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Atmospheric Measurement Techniques Discussions

Interactive comment on "Validation of CALIPSO space-borne-derived aerosol vertical structures using a ground-based lidar in Athens, Greece" *by* R. E. Mamouri et al.

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We would like to thank the anonymous referee for his constructive and helpful comments/suggestions on our paper. Referee comments (italics) and authors' replies are presented below.

-The authors state they are validating CALIOP aerosol retrievals, even though they are comparing with Level 1 profiles, which are calibrated, range-corrected signals. The authors use the term "aerosol attenuated backscatter coefficient" in at least one place. There is no such thing. The "attenuated backscatter coefficient" is the calibrated, range-corrected backscatter signal and there is no separation of contributions from

aerosol or other scatterers. The authors need to clarify what they are validating. The objectives are not stated very clearly.

The term "aerosol attenuated backscatter coefficient" has been corrected to "attenuated backscatter coefficient" in the text. The attenuated backscatter coefficients examined in our paper are mainly representing the aerosol contribution to the atmospheric vertical structure. Since lower clouds are not a subject in our study, the only scatterers that contribute at 532nm attenuated backscatter profiles are the atmospheric molecules. Since the molecular atmosphere is not likely to experience large differences between the attenuated backscatter profiles examined, the discrepancies found are mainly attributed to the aerosol inhomogeneity. However, the reviewer is right, and even if the attenuated backscatter coefficients examined are mainly representative of the aerosol vertical structure, the correct term is "attenuated backscatter coefficient". The term was additionally corrected in the new title of our paper ("Validation of CALIPSO space-borne-derived attenuated backscatter coefficient profiles using a ground-based lidar in Athens, Greece")

-Page 562, line 24 - should be NASA/CNES, not NASA/CNRS

Corrected in the final version of the manuscript

-Discussion of IIR, WFC, and CALIOP Level 2 data products in Section 2.2 seems to be unnecessary detail and should be removed as they are not relevant to the comparisons being presented here.

Following reviewer's suggestion, the description of IIR, WFC has been removed

One of the references in Section 2.2 (Hostetler et al., 2006) is project document which is only available on-line. A better reference on the A-train would be Stephens et al. (2003) and a better reference on the CALIOP instrument would be Winker et al. (2007) or Hunt et al. (2009).

The references suggested by the reviewer have been added in the text.

-Section 2.3 should provide a clearer description of what is actually being validated. The approach adopted is to convert an upward-looking lidar backscatter profile to an effective downward-looking backscatter profile by correcting for the attenuation profile. The authors are essentially validating the calibration and linearity of CALIOP, though this is not clearly stated anywhere.

Section 2.3 has been rewritten so our validation approach would be better presented.

-Because of spatial separation of the day and night orbit tracks from the ground-based system (80 km and 16 km, respectively), errors due to spatial mismatch of the measurements will be much larger within the mixed layer than in the free troposphere. This is evident in Figure 4. Results should be presented separately for comparisons of signals in the free troposphere and within the mixed layer.

An attempt to present our results separately in the free troposphere and within the mixed layer is already made in Figure 8 (in terms of mean difference values bellow and above 3km). The mixing layer height has not been processed/calculated for each day separately. However, the reader has the opportunity to observe the differences in high and low altitudes in Figures 5, 6 and 7 where complete atmospheric profiles are presented. In our opinion, lidar profiles and corresponding differences have to be presented in the current form. In the new version of our paper, we completely attribute differences within the mixed layer to spatial mismatch of the measurements, and we fully agree with the reviewer on that.

-In any validation comparison, uncertainties in the reference measurements should be discussed quantitatively. In this case, the authors mention uncertainties in the ground-based lidar profiles being compared with CALIOP due to incomplete near-range overlap, due to applying lidar ratios measured at night to daytime observations, and to spatial matching errors, and errors in calibration of the ground-based system itself. None of these errors are quantified. The authors mention that ground-based profiles below 1-1.5 km are affected by incomplete lidar overlap. If this is a concern, com-

parisons should be performed only above this altitude to avoid potential biases in the ground-based profiles. The ground-based lidar is calibrated using returns from the 7-9 km altitude region, which is quite low. The calibration procedure used, assumptions, and uncertainties of the procedure should be described. Given the uncertainties involved, the authors should add a short statement to the effect that nighttime comparisons above the boundary are most reliable, that comparisons within the boundary layer are more uncertain than comparisons above the boundary layer, and that daytime comparisons are less reliable than nighttime.

Systematic errors on ground-based retrieved aerosol backscatter with elastic Raman techniques are almost negligible, and however lower than 1%. Further details are reported in related references (Ansmann et al, 1992; Ferrare et al., 1998). Regarding the transmittance, the error resulting from extinction coefficient error is negligible. The statistical error of the NTUA's lidar is lower than 10% and the systematic error lower than 3%. Within the framework of EARLINET, several hardware and algorithm intercomparisons were performed, so the systems would be compatible with each other and the products (+errors) would be consistent with EARLINET prototype systems and algorithms. References for these intercomparisons are given in the text. However, in our final version of the paper, a paragraph in regard to the uncertainties of the ground-based system and further related references were added. Specifically for the overlap of the ground-based system, information has been added in Sec. 2.1. For NTUA lidar, overlap corrections are applied and only altitudes with overlap factor greater than 0.5 are used for the analysis. For these altitudes the overlap correction is considered safe. These corrections were tested for our lidar during lidar hardware intercomparisons taken place within EARLINET (Matthias et al., 2004). However, to remove overlap uncertainties from our validation in this paper, all heights bellow 1000 m were excluded from our figures, results and conclusions. Considering the calibration of the signal in the 7-9 km altitude region, we have tested our retrievals during lidar intercomparison campaigns taken place within EARLINET. Prototype systems were calibrating in higher altitudes, but the final intercomparison of our signals was satisfactory. Unfortunately at the moment errors on the CALIPSO attenuated backscatter are not available, therefore a complete discussion comparing observed differences and errors affecting data of both instruments is not possible.

-The primary results are presented in terms of mean bias, though this quantity is never defined precisely. To avoid ambiguity, the equation used to compute mean bias should be given.

The equation used for the calculation of mean bias has been given in the new version of our paper. In this equation, we use CALIPSO values as a reference, so our results would not been normalized in respect to our system. Following this approach, our results would be comparable with validation results of future studies, if the same methodology will be followed.

-CALIOP experiences significant multiple scattering effects in cirrus which result in an attenuation which is much less than that measured by a ground-based lidar. I suspect the large biases in comparisons of aerosol signals underneath cirrus noted by the authors in Section 3 are due to difficulties in their method of properly accounting for the cirrus attenuation experienced by CALIOP. There is no reason that CALIOP calibration would be worse when cirrus is in the column than in clear sky. It seems it would be more appropriate to be comparing retrieved aerosol backscatter and extinction under cirrus, than raw signals.

In the new version of our paper, we attribute the large biases underneath cirrus to the attenuation correction in CALIPSO signal which cannot be accurate due to multiple scattering effects in cirrus clouds. In our study we cannot account for this effect and so, the biases are more likely to be attributed on that as the reviewer mentions. However, we are not comparing retrieved aerosol backscatter and extinction in this paper, since, in that case, the discussion would be shifted to the lidar ratio assumption made by CALIPSO algorithm. This is a completely different study and will follow in a future work.

-There is an incorrect statement on page 572, line 25. Both daytime and nighttime profiles are calibrated but cirrus backscatter is not used for calibration of 532 nm signals, only for 1064 nm data.

The sentence has been removed according to the reviewer's suggestion.

-The conclusion that "CALIPSO profiles are possibly unreliable for the representation of boundary layer vertical aerosol structures" seems like an unwarranted, overly general statement given the lack of analysis of errors in the comparison procedure used here. Meaningful comparisons of "vertical aerosol structures" are dependent on good spatial matching of the two datasets, which is a major weakness of the study presented here.

To investigate CALIPSO performance within the mixed layer into detail, our data had to be retrieved closer to CALIPSO ground track and reviewer is right about the spatial matching of the two datasets which becomes very critical when we study aerosol within the mixed layer. This point will be addressed in future work of the full EARLINET network. However, within the mixed layer we found some differences case by case, but on average we did aspect a mean difference close to zero with a large standard deviation. This is not the case and we investigated this point and found out a reasonable explanation based on the locations of the ground-based lidar and of the CALIPSO ground track. For this reason, we decided to include the mixed layer comparisons and the related discussion in this paper, fully attributing however the discrepancies on strong aerosol inhomogeneities due to the distance between the instruments in the new version of our paper.

-The final paragraph of Section 3 states that the mean biases do not seem to depend on the horizontal difference between the two instruments. Visually subtracting a few outliers in Figure 8, it appears to me there biases do increase with horizontal separation. A quantitative statistical analysis of the dependence would be preferable to a qualitative statement.

Authors believe that a quantitative statistical analysis would be possible if more coincident measurements would be available. In our opinion, Figure 8 demonstrates that in regard to the differences, the distance between the instruments becomes more significant for the mixed layer. However, no relation of the mean difference is observed in that case, and this is reasonable since the aerosol inhomogeneity (and not the distance) is the reason for the discrepancies. The reviewer is right maybe in the case of the biases observed in the free troposphere, where if one excludes some outliers, it appears that biases do increase with the distance. However, our dataset is currently limited and, thus we believe that Figure 8 does not give strong indications for further conclusions.

-In Section 4, the authors state that discrepancies in the boundary are due in part to "decrease of the CALIOP signal-to-noise ratio in the boundary layer." This statement is never explained and seems counter-intuitive. Signal variability is driven by signal noise and also by atmospheric variability. An increase in variability of the profile in the boundary layer is likely due to an increase in aerosol inhomogeneity, while the SNR is probably improved in the boundary layer.

The text has been corrected according to reviewer's suggestion.

-A very large effort has been made by the European lidar community to acquire data for comparisons with CALIOP. To make best use of this dataset, refinements in the comparison technique are necessary and uncertainties in the conversion of groundbased up-looking profiles to equivalent down-looking profiles must be better understood and quantified.

The authors agree with the referee. EARLINET is currently performing coincident CALIPSO measurements in a number of lidar stations and the approach presented here has been adapted by other stations, as well for the validation of Level 1 CALIPSO attenuated backscatter coefficient profiles. The so-called "CALIPSO-like attenuated backscatter coefficient" and the validation approach/methodology used in this study and in the recently submitted paper of Mona et al., (2009), will be further quantified in a common EARLINET paper that will follow.

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