Dear Editor,

We are grateful to the two reviewers for their appropriate and constructive suggestions and for their proposed corrections to improve the paper. We have addressed all the issues raised and have modified the paper accordingly. We believe that, thanks to these inputs, the manuscript has sensitively improved. This is a summary of the changes we performed and our responses to reviewer #1's comments and recommendations.

Summary of the changes
(in black is the original comments of the reviewer, while our responses are highlighted in red)

Reviewer #1

Raman lidar measurements of both water vapor number density and temperature are not new. Worldwide a number of Raman lidars exist which use the water vapor Raman lidar technique and the rotational Raman lidar technique for temperature measurements in combination (see page 14739, line 13ff, of the manuscript). So, also relative humidity profiling with Raman lidar has been described in the literature before (e.g., Mattis et al. 2002), even in cirrus clouds (e.g., Behrendt et al. 2002). And in consequence, the measurements presented in this paper are not the first (the authors are wrong in assuming so; page 14373, line 23 ff).

Authors were not aware of the SPIE paper by Behrendt et al. (2001). However, measurements by Behrendt et al. (2001) were carried out in the visible region, while measurements reported in this paper represent to our knowledge the first UV Raman lidar measurements of relative humidity (RH) inside cirrus clouds, the UV region allowing for eye-safe measurements. Based on the these considerations, we could certainly better explain in the paper that we intended as "first UV Raman lidar measurements of relative humidity (RH) inside cirrus clouds"; however, we decided to completely remove the sentence under discussion, because it was not really relevant to the purposes of this paper.

A major benefit of Raman lidar compared to other techniques is that the statistical uncertainty of the measurement can be calculated with the signal intensities. Unfortunately, this error assessment is missing in this manuscript and it remains unclear, how precise especially the values of relative humidity over ice (RHI) inside the cloud are. I consider it essential to add a detailed discussion of the measurement errors of both the water vapor mixing ratio (Figs. 5, 6, 9) and RHI (Figs. 4, 5, 9) to proof the high performance of the lidar measurements as basis for the interpretation of this case.

The reviewer is certainly right when he/she requires a more detail error description in order to get a proper assessment of measurement precision for relative humidity over ice (RHI) inside cirrus clouds. In the paper, we had only specified that: "For a time integration of 10 min and a vertical resolution of 300 m, night-time measurement uncertainty at 8 km a.s.l. is typically 5% for the particle backscattering coefficient, 20% for particle extinction coefficient, 6% for water vapour mixing ratio, 0.5K for temperature and 4% for RH". However, this information refers to clear-sky, night-time operation at a specified altitude based on nominal laser power and consequently a more detailed assessment is certainly required for measurements performed in the dusk-to-night transition period, inside cirrus clouds located at different altitudes (in the region 7.5-10.5 km), considering the specific system performances (primarily laser power) on that day. This can be easily achieved as the statistical uncertainty affecting lidar measurements can be analytically estimated through the application to the measured signals of Poisson statistics, which is well suited in the case of data acquired in photon-counting mode, as in the case of *BASIL*. Thus, as suggested by the reviewer, we have now estimated the measurement errors of both the water vapour mixing ratio and *RHI* for the specific case study and we have introduced a new figure (figure 7), together with a detailed discussion of the errors affecting these parameters for the data illustrated in figs. 4, 5 and 6. Furthermore, we wish to specify that a thorough description of the characteristics of the present lidar system uncertainty in terms of both random and systematic errors was provided in a recent paper by Di Girolamo et al. (2009). The following new text was introduced at the end of section 2: "At the beginning of this section, information concerning the typical values of precision for the different atmospheric parameters measured by *BASIL* was provided. However, this information refers to clear-sky, night-time operation at a specified altitude, based on nominal laser power and consequently a more detailed assessment is required for the specific results reported in this study, with a specific reference to the measurements performed in terms of water vapour mixing ratio and RHI in the altitude region 5-11 km, inside and beneath the cirrus clouds, both at night and in the dusk-to-night transition period, considering the specific system performances on that day. This can be easily achieved as the statistical uncertainty affecting lidar measurements can be analytically estimated from the measured lidar signals through the application of Poisson statistics, which is well suited in cases of data acquired in photon-counting mode, as in the case of *BASIL*. Results shown in figure 7 (obtained considering a vertical and temporal resolution of 300 m and 10 min, respectively) reveal that water vapour mixing ratio measurements are affected by a percent random error, $\Delta x_{H_2O}(z)/x_{H_2O}(z)$, at night (19:00 UTC) smaller than 2 % up to 5.5 km, smaller than 5 % up to 7.5 km and not exceeding 25 % up to 10.5 km. For operation in the dusk-to-night transition period (18:00 UTC), $\Delta x_{H_2O}(z)/x_{H_2O}(z)$ is smaller than 10 % up to 5.5 km, smaller than 25 %up to 7.5 km and does not exceed 100 % up to 10.5 km. The random error for relative humidity measurements, *ΔRH(z)*, at night is smaller than 1.5 % up to 5.5 km, smaller than 3.5 % up to 7.5 km and smaller than 6.5 % up to 10.5 km. For operation in the dusk-to-night transition period, *ΔRH(z)* is smaller than 3 % up to 5.5 km, smaller than 7.5 % up to 7.5 km and smaller than 12 up to 10.5 km."

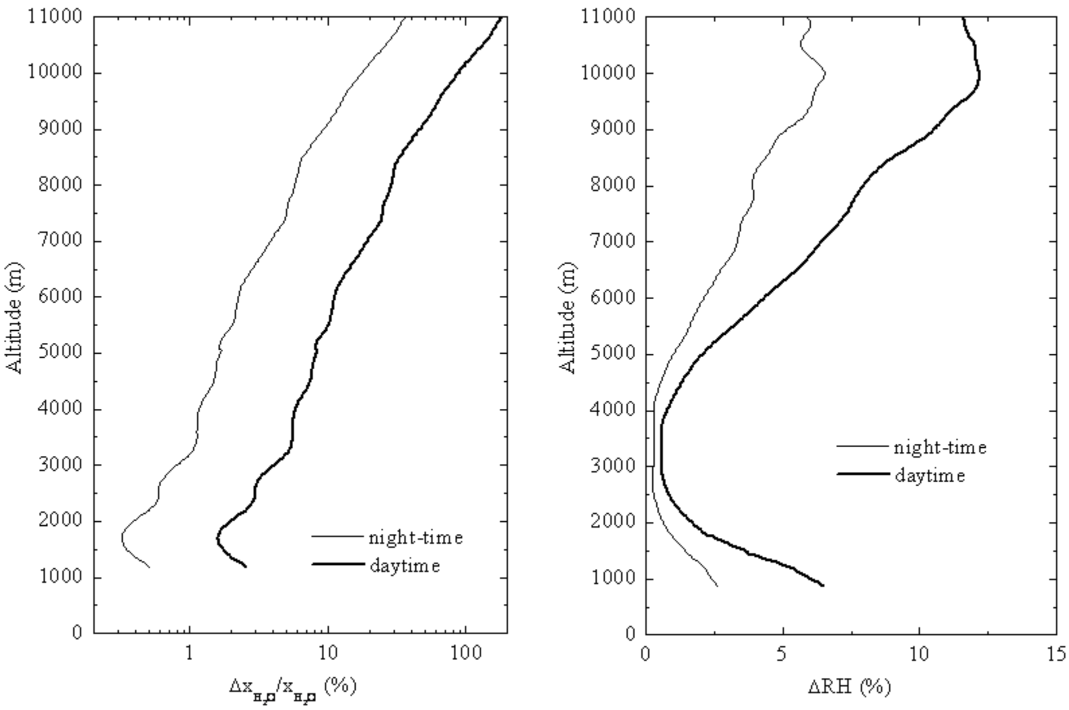


Figure 7: Random error affecting water vapour mixing ratio (left panel, expressed in percentage) and relative humidity measurements by *BASIL* at night (19:00 UTC on 6 September 2004) and for operation in the dusk-to-night transition period (18:00 UTC on 6 September 2004). Precision estimates are based on a vertical and temporal resolution of 300 m and 10 min, respectively.

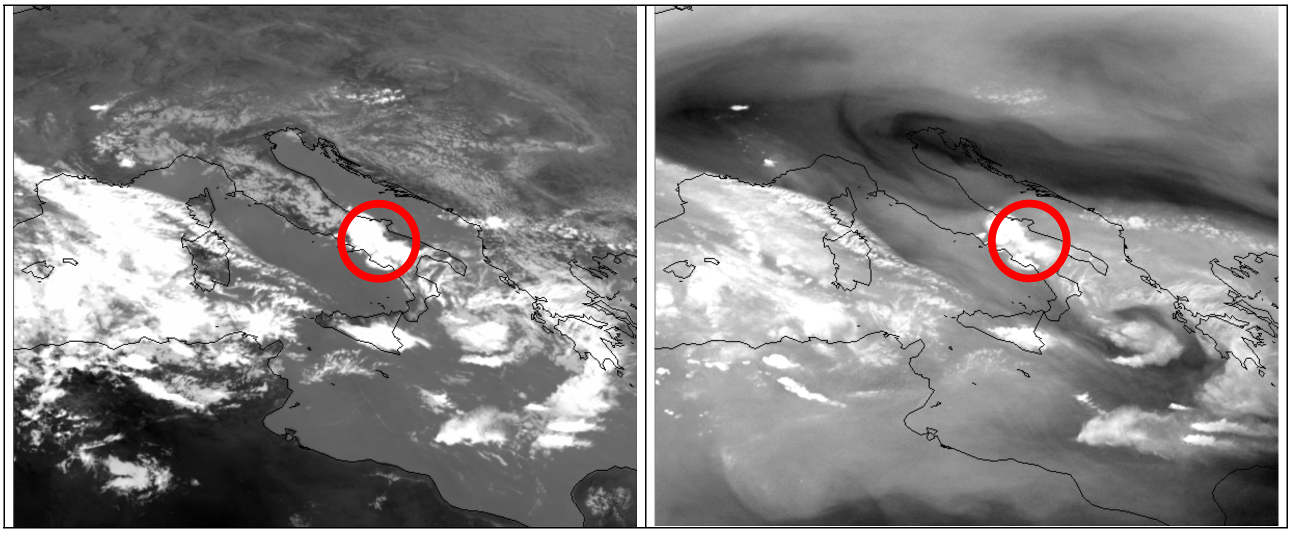
Minor comments

1. Page 14739, line 15: Larger values have been proven, e.g., at least 45 (Behrendt and Reichardt 2000).

The sentence was corrected in the way requested by the reviewer and now reads: "When particle scattering ratios are in excess of 45 (Behrendt and Reichardt, 2000), lidar temperature measurements are contaminated by elastic echoes".

2. Page 14740, line 5ff: I suggest marking these locations in Fig. 1

The locations of Molise, Northern Campania and Basilicata have been marked in Fig. 1. The caption of the figure has been changed accordingly and the following short sentence has been introduced: "In the images for 13:12:44 the region where intense convective activity was present in the morning hours (Molise, Northern Campania and Basilicata) is marked with red circles". Below are the modified panels of figure 1.



Upper panels of figure 1

3. Page 14741, line 10: Please delete "completely". The measurement of the particle backscatter coefficient uses both the N2 Raman signal and the elastic signal.

As suggested by the reviewer, the term "completely" has been removed by the sentence.

4. Page 14741, line 16ff; Fig. 3: Are there parts of the cloud which are not reached/penetrated by the lidar beam due to too large extinction and are therefore not taken into account in the measurements of the cirrus cloud optical thickness? Please comment on that.

In the original paper, we had already introduced the sentence: "Before 18:00 UTC optical thickness is in excess of 3 and the system cannot obtain a correct estimate." As requested by the reviewer, we have further commented on this. It is to be pointed out that the laser beam gets completely extinguished when the optical thickness is exceeding 2.8-3. Thus, it is possible that optical thickness values in excess of 3 are present before 18:00 UTC; however, these values cannot be measured by the present lidar system. The above sentence has then been substituted with the following text: "It is to pointed out that the laser beam is completely extinguished when the optical thickness is exceeding 2.8-3. Therefore, it is possible that optical thickness values in excess of 3 are present before 18:00 UTC, but the system cannot obtain a correct estimate of them."

I order to avoid any misunderstanding, I suggest to mention the definition of optical thickness (basis e not 10).

The definition of the optical thickness has been introduced. The corresponding sentence has been corrected as follows: "Figure3 also shows the evolution with time of cloud optical thickness τ (lower panel), obtained by integrating the extinction profiles over the vertical domain of the clouds (7-12 km), through the expression:

$$\tau = \int_{z_1}^{z_2} \alpha(z)dz$$

with $\alpha(z)$ being the particle extinction profile, and z_1 and z_2 being the lower and upper integration limit (in this case 7 and 12 km, respectively)."

5. Page 14742, line 10 ff; Fig. 4: It seems that there are also values of RHI > 100 % outside the cloud due to statistical noise of the data.

The reviewer is right as in fact values of RHI in excess of 100 % are occasionally observed also outside the cloud. The text has been modified to clarify this aspect and now reads: "Results plotted in Fig. 4 show that both super-saturation and under-saturation conditions (with respect to ice) are found inside the cloud. Additionally, values of RHI in excess of 100 % are found beneath the cirrus clouds (see regions identified with blue arrows in Fig. 4). Some of these values, especially those observed above 10 km, are due to the large statistical noise affecting the lidar data."

6. Page 14744, line 9: Please introduce the abbreviation FOVS.

The acronym FOVS has been defined. Now the sentence reads: "Table 1 lists the optical and microphysical properties retrieved by RT-RET at 4 field-of-views (FOVS) around the *BASIL* station, during the first Proteus overpass, assuming the mentioned mixture.

7. Page 14744, line 24 ff: This assumption can be validated by calculating the extinction-to-backscatter coefficient ratio (lidar ratio).

This comment from the reviewer is very appropriate and pertinent. In fact, the lidar ratio measurements by the Raman lidar show a very limited variability within the cirrus cloud. Values are found to vary within the range 25-35 sr, this variability being comparable to the noise error affecting the estimate of the mean lidar ratio within the cloud (29 ± 4 sr). The limited variability of the lidar ratio within the cloud implies a limited variability within the cloud of the particle size distribution and of the effective dimension. A detailed analysis of lidar ratio variability for this case study has been reported in a recent paper by Mona et al. (2007).

8. Page 14745, line 5: Please introduce the abbreviation DIFA.

As requested by the reviewer, we have defined the acronym DIFA. However, we have not done it in page 14745, but in page 14378, i.e. the first time this acronym appears in the paper. The sentence in page 14378 now reads: "The University of BASILicata UV Raman lidar system (BASIL), located at the Dipartimento di Ingnegeria e Fisica dell'Ambiente (DIFA) in Potenza-Italy ($40^0$38'45" ,N, $15^0$48'32" E), was part of the ground equipment involved in the experiment and collected approximately 80 hours of measurements distributed over four Intensive Observation Periods (IOPs)."

9. Page 14747: Why are radiosonde data used in the simulation and not lidar data?

In principle it would have been ideal to use the Raman lidar measurements of the water vapour mixing ratio or RHI profile to initiate the model. However, due to signal attenuation and noise problems, the full profile was not obtained until 1822 UTC (Figure 4). This is now clearly specified in the text, where the following sentence was introduced: "The use of the radiosonde data to initialize the model became necessary because, due to signal attenuation and noise related problems, the full profile of temperature and water vapour mixing ratio from Raman lidar was not obtained until 1822 UTC."

10. Page 14749,line 6: What is the lidar ratio measured by the lidar in this case (see also point 7 above)?

As already mentioned above, the lidar ratio measured by the Raman lidar *BASIL* in the time interval 18:20–18:50 was found to be 29 ± 4 sr. An extensive analysis of the lidar ratio variability for this case study, including the data from *BASIL* and the close-by IMAA-CNR Raman lidar, can be found in Mona et al. (2007).

11. Page 14749: Please explain all parameters used in the formulas.

All terms in the formulas for β_e, N_0 and N_{ice} in page 14749 are explained here or were explained previously in the text. I was not able to locate any term with a missing explanation in this page.

12. Page 14758, Table 1: Please introduce all abbreviations.

All abbreviations present in Table 1 have now been introduced in the table caption. Specifically, the table caption now reads: "Optical and microphysical properties retrieved from the RT-RET retrieval scheme during the first Proteus overpass at 18:02 GMT (Maestri et al., 2009), assuming a mixture of crystal habits. L and μ are the so called 'slope' and 'dispersion' parameters of the PSD and $D_e = \frac{3}{2}\frac{\int N(D)VdD}{\int N(D)AdD}$ is the effective diameter, where V is the volume and A is the projected area. The table also reports the values corresponding to the average properties over the four FOVS, computed from the mean radiance." Additionally, in table 1 the abbreviations SW and LW has been substituted with the extended terms "shortwave" and "longwave", respectively.

13. Page 14759, Table 2: Please introduce all abbreviations.

All abbreviations present in Table 2 have now been introduced in the table caption. Specifically, the table caption now reads: "Results of test cases obtained with the 1-D model. Column 1 is the fraction (expressed in percentage) of the initial ice water path that has been converted to water vapour in a given period of time, column 2 is the fraction (expressed in percentage) of the evaporated ice path that between 6.5 and 7.5 km in terms of the columnwise evaporated ice path at a given time and column 3 quantifies the significance of the evaporated ice path between 6.5 and 7.5 km, when compared to the measured vapour path in the same vertical interval. The simulation using w=0 m/s is not listed because it compares poorly with the observation. The total water path (the sum of vapour path and ice path) is not a conservative quantity. For this case of rather limited vertical mass displacement, the approximation of the total water path as a conservative quantity introduces a very small error."

14. Page 14760, Fig. 1: What is the scale of the plots?

Latitude and longitude range of the plots have now been specified. The figures cover the latitude range from 30°N to 48°N and the longitude range from 0°E to 22°E. This corresponds to a scene width of ~2300 km and height of ~2000 km. This information is now specified in the figure caption, where the following sentence was introduced: "The figures cover the latitude range from 30°N to 48°N (~2000 km) and the longitude range from 0°E to 22°E (~2300 km)."

15. Page 14761, Fig. 2: The red marks of the cloud boundaries are not clearly visible.

This figure has been modified and the red dots, which were previously used to identify the cloud boundaries, have been removed and substituted by a bold black line. The corresponding sentence has been changed in the text and now reads: "A threshold value of 2.5×10^{-7} m^{-1} sr^{-1} is considered to infer cloud base and top height (cloud boundaries are illustrated with a bold black line in Fig. 2)." Below is the modified version of figure 2.

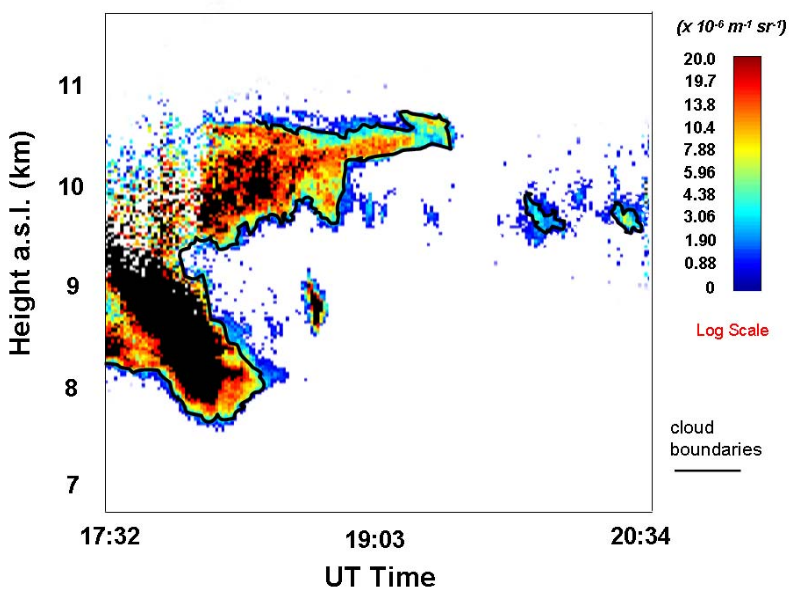


Figure 2

16. Page 14762, Fig. 3: I guess the leading digits of the scale are missing.

Figure 3 was modified and the correct digits are now present in the colour scale. Below is the modified version of figure 3.

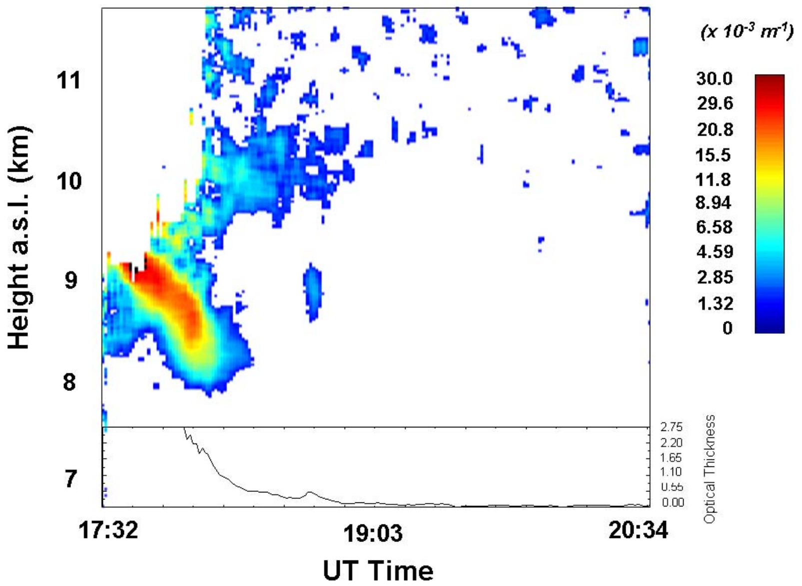


Figure 3

References

Behrendt, A. and J. Reichardt, "Atmospheric temperature profiling in the presence of clouds with a pure rotational Raman lidar by use of an interference-filter-based polychromator." Appl. Opt., 39, 1372-1378, 2000.

Mattis, I.;A. Ansmann, D. Althausen, V. Jaenisch, U. Wandinger, D. Müller, Y. F. Arshinov, S. M. Bobrovnikov, and I. B. Serikov, "Relative-Humidity Profiling in the Troposphere with a Raman Lidar," Appl. Opt. 41, 6451-6462, 2002.

Behrendt, A.; T. Nakamura, Y. Sawai, M. Onishi, T. Tsuda, "Rotational vibrationalrotational Raman lidar: Design and performance of the RASC Raman lidar at Shigaraki (34.8 deg N, 136.1 deg E), Japan." Proceedings of SPIE - The International Society for Optical Engineering, Vol. 4484, 151-162, 2002.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 14735, 2009.

Additional modifications

The text in former page 14741, line 9, hes been modified as follow: “Figure 3 shows the lidar measurements of particle extinction at 355nm over the same 3 h period as in Fig. 2, plotted as a succession of 1 min averaged consecutive profiles.

Because of the introduction of a new figure (figure 7), the numbering of all figures subsequent to this has changed: namely, former figure 7 is now figure 8, former figure 8 is now figure 9, former figure 9 is now figure 10 and former figure 10 is now figure 11.

References

Di Girolamo, P., D. Summa, R. Ferretti, Rotational Raman Lidar measurements for the characterization of stratosphere-troposphere exchange mechanisms, *Journal of Atmospheric and Oceanic Technology,* Ed. *American Meteorological Society*, Vol. 26, No. 9, pp. 1742–1762, 2009.