We would like to thank both reviewers for their constructive comments and suggestions that have really helped us prepare a new and improved version of our work. Following, our response to the referee's comments:

Anonymous Referee #2

Comment 1:

Page 76, ln.19: what is the line width of the Vailsala ceilometer? This sentence implies that all ceilometers have the same wavelength width. I thought that the Jenoptik CHM15k had a smaller laser line width (0.3 nm) than CL31

The reviewer is right. The text in the revised manuscript is as follows:

"The ceilometer used in this study is a Vaisala CL31 model. It is equipped with an InGaAs/MOCVD (Indium Gallium Arsenide/Metal-Organic Chemical Vapor Deposition) pulsed diode laser emitting at 905 ± 10 nm and having an energy per pulse of 1.2 μJ ± 20 % (factory adjusted). The emission frequency is 8.19 kHz, while the pulse duration is 110 ns".

Comment 2:

Page 76, lns. 24-25: 4 km was found during daytime. During nighttime aerosol was detected up to 8.5 km. See last sentences in the abstract of the cited paper.

The referee is right, therefore, in our revised manuscript the specific phrase has been revised as follows:

"…the ceilometer is able to detect aerosol layers in the PBL and also in the free troposphere up to altitudes of the order of 4 km during day time, while during nighttime, this altitude extends up to 8.5 km due to the low atmospheric background."

Comment 3:

Page 77, ln.14: "The full overlap height at 50 m". line 21: "The full overlap height at 10 m". Which one is right? Martucci et al., 2010 specified the CL31 full overlap to 70m. Vaisala specifies the range from 0-7500m. What do you see in the profiles yourself?

The Vaisala's algorithm basically calculates the backscatter coefficient from 0 to 7.7 km. In our study we compared aerosol backscatter coefficient profiles as follows: CL31 and Raymetrics lidar for altitudes higher than 500m above sea level (asl.), taking in account that the observing site is located at 100 m asl. (which supersedes the full overlap height of both systems, which are 70 m and 200 m, respectively); CL31 and NTUA lidar for altitudes higher than 1000 m asl., taking in account that the full overlap height of the NTUA lidar system is 1000 m. This is also visible in the lidar signals themselves.

We agree with Martucci et al. (2010) that the CL31 full overlap is set to 70 m.

The referee is right, therefore in our revised manuscript the specific phrase has been revised as follows:

"… The full overlap height of the instrument is achieved for altitudes higher than 10 m, although in practice this may increase to 70 m (Martucci et al., 2010). The separation between the two areas is achieved by an oblique mirror".

Comment 4:

Page 78: ln 10-11: "full overlap at 100 m". Are you sure about this? If so, why do you show profiles only above 500 m in Fig. 1, 2, and 4?

The referee is right; this is corrected in the revised version of our work. See also our answer to Comment #3. Moreover, the reason why we show profiles above 500 m asl. in Figs. 1, 2, and 4, is that we have to take into account the full overlap of the system + the height (asl.) of the site location, therefore this has to be higher than 200+100 m = 300 m.

Comment 5:

Page 80: ln 12: Why is the first derivative of the backscatter signal not available? Aren't the data in Fig. 1a and Fig. 2a not the received ceilometer signal?

The commercially available ceilometer's software gives as output the backscatter coefficient profile only. No option is given to the user, to retrieve the logarithm of the signal and thus, calculate its derivative. This is why we present the plot of the first derivative only for the lidar measurements.

Comment 6:

line 13: backscatter coefficient of the ceilometer data? and line 16: According to the ceilometer data (Fig. 1a) ... On page 79, line 19 and 20: the authors wrote: "in Fig.1a we present the temporal evolution of the backscattered signal (in arbitrary units A.U.)". I don't believe that this is the backscatter coefficient. Besides, it would be given in km-1 sr-1. I assume that Fig. 1a and 2a is the range corrected signal or the attenuated backscatter of the ceilometer! Compare especially Fig. 2 a and b, they look quite similar.

In the first part of the first version of our manuscript the inter-comparison between the Raymetrics lidar and the ceilometer was qualitative. The ceilometer by default provides only the aerosol backscatter coefficient. Thus, since the purpose of the comparison was to qualitatively show the ability of the ceilometer to provide information about the PBL height, we presented in Figures 1a and 1b and in Figures 2a and 2b the aerosol backscatter coefficient obtained by the ceilometer and the range-corrected signal obtained by the lidar, respectively.

In the revised version of our manuscript following the reviewer's suggestion we present now the aerosol backscatter coefficient retrieved by both CL31 and Raymetrics instruments.

Since the lidars and the ceilometer participated in this study emit at different wavelengths, we had to convert at a common wavelength, 355nm for the comparison between CL31 and Raymetrics lidar, and 1064 nm for the comparison between CL31 and NTUA lidar. To do that, we used the backscattered-related Angstrom exponent and not the extinction Angstrom exponent. However, this was not clear in the text. After the reviewer's comment the following text is added in our paper:

"Since our goal is to compare the retrievals of both instruments, in terms of the aerosol backscatter coefficient and the mixing height, a spectral conversion (for the retrieval of the first parameter) is needed when different wavelengths are used. The conversion factor used is the backscatter-related Angstrom exponent, which is retrieved from the extinction-related Angstrom exponent taken from multi-filter radiometer (MFR) measurements. Specifically, the backscatter-related Angstrom exponent equals the extinction-related Angstrom exponent, when the lidar ratio is assumed spectrally independent, according to the following equations:

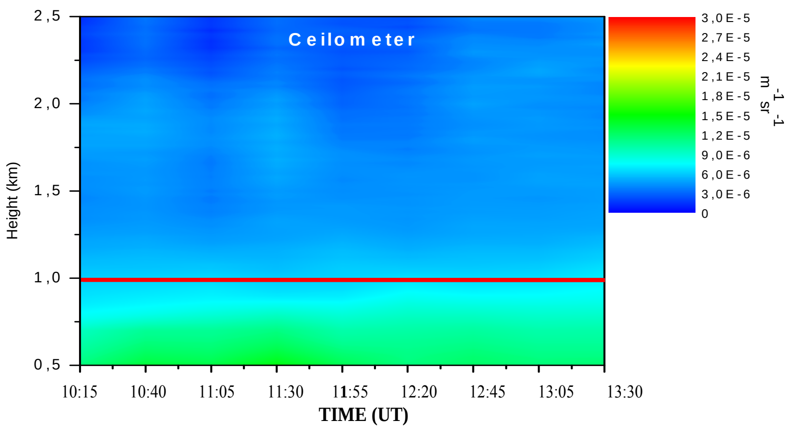
$$C(z) = -\frac{\ln\left(\frac{\alpha_{\lambda_1}}{\alpha_{\lambda_2}}\right)}{\ln\left(\frac{\lambda_1}{\lambda_2}\right)} = -\frac{\ln\left(\frac{S_{\lambda_1} * b_{\lambda_1}}{S_{\lambda_2} * b_{\lambda_2}}\right)}{\ln\left(\frac{\lambda_1}{\lambda_2}\right)} = -\frac{\ln\left(\frac{S_{\lambda_1}}{S_{\lambda_2}}\right)}{\ln\left(\frac{\lambda_1}{\lambda_2}\right)} - \frac{\ln\left(\frac{b_{\lambda_1}}{b_{\lambda_2}}\right)}{\ln\left(\frac{\lambda_1}{\lambda_2}\right)} \Leftrightarrow C(z) = -\frac{\ln\left(\frac{b_{\lambda_1}}{b_{\lambda_2}}\right)}{\ln\left(\frac{\lambda_1}{\lambda_2}\right)}$$

where: C(z) is the Angstrom exponent (backscatter or extinction-related); α_λ, b_λ are the extinction and backscatter coefficients, respectively; S_λ is the lidar ratio; λ_1, λ_2 are the wavelengths (e.g. λ_1=355 or 1064 nm, λ_2=910 nm)."

Besides, since the lidar ratio for CL31's aerosol backscatter retrievals is assumed by default to be equal to 30 sr, in our revised paper, we also adopted for the aerosol backscatter retrievals by our lidars the use of a lidar ratio equal to 30 sr, in order to have more comparable aerosol vertical profiles.

Thus, Figures 1a, 1b, 1c and 2a, 2b, 2c are revised as follows:

(a)



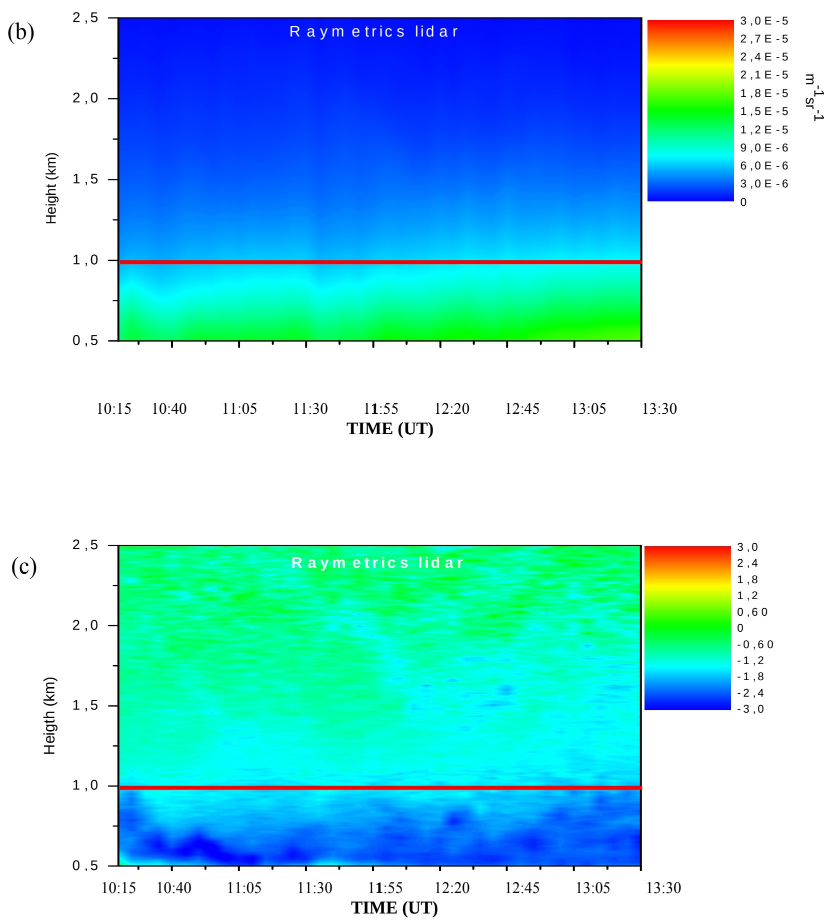


Fig. 1. Aerosol backscatter coefficient (in $m^{-1}sr^{-1}$) obtained **(a)** by the ceilometer and **(b)** the Raymetrics lidar. **(c)** The first derivative of the logarithm of the range-corrected lidar signal (in A.U.) obtained by the Raymetrics system. All curves are valid from 10:15 to 13:45 UTC on 26 November 2008. Red lines represent mean PBL height around 12:00 UTC.

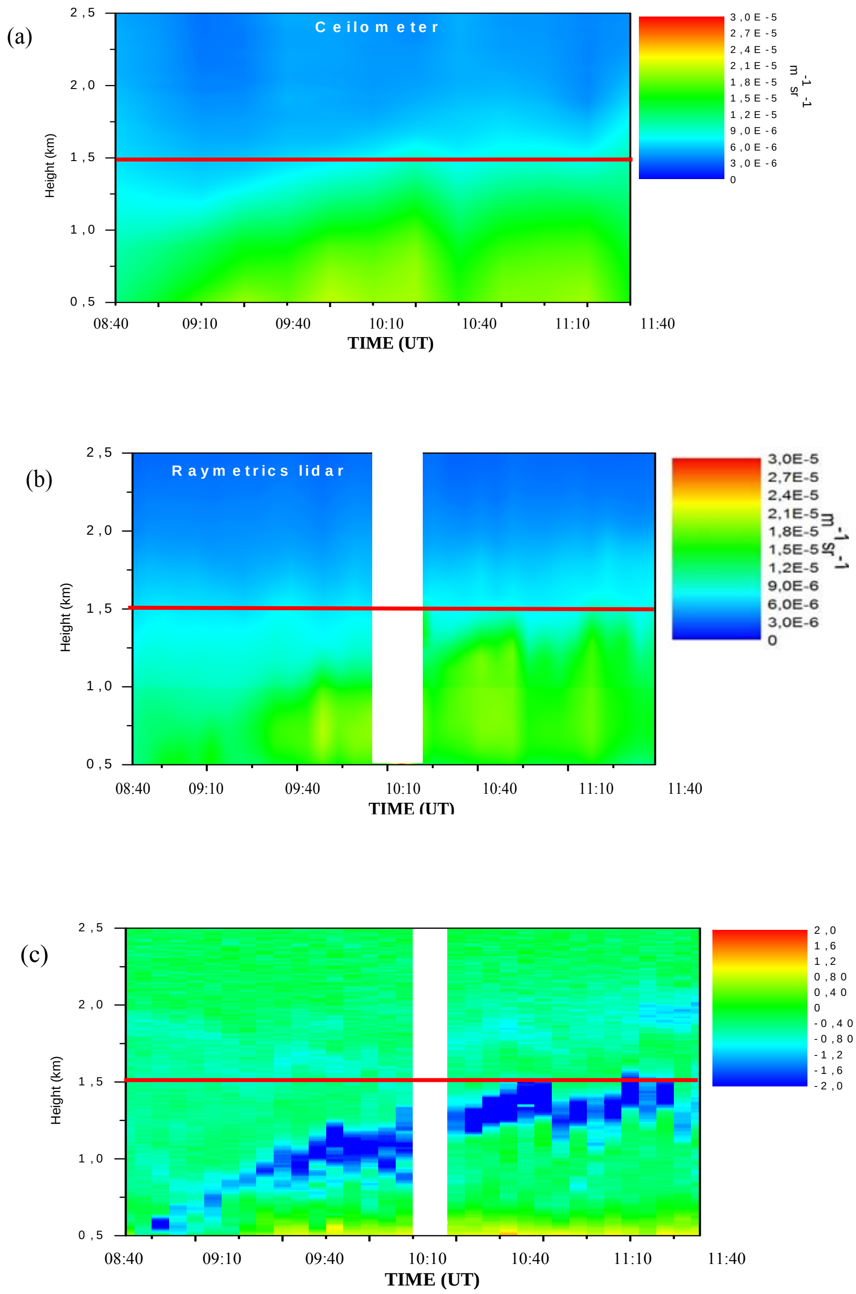


Fig. 2. Aerosol backscatter coefficient (in $m^{-1}sr^{-1}$) obtained **(a)** by the ceilometer and **(b)** the Raymetrics lidar. **(c)** The first derivative of the logarithm of the range-corrected lidar signal (in A.U.) obtained by the Raymetrics system. All curves are valid from 08:40 to 11:35 UTC on 27 November 2008. Red lines represent mean PBL height around 12:00 UTC.

Comment 7:

Pages 80 and 81: Why don't the authors use more objective criteria for the determination of the boundary layer top than detecting gradients and colors bye eye?

After the referee's suggestion we used more objective criteria to determine the mixing height. Thus we calculated the Richardson number (also taking into account the gradients of the relative humidity and potential temperature profiles) from the radiosonde data for the 26 and 27 November 2008, in order to give a more precise estimation for the PBL height, according to Joffre et al. (2001). The results are presented in the following plots which are now included in the new version of our manuscript.

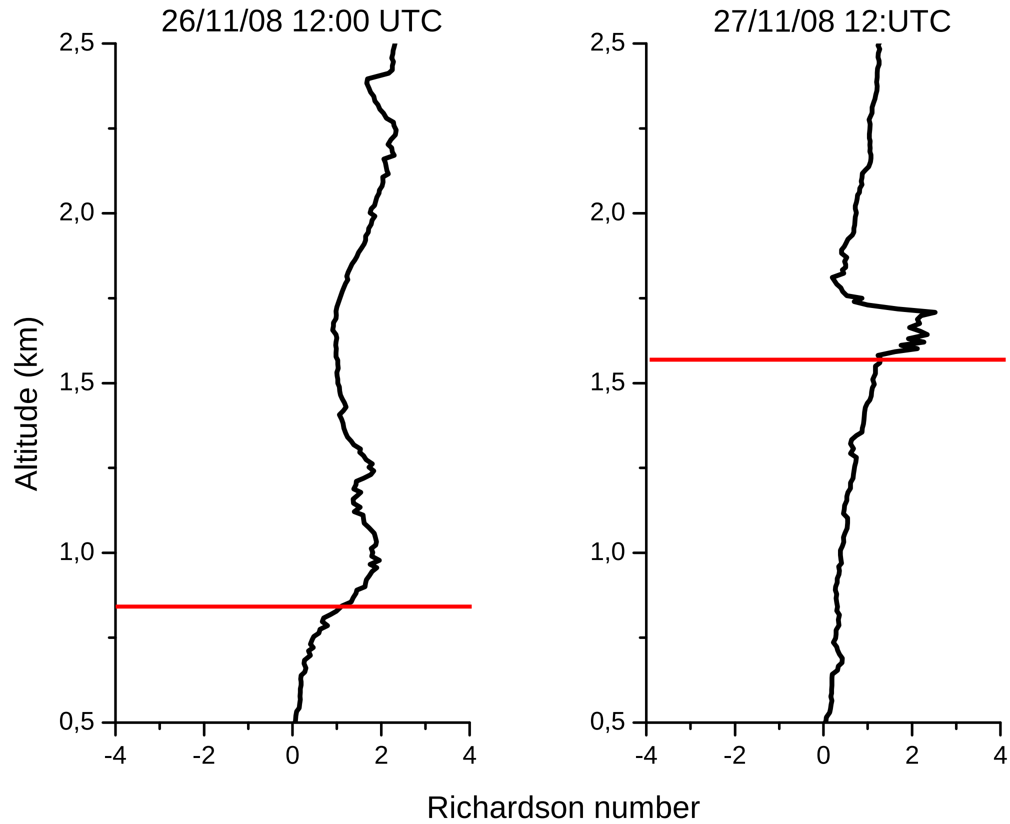


Fig. X. Vertical profile of the Richardson number obtained by radiosonde at 12:00 UTC) for 26 November 2008 and 27 November 2008. The red lines indicate the PBL height, located around 820 m and 1580 m, respectively.

"In Fig. X we present the vertical profile of the Richardson number (Ri) calculated for 26 November 2008 and 27 November 2008. The red lines indicate the PBL height. According to Joffre et al. (2001), the PBL height is identified by inspecting together the wind, humidity, potential temperature and Ri profiles for clear changes in the humidity profiles slope (Figs. 3a and 3b), and/or persistent large departures of Ri values beyond a critical value of about 1. In our case on 26 November, Ri clearly departs from around 1 at around 820 m height, while on 27 November, Ri clearly departs from around 1 at around 1580 m height".

Comment 8

Page 81: line 18-22: The most visible increase in pot. temperature and decrease in humidity is between 1500 and 2000 m! May be the detected PBL top in the plots could be indicated by a horizontal line.

The reviewer is right. See Figures 1a,1b, 1c and 2a, 2b, 2c and Comment #7, where the PBL top is indicated by horizontal lines (shown only around 12:00 UTC).

Comment 9:

Page 82: line 21-23: "Since the ceilometer's output energy is low we had to perform a 3-h average in order to sufficiently reduce the noise in the backscatter coefficient profiles obtained by the instrument." Exactly! Therefore Fig 1a and 2a cannot show the backscatter coefficient!"

The ceilometer calculates only the aerosol backscatter coefficient using an algorithm provided by Vaisala. All calculations are performed automatically without offering the user the ability to change any of the parameters. A general description of the aerosol backscatter coefficient calculation procedure is given in CL31's operation manual (Vaisala User's Guide, 2009).

The raw temporal resolution of the aerosol backscatter coefficient profile retrieved by the ceilometer is 2 sec. Since the ceilometers output energy is low, the received signals averaged every 2 sec. are quite noisy. In order to reduce the noise we were forced to average the aerosol backscatter coefficient profiles retrieved by the ceilometer every 2s into 10-min averages. Thus, in Figs. 1a and 2a the resulting integration time (or time resolution) is now 10 minutes. As far as the received lidar signals are concerned, since the raw temporal resolution was set to 1 min., we averaged 10 consecutive lidar signals to retrieve an average aerosol backscatter coefficient profile every 10 min. as well (see Figures 2a. 2b).

In the second part of our study we compared the aerosol backscatter coefficients obtained by the NTUA lidar and the ceilometer during special aerosol events over Athens (forest fire smoke and Saharan dust). We presented two case studies in which we performed a more quantitative analysis of the results. Thus, in order to reduce the ceilometer's profiles noise even more, the averaging time was increased to 3 hours. This was also applied to the lidar measurements for consistency reasons.

According to the reviewer's suggestions we revised our initial plots using the same integration time (3 hours) and lidar ratio (30 sr) for all instruments (see Figures 4a, 4b).

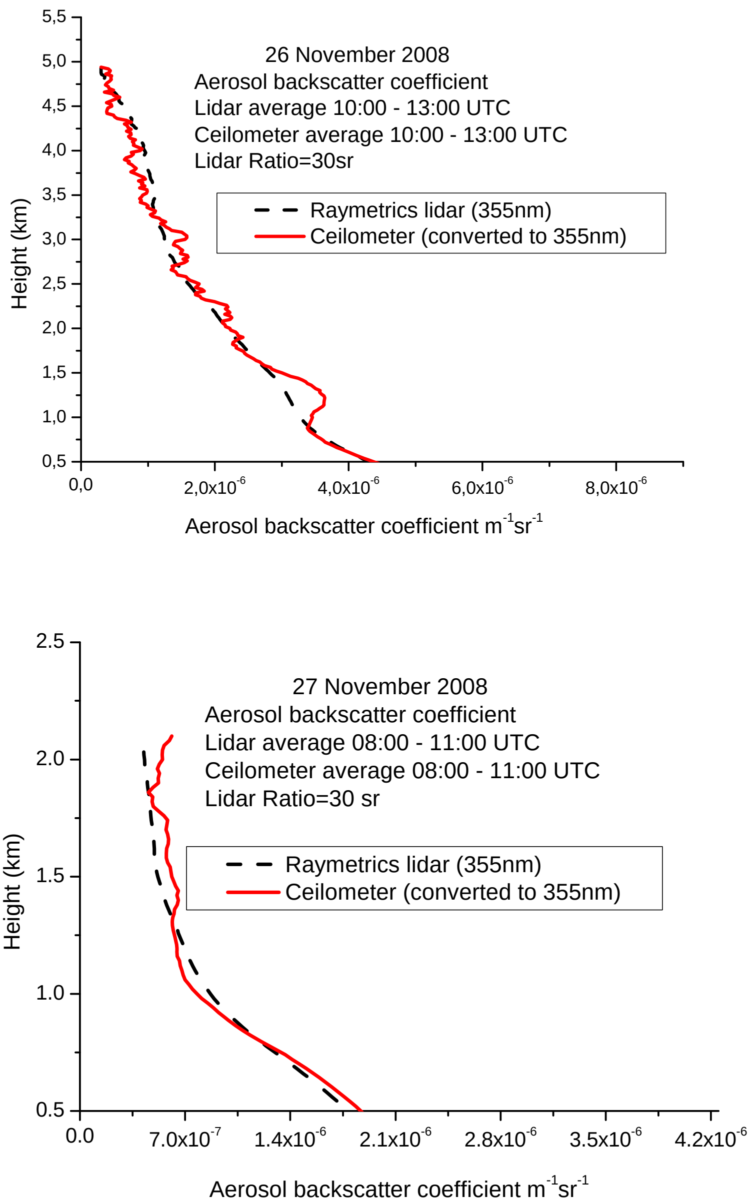


Fig. 4. Comparison of the aerosol backscatter coefficient profiles obtained by the Vaisala ceilometer and the Raymetrics lidar **(a)** on 26 November and **(b)** on 27 November 2008.

Comment 10:

How was the retrieval of the backscatter coefficient from the ceilometer data done? Finding a suitable reference height is difficult from the noisy data. At what altitude was it set? In the Figures no aerosol free height range is shown.

The choice of the reference point for our Klett calculations in the case of the lidar signals was set at 7 km, since the signal to noise ratio (SNR) is still quite high even during daytime (higher than 1, according to SNR calculations based on Heese et al. (2010), for averaging over more than 30 minutes). For the lidar signals in Athens, the lidar returns are first corrected for background light and range. The range-corrected signal return for the molecular atmosphere is then estimated using radiosonde data. The lidar range-corrected signal is then normalized on the molecular return to check for calibration of the system and find the total attenuated backscatter signal. Through this procedure, the aerosol-free tropospheric region is defined as the region where the total attenuated backscatter signal is equal to the molecular attenuated backscatter signal. This region for Athens is usual above 6-7 km. In this work, the pure molecular atmosphere was around 7 km, and this was the reference height assumed for our retrievals.

The ceilometer's retrieval of the aerosol backscatter coefficient is achieved by an automatic algorithm provided by Vaisala. As far as the retrieval of the reference height is concerned, the reference height is given internally in the CL31 software. No further information is provided except the information given in Münkel et al. (2007) and the Vaisala User's Guide (2009).

After the reviewer's comments the following text is added in Section 2.2 of our paper:

"…The choice of the reference height for our Klett-backscatter retrievals in the case of the lidar signals was set at 7 km, since the signal to noise ratio (SNR) is still quite high even during daytime (higher than 1, according to SNR calculations based on Heese et al. (2010), for averaging time over more than 30 minutes). For the lidar signals in Athens, the lidar returns are first corrected for background light and range. The range-corrected signal return for the molecular atmosphere is then estimated using radiosonde data. The lidar range-corrected signal is then normalized on the molecular return to check for calibration and find the total attenuated backscatter signal. Through this procedure, the aerosol-free tropospheric region is defined as the region where the total attenuated backscatter signal is equal to the molecular attenuated backscatter signal. This region for Athens is usual above 6-7 km.

The corresponding average uncertainty on the retrieval of aerosol backscatter coefficient when using the CL31 ceilometer data averaged over 30 min is briefly discussed in Münkel et al. (2007) and is of the order of 20%. As far as the reference height is concerned, it is given internally in the CL31 software. No further information is provided except that given in Münkel et al. (2007) and the Vaisala User's Guide (2009)."

Comment 11:

line 22-25: Why don't the authors also use a 3h-average of the lidar data to be more consistent? For example in the discussion of the discrepancies below 1000m on 26.11.2008. And the developing PBL is also not covered alike in both profiles by the different averaging times.

The referee is right. In our revised plots the time resolution now is the same and is set to 3 hours (see also answer to Comment #9).

Comment 12:

Page 83: line 2: "...from 500m (above the full overlap height)." See overlap discussion above.

See answer to Comment #4.

Comment 13:

Page 83, line 19-22: Please indicate the time steps of the back trajectories in Fig 6.

The time step in our trajectory calculations is equal to 6 hours, and this is now mentioned in the revised version of our manuscript. This is also visible to the air mass back-trajectory plot.

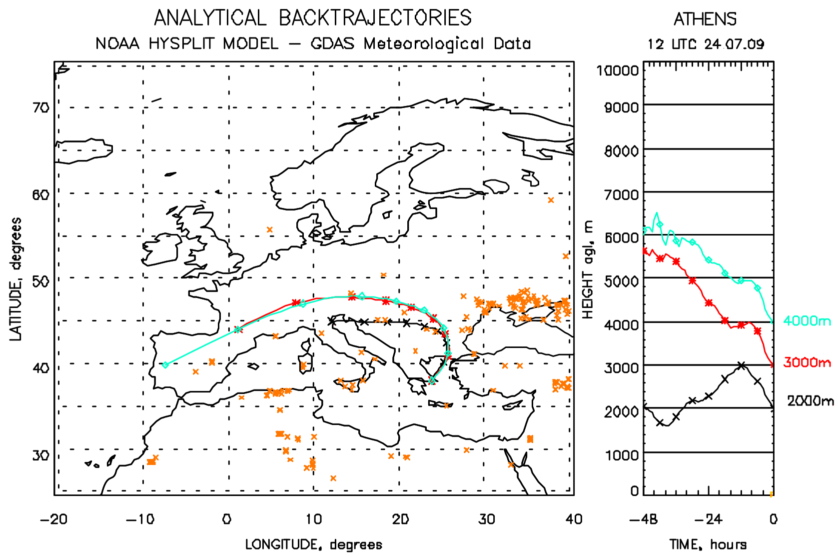


Figure. 6. Back-trajectories of air masses arriving over Athens on 24 July 2009 (12:00 UTC) at various heights (2000 m, 3000 m, 4000 m). The orange points indicate the active hot spots from biomass burning sites.

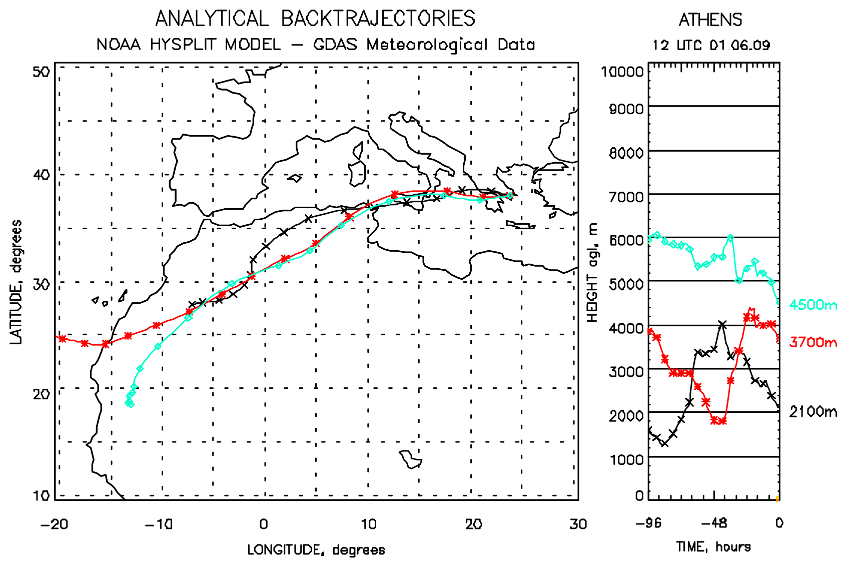


Figure 9. Back-trajectories of air masses arriving over Athens on 1 June 2009 (12:00 UTC) at various heights (2100 m, 3700 m, 4500 m).

Now the time steps are clearly shown in both Figs 6 and 9 fro every 6 hours.

Comment 14:

Page 84, line 1-11: Again, the same average time for both profiles should be used to avoid differences due to time averaging in the profiles. This is especially important in this case, because the dust layer is descending and thus produces a vertically broader layer over a longer averaging time.

The referee is right. In the revised version of our manuscript the Figs. are revised accordingly (see also answer to Comment #9)

Comment 15:

Page 84, line 16: The abbreviation NOA was not yet introduced, see page 74.

NOA stands for "National Observatory of Athens". This information is now included in the revised manuscript.

Comment 16:

Page 84, line 26-27: "...all averages were made around 12:00 UTC)." No, one was 11-13 the other 12-13! This is an additional hour of measurements included in the comparison. See time averaging comments above.

Figure 7 was revised according to the referee's suggestions (07:00-10:00 UTC) as follows:

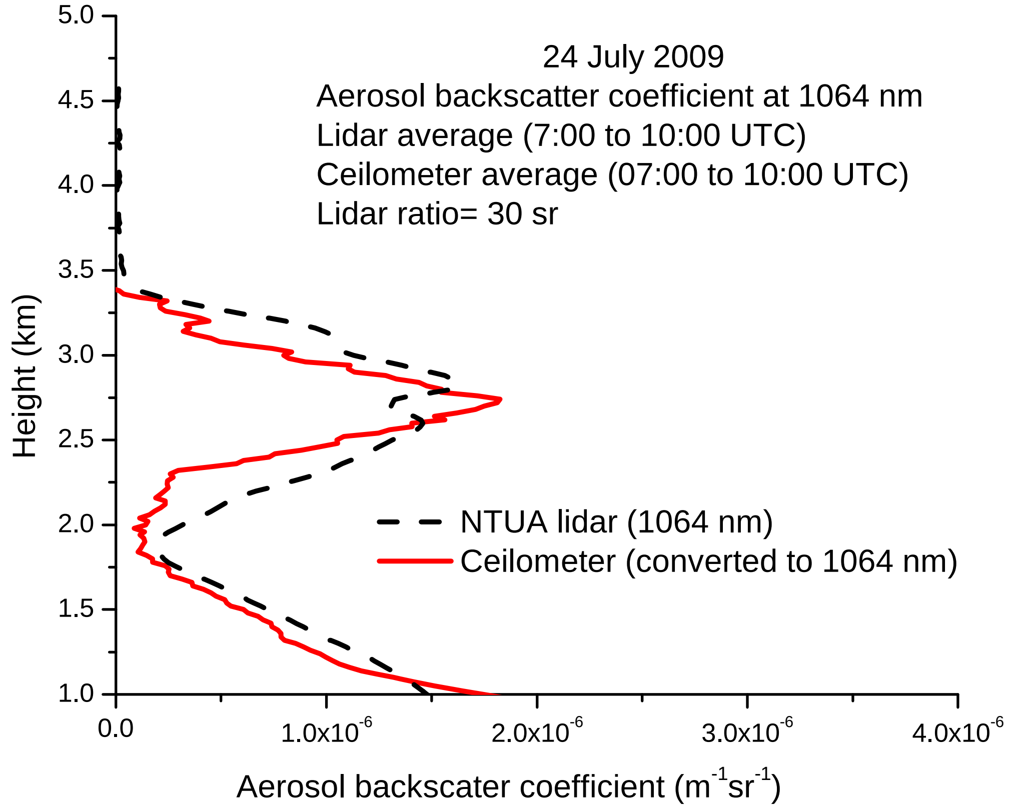


Figure. 7. Average vertical profiles of the aerosol backscatter coefficient obtained by the Vaisala ceilometer and NTUA Raman lidar system (07:00–10:00 UTC) on 24 July 2009.

Comment 17:

The retrieval of the backscatter coefficient profile (Fig 10.) seems doubtful. Negative values as at the heights 3250 - 3750 m are not realistic. See also discussion above.

The referee is right. Following the referee's suggestions we performed new calculations of the aerosol backscatter coefficient (with LR=30 sr) and the profiles in Figure 10 are revised as follows:

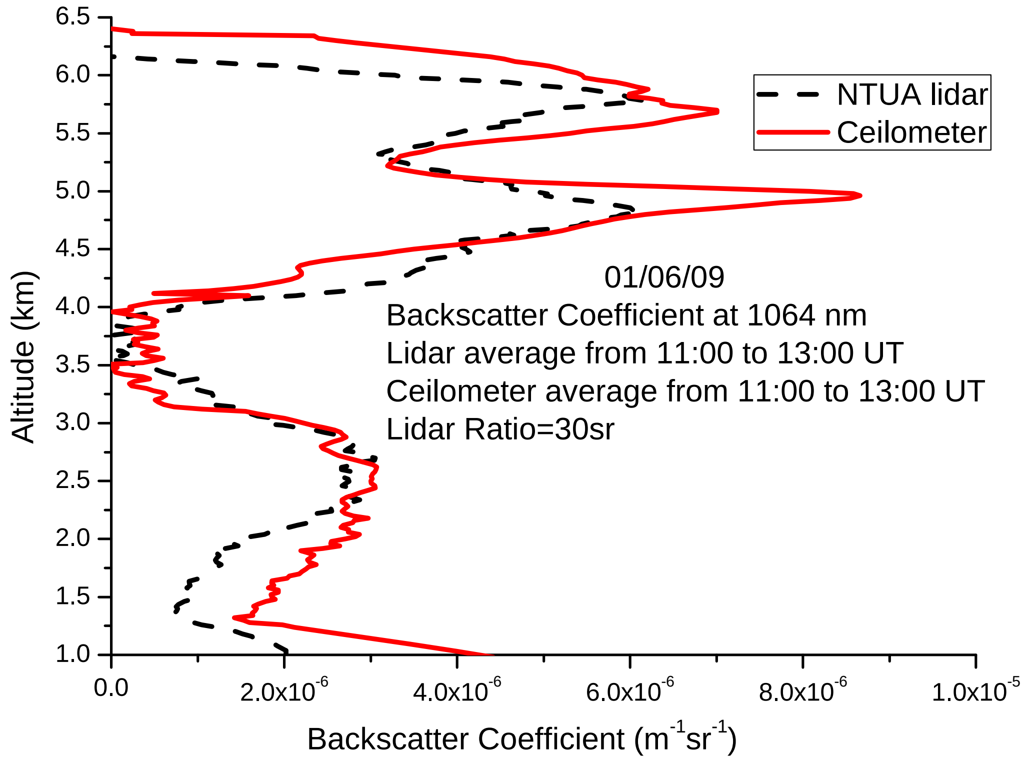


Figure. 10. Average vertical profiles of the aerosol backscatter coefficient obtained by the Vaisala ceilometer (11:00–13:00 UTC) and the NTUA Raman lidar system (11:00–13:00 UTC) on 1 June 2009.

Comment 18:

Page 85, line 24: Why not using the same LR for both profiles? If a LR of 30 sr was used by default for all ceilometer profiles, the comparison of the total values is useless. Why don't the authors use the AOD from the UV-MFR for calibration?

The referee is right. In our revised calculation, now we used the same LR=30sr in all cases. The Angstrom exponent was calculated using the aerosol optical depth (AOD) from multi-filter radiometer (MFR) measurements (see also answer in Comment #6).

The rest of the comments were technical ones and they will be included in the revised version of our manuscript.

References

Joffre, S., Kangas, M., Heikinheimo, M., and Kitaigorodskii, S. A.: Variability of the stable and unstable atmospheric boundary-layer height and its scales over a boreal forest, *Boundary-Layer Meteorol*., 99, 429-450, 2001.

Heese, B., Flentje, H., Althausen, D., Ansmann, A. and Frey, S.: Ceilometer-lidar inter-comparison: backscatter coefficient retrieval and signal-to-noise ratio determination, Atmos. Meas. Tech. Discuss., 3, 3907–3924, 2010.

Hennemuth, B., and Lammert, A.: Determination of the Atmospheric Boundary Layer height from radiosonde and lidar backscatter, *Boundary-Layer Meteorol.*, 120, 181-200, 2006.

Martucci, G., Milroy, C., and O'Dowd, C. D.: Detection of cloud-base height using Jenoptik CHM15K and Vaisala CL31 ceilometers, J. Atmos. Ocean. Tech., 27, 305–318, 2010.

Münkel, C., Eresmaa, N., Räsänen, J., and Karppinen, A.: Retrieval of mixing height and dust concentration with lidar ceilometer, *Boundary-Layer Meteorol.*, 124, 117-128, 2007.

Vaisala User's Guide, Vaisala ceilometer CL31, Vaisala Oyj, Helsinki, Finland, 2009.