Response to reviewer 2 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.

The paper presents comprehensive statistical analysis of lightning data associated with concurrent polarimetric radar observations in the Swiss Alps. There is no doubt that the manuscript contains rich information about statistical characteristics if intra-cloud and cloud-to-ground flashes such as their intensity, duration, area, altitude and temperature intervals where flashes originated, etc.

We thank the reviewer for this positive assessment.

It comes as no surprise that both IC and CG flashes mostly originate in the areas of dry graupel (called rimed particles in the manuscript) and hail well above the freezing level in sufficiently deep convective clouds.

Indeed that was expected but we have followed a statistical approach over a relatively large dataset in order to get objective information.

The authors relate lightning flashes to the output of the MeteoSwiss semi-supervised polarimetric classification algorithm and even estimate the entropy of hydrometeor classification in the flash locations. I am not sure that the use of such a "big gun" as the polarimetric classifier is fully justified in this context. Indeed, polarimetric radar variables such as ZDR, KDP, and hv bear very little classification potential in cold parts of convective storms unless large hail growing in a wet growth regime is observed in the cloud. In fact, discrimination between snow, graupel, and hail aloft is almost exclusively made based on the radar reflectivity factor. Radar reflectivity of hail is larger than the one of graupel and snow.

As it is described in the papers by Besic et al., our hydrometeor classification is based on the combination of reflectivity, differential reflectivity, specific differential phase, co-polar correlation coefficient and distance to the iso-0°/temperature. The algorithm essentially looks for the minimum distance between the observations and a set of centroids in the measurement space. While it is true that reflectivity is the dominant driver in the classification at sub-zero, the other variables play a non-negligible role in the allocation of the dominant hydrometeor. Moreover, in the liquid and mixed phase layers polarimetry plays an even more relevant role in the classification. Before this particular campaign, our hydrometeor classification has been extensively tested also by comparing the output with in-situ measurements on the ground in mountainous areas with positive results. Therefore we think it is fully justified to use our hydrometeor classification scheme. The centroids used in the processing of the data are summarized in the following table:

Hydrometeor type	Zh	Zdr	Kdp	RhoHV	Delta_Z
AG	13.5829	0.4063	0.0497	0.9868	1330.3
CR	02.8453	0.2457	0.0000	0.9798	0653.8
LR	07.6597	0.2180	0.0019	0.9799	-1426.5
RP	31.6815	0.3926	0.0828	0.9978	0535.3
RN	39.4703	1.0734	0.4919	0.9876	-1036.3
VI	04.8267	-0.5690	0.0000	0.9691	0869.8
WS	30.8613	0.9819	0.1998	0.9845	-0066.1
MH	52.3969	2.1094	2.4675	0.9730	-1550.2
IH/HDG	50.6186	-0.0649	0.0946	0.9904	1179.9

Large entropy simply means high variability of Z in a given spatial domain that spans typical range intervals of snow, graupel, and hail.

We respectfully disagree with the reviewer. As described in the paper by Besic et al. 2018, our concept of entropy is way more sophisticated than that and it refers to the entropy of the observations within the radar range gate. By estimating the entropy at the observations space, we are able to determine whether the composed signal is due to a single hydrometeor type or a combination of different hydrometeors, something that we think it is very relevant for this study.

I am surprised by the fact that the histograms of ZDR in the regions of lightning initiation above the freezing level are almost perfectly symmetric around 0 dB value. Graupel and hail – major source of lightning flashes – can grow only in sufficiently strong convective updrafts commonly manifested by the ZDR columns. Various researchers report close association of lightning locations and ZDR columns which is not examined and even mentioned in the paper.

ZDR columns as an indicator of lightning activity are indeed mentioned in the introduction:

Other authors have observed that the presence of a Zdr column is an indicator of a strong updraft (Snyder et al., 2015), which has been repeatedly reported to favor lightning activity (Calhoun et al., 2013).

While it is indeed an important mechanism for the generation of lightning activity it is certainly not the only one. As mentioned in the paper:

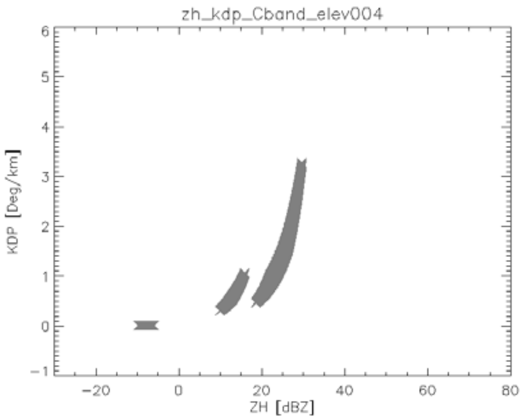
The Zdr data (upper-middle panels) exhibit a similar Gaussian-like shape both when all sources are considered and when only the first source is considered. In both cases the distribution is centered around 0 but with very long tails.

The tails of the distribution are fully compatible with the presence of ZDR columns in the data. However, ZDR columns are typically observable minutes before the intensification of a storm (see the paper by Snyder et al 2015) and from our data we can conclude that on average more lightning is produced at more mature phases of the storm when particles have grown into a more spherical shape.

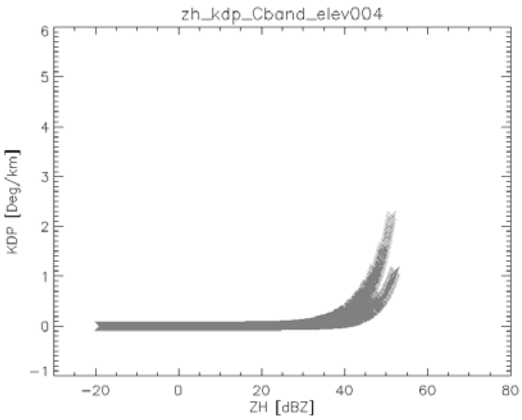
At the same time, there is apparent sign of nozero positive KDP indicated in the histograms in Figs. 7 and 12. What is the origin of these positive values of KDP in cold parts of convective clouds?

Horizontally oriented ice crystals in the proximity of graupel and hail or the tops of KDP columns? In the latter situation, ZDR columns with noticeably positive ZDR should be also observed.

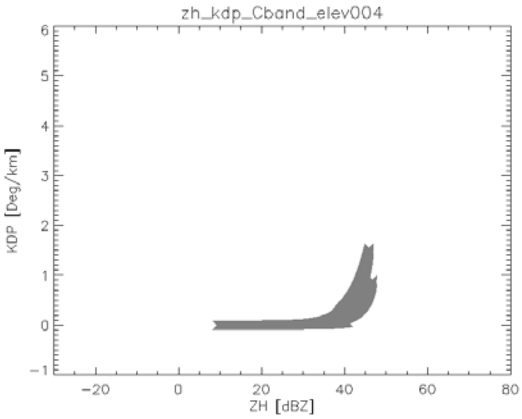
It is a well-known feature that large ice crystals (or not particularly large but rather oblate such as dendrites, i.e. Bechini et al. 2013), rimed particles and hail may have non-zero values of KDP. Simple T-matrix calculations already show this positive KDP values. For illustration, we show here relationships between Zh and ZDR for various hydrometeors computed using T-matrix simulations:



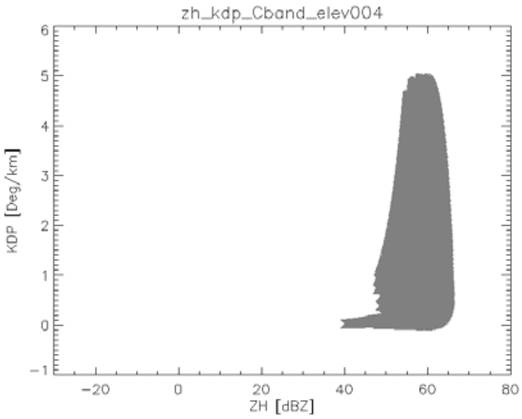
a)



b)



c)



d)

Figure 1 Zh-KDP relationship for different hydrometeors: a) ice crystals, b) wet snow, c) graupel, d) hail

Reference

Bechini, R., Baldini, L., and Chandrasekar, V.: Polarimetric Radar Observations in the Ice Region of Precipitating Clouds at C-Band and X-Band Radar Frequencies, J. Appl. Meteorol. Clim., 52, 1147–1169, doi:10.1175/JAMC-D-12-055.1, 2013