

Response to reviewer 3 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

The present study aims at combining LMA and polarimetric radar observations to infer relationships between lightning activity and cloud microphysics. It is based on a significant dataset collected in the northeastern part of Switzerland over a period of two and a half months during summer 2017. Overall this study provides interesting findings regarding potential interactions between the microphysical cloud structure and lightning initiation/propagation.

We thank the reviewer for his overall positive assessment.

It is, however, extremely descriptive and definitely lacks some physical interpretation to support the results. Section 3, for instance, mostly consists in a discussion of endless series of numbers and percentages / histograms with no interpretation and no comparison against previous findings.

We have added a subsection (Discussion) in Section 3 to put our results into context.

Authors also lack perspective on the performance of their classification algorithm, especially as we all know that dual-polarimetric HCA are subject to large uncertainties (low percentage values such as discussed in the paper don't really make sense and should definitely be avoided). Actually I believe that Section 3 should be simplified and rewritten to highlight the most significant results as it is very difficult to comment on the results as they stand.

We respectfully disagree with the reviewer. Our classification algorithm has been thoroughly tested in multiple scenarios with very good results. As for the low percentage values presented in the paper, we think they are still relevant to showcase that very few lightning initiates in such conditions regardless of the specific percentage. We do agree that a precision up to 2 digits after the comma may be misleading with respect to the accuracy of the classification and, therefore, in the revised version we rounded the values to just one.

In the revised version we also moved most of the numbers into tables in order to improve the readability of the manuscript and we provided more physical context to the measurements.

SPECIFIC COMMENTS

More details are needed regarding the Hydrometeor Classification Algorithm used in this study. Authors should also discuss the uncertainty associated with their method, especially regarding hail/graupel identification. Actually I am quite surprised by the high proportion of lightning initiation and propagation that takes place in hail. Most past studies have found that graupel is by far (70-90%) the preferred environment for lightning initiation. Also, authors are using a C-band radar. However we

know that at such frequency hail identification might be a problem due to resonance scattering effects. Please comment.

We believe that explaining the hydrometeor classification in detail would unnecessarily lengthen the manuscript. The algorithm has been thoroughly described in the two papers by Besic et al. and a considerable amount of work has been put in the validation of the algorithm in the past. The two papers are published in open access journals so the interested reader should not have any difficulty to access them.

The higher than reported percentage of lightning initiating in hail areas on the other hand may be due to the fact that in our dataset hail-producing convective cells may indeed be over-represented. A significant amount of lightning data was gathered on days (notably August the 1st) when hail was observed on the ground. We have added the following lines at the beginning of Section 3.4.1:

In any case, the proportion of +CG flashes with respect to the total number of CG flashes (41%) is significantly higher than that observed on the Sântis tower over a 2-year period (15%) (Romero et al., 2013). That is due to the fact that on three out of the 8 analyzed days (10 and 19 July and 1 August), the proportion of +CG flashes is abnormally high (see Table 2). The percentage of +CG the 19 July (72.6%) is particularly noteworthy. On that day, large swathes of terrain south of the Sântis tower were affected by hail according to the POH algorithm. There was also extensive hail recorded on August 1. 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)

As for the detection of hail, resonance effects may be an issue for hail quantification in the C-band (although using other parameters such as KDP partially mitigates that issue) but we do not see it as an issue for the actual hail detection.

Radar scientists claim to be able to identify as many hydrometeor types as possible. However, due to the high level of uncertainty in HID, it would be more realistic to use less categories. This would also ease the interpretation of the results.

We respectfully disagree with the reviewer. Based on the centroids on which our classification algorithm is based, we think that the current categories correspond to perfectly separable data and we have reduced the hydrometeor types to the bare minimum useful for microphysics studies.

As mentioned previously, this paper lacks physical interpretation of the results. Results should be compared with the literature (especially regarding hail) and more details should be given about the role of the microphysical environment in the initiation/propagation of lightning. Also what is the influence of orography on lightning? As mentioned by the authors, the particularity of this study is that it takes place over very complex terrain. Hence the effect of mountains should be considered when analysing the results.

The effect of orography on lightning are not explicitly discussed in the paper and it is a complex issue that requires further analysis that it is out of the scope of this paper. Nevertheless, some relevant aspects regarding the orography are shown in the paper such as the higher density of lightning in a narrow region at the footsteps of the Alps and the presence of hot spots of CG lightning activity visible in Fig. 14 in the paper at the location of some mountains.

The spatial extension of the domain of analysis seems rather small to me. LMA data can potentially be used up to 100/150 km without any problem. Please comment.

LMA networks typically consist of about 10 sensors or more whereas the LMA deployed had only between 5 and 6 sensors operating at any time which is the minimum to have reliable data. Moreover, as it is explained in Section 2.1.2, for practical reasons, the sensors were placed in the vicinity of mobile phone base stations which resulted in an increased ambient noise and, therefore, a decrease in sensitivity. Furthermore, the presence of the Alps resulted in the network being essentially blind south of its location. Nevertheless, there was indeed some level of detectability up to 100 km. If you examine Fig. 1, there are actually two domains presented. The extended domain, where some lightning activity was detected during the campaign, corresponds roughly to a 100-km diameter area. The reduced domain used is a conservative approach that ensures a high level of detectability even when only 5 VHF sensors were operational.

I do not see the need for 20 figures. Most of the results shown in Figs. 4 to 20 could be summarized in a few tables. Instead, authors should include the analysis of two contrasting events in their study and discuss the storm structures, associated horizontal/vertical cross-sections of reflectivity / polarimetric moments, and location of LMA sources within the storms.

The initial intention when writing the article was to show as much as possible the actual data used so that readers can also draw their own conclusions. We have already up to a certain extent reduced the number of figures presented. As requested by the reviewers, in the revised version we provide more physical interpretations of the results and relate them with past literature but we still think that the figures provided are relevant and useful.

As for the case studies, we plan to submit two other papers related to the campaign. One will deal with evidence of upward lightning produced by the Säntis tower while the other indeed focuses on two contrasting convective events. We think that the generalist statistical approach followed in this particular study is sufficiently worthy to be published.

A detailed comparison between EUCLID and LMA detection capability would be interesting.

That would be indeed interesting but we think it is out of the scope of this particular study. The EUCLID detection capability in the vicinity of the Säntis tower has been examined in the past by the authors (e.g. Azadifar et al., 2015). As for the LMA detectability, we are confident that it does not play a role in the presented data since most of the flashes analysed were detected in the reduced domain where we had high detectability.

The detection capabilities of LMA networks in similar rough terrain have been analysed in the framework of the HyMex campaign (Pédeboy et al, 2014) and with the LMA installed in Corsica (Pédeboy et al., 2018).

A discrimination between convective and stratiform regions of the storms would also help interpreting the results.

The discrimination between convective and stratiform regions poses several problems since these are ill-defined categories and never so clear cut. Our approach is radar bin-based, rather than radar region-based. We think there is a certain originality and usefulness in our approach based on

assessing the meteorological conditions from a radar point of view at the location of lightning initiation and through its propagation path that make it worth publishing as it is.

References

Pédeboy S., Defer E., Schulz W.: Performance of the EUCLID network in cloud lightning detection in the South-East France. 8th HyMeX Workshop, 15-18 Sept. 2014, Valetta, Malta

Pédeboy S., Barnéoud P., Defer E., Coquillat S.: Analysis of the Intra-Cloud lightning activity detected with Low Frequency Lightning Locating Systems. 25th International Lightning Detection Conference & 7th International Lightning Meteorology Conference, 12-15 March 2018, Ft. Lauderdale, Florida, USA