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Atmospheric Measurement Techniques Discussions

Interactive comment on "Characterisation of aerosol size properties from measurements of spectral optical depth: a global validation of the GRASP-AOD code using long-term AERONET data" *by* Benjamin Torres and David Fuertes

Anonymous Referee #2

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Review for Atmospheric Measurement Techniques

Title: Characterisation of aerosol size properties from measurements of spectral optical depth: a global validation of the GRASP-AOD code using long-term AERONET data

Authors: Benjamin Torres and David Fuertes

General Comments:

This paper presents a lengthy evaluation of the GRASP-AOD retrieval algorithm performance in comparison to both SDA and the Dubovik almucantar retrievals in AERONET.

Comparisons of fine mode AOD and also both fine and coarse size distribution parameters are made. Although these comparisons are comprehensive in some respects there is also a lack of analysis of why there are some biases in some of the results presented (see details below). Additionally, it should be noted that the author's suggested threshold of AOD(440) > 0.2 for retrieval of radii and other size distribution parameters results in the exclusion of most of the measurements in the global AERONET database. See Sinyuk et al. (2020) for the small errors in fine mode radius from the Dubovik retrievals for even very low values of AOD. Figures 26 and 27 in Sinyuk et al. (2020) show that the uncertainty in fine mode radius for fine mode dominated sites is less than 0.01 micron for AOD>0.10. This is much more accurate than the GRASP-AOD retrievals of fine mode radius (as expected when adding sky radiance information) and needs to be emphasized in this paper and included in discussions. The authors need to note that the percentage of cases excluded by the AOD(440)>0.2 is much larger for the entire AERONET database than for the 30 sites they have analyzed in this paper since they did not include many sites that have persistently low AOD (in Table 4).

One issue that requires additional discussion in the GRASP-AOD Inversion section is the selection of the refractive indices. Please write a few sentences about how the complex refractive index is selected for each site (so that readers do not have to go to your 2017 paper). Also state what the radius limits are for the two modes in the bimodal assumption of GRASP-AOD. A discussion on the effect of errors/uncertainty in refractive index is also warranted in the paper. Additionally, please be clear here that you create a climatology of the complex refractive index for each site based on the full sky scan retrievals (that include spectral AOD) in the AERONET database. Therefore this retrieval is not independent and it also cannot be done for a new site since a 'climatology' of the retrievals for that site are required first. How many retrievals over how many seasons would be required to declare that a sufficient climatology exits to run the GRASP-AOD algorithm for a given site? Also for low AOD sites there will never be a robust refractive index climatology therefore it seems that GRASP-AOD retrievals would never be possible for such sites. It would be very useful to provide

some information on the impact of the refractive indices on the retrieved parameters in this current paper or summarize the results from the 2017 paper. For example, what would the results be if the Real part was assumed to be 1.45 for all wavelengths and the imaginary part of 0.005 for all wavelengths? There needs to be some expanded discussion about the differences in the definition of fine versus coarse modes for the different retrieval algorithms in this paper. For the Dubovik retrieval (Dubovik et al., 2006) which you call the AERONET aerosol algorithm (a confusing choice of terms in my opinion), there is a variable radius cutoff from 0.44 to 0.99 micron depending on the minimum between modes in the retrieved size distribution, while for the SDA algorithm the fine mode includes the influence of the tails of the log-normal distributions. This results in some bias in the retrievals (see O'Neill et al. (2003) and Eck et al. (2010)) between these two independent retrieval methods. You should be clear about how the separation of fine and coarse modes are defined in the GRASP-AOD algorithm.

Figure 2: This plot is quite highly correlated with the AOD magnitudes at each site, as expected. Therefore, it is of relatively limited usefulness and should probably be eliminated. A much more informative comparison would have been the fine mode fraction (FMF) of AOD at 500 nm for these retrievals, as this would be less dependent in magnitude on the AOD levels at each site.

Please discuss the systematic underestimation by GRASP (Figure 7) of fine radius which gets significantly worse as fine radius increases, even for the best conditions of high AOD and high AE. It is surprising that the authors did not investigate this bias that occurred in multiple sites. Provide some analysis or at least speculation on the reasons for the GRASP-AOD underestimation of fine mode radius versus the Dubovik almucantar retrievals and why this error increases for the largest fine radius cases.

Also it is necessary to provide some analysis and discussion of the two distinct populations of the coarse mode radii in the top row plots in Figure 9. I suspect that the larger radii population is from fine mode dominated cases and the lower radii cluster from dust dominated cases, but this needs to be analyzed. If this is the case then the

claim for higher accuracy that you imply is somewhat suspect since the accuracy of the coarse mode radii when fine mode dominates the signal is VERY low due to very low coarse mode AOD resulting in very little coarse mode information content in the spectra of total extinction AOD. Additionally you have again neglected to include information from the study of Sinyuk et al. (2020) that shows that the accuracy of the retrieval of coarse mode radii is much less than that for fine mode aerosol.

Explain why the effective radius of both modes combined are analyzed at all in this paper. I have never seen a published peer-reviewed paper that shows the value or justification in combining the information from both modes into a total effective radius and total volume concentration value. If you have information that shows the value of these combined mode parameters then please discuss it in the text plus provide references in order to convince the reader of their value. The separate fine and coarse mode parameters on the other hand have much value and have been utilized in numerous published papers in the scientific literature.

Please quantify what you refer to as 'good capacity' of the GRASP-AOD retrieval of fine mode radius in the Conclusions section. For the Rvf the uncertainty of GRASP-AOD is $\sim$0.023 micron for fine mode dominated data while for the AERONET Dubovik algorithm almucantar retrievals the accuracy is $\sim$0.006 for AOD(440)>0.2 for the fine mode observations (large AE). You lack references to the values of Rvf and Rvc from Sinyuk et al. (2020) as a way to compare the accuracy of these retrievals (see Fig 27 for example for the fine mode sites Rvf uncertainty).

On a positive note: You should note that with the newer Cimel instruments the cross scan in the solar aureole is taken with every AOD spectra measurement sequence as a cloud screening data set for the detection of cirrus. This in effect provides aureole sky radiance values for every AOD measurement made with these newer Cimel instruments. This could provide a potentially powerful addition to your retrievals and should be explored for even the fine mode dominated cases to assess any impact of this added aerosol information.

Specific Comments:

Line 9: Misspelling of 'diverse'

Line 20: What about for low AOD cases? Sinyuk et al. (2020) show that the fine mode radius is retrieved very accurately down to very low AOD.

Line 21: Should be AE>1.2. Seems like this is a bit careless to get such a basic statement backwards in the Abstract.

Line 23: This is an odd choice of words here: oscillations implies somewhat periodic variability between two states, not sure the authors really mean that here.

Line 27-28: Strange terminology for presenting statistics. What exactly is the RMSE values of a correlation? Please be clearer and more precise.

Line 50: Should be 'continuous' instead of 'continued'.

Line 54-55: This sentence has some very awkward English and should be re-written. Hard to know the exact meaning as it is now.

Line 61: High accuracy is even more important than the high precision of the sun photometer measurements.

Line 73: "cloud processing" would be much more appropriate here than "cloud formation"

Line 73: 'plums' should be "plumes"

Line 77: Large solar zenith angles are no longer required with the Hybrid scan in AERONET, see a description of the hybrid scan in Sinyuk et al. (2020).

Line 110 & line 118: 'punctual studies': this is awkward English, better to choose a different word, perhaps 'specific studies'? However, not really sure what you are trying to say here.

Line 145-146: This is a very strange and misleading statement. The only cloud screen-

ing check from Smirnov et al. (2000) that is also utilized in the V3 cloud screening is the triplet variability check and even then the magnitude of this triplet threshold has been changed plus spectrally limited to longer wavelengths in V3 (see Giles et al. 2019). Other checks are unique to V3 and also V3 is completely automatic, while the V2 cloud screening of Smirnov et al. required an analyst to remove numerous cloud contaminated observations. This sentence needs to be re-written to be more factual and informative.

Line 146: You need to state that the accuracy of the Level 2 spectral AOD is $\sim$0.01 and $\sim$0.02 in the UV (Eck et al. 1999) since highly accurate data is the key to the applicability of the GRASP-AOD retrievals you are discussing.

Line 148-149: You should state here that the fine mode AOD from the Dubovik retrieval is given at 440 and 675 nm, not 500 nm. Since you are describing the data sources in this section you should be more accurate as there is no 500 nm fine mode AOD directly provided by the Dubovik retrieval. Please write how you computed the fine mode AOD at 500 nm from the Dubovik retrievals.

Line 153: 'teen' should be 'ten'

Line 155: It is common to most Cimels in the network, but the older PHOTONS group polarized Cimel model do not have the 340, 380 or 500 nm channels. Instead they have three polarized 870 nm channels. Five of your 30 selected sites Dakar, Capo Verde, Banizoumbo, Guadaloupe and Beijing do not have the 340, 380 and 500 nm channels for most or all years of this analysis. For Dakar 1997-2008 plus 2010 do not have the 340, 380 or 500 nm channels and for the Capo Verde site most of the record you analyzed 1997-mid 2016 lack these key channels. Additionally the Beijing site has spectral AOD only from 440, 675, 870 and 1020 nm for all the years 2002 through 2015. Guadaloupe lacks the 340, 380 and 500 nm AOD for 1999 through 2008. Banizoumbo lacks the AOD at 340, 380 and 500 nm for the entire measurement record. The spectral AOD information content of these instruments is much reduced

compared to the full wavelength range, therefore it is very important that you mention this and address this issue in the analyses of these sites. You should compare your algorithm with and without the 340, 380 and 500 nm channels for a few sites that have the full wavelength suite of channels. Note that the AERONET group did a full analysis of comparisons of the SDA algorithm with various wavelength combinations in order to determine the wavelengths necessary for Level 2 quality retrievals. The SDA algorithm excludes the 340 and 1020 nm channels since the uncertainties in AOD are higher for these wavelengths. The 340 nm filters have been the least stable (temporal degradation) of all the other wavelength filters plus have out-of-band blockage issues in many 340 nm filter batches. At 1020 nm the silicon detector has a large temperature sensitivity and must be corrected using the sensor head temperature, plus there is significant water vapor absorption at 1020 nm that is accounted for from the retrievals made at 945 nm. These two factors increase the uncertainty at 1020 nm relative to the other wavelengths. The lack of discussion of these issues in this GRASP-AOD paper should be corrected.

Line 162: Are these multi-year averages computed from daily averages or from all individual instantaneous vales weighted equally? Averaging daily first and then monthly gives a more representative values of the monthly and annual aerosol loading. It is important to clearly write in the paper how you computed these averages.

Line 197-198: This is not really true. The Lanai site does not have any L2 retrievals for refractive index since AOD(440)<0.4, but it does have very many L2 retrievals for the size distributions.

Line 203-204: Please provide a sentence or two to describe how the options for the dominant mode radii initial guesses change as a function of Angstrom Exponent. I do not see this for the coarse mode as for coarse mode dominated cases AE<0.6 in Table 2 as there are only 2 static choices of coarse radius while for mixed modes 0.6<AE<1.2 there is one static and one dynamic coarse mode radius.

Line 205-206: If the standard deviation (width) of each mode is fixed, then you need to give these values here instead of forcing the reader to look them up in another paper.

Line 220-222: Please explain the fitting here in more detail. I assume you compute spectral AOD based on the retrieved size distribution plus the assumed refractive indexes and then compare this to the measured spectral AOD. A written discussion in the text is needed.

Line 244-245: You need to be more precise here in your explanation for the lack of SDA retrievals at L2 for these sites that had old style polarization Cimels with only 4 wavelengths of measured AOD data. The reason for no L2 SDA retrievals is the lack of 380 and 500 nm AOD values for the instrument types deployed at these sites. You need to prove that the GRASP-AOD retrievals give the same values for 4 channel AOD input versus 7 channel AOD input. This should be especially important at the Beijing site which is fine mode dominated and therefore has much greater non-linearity in the AOD spectra in logarithmic space. For coarse mode desert dust sites this will not matter nearly as much as the AOD spectra is relatively flat with little non-linearity in logarithmic coordinates.

Line 255: It should be noted that the fine/coarse mode radius separation value is the same for Version 3 as it was in Version 2.

Line 258-259: Please add "for each mode as well as for the entire size distribution".

Line 260: This is the wrong vocabulary word ('mechanical') here. I suggest that this word can be eliminated and the sentence will be clearer. I suggest: "The separation between fine/coarse mode..."

Line 262: How do you make this interpolation? In log-log space by Angstrom Exponent relationship, or by 2nd order fit of AOD in log-log space which is the most accurate methodology.

Line 267: This is just way too simplistic an estimate for this paper. The number of

AOD spectra measured per day in AERONET depends on site latitude and day of year, resulting in differing number of day-length hours. In addition, the newer instruments are set to take 5-minute sampling interval data versus 15-minute sampling intervals in the old Cimels for direct sun AOD observations. More details on the variable number of AOD measurements per day in AERONET are required in a paper that utilizes AOD spectra as the primary input parameter.

Line 273: This is an inaccurate statement since some sites only have the 440, 675, 870 and 1020 nm AOD while most other sites add the 340, 380 and 500 nm channels to those.

Line 275-276: Except as you noted that the SDA does not make a retrieval when the 380 nm AOD are missing.

Line 322-327: No real surprise here as these 3 sites have the highest AOD levels in the entire AERONET network. I suggest adding the average AOD values in the table and plotting the RMSE versus this average AOD. For the La Reunion site you should add the phrase: "...because the AOD were lowest for this site."

Line 350-351: Please include an investigation and explanation of some cases in the two branches of the Fig 5 plots for AE<0.6 of GRASP-AOD versus AERONET and SDA versus AERONET (Dubovik). An attempt should be made to explain these two data populations and why they diverge as fine AOD increases.

Line 371: Please mention that this is a quality control issue for SDA due to insufficient AOD wavelengths for highest accuracy of the retrievals.

Line 381: It is not just 500 nm but also 340 and 380 nm that are not available in the old Polarized Cimels. Please add this to the text. To prove the level of robustness you have claimed, for Beijing you need to run the GRASP-AOD retrievals for the full 7 channels (340-1020 nm) for years when this type of Cimel was operating there and then subsequently run the GRASP retrievals with only the 440 , 675, 870 and 1020 nm

data as input for these same exact measurement scans. Only this direct comparison of the same AOD spectra and almucantars but with different spectral channels used as input can really determine just how robust the 4 channel GRASP-AOD retrievals are.

Line 413-415: It should be noted that the retrieval of the fine mode radius when the coarse mode dominates (AE<0.6) also has a large uncertainty in the Dubovik retrieval with sky radiance information, see Sinyuk et al. (2020). Therefore the lack of correlation with GRASP is also due largely to very weak information and thus large uncertainty for fine radius in the AERONET almucantar retrievals for coarse mode cases.

Line 423: This is an incomplete sentence here should probably be deleted.

Line 431: Should change 'column' to 'row' here.

Line 437: Please discuss the reasons for this systematic underestimation by GRASP which gets worse as fine mode radius increases in Figure 7 for all sites shown, even for the best conditions of high AOD and high AE.

Line 467: Please discuss the reason for the 2 populations that are obvious in most of the plots of Figure 8.

Line 482: It is interesting that you mention 1640 nm here since the GRASP-AOD retrieval does not use this wavelength of AOD data. Theoretically inclusion of the1640 nm AOD should indeed provide more information on the radius of the coarse mode, so you should discuss that here.

Line 485: Please be clear here that these are AERONET climatological values.

Line 695: This is the wrong word choice ('axes') here. Although the writing is in general relatively good from the English grammar and vocabulary aspects, please have a native English speaker review the manuscript to catch the various instances of awkward phrasings and/or poor vocabulary choices.

Line 701: Nothing involving real data is ever a perfect correlation. Please give the exact

value of correlation here even if it is very close to 1.

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