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 #2'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 #2

Page 14737, line 24-25. Manuscript states "Measurements reported in this paper represent to our knowledge the first Raman lidar measurements of relative humidity (RH) inside cirrus clouds." Is this really true? I am under the impression this has been done by other groups in the past, and already reported in international conferences and published in peer-reviewed journal articles. For example, consider work done by the NASA GSFC Scanning Raman Lidar group by D. Whiteman et al., e.g., "Scanning Raman Lidar Measurements of Atmospheric Water Vapor and Aerosols," R. Ferrare et al., 2004. Also, see, e.g., Immler, F., K. Krüger, S. Tegtmeier, M. Fujiwara, P. Fortuin, G. Verver, and O. Schrems (2007), Cirrus clouds, humidity, and dehydration in the tropical tropopause layer observed at Paramaribo, Suriname (5.8°N, 55.2°W), J. Geophys. Res., 112, D03209, doi:10.1029/2006JD007440.

The present paper has the value to include RH measurements inside cirrus clouds which are all lidar based, i.e. are obtained from a lidar system with both water vapour and temperature measurement capability. Specifically, water vapour measurements are obtained through the application of the vibrational Raman lidar technique, while temperature measurements are obtained through the application of the pure rotational Raman lidar technique. Both papers mentioned by the reviewer refer to RH measurements that are not entirely performed by lidar. In fact, the paper by Ferrare et al. (2004) reports RH measurements which are based on water vapour mixing ratio measurements by lidar, but the temperature measurements are obtained from simultaneous radiosondes. On the contrary, in the paper by Immler et al. an aerosol Raman lidar is used in support of a cirrus cloud study, but all RH measurements mentioned in that paper are obtained from radiosonde data (Snow White type). Based on the above considerations, we could certainly better explain in the paper what we intended as "first Raman lidar measurements of relative humidity"; however, we decided to completely remove the sentence under discussion, because it was not really relevant to the purposes of this paper.

Page 14739. Nominal Basil measurement uncertainties are given for nighttime measurements at 8 km; how do these vary for other altitudes and conditions assimilated in this case study?

This is a very important point. We have now introduced a new figure (fig. 7) which illustrates the variability of measurement uncertainty as a function of altitude for the specific instrumental and atmospheric conditions encountered in this study. The figure consider the fact that measurements were performed both at night and in the dusk-to-night transition period. A proper assessment of the system performances at different altitudes and in variable solar illumination conditions 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 the case of data acquired in photon-counting mode, as in the case of *BASIL* (Di Girolamo *et al.*, 2009). The following text has been introduced to accompany the new figure: "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 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."

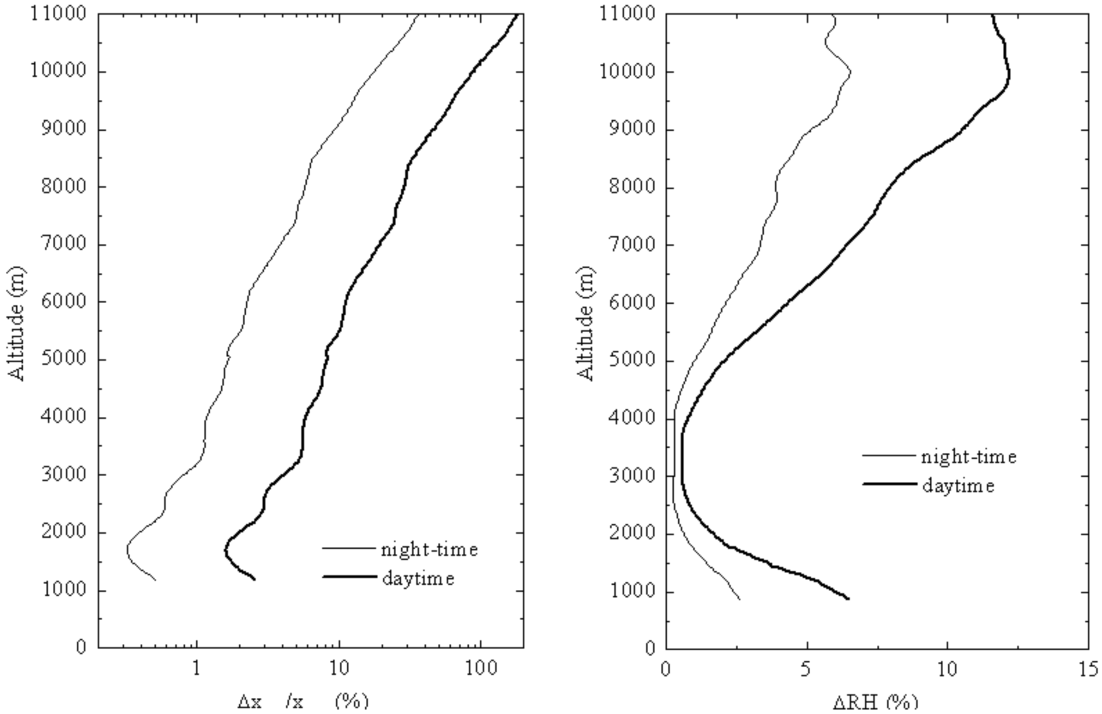

Figure 7: Random error affecting water vapour mixing ratio (left panel, expressed in percentage) and relative humidity measurements by *BASIL* at night (19:00 UTC on 6 September 2004) and for operation in the dusk-to-night transition period (18:00 UTC on 6 September 2004). Precision estimates are based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

Page 14739. It is mentioned that the Lidar temperature and water vapor profiles reported were calibrated using radiosonde data. How are the corresponding study results impacted from potential radiosonde dry bias artifacts commonly reported elsewhere for upper tropospheric regions?

Water vapour and temperature lidar measurements were calibrated based on an extensive inter-comparison effort involving radiosondes (Vaisala RS 90 and 92). The calibration procedure used for *BASIL* has been extensively described in Di Girolamo *et al*. (2009). Specifically, in water vapour lidar measurements the calibration coefficient is determined by comparing water vapour mixing ratio data from lidar and radiosondes for an extended measurement sample in the altitude region between 3 and 7 km. For this purpose, the radiosondes released from the near-by IMAA ground station were used. The selection of the altitude region 3-7 km comes from the necessity to exclude boundary layer data from the comparison as in the boundary layer the effects of water vapour heterogeneity may be large for the two sites, which are 8.2 km apart. A dry bias has been reported in literature for radiosonde measurements in upper troposphere, i.e. at very low temperature and humidity levels (especially for Vaisala RS 80s and to a much smaller extent for Vaisala RS 90 and 92). However, the comparison between lidar and radiosonde measurements of water vapour mixing ratio are carried at lower altitudes (3-7 km, as mentioned above), where radiosondes display a very reliable behaviour and are not affected by the above mentioned dry bias. Therefore, lidar measurements of water vapour mixing ratio and relative humidity reported in this paper are not impacted by radisonde dry bias problems.

Page 14741. What time is local "sunset" for the case study data reported? And, if there is any day/night transition among discussed data, please discuss Basil max altitude and uncertainty differences for these two different regimes.

The local sunset for the reported case study was at 17:51 UTC (civil twilight). Consequently, lidar measurements reported in this paper cover the day/night transition. As pointed out above, a new figure (fig. 7) has been introduced to illustrate the variability of measurement uncertainty as a function of altitude for the specific instrumental and atmospheric conditions encountered in this study, considering both night-time performances and those in the dusk-to-night transition period. This figure reveals that the maximum altitude reached by the lidar in terms of both water vapour mixing ratio and RHI, which is taken as the altitude where the percent random error affecting these parameters reaches 100%, is ~10 km. As mentioned above, a new paragraph has been introduced to accompany the new figure.

Page 14742. It is mentioned that GPS data are not contained with radiosondes for the referenced experiment. How does this impact usage of these radiosondes for calibration of the Lidar temperature and water vapor profiles? Significant horizontal drift can occur during radiosonde ascent and this can cause huge errors in the above-referenced calibration in the presence of geophysical gradients.

Although the radiosonde was not equipped with a GPS receiver for absolute positioning, wind information from ECMWF global model suggests that, when passing through the altitude region 3-7 km considered for the calibration of the water vapour lidar profiles or through the altitude region 5-10 km considered for the calibration of the temperature lidar profiles, the radiosonde is within a distance from the lidar system of 10 km and 12 km, respectively. In the altitude region 3-7 km, i.e. in the free troposphere, the horizontal variability of the humidity field over a distance of 10 km is limited, and thus the effect on the calibration of the not exact co-location of the lidar and the sonde is small. Di Girolamo *et al.* (2009) determined that the systematic error associated with the calibration procedure and due to a) differences in the air masses being sensed by the radiosonde and the lidar and b) bias affecting the radiosonde sensor is 3-5 %. Regarding the calibration of the lidar measurements of temperature, we have to point out that the temperature field is characterized by a much higher horizontal homogeneity than the humidity field: specifically, in the altitude region 5-10 km, the horizontal variability of the temperature field over a distance of 12 km is very limited and thus the systematic error affecting the calibration procedure is, again, small. Di Girolamo *et al.* (2009) estimated a bias in temperature lidar measurements of ~ 0.2 K associated with the application of the calibration procedure, this number including potential errors due to a) different air masses being sensed by the radiosonde and the lidar and b) radiosonde biases.

Page 14750, first paragraph. Is lack of exact co-location of synergistic measurements another factor in not correctly capturing the cloud layer evolution?

The lack of exact co-location of synergistic measurements from lidar, radiosondes and NAST-I is probably another factor playing a role in the missing capability of the model to correctly capture the upper cloud layer evolution. This is now considered in the text and the corresponding sentence has been modified as follows: "Evidently from the Fig. 10a and 10b, the simulations miss to capture the evolution of the upper cloud layer which might be due to the following reasons: (1) the specification of a uniform downward vertical velocity through out the entire model domain; (2) the use of a unimodal gamma size distribution that might have underestimated the number of small particles for the initial PSDs; 3) not accounting for the radiative diabatic effects and 4) the lack of exact co-location of synergistic measurements from lidar, radiosondes and NAST-I.

Technical corrections

Page 14736, line 4. Add "the" prior to "Italian phase"

Correction done.

Page 14736, line 10. Consider adding "," after "measurements"

Correction done.

Page 14736, line 18. Change "allows to determine" to "allow determination of"

Correction done.

Page 14736, line 20 (and at many places throughout manuscript). I am questioning the use of the term "cirrus cloud anvil" here and throughout paper. Used in this context generally refers to the cirrus cloud formed at the top of thunderstorms, from horizontal divergence of air where further vertical motion is constrained. Whereas in this case study, I believe, the cirrus clouds under evaluation are not associated with thunderstorms. If this is correct, I would suggest considering dropping the word "anvil."

The cirrus cloud discussed in the paper follows an intense convective event that took place until the early part of the afternoon, as described in the paper. The evolution of the cirrus cloud documented in the paper refers to several hours later. Therefore, we agree that the term "cirrus cloud anvil" can be changed into "cirrus cloud" and "cloud anvil" changed into "cloud". However the origin of the cloud deck is due to a convective development, followed by a dissipation stage.

Page 14736, line 22. Change "indicates" to "indicate"

Correction done.

Page 14736, line 28. Change "appears" to "appear"

Correction done.

Page 14737, line 7. Change "understanding" to "understanding of"

Correction done

Page 14737, line 15. Change “with humidification” to “with a humidification”

Correction done

Page 14738, line 9. Add “(NPOESS)” between “System” and “Airborne”

Correction done

Page 14738, line 11. NAST-I is reported elsewhere as being 0.25 cm-1 resolution.

Correction done, now spectral sampling is specified to be 0.25 cm^{-1}.

Page 14738, line 13-18. In reference to the radiance computations, it would be helpful to add a parenthetical note at this first occurrence regarding the approach or a pointer to the manuscript section where more detail is provided. Also, wherever the detail is provided, please add information on how the surface (e.g. temperature and emissivity) is handled.

As proposed by the reviewer, we introduced a parenthetical note to indicate where details on the approach are provided. Now the sentence reads: “NAST-I measurements were compared with spectral radiances computed using *BASIL* products (temperature and water vapour profiles, and cloud geometrical and optical information) leading to the determination of the temporal sequence of the cloud cooling/heating rates associated with the presence of the cirrus cloud (more details on the approach are provided in section 3)”. Information on how the surface (e.g. temperature and emissivity) is handled is now given in section 3, where the following sentences have been introduced: “Surface emissivity of the Potenza region is derived from SSEC (Space Science and Engineering Center, University of Wisconsin-Madison, USA) gridded dataset (Borbas *et al.*, 2007), using a baseline fit method on MODIS (The Moderate Resolution Imaging Spectroradiometer) surface emissivity retrieval algorithm (MOD11 measurements). As surface skin temperature we considered the lowermost atmospheric temperature value obtained from the radiosonde since a direct measurement was not performed and retrievals from remote sensing data were prevented by the cloudy sky.” The new reference has been introduced in the reference list.

Page 14740, line 14. Change “indicate” to “indicates”

Correction done

Page 14740, line 22. Change “data is” to “data are”

Correction done

Page 14740, line 24. Move “from” away from current location to after “measurements”

Correction done

Page 14742, line 9. Change “At this purpose, radiosondes” to “For this purpose, radiosonde”

Correction done

Page 14742, line 12. Change “thescloud” to “the cloud”

Correction done

Page 14743, line 21. Change “an horizontal” to “a horizontal”

Correction done

Page 14744, line 13. Change “provides also” to “also provides”

Correction done

Page 14744, line 14. Change “tha” to “the”

Correction done

Page 14744, lines 19-22. In 3 places, change “; [“ to “ [“

Correction done

Page 14745, line 3. Move “sets of” to in between “spaced” and “FOVS”

Correction done

Page 14745, line 5. Change “retrived” to “retrieved”

Correction done

Page 14745, line 7. Change “; [“ to “ [“

Correction done

Page 14745, line 17. Change “ratiative” to “radiative”

Correction done

Page 14746, line 26. Add “the” before “next”

Correction done

Page 14747, line 22. Add “the” before “same”

Correction done

Page 14748, line 2. Change “descent” to “descending”

Correction done

Page 14748, line 3. Change “to gravitational” to “with gravitational”

Correction done

Page 14748, line 17. Delete “that”

Correction done

Page 14748, line 19. Change “data available to us.” to “available data.”

Correction done

Page 14749, line 5. Add space “ “ before “are” and after “obtain”

Correction done

Page 14750, line 4. Change “to capture” to “capturing”

Correction done

Page 14750, line 6. Change “through out” to “throughout”

Correction done

Page 14750, line 15. Change “radio sondes” to “radiosondes”

Correction done

Page 14752, lines 8 & 19. Suggest changing “synergic” to “synergistic”

Corrections done

Page 14752, line 24. Change “indicates” to “indicate”

Correction done

Page 14753, line 7. Change “Eumersat” to “Eumetsat”

Page 14758. Average values given in Table are not equal to the averages of the specific IFOV values listed in Table.

As specified in the text, the last line of table 1 provides the values corresponding to the average properties over the four FOVS, computed from the mean radiance. So, these values are not obtained from the arithmetic average of the specific IFOV values listed in the table. This is now clearly specified also in the table caption, where the following short sentence is introduced: “The table also reports the values corresponding to the average properties over the four FOVS, computed from the mean radiance.”

Page 14766. In caption, change “firsts” to “first”. Is “3” correct in caption or should it be “4 panels”?

The sentence has been changed and now reads: “In the 4 panels the lidar measured cloud optical depths (in the short-wave) are also reported.”

Change “widow” to “window”.

Correction done

Make font size of “OD=” larger in bottom two panels (i.e. like upper two).

Correction done

Page 14767. Colors too similar for the dark curves and are hard to distinguish. What is the purpose of the arrows shown within the figure? Please label if they need to remain.

The colour of the blue curve was changes into yellow and it is now clearly distinguishable. The thickness of all curves has been changed and dots have been introduced in order to make curves even more clearly distinguishable. Below is the modified version of figure 9 (former figure 8).

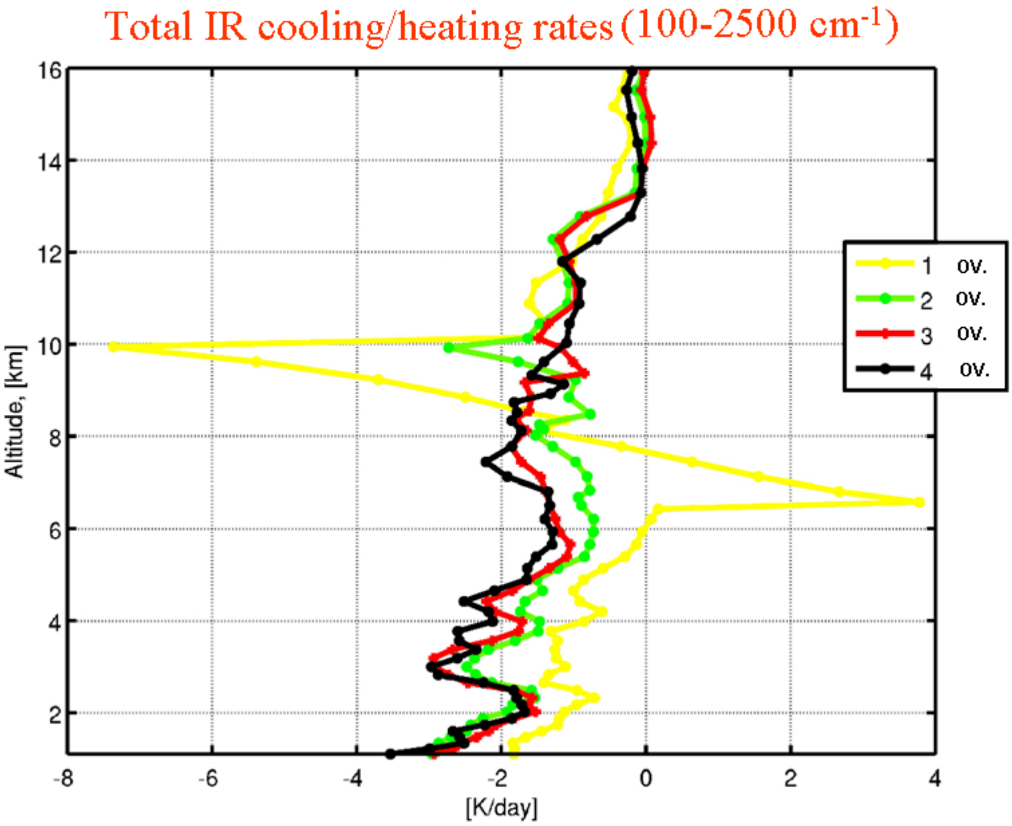

Figure 9

Page 14768. How are “idealized” profiles formed?

The “idealized” profiles of temperature and vapour mixing ratio are a smoothed version of the temperature and vapour mixing ratio profiles measured by the radiosonde launched at 17:13 UTC. The application of the smoothing operator allows to capture the larger scale features and remove small scale fluctuations that would complicate the understanding of the simulation results. As explained in the text, the RHI idealised profile is also set to 100% between 7.2 and 9.8 km in presence of fluctuations in the measured data that are amply discussed in the text."

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

Borbas E., L. Moy, S. Seemann, R. O. Knuteson, I. Trigo, P. Antonelli, J. Li, H. L. Huang, A global infrared land surface emissivity database and its validation. *Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface*, 11th, San Antonio, TX, 14-18 January 2007, American Meteorological Society, Boston, Paper P2.7, 5285, 2007.

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.