Author's response on "Mesospheric temperature soundings with the new, daylight-capable IAP RMR lidar" by Gerding et al.

Referee #2

This paper provides a technical description of a state-of-the-art Raman-Mie-Rayleigh lidar system which is in operation at the Leibniz-Institute of Atmospheric Physics since 2010. Several techniques (small field of view, narrowband optical filters in the receiver, transmission at a Frauenhofer line) are used to reduce the solar background, thus making it possible to retrieve temperature profiles up to approximately 75 km in full daylight. This is a significant achievement as the new lidar system allows temperature observations in the stratosphere and lower mesosphere over full diurnal cycles. Such long observations are of scientific interest for studies of e.g. thermal tides, diurnal variation of (convective) gravity waves. The lidar system is also notable for its stable operation with more than 6000 hours of observations so far (> 1000 hours per year). The work presented in this paper is appropriate for publication in Atmospheric Measurement Techniques.

We thank the reviewer for the constructive comments. Below we cite each comment (indicated by italics) followed by our answer. Line numbers are given with respect to the manuscript with marked changes.

Specific comments:

1. Gerding et al. present many interesting details of their lidar system in this paper. However, it is hard to compare the performance to other lidars based on retrieved temperature profiles. I suggest the authors add a figure showing a raw photon profile, e.g. one hour integration time.

We have added a new Figure 4 in the revised manuscript, showing the raw data with and without background correction. Following a similar comment by Reviewer 1, we have chosen a one hour period near highest solar elevation from the same sounding also used in Figure 3 and 6 (old Figure 5), and a period 12 h later. Cf. page 4, lines 28-33.

2. The correction of spectral distortions in the backscatter signal induced by the double etalon is enlightening. I am wondering: did the authors consider validating their calculations by comparing signal ratios measured by detectors before and after the etalons for different altitudes (temperatures)? For example, the authors could derive the transmission of the double etalon at the stratopause (high temperature) and in the mesosphere (low temperature). The comparison could provide insight whether the instrument function of the (real) etalon is indeed an Airy type function.

The different channels needed for calculation of transmission have different signal strengths. The count rate between channel 532/1 and 532/3 varies by a factor ~100, i.e. the lowest channel covers the stratopause but not the upper mesosphere. Therefore such a test is unfortunately not possible. We have checked the validity of our assumptions by comparison with our old lidar for several different nights and the full available altitude range. A representative example is shown in this paper. Data in Table 1 are given for real illumination of the double etalon system. Finesse of etalon 2 is higher if illuminated by single-mode fiber without first etalon (ideal conditions).

3. The calculations are based on the assumption that the lidar transmits at the wavelength of peak transmission of the etalons. What is the precision of tuning the etalons to a specific wavelength? Can the authors provide an estimate of the temperature error caused by an improperly tuned etalon (e.g. wavelength of peak transmission is offset by 0.5 pm)?

We estimate the potential wavelength offset as maximal 0.2 pm. This offset would result in an over-compensation (i.e. underestimation of true temperature) by ~0.4 K. Please note that this potential error has a different sign than the effect of spectral broadening of the laser pulse. We thank the reviewer for this comment. We have improved the manuscript accordingly (new page 4, lines 10/11 and page 6, lines 27-29).

Minor comments:

Page 3, line 11: "The emission wavelength of the seeder is monitored by a High Finesse WSU wavelength meter." Is the wavelength meter used to stabilize the seeder? Please clarify.

As described in lines 7 and 12 of page 3, the seeder is locked to an iodine absorption line. The wavelength meter is only used for coarse adjustment and to write the approximate wavelength into a logfile.

Page 3, line 24: "The fiber cable has a diameter of only 0.2 mm: : :". I assume the core of the fiber is 0.2 mm in diameter and the cable is larger.

We write now "core diameter" (page 3, line 26).

Page 4, line 2 and Figure 2: Please mark detectors "532/1", "532/2", "532/3" in Figure 2.

Done. Thanks for the suggestion.

Page 4, line 6: "Tuning of the etalons is done by changing the pressure inside the stainless steel housing". Please explain in more detail how the etalons are tuned. Is the transmission monitored as function of pressure? How often do the etalons need to be tuned?

The pressure is changed continuously while tracking the transmission of the seeding light; first for 1st etalon, than 2 nd etalon. Transmission is controlled for every sounding comparing the different channels, and re-adjusted every 2-6 weeks. We have slightly extended the description (page 4, lines 10/11).

Page 4, line 7: The transmission of the etalons ("_92%") is very high. How was the transmission measured?

We measured the transmission with the seeder using collimated light from a single mode fiber. We have added the description, emphasizing that the number is valid for ideally collimated light (page 4, line 8).

Page 4, line 14: “the background count rate form solar backscatter is reduced by about five orders of magnitude compared to our nighttime RMR lidar” How do the authors estimate the reduction in background count rate in daylight if the nighttime RMR lidar can only observe during darkness? Please explain. This also concerns Figure 3: How is the background extrapolated? Can the authors provide key parameters of the nighttime RMR system (e.g. field of view, bandwidth of interference filter)?

We apologize for a partially misleading phrasing, because the effect of a new low-noise detector is included. New phrasing is "more than four orders of magnitude" (e.g., page 4, line 19). FOV is reduced from 800 microrad to 62 microrad (factor ~170); spectral width from 350 pm to ~4 pm (factor 88 if shape is neglected). Overall factor ~15000. The dashed line in Fig. 3 is only a rough estimation what can be expected for a "standard" nighttime system.

Page 5, line 1: “As described in Table 1: : :” The bandwidth of the etalons is not listed in Table 1.

We have changed the phrasing (page 5, lines 11/12).

Page 5, line 6: “: : : from the pulse length”. Did the authors measure the pulse length? If yes, please provide information.

We measure the pulse length (10 ns, cf. page 5, line 17) by photodiode at least after each change of the flashlamps.

Page 5, line 7: “: : : calculated the effect of larger bandwidths and found that that the additional correction : : : is much below 0.1 K”. How large is the initial correction for 45 fm bandwidth? How large is the wavelength jitter of the laser and how much does this jitter affect the transmission?

The correction is up to 3-4 K in the lower mesosphere, but depends on the actual temperature profile. The wavelength jitter of the pulse laser is unknown, but will be measured in future. From a similar laser (Baumgarten, AMT, 2008; Fiedler, ILRC 2008) we can estimate a jitter of 20-40 MHz, i.e. the effect is similar to a larger bandwidth of the laser. We have slightly changed the manuscript to make this clearer (page 6, lines 23-27).

Page 5, line 18: “: : : the transmission changes between 0.86 and 0.79.” Figure 4 (left) suggest that these numbers are valid for ideal etalons with 100% peak transmission. The transmission of the real double etalon would be lower in this case. Please clarify.

The numbers are given with respect to an etalon with 100% transmission. We have improved the manuscript to make this clear (page 4, lines 29/30).

Page 6, line 7: “: : : this may be due to different (signal dependent) smoothing windows used for both lidars.” Please explain.

The temperature profiles are smoothed by 1-2 km, depending on altitude. Further description can be found at Alpers et al., 2004 or Gerding et al., 2007. We have added the text accordingly (page 6, line 21).

Page 7, line 15: “The diurnal tide maximizes at _43 km (amplitude _5 K), nearly vanishes below 50 km…” “Vanishes” is not quite correct, in my opinion. The maximum (_43 km) is below 50 km.

We rephrase "gets small close to 50 km (< 0.5 K) and then generally ..." (page 8, line 6).

Page 7, line 17: “The semidiurnal tide in March 2014 is alternately increasing and decreasing, suggesting several filtering layers for the particular tidal mode”. I am not entirely convinced. The vertical wavelength of the diurnal tide is large compared to the vertical separation of the “filtering layers” (e.g. minimum at 57 km, maximum at 62 km). Could the modulation in amplitude be caused by gravity wave-induced temperature perturbations which are not entirely suppressed in the composite analysis?

We rephrase "... suggesting several filtering layers in the course of the month for the particular tidal mode. Additionally it cannot be ruled out that some signatures of a strong gravity wave with about 12 h period are still visible even in the composite of 125 h of data." (page 8, line 8/9)

Figure 4: Caption reads “… Rayleigh backscatter spectrum before etalons (blue)…”, but the blue label reads “Voigt after FPE 1”

We apologize for similarities in the line colors and an error in the caption. We improve the colors and change the caption accordingly.

Figure 7: Please state the temporal resolution.

We add "The profiles are calculated every 15 min with 2 h integration time." (new Figure 8)

The language may be improved, e.g. “The computer-controlled beam stabilization fixes the beam axis…”, “The thin fiber with numerical aperture NA= 0.11 allows to build up…”

We edited the whole text again and improved several odd phrases.