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Atmospheric Measurement Techniques Discussions

Interactive comment on "Tropospheric water vapour and relative humidity profiles from lidar and microwave radiometry" *by* F. Navas-Guzmán et al.

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titleAnswers to the referees (AMT-2013-254)

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Referee 2

The paper entitled "Tropospheric water vapour profiles from lidar and microwave radiometry" by F. Navas-Guzmán, J. Fernández-Gálvez, M.J. Granados-Muñoz, J.L. Guerrero-Rascado, J.A. Bravo-Aranda, and L. Alados-Arboledas describes a method to derive profiles of relative humidity from water-vapor-to-dry-air mixing ratio profiles (obtained by Raman lidar) and from temperature profiles (obtained by a microwave radiometer). The paper is of scientific significance, a new idea of relative humidity profiling is described. The scientific approaches and applied methods are valid. The presentation of the results can be improved.

Specific comments:

The title of the paper should be improved. It implies that the radiometer measurements delivered humidity profiles.

Following the referee's suggestion the new title is:

"Tropospheric water vapour and relative humidity profiles from lidar and microwave radiometry".

line 95: operating -> operated

Done (line 94)

line 158: I suggest a new structure of the paper. Insert a new subsection "3.1 Retrieval of mixing ratio with Raman lidar". Shift sections 4 and 5 to subsections 3.2 and 3.3, respectively.

Following the suggestions of both referees we have restructured the section 3. The section has been also renamed (**"Water vapour and Relative Humidity retrievals"**). The new subsections are now:

3.1 Water vapour profile from Raman lidar measurements.
3.2 Raman lidar water vapour calibration.
3.3 Retrieval of relative humidity using Raman lidar and temperature from microwave radiometer.

Moreover, we have modified the last paragraph in the introduction where we have updated the new structure of the paper. The text read now as follow (lines from 69 to 75):

"The paper is organized as follows: in section 2, the instrumentation and the experimental site are briefly described. Section 3 deals with the methodology applied to retrieve water vapour and relative humidity profiles, including details about the lidar calibration. A statistical analysis of water vapour and relative humidity is presented in section 4. Finally conclusions are found in section 5".

line 160: remove one "used"

Done.

equations (1) and (2) can be written as a single equation with index i; $i = H2OorN2$

As the referee suggests we have unified equation (1) and (2). The new equation and the text that describes this equation read as follow (lines 175 to 188):

$P(R,\lambda_i) = P(\lambda_0)K_i\frac{O_i(R)}{R^2}\beta(R,\lambda_i)\exp\{-\int_0^R[\alpha(r,\lambda_0)+\alpha(r,\lambda_i)]\,dr\}$ **"where the index i indicates the species nitrogen (N_2) or water vapour (H_2O). $P(R,\lambda_i)$ is the backscattered laser power at the Raman-shifted wavelengths, from range R; $P(\lambda_0)$ is the emitted laser power at wavelength λ_0; K_i is the range-independent constant; $O_i(R)$ is the overlap function; $\beta(R,\lambda_i) = N_i(R)\sigma_i(\lambda)$ is backscatter coefficient for each species, where $N_i(R)$ is the number density and $\sigma_i(\lambda)$ is the Raman backscatter cross section at the Raman-shifted wavelength; α is the total extinction coefficient at wavelength λ_0, λ_{N_2}, and λ_{H_2O}; and r is the range considered as an integration variable."**

line 192: magnitudes -> quantities ?

This word has been deleted after re-grouping equations 1 and 2. Now that term is named as backscatter coefficient.

line 200: The statement "Equation 3 assumes identical overlap factors and range independent Raman backscatter cross sections for the two signal." should be discussed. The authors should estimate the uncertainties related to deviations from these assumptions. Refer e.g., to the corresponding papers by David Whiteman.

As the referee suggests we have commented the fact that the overlap functions are not equal in the near range. We have noted the error estimation that Whiteman et al. (2006) obtained in this study. Moreover, we have pointed out that we did not use the near range for the water vapour calibration. The text can be read as following in the manuscript (lines 210 to 216):

"The assumption of identical overlap for nitrogen and water vapour is not true

in real applications and differences between both overlap functions are found in the near range. Whiteman et al. (2006) found errors around 6% at an altitude of 300 m above the lidar system. To avoid any incomplete overlap we have not used the near range for the water vapour calibration."

equation(5) The sign in the integral term should be minus : exp- integral[a(r,N2)-a(r,H2O)]dr

This typo has been corrected. After regrouping the equations this one corresponds to eq. 3.

lines 225-228: The exponential term can not be neglected. The signal ratio needs to be corrected at least for the different molecular transmissions. Only different transmissions due to aerosols might be neglected. The statement in the reference (Mattis et al. 2002) is "The difference between the atmospheric transmissions at 407 nm and at 387 nm is caused mainly by Rayleigh scattering and can easily be corrected for by use of standard-atmospheric profiles of temperature and pressure or, if available, actual radiosonde data. ... Differences in transmission at the two Raman wavelengths as a result of wavelength dependent particle extinction are negligible for clear-air conditions."

We agree with the referee's comment and the difference between the atmospheric molecular transmissions at 407 nm and at 387 nm have to be considered. We have evaluated the deviation of the unity of this exponential term for different tropospheric conditions. Considering only Rayleigh scattering the deviation of the unity was bellow 3% in the range from 0 to 6 km (agl). The sentence has been rewrite according to our analysis and the study of Mattis et al., 2002. It reads now as (line 221 to 228):

"This exponential can be evaluated for Rayleigh scattering by using radiosonde or standard atmospheric profiles of temperature and pressure while the particle contribution can be neglected in most cases (Mattis et al., 2002). Considering

only Rayleigh scattering the exponential term deviates less than 3% from the unity, for most atmospheric conditions found in our station."

line 230: "4 Raman lidar water vapour calibration" -> "3.2 Raman lidar mixing ratio calibration"

Following the referee's suggestion the section has been restructured and now this sub-section is call (line 229)

"3.2 Raman lidar water vapour calibration"

line 280: Why are data below 1.5 km not used for the calibration? Is it because of overlap problems?

Yes, this altitude was chosen in order to avoid any overlap problem in the water vapour calibration. It was mention in the methodology section as the referee suggested and it is also indicated in this part of the manuscript. The sentence reads now as (line 280 to 285):

"This range was chosen in order to assure a region with high water vapour mixing ratio (minimizing the error in radiosonde data) and to avoid the large differences that could be found between lidar and radiosonde measurements at higher heights due to radiosonde drift and the incomplete lidar overlap in the near field."

line 353: The section title should be "3.3 Retrieval of relative humidity using Raman lidar and temperature from microwave radiometer"

Following the referee's suggestion the section has been restructured and now this sub-section is renamed as (line 363)

"3.3 Retrieval of relative humidity using Raman lidar and temperature from

microwave radiometer."

line 375: The paper by Hanel is not about rotational Raman lidar technique. It has a completely different topic. Instead, references to the lidar systems of MeteoSwiss Payerne, MPI Hamburg, and DWD Lindenberg should be provided.

Following the referee's comment we have delete the reference of Hanel and we have added new references which present the rotational Raman lidar technology. The sentence reads now as (lines 383 to 387) :

"At present, the rotational Raman lidar technology allows simultaneous measurements of temperature and water vapour mixing ratio profiles to retrieve RH profiles (Brocard et al., 2013; Mattis et al., 2002; Reichardt et al., 2012; Ristori et al., 2005)."

table 2: The deviations between lidar and radiosonde data could be better illustrated in figures. How does the deviations depend on distance between lidar and sonde? Distances could be estimated from trajectories.

Following the referee's suggestion we have included a new figure (Fig. 3) in order to illustrate better the deviations between the lidar and the radiosonde. Moreover, we have discussed the discrepancies of some data basing on the loss of vertically of the radiosonde. After theses changes this part of the manuscript reads now as (lines 339-361):

"A statistical analysis in terms of mean absolute deviations and standard deviations between lidar and radiosonde water vapour mixing ratio profiles is presented in Table 2. This table shows the discrepancies observed at different heights between 1.5 and 5.5 km (asl), with surface level at 0.68 km (asl). The mean absolute deviations have been plotted (Fig. 3) in order to illustrate better the dependency of these values with altitude. The mean absolute deviation is

below 0.5 g/kg for 55% of the selected ranges. We can observe that the largest discrepancies are found between 4.5 and 5.5 km (asl), reaching a maximum mean absolute deviation of 2.2 g/kg on 17th November. Inspection of the RCS temporal evolution reveals that clouds were present at this height range during this night. On 28th and 24th November an important loss of verticality in the radiosonde was observed at 5 km (asl). At this altitude the horizontal distance from the radiosonde to lidar station were 6.6 km and 9 km respectively. The loss of vertically and the atmospheric inhomogeneities could explain the differences in water vapour observed between the lidar and radiosondes. Anyway, the mean absolute deviation for the whole profile including the six dates was 0.6

$\pm$

0.6 g/kg, thus indicating a good agreement in the water vapour mixing ratio retrieved by both techniques."

lines 434, 445, 449: Temperature differences should be provided in Kelvin.

As the referee suggests we have expressed the temperature differences in Kelvin (lines 458, 460, 462 and table 3).

figure 3: It seems that there is a mismatch in the legend of 3b or 3c. Mixing ratios are very similar in the altitude range between 3 and 3.5km. If the temperature from radiosonde (black) is larger, the resulting relative humidity (black) should be smaller. Probably, the black curve in figure 3b is from MR (less vertical structures) and the blue curve could be from radiosonde. Please, check your data again and modify the discussion accordingly.

Yes, there was a mistake in the legend of Figure 3.b. As the referee indicates the profile with higher vertical variability corresponds to radiosonde data. It has been corrected. All the discussion was coherent with the correct profile. After including

a new figure in the manuscript the corrected figure that we mention in this point corresponds to Fig. 4.b.

lines 472-478: Are those measurements useful for hygroscopic growth studies? Discuss the required accuracy of humidity measurements of hygroscopic growth studies related to the uncertainties of the presented method.

Following the referee's suggestion we have discussed a little bit more about the useful of these measurements for hygroscopic growth studies and about their accurate. Moreover, two new references has been included. This part of the manuscript read now as (lines 485-498):

"Measurements of relative humidity profiles presented here are very useful for the analysis of hygroscopic growth based on Raman lidar and microwave radiometer measurements. The combination of these RH profiles with aerosol optical data retrieved with the lidar system allows to obtain hygroscopic growth factors for different aerosol types (Di Girolamo et al., 2012; Veselovskii et al., 2009). In addition, this methodology allows the possibility to get RH profiles measurements with higher frequency than radiosoundings and simultaneously to lidar measurements. However, the accuracy needs to be improved to obtain accurate values of the hygroscopic growth factors. Especially, it is necessary to improve the vertical resolution of the temperature profiles to reduce the uncertainties."

line 509: years -> year

Done.

line 522: What was the altitude range of these layers? 500m layers between 1 and 4 km?

Yes. To clarified this point we have added the range of the layers in this sentence. It now reads as (lines 542-543):

"Finally Figure 8 presents the RH value distribution obtained for 500 m layers between 1 and 4 km (asl)".

figure 7: porcentage -> percentage

Done.

line 597: Bosenberg -> Bösenberg

Done.