Response to reviewer 1 of amt-2019-31

In this document we provide answers to the comments of reviewer 1 of the paper amt-2019-31. Our answers to the reviewer are given in *italic* font. Proposed changes to the manuscript are highlighted in blue color.

GENERAL COMMENT

This paper presents a detailed study on lightning strokes in Switzerland, in relation with hydrometeor classification from dual-polarization weather radar. The topic is original and certainly interesting for a wide range of cloud physics applications. The paper is in general well written, with a comprehensive introduction including the scientific background and a proper description of the instrumentation and analysis methods adopted. The data analysis is highly descriptive, including a consistent amount of results organized according to partitions including IC, CG, positive and negative strokes, and finally lightning originating at lower levels (mixed-phase region). The illustrated results are very interesting and worth to be published on AMT journal.

We thank the reviewer for his/her kind words and thorough review

As also detailed in the specific comments below, I found this part (section 3) not enough fluent due to an overwhelming amount of numbers in the text. For this reason, I suggest making use of tables to organize at least some of these numbers and try to improve the fluency focusing on the relevant qualitative behaviors. In addition, while the introduction is properly developed with many relevant references, in the data analysis I missed references helping to understand whether the results are supported by previous findings or the authors are showing some phenomenological behavior not yet comprehensively studied, lacking physical explanation. This is my only major concern, which I'm sure could be easily addressed by the authors. Providing a better context to these results would help the paper readability, and provide other researchers a more solid background to work with lightning data in association with dual-polarization measurements.

We have added a subsection Discussion in section 3 to put our results into context

Consider adding a figure showing an example of radar hydrometeor classification. A vertical cut, possibly with lightnings over plotted, would greatly help readers not familiar with radar classification, and may serve as an effective visual introduction to the main topic of the paper.

We thank the reviewer for the suggestion. We have added an explicit reference to one of the examples in the paper by Besic et al. (2016):

An example of output can be found in Fig. 11 of the aforementioned paper.

However, we have not added an extra figure since there are already 20 complex figures in the paper and a hydrometeor classification cut is not strictly relevant for the understanding of the paper. Moreover, we are preparing a new submission focusing on two relevant events observed during the campaign where there will be plots as suggested.

SPECIFIC COMMENTS AND MINOR CORRECTIONS

- When discussing the hydrometeor type in relation with the lightnings, percentages are given to represent the relative occurrence of given particle types. The first comment I have is that providing these numbers with two decimals accuracy is misleading. We know that hydrometeor classification is subject to many assumptions and uncertainties, so I would recommend providing these percentages with a lower level of accuracy (rounding to integers may be enough in general). The second comment is that there are large portions of the manuscript with a detailed listing of these percentages (e.g. page. 11, lines 3-9) which makes reading a bit hard. I recommend moving as much as possible those numbers to tables and leave in the text only the most relevant ones, focusing on the relevant qualitative behavior.

We have reduced the accuracy to 1 decimal instead of two. We think we should not reduce it further since there are categories that do not reach 1% but their presence is relevant. We have also created a table summarizing these figures as suggested.

- P.6, Line 24: “ZPhi” method should read “ZPHI”, and the proper reference should be the Testud paper:

Testud, J., E. Le Bouar, E. Obligis, and M. Ali-Mehenni, 2000: The rain profiling algorithm applied to polarimetric weather radar. J. Atmos. Oceanic Technol., 17, 332–356.

Indeed, Ryzhkov used the ZPHI method for rainfall estimation using the same ZPHI method as in Testud et al., 2000 for deriving specific attenuation.

We changed the naming of the algorithm and added the reference to Testud. We kept the reference to Ryzhkov though, because there are subtle differences in the implementation between the two papers and our approach resembles better the one of Ryzhkov.

- P. 7, Lines 9-10: according to Besic et al., 2018, if there is a dominant hydrometeor type, the entropy is low (close to 0), while in case of mixtures, the entropy is higher (up to 1). Please explain and/or correct why it is here stated the opposite (“..within the radar resolution volume there is a clearly dominant hydrometeor type (entropy 1) or if it is an heterogeneous mixture without any dominant hydrometeor type (entropy 0).”). Also check that the values of entropy discussed through the paper are consistent with the correct definition.

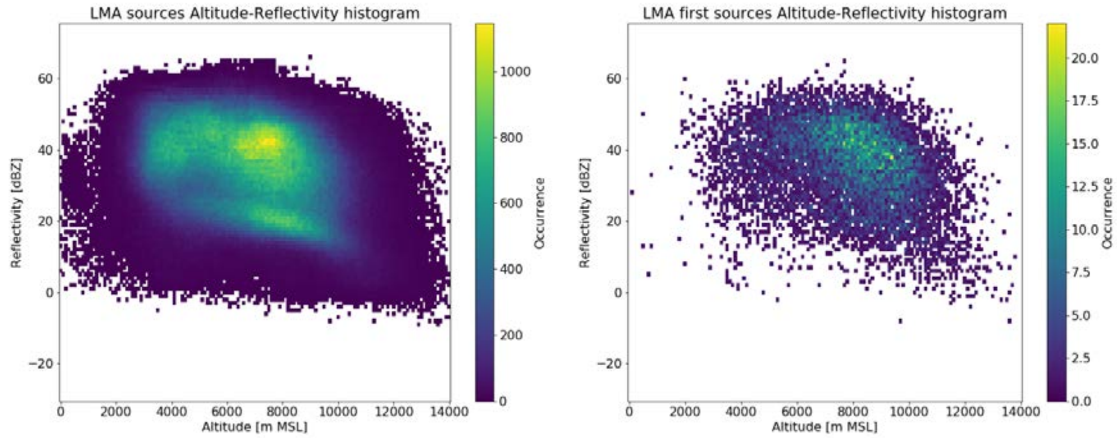
We thank the reviewer for having spotted this mistake. We have corrected it and revised the text throughout.

- P.7, Line 29. “extend” -> “extent”

We corrected that in the new version

- P. 9, L25: “The reflectivity data (topmost panels in Fig. 7) of all sources show a bi-modal distribution” Any idea why? Could there be a relation with the bimodality of lightning data?

We have analyzed data collected on individual days and also plotted 2D histograms of altitude-reflectivity for the entire dataset. What we have observed is that flashes tend to originate at relatively high altitudes (6000-10000 m MSL) and in regions of high reflectivity (30-50 dBZ). When considering all VHF sources, though, several possibilities appear. Most sources are confined to an altitude *between 6000-8000 m MSL and a reflectivity of about 40 dBZ. However, two secondary regions appear: one at a similar altitude but with reflectivity 20 dBZ and another with similar reflectivity but at lower altitudes. See the Figures below:*



We think that the reason for this is that flashes tend to propagate in horizontal layers. Thus, a flash will initiate at the core of a convective cell and then either propagate horizontally at a similar altitude reaching areas out of the core (and therefore with lower reflectivity) or move down to a lower layer within the convective core. We have added this analysis to the text:

It is worth noticing that a similar behavior was observed when looking at the altitude of the VHF sources (Fig. 6) We think that this is due to the tendency of flashes to preferentially propagate horizontally through layers of high density of charge. The 2D-histogram of altitude-reflectivity and the analysis of individual storms (not shown) show that there are 3 areas with higher density of flashes. Indeed, most sources are concentrated in an area with roughly the same altitude and reflectivity as the flash origin while two other less dense preferential areas appear: One at roughly the same altitude but with lower reflectivity and another with similar reflectivity values but at another altitude. Our interpretation is that flashes are likely to either propagate horizontally at similar altitudes to where they are generated, sometimes extending beyond the convective core (hence the lower reflectivity), or move to a lower layer within the convective core.

- Please check the label for aggregates, sometimes it is referred to as “AG” (P. 6, L. 32), but in fig. captions it is often called “DS”.

We corrected that in the new version.

- P. 13, Lines 11-14. Here the authors hint at a possible relation between the very high proportion of positive lightnings and hail at the ground. Please add proper references.

We have added the following lines:

A higher proportion of +CG flashes have been linked to severe hail-bearing storms in past studies (see the introduction of Pineda et al., 2016 for a summary)

- P. 15, Lines 3-4: “For our classification we have considered as belonging to the mixed phase or liquid regions flashes the first VHF source of which was located in areas where the dominant hydrometeor: : :” I suggest rewording, i.e. “For our classification we have considered as belonging to the mixed phase or liquid regions flashes whose first VHF source was in areas where the dominant hydrometeor..”

We changed the sentence accordingly in the revised version.

- P. 16, Lines 6-7: have you analysed in detail the “origin” of these 2 deg/km Kdp values (lower-right panel in fig. 18)? Such anomaly in the distribution is quite suspect, could it be due to some artifact in the data processing?

We have decided to add the values out of the range of the presented histograms in the first and last bin respectively. Thus the 2 deg/km value should be read as 2 deg/km or larger (we already say so in the mentioned text) and there is no anomaly in the data processing. We explain that at the beginning of section 3.2:

It should be noticed that in all the histograms presented in this paper, the values outside of the histogram range are added to the bins at the extremes, e.g., the last bin in the histograms in Fig. 4, top left, include all the values above 900 ms.

We have also added the following sentence to all the figures showing histograms:

Note that the values outside of the histogram range are added to the bins at the extremes.

- P.17, Line 2: “flashes with origin in the liquid and mixed phase layers as a proxy for upward lightning”. Is there a proper reference to add here? Or is it just a “common sense” expectation?

This is common sense expectation. We have not found an explicit reference in the literature.

- P. 17, Lines 20-22: I also suggest considering “riming” (which implies the presence of supercooled water) in addition to particle concentration/size to explain the higher reflectivity.

We agree with the reviewer and we have modified the sentence as follows:

The reflectivity at the flash origin location, in particular, has a significantly larger median, suggesting that CG flashes are more likely to occur in regions of higher particle concentration and/or larger particle size and density, increased for example as a consequence of riming.

- Fig. 1. Either add a length scale in the image, or at least mention the size of the domain in the caption. A map with lat, lon axes would be more useful for easier interpretation of fig. 3.

We have added the scale and lat, lon axes to both images.

- Fig. 2 Need larger font for the dates.

We enlarged the font

- Fig. 4 (and all other similar histograms). Please add a legend with the color meaning (in addition to mentioning in the caption), it is sufficient in the first panel.

We added a legend to the first panel of each plot.

- Fig. 8, top panels: it may be better to add the hydrometeor type (e.g. “RN”,..) directly on the x-axis (so the reader is not forced to keep switching between the number and the label), or at least mark the most relevant hydrometeor types directly on the histogram bars.

We added the hydrometeor type in the x-axis.

- Fig. 9: same as above, please mark the hydrometeor type on the axes, try to avoid using the numeric index. Suggestion: consider using a monochromatic color scale (e.g. gray scale), with light tone for low occurrence and dark tone for higher occurrence. I argue this may improve the readability (this is just a suggestion!). The current dark blue really dominates the visual impact.

We added the hydrometeor type in the axis as suggested. As for the colour scale we think the current colour scale highlights best the most dominant hydrometeors.

References

Pineda, N., Rigo, T., Montanyà, J., and van der Velde, O. A.: Charge structure analysis of a severe hailstorm with predominantly positive cloud-to-ground lightning, Atmospheric Research, 178-179, 31 – 44, 2016