Reply to the Interactive comment on "Quantifying the value of redundant measurements at GRUAN sites" by F.Madonna et al.

Anonymous Referee #2

- *The authors of the manuscript "Quantifying the value of redundant measurements at GRUAN sites" by F. Madonna et al. have checked the received review of their manuscript and they would like to acknowledge the anonymous reviewer for his/her useful comments. In the following, the authors report their general comments as well as well a detailed reply to the reviewer (in italic).*

*Overall the subject matter and innovative approach of the manuscript are well-suited to AMT. The manuscript presents a novel method for quantitatively determining the correlation between time series or profiles made for the same measurement site by diff*erent measurement techniques. This method generalizes familiar statistical techniques that are best suited to normally distributed, linearly correlated datasets for datasets that may have substantially non-normal probability distributions and may have non-linear or non-monotonic correlations. This generalization represents a significant improvement over current state-of-the-art given the statistical properties of many observational datasets of interest in atmospheric science.
General comments: 1. Overall, the innovation and utility of the proposed method is that it is insensitive to outliers and does not assume underlying normal (Gaussian) statistics. This is a big advantage relative to many common methods used in atmospheric science. I think the paper could be more compelling if this aspect of the demonstrated method appears before 6337/19-22.

- *In agreement with the comment #2 of the anonymous reviewer #1, in order to show the reader the real advantages of using entropy and MC with respect to standard deviation and correlation and to make the reader more familiar with the concepts of information theory, the authors added a new figure (Fig. 3) showing the traditional Taylor diagram obtained for the GPS IWV time series collected at Lindenberg (already shown in Figure 2): the values of the Taylor diagram are obtained from the original series by adding 5, 10, 15, 20, and 40 outliers to the IWV probability density function. The value of the standard deviation in the diagram obtained from the original time series is reported as observed. This is compared, following previous studies, with a modified Taylor diagram (Correa and Lindstrom, 2012) obtained by replacing the standard deviation with the entropy and ρ with MC. Correlation and MC have been calculated with respect to an underlying Gaussian distribution, fit in with the data.*

2. The concepts of entropy and mutual correlation presented here are may be unfamiliar to many readers. Although it is beyond the scope of the paper to provide a comprehensive introduction to these concepts, it would be beneficial to these readers
to include some more illustrative introductory material. Something like Anscombe's quartet (Am. Stat. 1973) adapted to atmospheric data might be very powerful. Alternatively some text describing the kinds of differences that can be discerned in using

entropy rather than standard deviations could be provided.

- *Previous comment should also address this reviewer's observation.*

3. About "redundant information": one challenge in presenting this material is that "redundant" has the connotation of "unnecessary" to some readers, whereas in fact redundancy is highly beneficial for reducing uncertainty and increasing the credibility and scientific value of atmospheric datasets. A short paragraph providing an overview of the meaning and benefits of redundancy would be useful for this reason.

- Indeed, a short paragraph providing an overview of the meaning and benefits of redundancy is reported after the second paragraph of the introduction. To make it more explicit, the authors also added a definition of redundancy, and now the paragraph is as follows: "Redundancy can be defined as the duplication or the multiplication of the estimation of an atmospheric variable with the aim of increasing reliability in the study of the same variable over the time. Without doubt, redundant measurements provide added value towards the full exploitation of the synergy among different measurements techniques: the main advantages are related to:
- Filling gaps and improving measurement continuity over time and vertical range,
- Increasing the sampling rate by merging measurements from different instruments,
- Addressing instrument noise and identifying possible biases or retrieval problems by comparing different techniques and instruments."

Specific comments: 6328/16 not sure what is meant by "conditioning" of the lidar measurements here 6332/17 "MC can be applied to" or "MC is applicable to"

- Ok.

6334/15-16 Generalized distances and metrics may be too unfamiliar to the average AMT reader; an introductory citation or sentence or two of elaboration would be useful

- *The authors included the reference: Arkhangel'skii, A. V.; Pontryagin, L. S. (1990), General Topology I: Basic Concepts and Constructions Dimension Theory, Encyclopaedia of Mathematical Sciences, Springer, ISBN 3-540-18178-4*

6335/8-9 "a relative error ... at 7 km a.g.l. of <25%"

- Ok.

6335/28 "ancillary information" seems unclear; maybe "additional measurements"?

- ok

6336/20-25 Would be useful to have a discussion of the disadvantages of too many bins in this paragraph or previous to it.
6338/1-15 A table summarizing the estimated uncertainties for the different IWV measurements would be useful in interpreting this paragraph.

- *The authors did not put any table because the uncertainty on MWR and MW profiler is strongly depending on the used retrieval algorithm and it is not always delivered by the stations. For the GPS, the GRUAN community took the lead for this issue and the work is still in progress. For the sondes, GRUAN is providing the full uncertainty budget for the first time but the data presented here (this is explained in the paper) are selected in a period not always covered by GRUAN processing at all the stations. So, this heterogeneous situation suggested the authors not to deal yet with this issue.*

However, (to help the reader in the interpretation of the results), typical uncertainties affecting the considered measurements are mentioned: radiosonde water vapor mixing ratio profiles have a relative uncertainty typically lower than 6 % from the surface till 15 km a.g.l., though the uncertainty might change depending on the measurements conditions (more details in Dirkseen et al., 2014); Raman lidar relative random uncertainty increases with height and keeps less than 25 % at 7-8 km a.g.l. plus a calibration error typically within 5-10 % affecting the entire profile; the uncertainty on the integrated water vapor content achievable with microwave radiometers and profilers is strongly depending on the retrieval types, but it is typically within about ±0.07 cm; the GPS uncertainty on the integrated water vapor content is typically within about ±0.15 cm (first results from GRUAN comparisons with CFH).

6339/13 Would be useful to have a citation for the AERI retrieval used. The standard
retrieval product available through the ARM archive uses the Feltz et al. (J. App. Meteorol. 2003) algorithm that utilizes a variety of a priori information. Information in this
retrieval product for altitudes greater than 3 km is likely to be from the a priori. There
is a newer optimal estimation algorithm (Turner and Loehnert J. Appl. Meteorol. Climatol. 2014) that is probably better in this respect, but is not operationally available.
In any case, the paper should specify which algorithm is used for the product that is investigated.

- *The authors mentioned the retrieval as the "statistical one". Now, it is also mentioned the reference: Turner and Loehnert J. Appl. Meteorol. Climatol. 2014.*

6341/5-19 This paragraph is a bit abstract and challenging to follow. I can imagine synergistic products that utilize multiple measurements to a) reduce uncertainty via

redundant information, or b) to add information by combining all-weather capability with cloud-sensitive measurements, or imaging with hyperspectral data. It is difficult to interpret this paragraph definitely with these different possibilities in mind. I would suggest either adding some specific details of synergistic products and implications of the analysis for developing these products, or more specifics on the types of synergies the authors have in mind.

- *The authors are referring, for example, to those retrievals integrating radiances measured by different sensor in different spectral ranges (e.g. Romano et al., 2007).*
  Ideally, this could be also the case for all the optimal retrieval methods based on the Bayes' theorem based on the use of the conditional probability. A frame to study the algorithm before its implementation using the conditional entropy would be very interesting to estimate the real increase in the accuracy of the retrievals coming from integrating measurements from different sensors.

6342/1 Not sure what is meant by "higher-order terms in the PDF"

- *The authors removed the sentence, maybe not needed and confusing.*

6343/21-24 This conclusion seems less clear-cut to me; figure 4 suggests to me that MWR is a clear winner for SGP, but not for PAY or LIN.

- *This conclusion comes from the overall analysis of all the sites not only SGP, though the situation was a bit heterogeneous among the sites. However, the authors apologize for the mistake, maybe a remnant of a previous version of the manuscript, and the reviewer is right, so the authors corrected the sentence.*