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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Lidar and in situ observations of continental and Saharan aerosol: closure analysis of particles optical and physical properties" *by* G. P. Gobbi et al.

G. P. Gobbi et al.

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Compared to the first version of the manuscript, a major change (not requested by the reviewers) concerned the correction of the in-situ (DMA and OPC) data. In fact, these data were provided without indication they referred to STP conditions. So, we originally used them assuming they referred to local pressure and temperature conditions (as lidar data necessarily are) at Mt. Cimone Station (2167 m asl). The introduced correction for local conditions (approximately a 20% decrease in volume concentrations of the DMA and OPC data) led to a better agreement between the lidar and the in-situ observations. All relevant changes have been marked in yellow in the revised manuscript. We apologize about this misunderstanding.

Answers to Reviewer #1 comments.

The reviewer makes a general comment plus several detailed ones. Both comments are rather aggressive and, as it will be shown hereafter, many of them are incorrect. When applicable, we introduced the proposed changes. Here follow our replies to all these comments.

General comment.

"this is the clear message of the literature published during the past five years. Even in the case of five or more backscatter coefficients (at five or more wavelengths) it is not possibile to retrieve any trustworthy information on (aerosol) microphysical properties".

As a matter of fact, such a "clear message" (that now definitely seems to have an 18-year cycle) was already sent out by Twomey and Howell in 1967 (Appl. Opt., 6, 2125-2131) and confirmed in 1985 by Ben David and Herman (Appl. Opt., 24, 1037-1042). It was on the basis of that "clear message" that in 1995 we decided to address not microphysical (size distribution) but bulk (extinction, surface area, volume per unit airmass volume) properties of the aerosols by means of single-wavelength lidars (Gobbi, J.Geophys. Res, 100, D6, 11,219-11,235, 1995, first paragraph of page 11,221). Such an approach led to the definition of models for stratospheric aerosols (Gobbi, J.Geophys. Res., 100, D6, 11,219-11,235, 1995; Gobbi, Appl. Opt., 37, 4712-4720, 1998), marittime aerosol and desert dust (Barnaba and Gobbi , J.Geophys. Res, 106, D3, 3005-3018, 2001) and continental aerosols (Barnaba and Gobbi, J. Atm. Ocean. Techn., reviewed 2003). This means that the proposed approach has been reviewed and accepted by major journals. These reviewers agreed there is a statistical correlation between aerosol backscatter coefficient and extinction, surface area and volume. This manuscript confirms once again the existence of such correlations and shows the actual retrieval uncertainties to be even smaller than the ones estimated in our papers.

Furthermore, the reviewer statements also object one of the most common techniques employed in current space-based aerosol retrievals: measuring the scattererd radiance

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at one (GOES, METEOSAT) or more wavelengths (MODIS, uses 6 wavelengths over ocean) to retrieve aerosol bulk properties as total extinction, effective radii, etc. Such retrievals are done in much worse conditions than lidar ones: 1) unknown reflectance of the ground, 2) assumption of a homogeneous aerosol column; 3) variable scattering angle. Still, this space-based knowledge about aerosols is unparalleled and accepted worldwide. An excellent list of these retrievals (including single wavelength ones) can be found in Kaufman et al., Nature, 419, 215-223, 2002.

"The authors permanently ignore all the state-of-the-art papers regarding the ill-posed problems associated with lidar data inversion, e.g., published in Applied Optics. So, most of the lidar results presented here are just speculation. This has nothing to do with solid careful, quantitative measurements."

The reviewer does not indicate any of these "state of the art papers". The comments just made above perfectly fit to this reiterated opinion. With respect to the "solid, careful, quantitative measurements", our manuscript shows that in aerosol observations: 1) even the most "solid" measurements as determining aerosol surface area (or volume) by combination of DMA and OPC techniques (these are actual observations of microphysical properties) are affected by errors of 22% (29%); 2) The "simple one wavelength lidar" retrievals presented here agree with such "solid measurements" always to within 42% (43%). In our opinion this is (systematic) good agreement.

"Detailed" comments

page 447, line 19: The referee is right "retrievals" was used instead of "observations". This has been corrected in the text.

447, 27: To the authors knowledge, ESA and NASDA together will launch (in 2007-2010) a backscatter, polarization-sensitive lidar (ATLID) within the EarthCARE mission. Configuration of this lidar is not yet defined: it might either be a two wavelength system or a HSR (High Spectral Resolution) one. So, unless the reviewer is thinking of another mission, it is not sure a HSR lidar will be launched to observe aerosols.

449. A detailed description of the model methodology needs a whole paper per aerosol type. So it would be illogic to put it here. We give full reference of the papers describing such methodology. In the literature, authors stating they use a "typical" lidar ratio usually cite the source, not the entire methods employed therein.

450, 13 As above, a detailed description of the methodology needs a whole paper per aerosol type, it would be illogic to put it here. We give full reference of the papers describing the statistical dependence of physical parameters as extinction and backscatter on aerosol size distribution (which includes number concentration), chemical composition, shape (for Saharan aerosols) and hygroscopicity (for maritime and continental aerosols).

450, 3rd paragraph. Expected uncertainties in the lidar-retrieved products (backscatter, extinction, surface area and volume) are fully described in the referenced papers (each of them requires one figure). To respond to the reviewer suggestion, typical values have been inserted at the end of Section 2.1. The outcomes of this study (Section 4.4) show the lidar retrievals of these products to be characterized by (combined, i.e., lidar+in-situ) uncertainties lower than 43%, that is definitely better than the model-expected errors. Uncertainties guessed by the reviewer are absolutely out-of-range.

451, 15. We added to the text (Section 2.2) a sentence indicating that Mishchenko (1997) employed oblate and prolate spheroids for his computations. As in the case of our aerosol model, the computational approach of Mishchenko is quite complex. We then prefer the reader to refer directly to that paper rather than summarizing opinions which could slip into a treatise on scattering by non-spherical particles.

451, 22-25 Expected uncertainties in the estimated products (backscatter, extinction, surface area and volume) are now given at the end of Section 2.1. Discussion of Figure 1 has also been referred to these given uncertainties (beginning of Section 3). As stated above, the outcomes of this study (Section 4.4) show the lidar retrievals of these products to be characterized by quite lower uncertainties.

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452, 25 The reviewer might be missing the fact that several definition of lidar depolarization ratio are reported in the literature. Some examples (B stands for backscatter coefficients Beta, _ and // standing for perpendicular and parallel polarization): D1= (Ba+Bm)_ / (Ba+Bm)//; defined in Section 2.1 of the manuscript and used in Fig.1; D2 = (Ba+Bm)_ / ((Ba+Bm)// +(Ba+Bm)_), used in the Asian Lidar Network (http://info.nies,jp:8094), with typical values for dust of D2 = 20-30%; or D3=Da = (Ba)_ / (Ba)// , also defined in Section 2.1 of the manuscript and used in Fig. 4. Of course, D1 tends to D a when Ba $>>$ Bm (as in cirrus clouds), while it is smaller when Ba is similar to Bm (as in dust clouds). Even though Da is more interesting because related to aerosol alone, it tends to diverge for small aerosol loads, so D is a more stable parameter to plot. Therefore, in our paper (and in all the previous ones) we use D=D1 for general presentation of depolarization (and this is of the order of 15-30% for dust, e.g., all single profiles in Gobbi et al., Atmos. Env., 34,5119-5127, 2000) and Da to study depolarization of particles alone (and this is of the order of 40-50% as indicated here and thoroughly discussed in Gobbi et al., 2000). So, as in the literature read by the reviewer, our typical depolarization (D) is about 22% for Saharan dust, which typically shows Ba of the order of Bm, i.e. backscatter ratio of about 2. When translated into Da this converts into 45%, that is the typical dust depolarization mentioned in the manuscript.

Concerning the doubts about the quality of the lidar receiver, it is well known that ice clouds typical depolarization is 50-60% (Sassen, Bull. Am. Met. Soc., 72, 1848-1866, 1991). We hope the reviewer can believe our lidar reacts to photons depolarized by cirrus clouds in the same way as it does to photons depolarized by dust. Now, our lidar detects cirrus depolarizations of the order of D1 = Da of the order of 50% and dust depolarization of the order of D1= 20-30% , Da of the order of 45% (e.g., single profiles in Gobbi et al., 2000). So, we are convinced that our system provides reliable depolarization observations and that ice clouds are easily discernible from dust ones since their backscatter is usually one order of magnitude larger. A good review on lidar depolarization (and causes of its non immediate portability) can be found in Cairo et al., Appl. Opt., 38, 4425-4432, 1999.

453, 3: The paper is also intended to validate the aerosol model and it does so within acceptable uncertainties (Section 4.4 and Table 3).

453, 6 Model expected uncertainties are now given in Section 2.1. Validation results (Section 4.4 and Table 3) show a much better performance of the model.

455, 11-20 This section has been re-organized. The agreement between lidar and in-situ observations before (Fig. 2a) and after (Fig. 2b) RH-correction is now discussed in the new Fig. 3. In this way, the improvement achieved after RH-correction (already well visible in Fig 2) is now quantified in Fig. 3.

"Another story": Correction for hygroscopicity has been done to the best of current capabilities (e.g., references in Section 4.1) and correction coefficients are now listed in the new Table1. Results presented in Fig. 2 and in the new Fig. 3 demonstrate the sharp improvement introduced by this procedure. Minimization of dBa/Ba for single measurement pairs (Section 4.3) show the resulting values of refractive indices to be in the proper range and statistically significant (as demonstrated by the new Figure 6). Finally, in-situ and lidar-retrieved aerosol surface area and volume all agree to within 43% (it was 50% in the previous manuscript). The scatter of results in Fig. 2b mentioned by the referee is fine if they vary (as they do) within realistic values of the refractive index. Actually, this provides the means to retrieve refractive index (Section 4.3). In our opinion this closure is rather satisfying.

456, 10: The reviewer is right, we eliminated Fig 2c. Relevant results are more quantitatively presented in the new Fig. 3.

456, 15: The point made by the reviewer is not clear. Both extinction and backscatter retrieved by the lidar depend on their profile above. Their relationship is always defined by the employed aerosol model. So, agreement between the two minimizations (dBa/Ba and dSIGMAa /SIGMAa with respect to m) is due to the model. However, the

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new Fig. 3 clearly shows what was discussed in these lines, i.e., both dBa/Ba and dSIGMAa /SIGMAa minimize for the same refractive index, with dBa /Ba showing a smaller variability range. Relevant sentences have been re-formulated in Section 4.2.

457: Due to the introduction of three new figures, Fig. 3 is now Fig. 4 and Fig 4 becomes Fig. 7. These two figures still show the good agreement between lidar and in-situ retrieved aerosol properties at Mt.Cimone together with a wealth of information provided by this comparison (e.g., Section 4).

459: Of course, "general" statements refer to the campaign period. As a matter of fact, average absorption coefficient measured by aethalometer at Mt. Cimone (R. Van-Dingenen, personal communication) was of 5.86E-6 (m-1) for the June 4-6 West Europe aerosol, it was 4.52E-6 (m-1) for the June 25-27 West Europe aerosol, conversely it was 4.14e-6 (m-1) for the East Europe aerosol of June 19. Not big differences, but West Europe aerosol was always more absorbing than East Europe aerosol. Nevertheless, Section 4.3 has been widely reformulated after the improvements in the results following correction of the in-situ data for local conditions and these sentences have been smoothed-out.

461: As previously discussed, the outcomes of this study (Section 4.4) show the lidar retrievals of these products to be characterized by (combined, i.e., lidar+in-situ) uncertainties lower than 43%, that is definitely better than the model-expected errors and far away from the reviewer guesses.

463-464 (conclusions) As stated before, and demonstrated in the improved version of the manuscript, we are confident this work provides a good (within the provided error bars) validation of the lidar-retrieved aerosol bulk properties of extinction coefficient, surface area and volume in continental and Saharan dust conditions.

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