Interactive comment on “Can AERONET data be used to accurately model the monochromatic beam and circumsolar irradiances under cloud-free conditions in desert environment?” by Y. Eissa et al.

Anonymous Referee #5

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Review for Atmospheric Measurement Techniques

Title: Can AERONET data be used to accurately model the monochromatic beam and circumsolar irradiances under cloud-free conditions in desert environment?

Authors: Y. Eissa, P. Blanc, L. Wald, and H. Ghedira

General Comments:

Firstly, we thank you for your detailed review of the paper. We have addressed each one of your comments, and provide the changes made to the revised manuscript.

The authors of this study have utilized AERONET measured spectral AOD and sky radiances extensively in this study. Unfortunately they have incorrectly analyzed much of this data due to misinterpretation of the data itself.

First, it is suggested that the AERONET measured AOD is biased by ~0.01 too high as a result of inter-comparison with the SAM measured AOD. This conclusion itself is problematic since the SAM instrument has an AOD uncertainty of 0.03 as compared to 0.01 for AERONET, so how could the less accurate SAM data possibly be used to determine a bias of 0.01 in AERONET data? The authors suggest that the diffuse radiation forward scattered into the AERONET instrument FOV is the reason for the low bias in AERONET measured AOD. However Figure 2 shows this relatively small bias is largest for low AOD and then decreases as AOD increases. This is exactly the opposite trend that would be expected if diffuse radiation in the FOV were the real reason for the bias. Surprisingly the paper of Sinyuk et al. (2012; GRL), which describes this bias (due to diffuse in the FOV) in detail for AERONET data, is not cited in the present paper. See Figure 3 in Sinyuk et al. (2012), where it is shown that the diffuse effect on measured AOD for AERONET instruments is only 0.003 or less for AOD < 0.8 at 675 nm, for the case of coarse mode dominated aerosol with Angstrom Exponent of 0.24. Additionally, the diffuse circumsolar effect on AOD is much greater for coarse mode particles with strong forward scattering (again, see Sinyuk et al. (2012)), and the aerosol in the UAE region are often mixtures of fine mode aerosol (from petroleum industry emissions) and coarse mode desert dust aerosol (see Eck et al. (2008; JGR)), therefore the effect may vary from day-to-day or seasonally as the relative fine-coarse mode percentage mixture varies. The authors are encouraged to analyze the data as a function of Angstrom Exponent in future analyses for the UAE region.

REPLY:

In the revised manuscript we have updated the comparison and no longer propose a correction to the AERONET AOD. Also, we are no longer filtering any data based on the uncertainty of SAM.

CHANGES IN MANUSCRIPT:

The AOD comparison now reads:

"The AERONET AOD is not provided at the specific wavelength of the SAM instrument of 670 nm. Therefore, the AERONET AOD at this specific wavelength was computed using a second order polynomial fit of AOD versus wavelength using the AERONET measurements of AOD in the interval [440 nm, 675 nm] (Eck et al., 1999) as:

$$\ln(\tau_{a,\lambda}) = a_0 + a_1\ln(\lambda) + a_2\ln(\lambda)^2. \quad (5)$$

This method to compute the reference AOD at 670 nm was selected because the fine mode pollution aerosols, mainly produced by the petroleum industry in the UAE, affect the linear fit of $\ln(\tau_{a,\lambda})$ versus $\ln(\lambda)$ (Eck et al., 2008).

5024 pairs of coincident observations remain, for which the maximum difference in time stamp of both instruments is 1 min. Similar to the cross-comparison of the radiance measurements to remove potentially cloud-contaminated measurements, the standard deviation of the differences between these remaining pairs of observations was computed. All coinciding samples with a difference greater than three times the standard deviation were filtered out. 150 pairs out of 5024 pairs of samples were excluded.

The Fig. 2 exhibits the density scatter plot of the 4874 pairs of SAM versus AERONET AOD at 670 nm. The relative RMSE is 10% and the relative bias is +7% meaning that the SAM $\tau_{a,670\text{ nm}}$ is greater in average than the AERONET $\tau_{a,670\text{ nm}}$. The R^2 value is high at 0.990. Even though AOD values sometimes exceed 0.8, the limits of the axes have been set to have a maximum value of 0.8 in order to better examine the regions with higher sample densities.

There are several interpretations for the discrepancies observed between the SAM and AERONET $\tau_{a,670\text{ nm}}$. The difference in the field of view of both instruments may partially explain such discrepancies, where the AERONET Sun photometer has an aperture half-angle of 0.6°. This implies a portion of the circumsolar radiation is intercepted within the field of view of the instrument, hence a smaller AOD than that observed by SAM. Although in Sinyuk et al. (2012) the error due to the field of view is quantified to be less than the uncertainty in the AERONET AOD retrievals, being 0.01 for $\lambda > 440$ nm.

Another possible cause for such discrepancies is how the Rayleigh scattering and small atmospheric absorption is accounted for at 670 nm in the SAM AOD retrievals. A fixed correction of −0.0556 is used, which was derived empirically by cross calibrations between SAM and AERONET using measurements collected in Oklahoma, USA (Pers. Comm. with J. DeVore and A. LePage, 2015). This fixed correction may induce errors in the SAM AOD retrievals, but it is stated by the team at Visidyne Inc. to be less than the uncertainty of the SAM AOD, being 0.03. Indeed, the bias of 0.02 between AERONET and SAM AOD retrievals is less than the reported uncertainty of the SAM AOD."

An even more problematic interpretation of the AERONET data involves the sky radiances from the almucantar scans. The authors have analyzed the data as though the measurements were made in scattering angle increments, whereas in reality the measurements were acquired in fixed increments of relative azimuth angle from the sun. Therefore there are significant errors in the way these data were utilized in the study, which vary in magnitude as a function of solar zenith angle. Additionally, it is noted that for retrieval data input, AERONET averages the sky radiances acquired in the almucantar scans at 'equal' azimuth angles from both sides of the scan to minimize any effects of small pointing errors, see Torres et al. (2014; ACP). If these sky radiance data in the current paper are re-analyzed with the correct angles, then it is suggested that the authors also average the data from both sides of the almucantar scan. Also note that the AERONET sky radiance data for scattering angles less than 3.2 degrees are contaminated by stray light and thus are not used as input to the AERONET retrievals (see Holben et al., 2006).

REPLY:

We misread the angles reported with the AERONET almucantar radiance measurements. We repeat the comparison as proposed.

CHANGES IN MANUSCRIPT:

The revised text now reads:

"To compare the AERONET and SAM radiance measurements, the 2241 profiles of AERONET almucantar radiance measurements in the period June 2012 to May 2013 were matched to the SAM horizontal monochromatic radiance measurements which pass the procedures presented in Sect. 4 in terms of time stamp. In the temporal matching process, the measurements between the two different instruments had to be at most 1 min apart and θ_S reported by the two instruments had to match: the bias between the matched θ_S was found to be 0.00° and the maximum absolute error in angle for all observations was 0.22°.

The corresponding ξ of the AERONET almucantar radiance measurements were computed from θ_S and the reported relative azimuth angles. The SAM radiance measurements were then angularly aggregated to match the 0.6° half field of view of the CIMEL 318 Sun photometer using the weighting method described in Wilbert (2014). After matching the measurements, 1067 AERONET and SAM profiles remained. The measurements with the same ξ to the east and west directions of the Sun were averaged to minimize the effects of small pointing errors (Torres et al., 2013). Ideally for these 1067 profiles there should be 5335 measurements of radiance corresponding to the five values from AERONET for $\xi < 6°$, where the maximum ξ from the AERONET measurements was found to be 5.8°. Instead there is a lower number of observations, 5236 to be exact, due to missing data in the almucantar measurements from AERONET which could occur at any ξ. The standard deviation of the differences between these remaining pairs of observations was computed. Then, all samples exhibiting a difference greater than three times this standard deviation were filtered out. This filter is meant to remove extreme cases which could occur if one instrument is shaded by clouds while the other is not. This situation can occur since the two instruments are not exactly at the same place, ~55 m apart, and the time matching is in minutes. 133 pairs out of 5236 were excluded.

The Fig. 1 exhibits the density scatter plot (or 2-D histogram, Eilers and Goeman, 2004) of the SAM and AERONET radiance measurements. Red dots correspond to regions with high densities of samples and the dark blue ones to those with very low densities of samples. The relative RMSE is 14%, the relative bias is 0% and the coefficient of determination R^2 is high at 0.933. The observations are well-scattered around the 1:1 line. The comparison results are good, implying reliable measurements from both instruments. The AERONET measurements were collected at 675 nm while those of SAM were collected at 670 nm. This may induce minor errors in this comparison. Also shown in Fig. 1 are the mean value of the observables on the x-axis, the correlation coefficient (CC), the 1:1 line, the least-squares (LS) affine regression, the robust affine regression, and the first axis of inertia, also known as the first component in principal component analysis (PCA)."

I recommend that this paper be re-considered for publication after substantial revisions to address the issues I have raised above and also in response to the specific comments below.

REPLY:

We hope our responses to your general and specific comments suffice.

Specific Comments:

Page 7703, lines 10-12: Please note that the AERONET direct sun measurements of AOD in the visible and near-infrared wavelengths have an accuracy of 0.01 for overhead sun (optical airmass=1), Eck et al (1999; JGR).

REPLY:

The uncertainty of the AERONET AODs has been added both when the AERONET DSA AODs are listed, and once again in the text shown in response to your first general comment.

Page 7704, line 5: For the AERONET retrievals of single scattering albedo (SSA), it should be mentioned that the uncertainty in SSA is _0.03 for AOD at 440 nm > 0.4 (see Table 4 in Dubovik et al. (2000).

CHANGES IN MANUSCRIPT:

The following text has been added:

"The uncertainty of the AERONET $\omega_{a,675\text{ nm}}$ retrievals is not provided, it is reported at $\omega_{a,440\text{ nm}}$ and is 0.03 (Dubovik et al., 2000)."

Page 7705, line 11-12: However, in the UAE it should be noted that the SSA at 675 nm varies significantly as a function of Angstrom Exponent, see Eck et al. (2008; Figure 13).

CHANGES IN MANUSCRIPT:

The following text has been added (which appears to our reply to your first general comment):

"This method to compute the reference AOD at 670 nm was selected because the fine mode pollution aerosols, mainly produced by the petroleum industry in the UAE, affect the linear fit of ln($\tau_{a,\lambda}$) versus ln(λ) (Eck et al., 2008)."

Page 7705, line 15-19: Therefore you suggest here that you are accepting a 6% range in circumsolar diffuse irradiance as a result of variability in SSA alone. Discussion of this should be included in the text.

CHANGES IN MANUSCRIPT:

The revised text now reads:
"On the contrary, the relative standard deviation of $\omega_{a,675\text{ nm}}$ is small at 0.019 (2% of the mean value) for the 491 samples. The uncertainty of the AERONET $\omega_{a,675\text{ nm}}$ retrievals is not provided, it is reported at $\omega_{a,440\text{ nm}}$ and is 0.03 (Dubovik et al., 2000). If the multiple scattering effects are ignored, the diffuse radiance is linearly proportional to the single scattering albedo (Dubovik and King, 2000; Liou, 2002; Wilbert et al., 2013). A practical consequence is that a mean value of $\omega_{a,675\text{ nm}}$ can be used with an acceptable loss of accuracy. In addition, using a mean value of $\omega_{a,\lambda}$ is a means to tackle the issue of the missing $\omega_{a,\lambda}$ values at instances when $P_{a,\lambda}(\xi)$ data are available. The AERONET retrievals of $\omega_{a,\lambda}$ are not provided under small aerosol loading situations and this causes the gaps in $\omega_{a,\lambda}$ (Dubovik et al., 2000; Yin et al., 2015).

The mean value of $\omega_{a,675\text{ nm}}$ for the available 491 observations over this study area and for this study period is 0.954, this number is fairly close to the monthly mean values of $\omega_{a,675\text{ nm}}$, which range from a minimum of 0.917 in December 2012 to a maximum of 0.974 reached in March 2013. In the extreme case of the minimum observed value (0.881), an error of 8% will be induced on the diffuse radiance by opting to use a mean value of $\omega_{a,675\ \mathrm{nm}}$. However, this is a rare situation. Indeed, 67% of the $\omega_{a,675\ \mathrm{nm}}$ samples lie within the mean ± 1 standard deviation and 96% lie within the mean ± 2 standard deviations."

Page 7706, line 8: Therefore the bandpass of the SAM instrument at 670 nm is double the width of the AERONET at 675 nm. You should mention how ozone absorption was accounted for in the 670 nm SAM data. AERONET uses a monthly climatology of total column zone amounts determined from the TOMS satellite data. (also see Page 7709, lines 11-12, for a directly related sentence).

CHANGES IN MANUSCRIPT:

From our reply to your first general comment, the following text appears in the revised manuscript:

"Another possible cause for such discrepancies is how the Rayleigh scattering and small atmospheric absorption is accounted for at 670 nm in the SAM AOD retrievals. A fixed correction of −0.0556 is used, which was derived empirically by cross calibrations between SAM and AERONET using measurements collected in Oklahoma, USA (Pers. Comm. with J. DeVore and A. LePage, 2015). This fixed correction may induce errors in the SAM AOD retrievals, but it is stated by the team at Visidyne Inc. to be less than the uncertainty of the SAM AOD, being 0.03. Indeed, the bias of 0.02 between AERONET and SAM AOD retrievals is less than the reported uncertainty of the SAM AOD."

Page 7709, lines 17-22: For spectral interpolation of the AERONET data to 670 nm, it would be most accurate to use a 2nd order fit of AOD versus wavelength in logarithmic coordinates (see Eck et al., 1999), using the 440 nm, 500 nm, and 675 nm measurements of AOD from AERONET.

REPLY:

Done, we refer you to our reply for your first general comment.

Interactive comment on Atmos. Meas. Tech. Discuss., 8, 7697, 2015.