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Atmospheric Chemistry and Physics Discussions

# *Interactive comment on* "Recent trends in aerosol optical properties derived from AERONET measurements" *by* J. Li et al.

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Comments on "Recent trends in aerosol optical properties derived from AERONET measurements" in ACPD

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General Comments:

The sections of this paper that focus on the trends in AOD are reasonable since these measured data are highly accurate, although it needs to be clearly stated that only Level 2 AOD were utilized in the paper. Currently, there is insufficient discussion in the manuscript concerning the uncertainty of all of the various measurements and re-



trieved parameters provided by AERONET. The use of Level 1.5 data for absorption parameters is extensive (~94% of sites analyzed; page 14356 lines 26-28) due to the analysis of data where AOD at 440 nm is less than 0.4. At the minimum, if L1.5 retrievals data are used to analyze lower AOD observations then the data must have solar zenith angle > 50 degrees (this ensures sufficient scattering angle range of input data; larger airmass increases sensitivity to absorption) and also sky error (residual of computed versus observed sky radiances) less than 5% to ensure a robust retrieval. These are the main data quality controls of L2 retrievals in addition to the AOD(440 nm)>0.4. Only L1.5 data should be analyzed that have L2 AOD data and also subsequently a L2 retrieval (but with AOD(440 nm)<0.4) to ensure high quality of input AOD and sky radiance data. Additionally, the authors should still impose some lower limit on the AOD(440 nm) for analysis of absorption parameters since the uncertainty of SSA increases exponentially as the product of optical airmass and AOD decreases (Sinyuk, personal communication). A reduction of the lower limit of AOD(440 nm) to 0.20 or 0.15 would result in much less data to analyze than in the current paper, but eliminate observations where there is little real sensitivity to actually measure an absorption signal. For example the annual average AOD at Birdsville, Australia is only 0.06, therefore sky radiance calibration uncertainty and assumed input surface reflectance uncertainty (as a function of SZA) would dominate any real ability to actually measure the aerosol absorption at that particular site and other sites with low AOD.

Section 3.4 of the manuscript compares L1.5 with L2.0 retrievals, but only for sites that have extremely high AOD, and these are the sites with the highest annual and monthly average AODs in the entire AERONET network (typically having monthly average AOD(440 nm) > 0.4 ). As a result of the very high AOD it is expected that L1.5 would still have relatively small uncertainties since the very large aerosol signal at these selected sites overwhelms any biases in calibration or incomplete scan angle range of the sky radiance data. For example, at the Beijing site the average AOD at 440 nm for Level 1.5 retrievals for the years 2001 through 2012 is 0.62 (from 11487 retrievals) while the average AOD(440 nm) for L2 retrievals with AOD>0.4 at 440 nm at the same site is 1.04 (3209 retrievals). Therefore the AOD of the L1.5 retrieval data at Bejing is higher than the average AOD at nearly all AERONET sites. Please also add a discussion in the manuscript text that L2 retrievals are a subset of L1.5 retrievals, with only those retrievals that pass quality control checks (primarily for sky radiance error) and also AOD >0.4 for the absorption parameters of SSA and refractive indices, reaching Level 2. The main problem in the current paper is with using L1.5 retrieval data for absorption parameters when AOD is low, and this results in very large uncertainties. Therefore the analysis presented in this section does not address this major issue at all due to the high AOD levels of all sites mentioned in this section, and therefore it remains unaddressed in the entire manuscript. As a result the last sentence of this section is a completely false assumption, since the large uncertainty in absorption parameters at Level 1.5 for sites with low average AOD can have a significant influence on trend analysis at those sites.

Additionally some key sites seem to be missing from the analysis presented here, such as the Solar Village site in Saudi Arabia for which other studies (both Hsu et al. (2012) and Yoon et al. (2012)) have found a large trend in AOD (in fact the largest AOD trend in the entire network)). The Solar Village site has data from 11 to 14 different years of data for each of the 12 months. Additionally there are some sites in Brazil, notably Alta Floresta (seasonal biomass burning site) that are also not analyzed in the current paper even though they have large and long-term data records. The longest and most complete data record of any AERONET site is the GSFC site yet it is also missing. Perhaps the data section criteria should be revised somewhat to accommodate these important data sets that have been omitted from your study.

Specific Comments:

Page 14355-14356, Section 2. AERONET data: The authors should be clear in this section that the AOD that were analyzed are all Level 2 direct sun measured data and that the accuracy of the AOD data for the channels studied in this manuscript is very high at ∼0.01 (Eck et al., 1999). This is also very important for the retrievals since



the a priori assumption of the Dubovik and King algorithm almucantar retrievals is an accuracy of 0.01 for the input AOD data at 440, 675, 870 and 1020 nm. The resultant retrieved size distribution and refractive indices are consistent with the measured AOD to within ∼0.01 at all four wavelengths, due to the assumed high accuracy of AOD. Additionally in section 2 it should be explained whether the Angstrom Exponent was computed by using all 4 wavelengths in the 440 to 870 nm wavelength interval by linear regression or whether just the AOD at two wavelengths 440 nm and 870 nm were utilized.

On page 14356 lines 6-10, the claim that there would likely be no biases in the L1.5 retrievals (even at low AOD) is misleading since it is well known that the AERONET sky radiance calibration is accurate to ∼5% (Holben et al, 1998). Calibration uncertainty is not a random error in a given year, and therefore would bias retrievals of absorption parameters (imaginary index and subsequently SSA). Trend analysis with data having different biases in differing years is therefore problematic in detecting true trends. Additionally, surface reflectance used by AERONET is based on MODIS satellite climatology and generic global ecosystem BRDF models. These estimates would also introduce small biases (not random variations) in the retrievals, and become an increasingly important contribution to retrieval bias as AOD decreases. Additionally, the Kaufman (2002) paper is a poor reference to use to claim lack of bias in absorption, especially since they did not analyze SSA directly in that paper, and their results are primarily constrained by the highly accurate AOD measurements made by AERONET.

On Page 14356, lines 15-17, the authors say that SSA data is screened when values are less than 0.5 due to data quality limitations, however the lower limit of 0.5 is very low. There are no published papers in the literature to support such low column-integrated SSA values (less than 0.7) in homogenous aerosol haze (required for an almucantar retrieval). In fact, columnar averaged SSA is very rarely reported as lower than 0.75 and even these values are quite uncommon. AERONET Level 2 SSA retrievals are rarely less than 0.80 and many of those lower values have data quality issues that will be screened in the upcoming Version 3 database with improved quality controls. The authors need to discuss why Level 1.5 SSA retrievals that are so low (<0.5) exist in the AERONET database, since this is inconsistent with their claims of high accuracy SSA even for low AOD. The percentage of SSA retrievals with values <0.5 and also <0.7 should be given in the text of the manuscript. Additionally, truncating a data set of retrievals at some cutoff (such as 0.5 SSA) is also statistically problematic as it biases the dataset, especially since the maximum SSA is constrained by the AERONET retrieval algorithm to be slightly less than 1.0, therefore the data set can only be truncated in the low extreme and not the high extreme.

Page 14339, line 22: The reference of Ignatov et al. (2000) is an error, as it should be O'Neill et al. (2000). You have truncated the first author from this citation in both the reference list and in the text of the paper (cut and paste type of error).

Page 14362, section 4.1: It should be noted in the text here that the AOD trends are the only robust trends in the entire paper for the majority of stations, due to the very high accuracy of the measured AOD in the AERONET database.

Page 14364, lines 8-10: Please note that the uncertainty in SSA and ABS is generally very high in Europe due to AOD magnitude, except for the summer season when AOD is much higher. Some of the sites in Spain show positive trends while other sites show negative trends and this suggests possible non-physical reasons (relatively low AOD signal leading to high retrieval uncertainty as a result of both radiance calibration bias and surface reflectance biases) for these spatially variable trends.

Page 14364, section 4.3: This is currently an inadequate and non-rigorous description of the reasons for noisy AE data. It is well known that AE has very large uncertainties at low AOD that increase as AOD decreases. Some discussion should be added about how AE error increases as AOD decreases, using some calculations from Equation 6 of Kato et al. (2000; JGR) to estimate the uncertainty in AE (Kato calls it the Lundholm exponent although it is equivalent to the Angstrom exponent).



Page 14365-14366, Section 4.4: In this section it should be noted that the AAE has very large uncertainty (even larger uncertainty than AE) since ABS has smaller values and larger uncertainties than AOD. See Giles et al. (2012) for a discussion of the uncertainty of AAE. Please include some discussion and analysis of uncertainty in AAE in your manuscript. On page 14366 Lines 25-26, please mention that AAE uncertainty is very large at low AOD levels and the majority of the data you have analyzed are at low AOD.

Page 14367, lines 19-21: You seem to imply here that the satellite studies of Zhang and Reid (2010) and Hsu (2012) validate your trends of absorption (ABS). However these papers have analyzed AOD trends only and not aerosol absorption. Please explain your reasoning/justification better regarding this issue in the text.

Page 14370, line 13-14: You suggest that "…uncertainties in individual measurements largely cancel out in the monthly medians…". This is not true since the AERONET retrieval uncertainties at low to moderate AOD levels are mainly caused by biases in radiance calibrations and/or biases of input surface BRDF and therefore are not random and do not cancel out with time interval statistics on a monthly or even yearly time scale.

Page 14371, Conclusions: It is important to mention in the Conclusions section that there are large uncertainties in all parameters analyzed except AOD and SCT (since SCT is dominated by AOD). The exceptions are sites with very high AOD such as Beijing, Kanpur, XiangHe, IER Cinzana, Hong_Kong_PolyU and Agoufou where very high AOD levels allow for accurate retrievals of all parameters analyzed (including SSA and ABS).

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