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Atmospheric Measurement Techniques Discussions

Interactive comment on "Ceilometer-lidar inter-comparison: backscatter coefficient retrieval and signal-to-noise ratio determination" *by* B. Heese et al.

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We would like to thank Referee #3 for fruitful comments and suggestions. Before we answer in detail to the specific remarks, we would like to answer the general comments.

General comments:

However, some points are not accurately formulated and it is not at all convincing that the conclusions are justified in general. With respect to this problem the authors must either give better evidence or weaken their statements. The former would require discussions of much more cases, the latter would require the re-formulation of the conclu-

sions. I would suggest to go for the second way: this means that the authors clearly state, that they only outline an approach how the potential of ceilometers can be assessed (under favorable condition, e.g. additional infrastructure) and omit any conclusions that could be misunderstood as 'generally applicable'. For a general assessment, two case studies are not sufficient! Furthermore, the proposed procedures cannot be routinely applied. Before publication, these issue must be solved.

Answer: The question of representativeness of this study has also been raised by Referee #2 and we have addressed the point further in the introduction, discussion and in the conclusions. Please refer also to the answers to general remarks of Referee #2 and modified text.

However, we felt that also this issue should also be addressed in the abstract:

new 'Abstract': The potential of a new generation of ceilometer instruments for aerosol monitoring has been studied in the Ceilometer Lidar Comparison (CLiC) study. The ceilometer was developed by Jenoptik, Germany, and is designed to find both thin cirrus clouds at the tropopause and aerosol layers also at close ranges during day and night-time. The comparison study was performed to determine whether the ceilometers are capable to deliver quality assured particle backscatter coefficient profiles. For this, the derived ceilometer profiles were compared to simultaneously measured lidar profiles at the same wavelength. The lidar used for this comparison was the multi-wavelengths Raman lidar PollyXT. Two examples of the comparison results are shown to demonstrate the capabilities and limits of ceilometers for the derivation of particle backscatter profiles from their measurements. One daytime case with high background noise and one less noisy night-time case are chosen for this. Both profiles compare well with the lidar profiles in atmospheric structures like aerosol layers or the boundary layer top height. However, the determination of the correct magnitude of the particle backscatter coefficient profile needs a calibration of the ceilometer data by an independent measurement of the aerosol optical depth by a sun photometer. A comprehensive signal-to-noise ratio study characterizes the ceilometers signal performance with in-

creasing altitude. During daytime the SNR can be above 1 up to 4-5 km depending on the aerosol and during night-time even up to 8.5 km. This means that also aerosol layers in the upper troposphere can be detected by a ceilometer.

Answers to further comments:

Page 3908, line 14: The number of 150 m for complete overlap seems to me unrealistic. Can the authors give evidence to this (one of the authors is from Jenoptics).

Answer: The overlap function for the new CHX instrument is indeed complete at 150m. Please refer also to http://www.isars2010.uvsq.fr/images/stories/PosterExtAbstracts/P_BLS12_Frey.pdf where a plot of the overlap function of both instruments is included.

Page 3909, line 24: 'being setting up' ! 'set up' ?

Answer: corrected to "is setting up"

Page 3908, line 26: modify to 'a narrow'

Answer: The laser has a line width of 0.38 nm, see section Instruments. However, this sentence has been taken out of the Abstract, see above.

Page 3909: It is not very clear (whole paper), whether the discussed comparisons were provided in EARLI09 or separately, and if the 'ceilometer' is the CHM15k or CHM15k-X. Please give details to help the reader.

Answer: The data used for night-time example were only taken during EARLI09, but the comparison is not part of the official EARLI09 comparison procedure. See also answer to p. 3910 ln. 6.

For clarification of the used ceilometer type, CHM or CHX is now indicated in the legend of all plots and a paragraph was modified in the "instrument" section for better understanding:

new text: The instrument type CHM15k (CHM) is the standard instrument with a complete overlap at about 1500 m and a measurement range of 15 km. A new version of the instrument, the CHM15k-X (CHX) has a 4-times wider field-of-view and improved optics facilitating a complete overlap at 150 m

Page 3909, line 14: 'quantitatively detect': the meaning how the authors use 'detect' (throughout the paper) is not clear to me: 'detection' could be a yes/no answer, whereas 'quantitatively' should be associated to physical quantities, e.g. backscatter coefficient.

Answer: "Detection" has been replaced by "measure" or "determine" the particle backscatter coefficient in several occasions.

Page 3909, line 26: Give a reference to EARLI09 if available.

Answer: The following reference was added: Freudenthaler, V., S. Gross, R. Engelmann, I. Mattis, U. Wandinger, G. Pappalardo, A. Amodeo, A. Giunta, G. D'Amico, A. Chaikovsky, F. Osipenko, A. Slesar, D. Nicolae, L. Belegante, C. Talianu, I. Serikov, H. Linne, F. Jansen, K. Wilson, M. de Graaf, A. Apituley, T. Trickl, H. Giehl, M. Adam (2010): EARLI09 - direct intercomparison of eleven EARLINET lidar systems Proceedings of the 25th International Laser Radar Conference, 5-9 July 2010, St.-Petersburg, Russia, 891-894

Page 3910, line 2: It is not clear whether the comparison described in the paper is a EARLI09- activity or just a IfT/DWD-activity. If the former is correct the comparison must be done with respect to an EARLINET- or EARLI09-standard, and this standard must be explained.

Answer: see answer to page 3909 above

Page 3910, line 9: CLIC is not explained, only mentioned in the abstract.

new text in introduction p. 3910 line 3 This was done in the frame of the ceilometer lidar comparison (CLIC) study.

Page 3911, line 1: 84 μJ: is this true? decimal point missing!?

Answer: Yes, corrected

Page 3911, line 18: 'several thousands': It seems to me that the total number is 2880 data sets per day; so 'several' only means 3.

Answer: 'Several thousands' was replaced by 2880.

Page 3911, line 21: 'at least 150 m': this is an even stronger statement than before, suggesting that the overlap begins at 100m or so. I don't believe this, give evidence!

Answer: In this case it begins indeed at 120m, see also answer to Page 3908, line 14 above.

Page 3912, line 11: 'exacerbates': I would rather say 'makes it impossible'.

Answer: It is not impossible but difficult. The ceilometer profile in Figure 2 shows, that a reference height could be found above 5 km that leads to the right profile (as the comparison with the lidar profiles shows).

new text: ... makes this calibration difficult.

Page 3912, line 13: It is surprising that first 25/05/2009 is selected as an example to show the potential of the ceilometer (Fig.1), and then it is switched to another date (Fig.2). What is the reason?

Answer: Figure 1 shows an overview of the data one of the two examples shown in this paper. We could also have chosen the other day without changing the message.

Page 3911, line 16: The authors never mention the fact, that AOD-measurements by a sun photometer are only possible during day-time, under cloud-free conditions and that a stable aerosol stratification is required for the time period between photometer- and ceilometer-measurements. This is not acceptable.

Answer: Yes, we have added a paragraph in the data evaluation chapter to clarify the

use of the AOD measurements. Adjustments have also been added to the discussion chapters and in the Figure captions. See also answers to Referee #2.

new text: In chapter "Data evaluation" This sun photometer measures the radiance at eight channels ranging from 340 nm to 1640 nm. For the comparison with the lidars' and the ceilometers' AOD the AERONET level 2.0 data of all channels were interpolated and the value at 1064 nm was used. During night-time no AOD measurements from a sun photometer are available. In this case the measurements from the evening before or the morning after have to be used and extrapolated to the ceilometer measurement time. If both measurements are available, the AOD can also be interpolated to achieve a reasonable value during night-time.

new text in discussion: The AOD measured by the sun photometer in the evening during the last hour before sunset when no cirrus war present was 0.115.

Page 3912, line 18: 'at Leipzig' can be omitted (already stated 'at IfT')

Answer: Right!

new text: The AOD is measured by the Aerosol Robotic Network (AERONET) sun photometer at IfT.

Page 3912, line 19/20: Genitive-apostrophes are missing.

Answer: Corrected to lidars' and ceilometers'

Page 3913, line 1: 'extrapolated as constant and' can be omitted.

Answer: corrected

Page 3913, line 4: It seems that the errors are indeed 'estimates', just numbers that sound familiar. In this case, 50% seems too pessimistic; what kind of boundary layer should produce such a large error? Why have the profiles an overlap of 1000 m in this example; it should be either 150m or 1500m according to previous statements.

Answer: Not the boundary layer produces the error, but the incomplete overlap of the ceilometer and lidar, and the resulting extrapolation to the ground. The overlap is not at 1000 m. This is the height where the value for the extrapolation was chosen and gave reasonable results. See also answer p 3913, lines 2-5: to Referee #1 and new text there.

Page 3913, line 5: BLT is not defined.

Answer: corrected to: boundary layer top

Page 3913, line 10: What is 'ceilonet'?

Answer: The DWD ceilometer network, corrected

Page 3914, line 1-6: Is this relevant for this paper? Answer: This paragraph gives an overview over the sources that can be used to identify aerosol layers like these ones at upper altitudes, which origin is unclear. We would like to leave the paragraph in the paper.

Page 3914, line 9-11: I don't understand the numbers given (0.18/0.17/0.15); they are in contradiction to Fig.2. And I don't come up with errors of 11/12%, if I use the given numbers.

Answer: Yes, the numbers in the plot were indeed from another case and were mixed in here by accident. To be on the safe side, I calculated all profiles and resulting AODs again and came up with the numbers in the text.

modified text and new Figure 2:

On 1 May 2009 the AOD derived from the ceilometer profile is 0.180 and the one from the lidar profile was calculated to 0.168. The independent measurement of the AOD by IfTs sun photometer interpolated to 1064 nm over the same time period yields a value of 0.140. These are differences in the order of 20%, which may be explained by the distance between the measurement sites as well as to the extrapolation of the

extinction profile to the ground with a constant value. Differences in this range were to be expected considering the different measurement sites. However, the shape of the particle backscatter profiles from both instruments compare quite well.

Page 3914, line 17: 'was calculated from the ratio...'. This procedure must be explained in more detail. It must be clear, whether the agreement between the green and blue curves is a inherent consequence of this procedure or an independent criterion for quality assurance. If the former is true, then it is not an 'agreement'!

Answer: Here, we compare the backscatter profiles derived by the Raman and the Fernald-Klett method. The Raman Method is a well established lidar retrieval method and is described in the reference Ansmann (1992). See also answer to p 3912, lines 1-4 of Referee #1.

But indeed, not the signal is shown in the figure but the backscatter profile:

new text: The resulting backscatter profile is shown in green in Fig.3.

Page 3914, line 23-27: What is the relevance of this statement? Under normal conditions lidar measurements of a cirrus for calibration are not available. So, this method cannot be used operationally.

Answer: No, it is just a further proof of the correctly retrieved lidar profile that is used in the comparison. See also answer to p 3914, lines 24-28 of Referee #1.

Page 3915, line 13: How is the AOD derived from sun-photometer data during nighttime. This is impossible (see one of my previous comments).

Answer: See my answers above to Page 3911, line 16, and refer to my answers to Referee #2. (p. 3915 ln. 10 and Fig. 3)

Page 3915, line 22: 'wanted and unwanted': maybe better wording possible.

new text: It is the ratio of the incoming signal to the amount of interfering noise.

Page 3916, line 6: If 'all' equations are given, one should add delta P = square-root(P) as well.

Answer: We prefer to not include this one since it is indicated by mentioning Gauß' error propagation law.

Page 3916, line 8: typo: 'square-root'.

Answer: corrected

Page 3916, line 16: 'receiver power' sounds a little bit weird.

Answer: corrected to: Due to the higher laser power and receiver efficiency.

Page 3917, line 1-2 and 3917/14: This statement is too general. It certainly depends also on the optical depth of the boundary layer.

Answer: In the boundary layer the SNR is always above 1. Here we mean the SNR at higher altitudes where it is above 1 as soon as aerosol is present.

Page 3917, line 5: The SNR does not 'increases again' as can be clearly seen from the figure. The text was indeed misleading here and has been changed.

new text: Here, the SNR is greater than 2 up to 6.5 km, which is the dust layer top. Above this height the SNR decreases slowly and stays above 1 up 8.5 km, even for a 30 min mean profile. In the range of the cirrus cloud where the signal gets rapidly higher the SNR is increasing again above 1.

Page 3917, line 6-10: 'Thus, although...': I don't understand this sentence. What is the message?

Answer: Although the lower noise of the ceilometer signal implied a better SNR at higher altitudes during night-time, the SNR calculations shows that it is only better 1 up to 8.5 km.

Page 3917, line 22: 'Here, also...'. This is a severe problem, that deserved more than

one short sentence.

Answer: The choice of the right lidar ratio is a general problem when using the Fernald-Klett method and not specific to the ceilometer data retrieval. For this comparison study the same lidar ratio was chosen for all instruments and is not subject to this paper. With this sentence we just wanted to remind the reader that the lidar ratio of course has to be kept in mind when deriving particle backscatter coefficient profiles from ceilometer data. To emphasize this problem we added a new small paragraph to the "Conclusions".

new and corrected text:

Another uncertainty of deriving the backscatter coefficient profile from ceilometer data is the unknown lidar ratio that has to be assumed for the respective aerosol type. The choice of the right lidar ratio is indeed a problem that is affecting the ceilometer measurements as long as the instruments do stand alone. A network of ceilometers for the determination of the aerosol distribution over an area like Germany would need at least a few anchor stations with AOD measurements from sun photometers. At these stations also a lidar would be helpful to determine the correct lidar ratio and thus the particle backscatter coefficient. With the measurements from these anchor stations also a scaling of all ceilometer profiles of the network would be possible and thus contribute to the spatial aerosol monitoring over Germany or even Europe.

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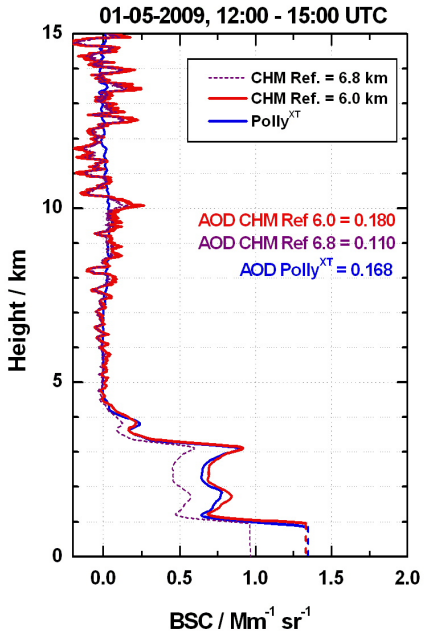

Fig. 1. is Fig. 2 of the original paper: Daytime particle backscatter coefficient profiles derived from the CHM ceilometer data from DWD in Holzhausen (in red) and lidar data (in blue). ...