REPLY TO ALEXANDER HAEFELE

The authors highly appreciate the constructive comments. They are very useful contributions that will certainly help to improve the revised manuscript. In the following, the authors reply point by point to all Reviewer comments, which are written in italic while our replies are in standard font. Within the manuscript all changes from the submitted version are highlighted in red.

COMMENTS:

The issue of the Raman lidar (RL) covariance matrix is correctly presented. I regret a lot that the averaging kernels have been removed again, it would be very interesting for the community to see averaging kernels of a combined retrieval! I encourage the authors to include averaging kernels in the response to this review and to discuss the difficulties in their interpretation.

The averaging kernels are plotted below and an explanation is given in the following:
Because the retrieved parameter *x* is a vertical atmospheric profile, the *Ak* columns represent the information distribution of the retrieved profile as a function of the altitude. For the sake of clarity, the averaging kernels have been plotted for a AH profile retrieved with constant retrieval grid with 90 meters separation. Figure R.4.1 shows the *Ak* corresponding also to the case study in figure 2 in the manuscript, where the lidar useful data covers the region from 180 meters to 2.5 km. In addition, figure R.4.2 is presented as tool to better understand figure R.4.1. The first considers the same retrieval profile than figure R.4.1 but takes into account a diagonal *Sa* in the retrieval calculation, i.e. canceling the vertical correlations.

If the RL water vapor mixing ratio values are vertically independent, i.e. *Sop* and *Sa* are diagonal matrices, the RL information at a given height will only affect this specific altitude. In the *Ak*, this is translated into delta functions at each height were RL is available (see figure R.4.2). Instead, and because of the vertical correlation introduced by the off-diagonal elements in the a priori covariance matrix *Sa* (figure 1 in manuscript), the *Ak* columns present a smooth shape. This implies that the information from a given atmospheric layer is redistributed in altitude, affecting to the neighboring regions (figure R.4.1).

The only-MWR provides much lower information content, i.e. one order of magnitude smaller than the RL, as expected. If the a priori covariance matrix is diagonal, the strongest information content will be expected close to the surface, where the instrument is more sensitive (see figure R.4.2). Nevertheless, due to the altitude correlation defined by *Sa*, the information content is re-organized in the atmosphere, showing its maximum at ~2 km, i.e. the typical boundary layer height. The *Ak* for the MWR+RL combination shows in both cases, i.e. figure R.4.2 and R.4.1, how the information content of the two sensors is optimally combined.

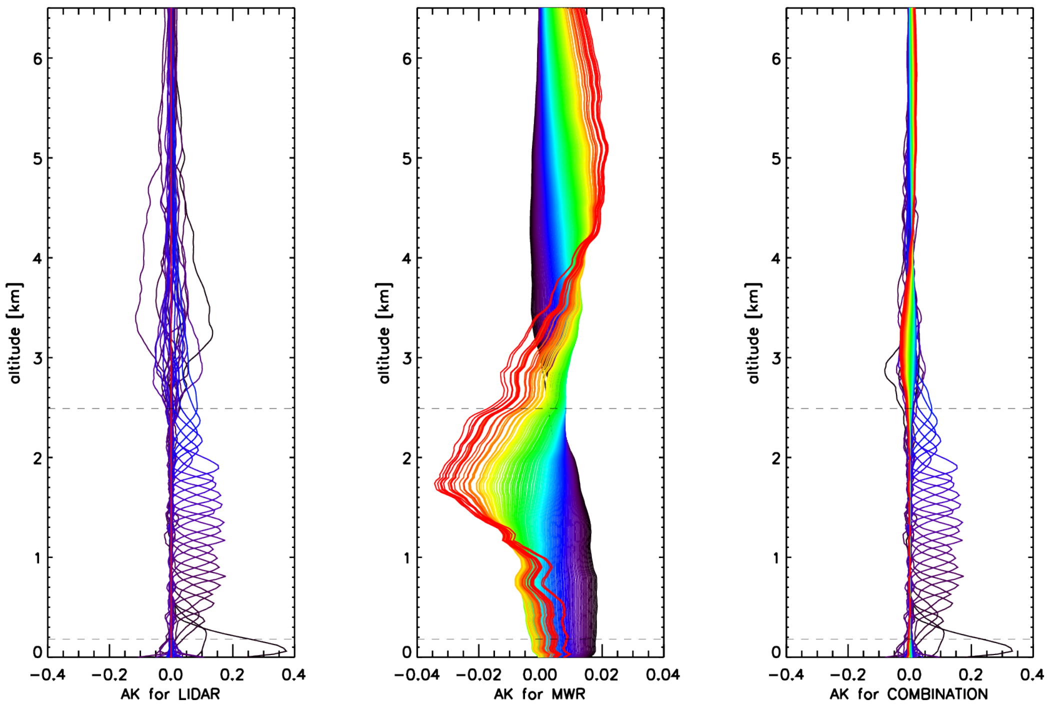

Figure R.4.1: From left to right: averaging kernels of only-RL, only-MWR and MWR+RL. Each color corresponds to a different altitude: ground is represented by black, higher altitudes are represented with reddish colors. The averaging kernels are only shown every 90 m in altitude for clarity.

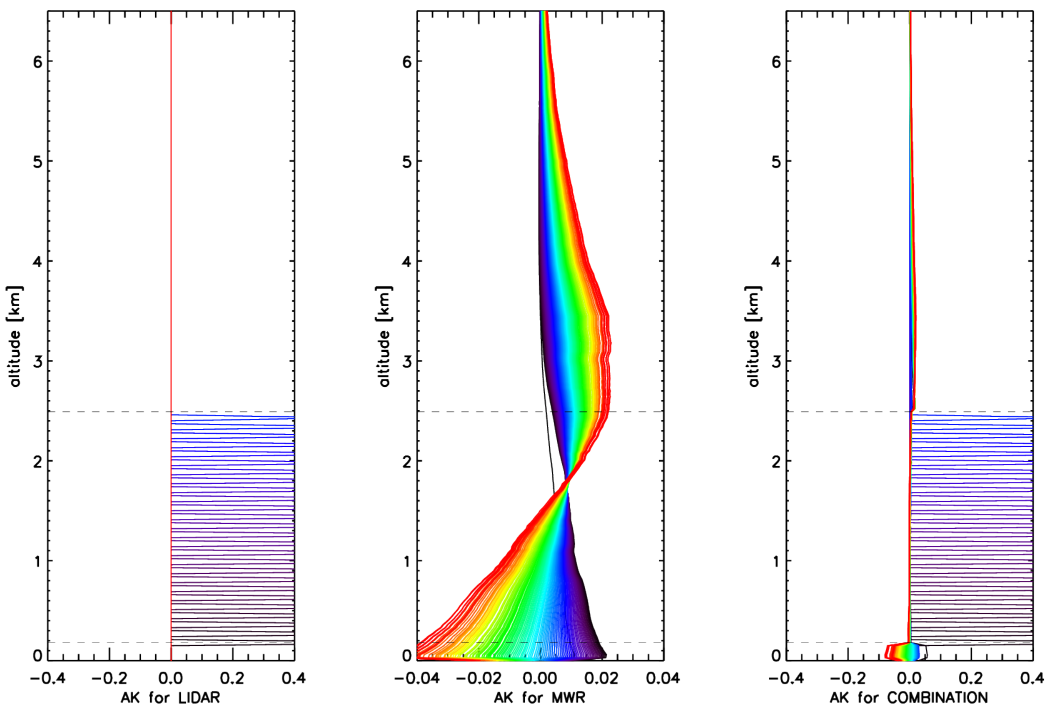

Figure R.4.2: From left to right: averaging kernels of only-RL, only-MWR and MWR+RL. Each color corresponds to a different altitude: ground is represented by black, higher altitudes are represented with reddish colors. the *Ak are* calculated using a diagonal covariance matrix *Sa*. The averaging kernels are only shown every 90 m in altitude for clarity.

MINOR REMARKS:

L 42: Include also R. J. Sica and A. Haefele, "Retrieval of water vapor mixing ratio from a multiple channel Raman-scatter lidar using an optimal estimation method," Appl. Opt. 55, 763-777 (2016)
Included in the manuscript.

L 49: This is demanding but demonstrators exist. Include:
Dinoev, T., Simeonov, V., Arshinov, Y., Bobrovnikov, S., Ristori, P., Calpini, B., Parlange, M., and van den Bergh, H.: Raman Lidar for Meteorological Observations, RALMO – Part 1: Instrument description, Atmos. Meas. Tech., 6, 1329-1346, doi:10.5194/amt-6- 1329-2013, 2013.

Brocard, E., Philipona, R., Haefele, A., Romanens, G., Mueller, A., Ruffieux, D., Sime- onov, V., and Calpini, B.: Raman Lidar for Meteorological Observations, RALMO – Part 2: Validation of water vapor measurements, Atmos. Meas. Tech., 6, 1347-1358, doi:10.5194/amt-6-1347-2013, 2013.
Included in the manuscript.

L 141: Say explicitly how much the standard deviation is.
Included in the manuscript.

L 330: Something is wrong with "as to be expected 2".
The number two was the reference to Fig. 2. It has now been corrected in the manuscript.

L 350: The vertical resolution tends to infinity because the diagonal elements of the averaging kernels tend to zero. Include this explanation.
Thanks for the clarification. The sentence has been included in the manuscript as follows:

"But outside this region, the vertical resolution for only-RL becomes infinite, because the diagonal elements of the averaging kernels tend to zero."

L 354: Low resolution is bad, high resolution is good!
Modified in the manuscript.

L 391: It seems the panels of Fig. 5b are not in the right order. Reading the caption I understand 1.96 for combined, 0.84 for MWR and 0.96 for RL. The authors should also comment on the biases.
The reviewer is right: there was a mistake in the figure caption, which has been now changed to:

"Figure 5. (a) Time series of IWV during the whole HOPE period from: the continuous GPS signal (black) and the one calculated from the joint retrieval, which is available only in clear sky cases (blue). Shaded areas represent the RL availability. (b) Scatterplot for the three cases: only Raman Lidar, only MWR and the joint retrieval (from left to right), against the GPS."

A sentence commenting the biases has also been included in line 391:
"While the only-MWR case presents a negative bias of ~0.5 kg/m2, the inclusion of the RL in the RL+MWR case, corrects this bias reducing it one order of magnitude. The combination of the two instruments and the only-MWR case present similar standard deviations, whereas the only-RL case presents a twice as large standard deviation in comparison to the other two cases. This results give us confidence that the developed OEM water vapor profiles are well constrained with respect to the integrated value. "

L445: There is no a and b in Fig. 7.
Corrected in the text.

L 548: This does not sound right. It seems you scaled the variance by a factor of 4 and hence the standard deviation scales by a factor of 2. I expect in the RL region the a posteriori uncertainty if fully determined by the RL uncertainty.

Here the standard deviation, and not the variance, was scaled by a factor of 4. The final error affecting the combined retrieval increases by a factor of 2-3, instead of 4, because of the stabilization by the prior.