., 0.35%, of the strokes are followed by a CC longer than 500 ms.

\* Ballarotti, M. G., C. Mediros, M. M. F. Saba, W. Schulz, and O. Pinto Jr. (2012), Frequency distributions of some parameters of negative downward lightning flashes based on accurate-stroke-count studies, *J. Geophys. Res.*, 117, D06112, doi:10.1029/2011JD017135.

**This will be included in the new version of the manuscript.**

- lines 160-161 and other places where the data from South Africa are discussed: comparisons of upward-initiated flashes from the Sentech and Hillbrow towers in Johannesburg with observations from other towers, such as Gaisberg, Peissenberg, and Santis in the Alps, or the CN tower in Toronto. The comparison with the towers in the Alps might be particularly interesting insofar as so much of their lightning occurs in winter, if I am not mistaken, whereas the Johannesburg site is noted in this manuscript as having essentially no winter lightning.

**=> Upward lightning flashes are not taken into account in the South African data set. This will be highlighted in the next version of the manuscript. Therefore, the comparison with upward-initiate flashes in other locations, e.g., Alps or Toronto, is out of the scope of this work.**

- also related to lines 160-161: is the fact that the South African data set has a much larger percentage of single-stroke flashes than the others partly influenced by the population of upward-initiated flashes in that data set? It would be interesting to know, one way or the other

**=> As noted above, all upward flashes in SA are extracted from the SA data set in this work.**

**=> The percentage of single-stroke flashes as described in the 2013 CIGRE Brochure 549 (Table 2.1) range from 13% (New Mexico; Kitagawa et al., 1962) up to 21% (Sri Lanka; Cooray and Jayaratne, 1994). The values found in this manuscript (Table 1) are somewhat higher ranging from 23% (BR) up to 38.4% (SA).**

Note that in our study flashes are removed if at least one channel is partly visible, diffuse or simply out of the field of view. As such only flashes are kept of which the different GSPs in the video images could be determined with great confidence. The number of flashes that are removed from the data sets is anyhow minimal w.r.t. total number of flashes per data set. However, taking those removed flashes into account to re-calculate the percentage of single-stroke flashes it turns out that the percentage in case of AT drops from 29.2% to 28.2%, for BT from 23% to 21.4%, for SA from 38.4% to 37.9%, whereas it remains unchanged for US at 25.6%.

For AT: We would like to draw your attention to the recently published article by Schwalt et al. (2021)\* in which the authors investigate specifically the percentage of single-stroke flashes in Austria. It is found that the percentage of single-stroke flashes among all negative flashes is 27%. A possible dependency of the occurrence of single-stroke flashes with the underlying terrain (Alpine versus pre-Alpine) is found in this study. The 28.2% found in the present study is therefore in line with the findings of Schwalt et al. (2021).

For BR: the newly calculated percentage of 21.4% is only slightly higher compared to the 17% quoted in the 2013 CIGRE brochure 549.

For SA: Looking into the LLS data (thus not just the correlated high-speed camera cases) in a corresponding area as in this study and averaged over a few years, a similar value of 1.2 strokes per flash is found. It seems that this area, at an altitude of about 1600 m asl, is prone to single-stroke flashes. The origin of this discrepancy, compared to the other regions, is indeed worth a thorough investigation but out of the scope of this study.

For US: We would like to draw your attention to Fleenor et al. (2008)\*\*. In this study 40% (41/103) of the negative cloud-to-ground flashes are single-stroke flashes. It was noted that the time-resolution of the camera was limited to 16.7 ms, which could lead to an underestimation of the true negative multiplicity by about 11% (Biagi et al., 2007). However, even taken this underestimation into account, the percentage of the single-stroke flashes in the present study is still in line with Fleenor et al. (2008).

\*Schwalt, L., Pack, S., Schulz, W., and Pistotnik, G. (2021). Percentage of single-stroke flashes related to different thunderstorm types, *Electric Power System Research*, 194, 107109

\*\*Fleenor, S. A., Biagi, C. J., Cummins, K. L., and Krider, E. P. (2008). Characteristics of cloud-to-ground lightning in warm season thunderstorms in the Great Plains, 20<sup>th</sup> International Lightning Detection Conference, 21-23 April, Tucson, Arizona, USA.

- The only other comment is about references in lines 48-49 – at least some are outdated, and should be updated where possible; the Cummins et al. reference on the NLDN is especially old, and in fact, there's a brand new paper in the March 2021 *Journal of Atmospheric and Oceanic Tech.* about the 2013++ NLDN.

=> Cummins et al. (1998) will be replaced by ‘Murphy, M. J., Cramer, J. A., and Said, R. K.: Recent History of upgrades to the U.S. National Lightning Detection Network, Journal of Atmospheric and Oceanic Technology, <https://doi.org/10.1175/JTECH-D-19-0215.1>’

=> Lay et al. (2004) will be replaced by ‘Burgesseur, Rodrigo E., Assessment of the World Wide Lightning Location Network (WWLLN) detection efficiency by comparison to the Lightning Imaging Sensor (LIS), Q. J. R. Meteorol. Soc. 143: 2809–2817, October 2017 A DOI:10.1002/qj.3129’

=> Thomas et al. (2004) will be replaced by ‘Coquillat, S., Defer, E., de Guibert, P., Lambert, D., Pinty, J.-P., Pont, V., Prieur, S., Thomas, R. J., Krehbiel, P. R. and Rison, W., SAETTA: high-resolution 3-D mapping of the total lightning activity in the Mediterranean Basin over Corsica, with a focus on a mesoscale convective system event, Atmospheric Measurement Techniques, 12, 2019, doi:10.5194/amt-12-5765-2019.’