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Atmospheric Measurement Techniques Discussions

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Interactive Comment

Interactive comment on "Study of aerosol microphysical properties profiles retrieved from ground-based remote sensing and aircraft in-situ measurements during a Saharan dust event" *by* M. J. Granados-Mu noz et al.

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The authors would like to thank both reviewers for their thoughtful and helpful comments and suggestions. Their reviews have made a significant contribution to the improvement of the paper. The line numbering in the reviewers' comments refers to the manuscript published in AMTD whereas the line numbering in the responses refers to the new version of the manuscript.

Comment: The manuscript "Study of aerosol microphysical properties profiles retrieved from ground-based remote sensing and aircraft in-situ measurements during a Saharan dust event" of Granados-Munoz et al. deals with the interesting topic of dust observations with multiple techniques. This is an interesting study, including a promising comparison of remote-sensing and in-situ depolarization measurements. However, several aspect of the manuscript need to be changed and improved before it is appropriate for publication in Atmospheric Measurement Techniques. Find below some general and some detailed comments.

Overall comments: * Define the scope of the paper: The manuscript sets several goals and, naturally, cannot reach all of them. The title and abstract suggest that this work is about the study of an interesting dust case (a topic more suitable for ACP, rather than AMT). The introduction suggests that the focus is on evaluating the LIRIC algorithm, or in any case on microphysical properties profiles. The conclusions stress the use of both columnar and profiling measurements. The same confusion propagates also in the presentation of the results. For example, it is not clear what is the usefulness of the Linear Estimation technique in the present form. On its own it is an interesting analysis, but why do you present it here? You should define a consistent scope for your publication and explain how all parts contribute towards that goal.

Answer: We agree with the reviewer that the manuscript was confusing at this respect. The manuscript has been modified to address the reviewer's concerns and to clarify the objectives of the study. The main focus of the paper, as now highlighted throughout the manuscript, and reflected in a slight change in the title, is to evaluate the potential of the synergy between different remote sensing techniques to retrieve the evolution of microphysical properties of a mineral dust event during day and nighttime at different levels. That evaluation includes a comparison of independent data obtained from aircraft measurements with both LIRIC volume concentration profiles and the depolarization ratio retrieved with the lidar, which is presented here for the first time. Additional subsections have been also added so that the manuscript is clearer, especially in the results section. The specific usefulness of the Linear Estimation technique in our study

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is the retrieval of the column-integrated microphysical properties from the star photometer measurements, which are not possible with other retrieval algorithms.

Comment: * Improve the comparison between different remote-sensing techniques: Assuming that your aim is to evaluate different retrieval approaches, what is missing is their actual detailed comparison. For example, how do LIRIC backscatter coefficient profiles compare to those derived by Klett-Fernald approach? How do the depolarization parameters assumed in LIRIC compare with the ones measured with the lidar?

Answer: The comparison of the optical properties and the depolarization retrieved with LIRIC and those obtained by the Klett-Fernald approach it is out of the scope of this paper since it has already been done elsewhere (see Granados-Muñoz et al., 2013 and Wagner et al., 2013) and would not be a significant scientific contribution of the manuscript. Additionally, the focus in this study is on the microphysical properties, as we tried to make clear in the new version of the manuscript. The use of the optical properties in some sections of the manuscript is only intended to contextualize the mineral dust event and to provide enough background to be able to properly discuss and evaluate the microphysical properties. Detailed analysis of the optical properties during this campaign can be found in Bravo-Aranda et al., 2015. The depolarization information used in LIRIC comes mainly from the AERONET sphericity parameter and comparison with the lidar profile is not a straightforward.

Comment: How does the refractive index derived using the regularization technique compare with those retrieved by AERONET or the linear estimation technique?

Answer: The refractive index obtained with the Linear Estimation technique was not included in this study. A simultaneous comparison of the refractive index from the regularization technique and AERONET is not possible because there were no simultaneous measurements. The regularization technique was applied between 00:00 and 01:00 whereas AERONET data were retrieved during daytime. However, comparing the closest in time AERONET values with the average value obtained from the regular-

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ization technique we can see a difference of 0.1 (1.55 for the regularization technique and 1.45 for AERONET). Lower values observed by the sun-photometer are related to a considerable presence of fine particles below 2 km, which is not observed by the lidar because of the incomplete overlap. The presence of these fine particles is clear when comparing the lidar profiles with the column-integrated values. The following information has been included in the manuscript (Lines 464-472) :

“The low column-integrated values of reff obtained with the LE algorithm in Figure 2 together with the AERONET distribution suggest an important contribution of fine particles in the region below 2 km a.s.l. during the analysed period, not observed by the lidar because of the incomplete overlap. This contribution of fine particles also explains the difference in the real part of the refractive index between the closest in time AERONET retrieval, which was 1.45, and the value obtained with the regularization technique (1.55). The limitations of the APS to measure fine mode particles at the surface do not allow to confirm this, but in-situ measurements presented by Bravo-Aranda et al. (2015) also pointed in this direction.”

Comment: How does the extinction to-volume ratios used in LIRIC compare with the ones derived with the regularization techniques How does the mean effective radius derived by the regularization technique compares with the columnar values derived using Linear Estimation? Such comparisons will improve confidence to the results and will help clarify the underlying reasons for any discrepancies.

Answer: See previous responses.

Comment: * Improve the comparison with aircraft measurements: There are several open issues with the aircraft comparison. Most importunately, lidar and CAS-POL seem to measure different depolarization quantities! In lidar studies depolarization is typically defined as “perpendicular” / “parallel” signals, while CAS-POL uses “perpendicular” / “total” signals. If this is correct, you will need to revise the manuscript and add detailed discussion on how these quantities are related, and in what extend you

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can compare them.

Answer: The reviewer is correct that the “perpendicular” to “Total” was originally used. This has been corrected by recalculating just the “perpendicular” to “parallel” ratio for the CAS-POL as is done by the lidar community. As a result, the CAS-POL polarization ratios are now larger. The differences between the polarization ratio derived from the lidar measurements and the CAS-POL are not a result of either the difference in collection angle or how the polarization ratios are defined. The differences in actual magnitude are due to the lack of calibration of the CAS-POL polarization signals. In the initial paper, we did not emphasize strongly enough that we are not expecting to see a quantitative agreement but are seeking to compare, for the very first time, an in situ measurement of depolarization ratio with that measured remotely. In addition, given that dust layers are not homogeneous vertically or horizontally, the agreement between the general shapes of the vertical profiles is remarkably good. What we have now added in the summary is that the results of these comparisons show that airborne in situ measurements can be of great value for validating those from remote sensors. We encourage future such studies, but a reduction on the uncertainties associated to the different techniques is still needed.

Comment: Additional, as you explain in detail, there are differences in depolarization because of the different measurement angles. Your estimation of the errors is however only qualitative. It seems to me that you could actually do a quantitative calculation, as you have retrieved dust micro-physical properties and have a spheroid scattering model already implemented. What you are presenting here is a unique and valuable dataset, and it is worth to carry the analysis in detail.

Answer: Given the lack of reference particles to calibrate the perpendicular and parallel channels, we illustrate the expected variation due to particle shape and orientation with laboratory measurements of various types of spherical and non-spherical particles made with a CAS-POL. In addition, we refer to the study by Volten et al. (2001) who measured the scattering matrix components of various dust types in the laboratory and

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showed the large variation due to the varying orientations of these particles.

Detailed comments: âĂŤâĂŤâĂŤâĂŤâĂŤâĂŤâĂŤâĂŤ– p. 9293 l.2: Should be "non-spherical models" instead of "non-spherical particles"

Answer: Done

Comment: p. 9293 l.22: You are implying that you can apply this LIRIC algorithm to micropulse lidars. Please provide evidence or rephrase. Also, in Pappalrado et al. 2014, it seems that most EARLINET instruments are anyway multi wavelength Raman lidars, so I don't see how this is a benefit of the LIRIC approach. Answer: This part has been rewritten (Line 44-50): "Even though multiwavelength lidar measurements are required at least in three wavelengths, the widespread use of multiwavelength elastic backscattered lidar systems in networks such as EARLINET (European Aerosol Research Lidar Network, Pappalardo et al., 2014) and LALINET (Latin American Lidar Network, Guerrero-Rascado et al., 2014) provides enough global coverage. The availability of collocated simultaneous AERONET measurements in most of these lidar stations widely expands the applicability of LIRIC."

Comment: p. 9295 ll. 20: You need to specify the methods used to retrieve aerosol optical properties, together with all used assumptions / parameters for this specific case.

Answer: The following sentences have been included in lines 107-114: "The aerosol optical properties profiles presented in this study were obtained by means of the Klett-Fernald (Fernald et al., 1972; Fernald, 1984; Klett, 1981) algorithm during daytime and using the Raman (Ansmann et al., 1990) technique at night. The depolarization profiles were retrieved according to the methodology described in Bravo-Aranda et al., 2013 and Freudentaler et al., 2009. More details on the retrieval of the aerosol optical properties profiles from the lidar data presented in this study can be found in Bravo-Aranda et al., 2015."

Comment: p. 9295 ll. 20-23: Provide a reference for these uncertainties. Also specify if these refer to statistical uncertainties due to expected signal-to-noise ratio or consider the assumptions of the retrieval algorithm.

Answer: Text has been modified (Line 114-118): "The estimated uncertainties associated with the lidar signals are between ±15% and 20% for the aerosol particle backscatter coefficient, βaerλ, and ±20% for the aerosol particle extinction coefficient, αaerλ. These estimates are based on the statistical uncertainties retrieved with Monte Carlo techniques according to Pappalardo et al. (2004) and Guerrero-Rascado et al. (2008)."

Comment: p.9297 Sec 2.3: The length and content of this section is very unbalanced compared to ground based instruments (Sec. 2.2). This is your validation instrument, it should be described in more detail. You should move at least part of the Appendix here. Discussing the uncertainties of CAS-POL is a core part of the paper.

Answer: We have now moved the part of the appendix that describes the inherent measurement uncertainties and limitations to the main body, accompanying a very brief description of the measurement technique.

Comment: p. 9299 l. 1-3: You only describe uncertainties due to AERONET volume concentration. Lidar data don't have any impact in the final result? Please discuss.

Answer: A detailed analysis on LIRIC output uncertainties due to the uncertainty in the input data, although clearly needed, awaits further evaluation by the code developers. LIRIC is not an open code and a detailed analysis of the uncertainties would require modifications that are not possible for the users community. A simplistic estimation for our specific dust event was performed here in order to better asses the discrepancies between LIRIC and the aircraft retrieved profiles, considering the uncertainties associated to AERONET input parameters. However, since the use of the lidar signals in LIRIC is mainly restricted to the vertical distribution of the microphysical properties, whereas the magnitude of the values is driven by AERONET input data, it is expected

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that the uncertainty associated to the lidar profiles is almost negligible in the final output profiles. Because of that, the lidar uncertainty was not considered in the manuscript. Actually, to corroborate this hypothesis several retrievals were performed with LIRIC by varying the lidar input profiles within their uncertainties and variations below 2% were found for the output profiles.

Comment: p. 9299 l. 15-16: You need to specify the parameters / details of your retrieval. Min/max particle size? What was the assumed limits of the complex refractive index. Also, specify how you specify the unknown uncertainties.

Answer: As explained in detail by Veselovskii et al., (2010), the minimum and maximum particle size are determined during the retrieval itself and numerous inversion windows are tested. Look up tables are introduced including radii between 0.05 and 25 μm. The real and imaginary part of the refractive index in our simulations varied in the range 1.45 < mR < 1.55; 5*10$-$4 < mI < 0.01. A detailed description of the uncertainties is included in Veselovskii et al., (2010). The following sentences have been included in the manuscript in lines 264-274: “To account for mineral dust particles non-sphericity the model of randomly oriented spheroids was used, as described in Veselovskii et al., (2010). Following this approach, the minimum and maximum particle size are determined during the retrieval. A large number of inversion windows are tested by using the look up tables introduced in Veselovskii et el. (2010), which comprise radii between 0.05 and 25 μm. The real and imaginary part of the refractive indices are varied in the range 1.45-1.55 for the real part and 5âĂć10-4-0.01 for the imaginary part. The particle volume concentration and effective radius in our case were estimated with an uncertainty of about 50% and 25%, respectively. The real part of the refractive index, mr, was also estimated, with an uncertainty of $\pm$0.05. A detailed description on the procedure to calculate the uncertainties is included in Veselovskii et al., (2010).”

Comment: p. 9300 l.22, also Figure 1: Specify the wavelength.

Answer: Wavelength presented here is 532 nm. It was included in both the manuscript

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and the figure

Comment: p. 9302 l. 14: Lidar ratio is measured in sr, not sr-1

Answer: Units have been corrected throughout the manuscript.

Comment: p. 9302 ll. 13-14: Specify how do you choose these values. Are they different for each retrieval?

Answer: Different values were used for each one of the retrievals in the range 40 to 48 sr. The values were calculated by minimizing the difference between the integral of the aerosol backscatter coefficient profile multiplied by the lidar ratio and the aerosol optical depth provided by AERONET for each wavelength as described in Landulfo et al., (2004).

Landulfo, E., Papayannis, A., Artaxo, P., Castanho, A. D. A., de Freitas, A. Z., Souza, R. F., Vieira Junior, N. D., Jorge, M. P. M. P., Sánchez-Ccoyllo, O. R., and Moreira, D. S.: Synergetic measurements of aerosols over São Paulo, Brazil using LIDAR, sunphotometer and satellite data during the dry season, Atmos. Chem. Phys., 3, 1523-1539, doi:10.5194/acp-3-1523-2003, 2003.

Comment: p. 9303 ll.1-6: You need to give more details on how the retrieval was made. Photometer data are available only up to 08:12. How did you handle that for the last two profiles?

Answer: AERONET Level 1.5. inversion data were available at 10:19 and 11:19 UTC and those data were used for LIRIC retrieval. Data shown in Figure 2 correspond to AERONET Level 2 data only. Figure 2 has been modified including AERONET Level 1.5 data to avoid confusion.

Comment: p. 9303 ll. 3-6: You mentioned that the total volume concentrations values of LIRIC are constrained by the photometer data. No surprise that you see the same trends. Please rephrase to indicate the correct causal relation.

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Answer: This sentence has been rephrased (lines 362-365): “In addition, a decrease of the total volume concentration values occurred throughout the morning, as expected from the observed decrease in β532nmaer (Figure 3) and the decrease in the integrated volume concentration V (Figure 2d).”

Comment: p. 9303 l. 28: You convincingly highlight the qualitative coherences of the retrieved data. What about the quantitative coherence? You need to compare backscatter and depolarization coefficient profiles retrieved by LIRIC and those presented in Figure 3.

Answer: As explained in previous responses, a detailed discussion on the comparison of LIRIC with the lidar retrieved optical properties profiles was performed elsewhere and the similarities and discrepancies are discussed in detail (see Granados-Muñoz et al., 2014 and Wagner et al., 2013). That comparison would require and in depth discussion which is out of the scope of this study, since it has been presented before and our focus is on the analysis of the microphysical properties.

Comment: p. 9304 l. 24: Figure 5a) and b) shown only part of the 3b+2a+1d analysis that you use for the regularization technique. Please include all the used profiles (either directly, or through profiles of angstrom exponent and lidar ratios).

Answer: Figure 5 has been modified including the 3b+2a profiles

Comment: p. 9305 l. 9 : 2000m a.s.l.

Answer: Done Comment: p. 9305 l. 12: “1000m layer” (singular). According to figure 5, only one layer with 1000 m resolution.

Answer: Done

Comment: p. 9305 l. 12: The averaging procedure is not clear. In Fig. 5a and b you present data up to 4500m. The 1000m layer should then be from 3500m to 4500m. But on Figs 5c and d you indicate points at 4400m. Did you assign the value at the top of the averaging layer or at the bottom. Please be more specific.

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Answer: The value corresponds to the middle of the layer. Data in Figure 5a and b were displaced due to a mistaken use of the altitude in m a.g.l. instead of m a.s.l. Figure has been corrected.

Comment: p. 9306 l.2: Introduce the APS-3321 instrument in Sec. 2. Add a discussion of related uncertainties. What was the sampling setup? What exactly is the quantity presented in Fig. 5E? Is this aerodynamic radius or it has been converted? If yes, with what assumptions / procedure? You state that the instrument measured from 0.25 to 10um. In the plot you present data above 0.4um. Why do you have this discrepancy? Please explain.

Answer: The APS has been included in Section 2, including information about the sampling setup. The following text has been included in the manuscript (lines 161-175):

“2.2.4. Aerodynamic Particle Sizer APS-3321 Auxiliary measurements of the particle size distribution and concentration at the surface were performed with an aerodynamic particle sizer (APS-3321; TSI). This instrument is an optical particle counter that measures particle diameter and aerosol concentration, in real time, in 52 nominal size bins in the aerodynamic diameter range 0.50–20 μm by determining the time-of-flight of individual particles in an accelerating flow field. The APS can measure concentrations up to 1000 particles cm$-$3 at 0.5 and 10 μm, with coincidence errors inferior to 5% and 10%, respectively. The minimum and maximum concentrations that can be measured are 0.001 and 10 000 particles cm$-$3, respectively. For solid particles, counting efficiencies range from 85% to 99% (Volcken and Peters, 2003). The APS was operated at flow rate of 5 l min$-$1 and with data averaging time of 5 min. Air sampling for APS instrument was obtained from the top of a stainless steel tube, 20-cm diameter and 5-m length (Lyamani et al., 2008). The inlet was located about 15 m above the ground surface. The measurements were performed without aerosol size cut-off and no heating was applied to the sampled air.”

In Fig. 5e we presented the hourly averaged volume size distribution in the aerodynamic radius range 0.4-10 μm obtained at surface level from the APS for the period 00:00–01:00UTC on 27 June 2011. The radius presented is the aerodynamic radius as directly measured by the APS.

Even though the instrument can measure from 0.25 μm in radius, Pfeifer et al., (2015) have shown that data below 0.4 μm are affected by a large uncertainty. Since we do not consider the measured size distribution reliable for radius below 0.4 μm we chose to omit them from the figure.

S. Pfeifer, T. Müller, K. Weinhold, N. Zikova, S. Santos, A. Marinoni, O. F. Bischof, C. Kykal, L. Ries, F. Meinhardt, P. Aalto, N. Mihalopoulos, and A. Wiedensohler. Intercomparison of 15 aerodynamic particle size spectrometers (APS 3321): uncertainties in particle sizing and number size distribution. Atmos. Meas. Tech. Discuss., 8, 11513–11532, 2015

Comment: p. 9306 l.22: Specify is this is the total volume concentration, or one of the components.

Answer: It is the total volume concentration. Text has been modified accordingly.

Comment: p. 9306 l.26: AERONET retrievals includes particles up to 15um!

Answer: Text and figures have been modified accordingly.

Comment: p. 9307 l. 23: Bravo-Aranda et al. (2014) is not included in the bibliography!

Answer: It was a mistake. The correct reference is Bravo-Aranda et al., 2015. Text has been modified accordingly

Comment: p. 9307 ll. 23-29: This sentence is not clear, and needs to be rephrased. You should consider including a POLIPHON analysis for your case. It could provide further insight about the observed differences.

Answer: The phrase has been suppressed. The comparison with POLIPHON was

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already included in Bravo-Aranda et al., 2015 using the same dataset and would not provide additional information if included here.

Comment: p. 9308 l. 16: Define EOD both in main text and appendix.

Answer: EOD stands for Equivalent Optical Diameter. It is now included in the manuscript.

Comment: p. 9311 l. 20-22: Add references.

Answer: Done. Line 616-618: "Advances in vibrational Raman will allow measurement of the extinction coefficients during the daytime (e.g. Brocard et al., 2013) and measurements from HSRL systems could also help in this aspect."

Comment: p. 9331 Fig 3: Change caption of middle panel from AE to beta-AE, to be consistent with the caption.

Answer: Done

Comment: p. 9332 Fig. 4: Explain briefly what is included in the errorbars. It's not enough to reference a paper, just to understand one plot.

Answer: The figure caption has been modified to include additional information: "Figure 4. Volume concentration profiles of the fine, coarse spherical and coarse spheroid modes obtained with LIRIC from 30-min averaged lidar data for different periods on the 27th of June 2011. The error bars represent the uncertainty associated to the selection of the user-defined input parameters in LIRIC, obtained as indicated in GranadosâĂŘ-Muñoz et al., (2014)"

Comment: p. 9333 Fig. 5E: Add the retrieved size distribution for 4.5km.

Answer: Done.

Comment: p.9334 Fig. 6: You should add errobars to the red line. The figure in general is not very legible, you should improve the presentation.

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Answer: The figure has been redrawn with only a few error bars rather than at each level. The red curve has been removed since the other reviewer pointed out that the AERONET derived distribution actually goes out to 15 μm radius (30 μm diameter) so there is no reason to include a less than 10 μm comparison. Text has been modified accordingly.

Comment: p. 9335 Fig. 7: Take care to represent the same quantities in Fig. 7 and Fig 6a. Is this dV/dlnr? Change the caption accordingly.

Answer: The reviewer is correct; the quantity in Fig. 7 is dV/dLogD. The label has been corrected.

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/8/C4292/2015/amtd-8-C4292-2015-supplement.pdf

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