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.

S. Wilbert (Referee)

stefan.wilbert@dlr.de

Received and published: 1 September 2015

General comments:

The paper presents an interesting work on a relevant question with applications in solar energy and atmospheric research. However, there are some errors in the analysis of the measurement data that lead to partially wrong conclusions.

REPLY:

We thank you for your thorough review of our manuscript. We respond to each one of your comments brought up. The manuscript has been updated accordingly.

Previously published information on the measurement data was not considered. This is one explanation for the errors in the presented discussion paper. In particular this concerns information on nearly the same data set and results derived from it in Wilbert, 2014 (see below).

REPLY:

We now refer to Wilbert (2014) where applicable.

Apparently there is one error that concerns the angles provided in SAM’s h files and the angles in the Aeronet almucantar files. In the almucantar files the angles are azimuthal angular deviations from the solar position. In the h files angular distances from the center of the sun are given. I assume from the text that Figure 1 was created under the assumption that both the Almucantar files and the h file contain angular distances from the center of the sun. This would explain why Figure 1 contradicts the calibration results from Wilbert, 2014. Another additional influence could be that you used a different version of the SAM cdf files created with different manufacturer calibration factors (please specify the file version you used). The good news is that this basically concerns Figure 1 and the conclusions, but not the rest of the calculations. Figure 6 corroborates results from Wilbert 2014. Fig. 6 is produced without using the incorrectly interpreted almucantar angles, but using the angles from Aeronet’s phase function files. The calibration from Wilbert, 2014 indicates that the deviation between libRadtran results and the SAM CSNI is basically a result of a calibration error of SAM’s aureole camera. In Wilbert, 2014 it was found that the Aeronet almucantar radiances are typically only 80% to 90% of the SAM’s radiance. This would mean that the Aeronet data can be used to accurately model circumsolar radiation with the selected libRadtran option. In your conclusion and at the end of the result section you rather give the impression that the errors of the Aeronet data are an important contribution to the deviation. The Aeronet data is of course not perfect, but with the discussion of the calibration errors you will find that you were looking in the wrong direction. The specific comments concerning this calibration topic are marked with * below.

REPLY (a):

You are correct. We have misread the angles reported with the AERONET almucantar radiance measurements as scattering angles. We have repeated the comparison, also following the recommendation of Reviewer #5 to average the angles on the east and west respect directions from the Sun.

CHANGES IN MANUSCRIPT:

The 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)."

REPLY (b):

It is a little difficult to compare with the figure in Wilbert (2014) because the comparison is performed in terms of ratio for different bins of the CSR. Besides it is not so clear either which SAM files were used in Wilbert (2014). In our case we used the files downloaded from the Visidyne ftp, where for the study period June 2012 to May 2013 the vast majority of SAM files [Sept. 2012, May 2013] used were the ones ending in _400v02_rev01.cdf. No files exist for August 2012. While those of July 2012 were ending in _400v02_.cdf and June 2012 were a mix of _400v02_.cdf and _.cdf.

For November 2012 our comparison results do agree quite well.

CHANGES IN MANUSCRIPT:

In the discussion the following is added:

"Other errors may in fact be due to the reference SAM measurements. For example, the monthly relative bias for November 2012 from the radiance measurements comparison (cf. Fig. 1) is +23%, where the SAM radiance measurements are overestimated in average with respect to the AERONET radiance measurements. This comparison for November agrees with the similar comparison performed by Wilbert (2014), and is partly explained by the broken entrance window of the SAM instrument. This would in turn induce a larger underestimation in this month."

This information has now been considered in the discussion, which now reads:

"When using the TTHG phase function determined from the AERONET measurements instead of the HG function, all statistical indicators show a very significant improvement. The scatter density plot for this case is exhibited in Fig. 6. The relative RMSE is 27%, the relative bias is −24% and R^2 is 0.882. The underestimation is nevertheless still non-negligible. This bias may partly originate from the phase function $P_{a,675\ \mathrm{nm}}(\xi)$ used as input. The aperture half-angle of the Sun photometer used in the AERONET stations is 0.6°, which is relatively large considering that the angular radius of the solar disc is 0.266° ± 1.7%, and that the circumsolar region in this context is defined up to 6°. In fact, for $\xi < 6°$ the AERONET $P_{a,675\ \mathrm{nm}}(\xi)$ is only provided at three ξ: 0°; 1.71°; and 3.93°. In addition, for the study area, $P_{a,675\ \mathrm{nm}}(\xi)$ at the first two ξ are assumed to be extrapolated values, because in the AERONET Version 2 Inversion products only almucantar radiance measurements for $\xi \geq 3.2°$ are considered (Holben et al., 2006). This is a limitation of using the AERONET $P_{a,675\ \mathrm{nm}}(\xi)$.

Other errors may in fact be due to the reference SAM measurements. For example, the monthly relative bias for November 2012 from the radiance measurements comparison (cf. Fig. 1) is +23%, where the SAM radiance measurements are overestimated in average with respect to the AERONET radiance measurements. This comparison for November agrees with the similar comparison performed by Wilbert (2014), and is partly explained by the broken entrance window of the SAM instrument. This would in turn induce a larger underestimation in the CSNI in this month.

Indeed, it is observed that the CSNI is underestimated in November 2012 by −39%. Other months exhibiting large underestimations in the estimated CSNI are October and December 2012, with a relative bias of −38% and −37% respectively. The remaining months have a bias ranging from −24% to −20% (excluding August 2012 and May 2013 which have no observations).

The residuals of the libRadtran and SAM monochromatic CSNI versus the AERONET $P_{a,675\ \mathrm{nm}}(\xi = 0°)$ are exhibited in Fig. 7 for the months of June, July, September 2012, and January, February, March, April, 2013, and Fig. 8 for the months of October, November, December 2012. Although the number of samples is relatively low for the AERONET $P_{a,675\ \mathrm{nm}}(\xi = 0°)$ with the sharpest peaks, it is evident that the underestimation is greater in the negative direction for the AERONET $P_{a,675\ \mathrm{nm}}(\xi = 0°)$ with the sharpest peaks. This observation supports the hypothesis that the AERONET $P_{a,675\ \mathrm{nm}}(\xi)$ might not be very accurate for the smallest ξ, especially for those with the sharpest peaks. It is also evident in Fig. 8 that the larger underestimation of October and December 2012 is due to the underestimation in the libRadtran monochromatic CSNI for the $P_{a,675\ \mathrm{nm}}$ with the sharper peaks. However, the same cannot be said for November 2012, because $P_{a,675\ \mathrm{nm}}(\xi = 0°)$ have relatively moderate values but the modelled libRadtran monochromatic CSNI generally exhibit a larger underestimation than other samples with similar values of $P_{a,675\ \mathrm{nm}}(\xi = 0°)$. Again this is due to an overestimation in the SAM radiance measurements for this month."

Another wrong conclusion concerns the assumed underestimation of AOD from Aeronet. For AOD measurements a calibration error will cause wrong irradiance measurements which then cause AOD errors. The error in irradiance is proportional to the calibration error. The error in vertical column AOD is not proportional to the calibration error. Hence, a linear correction of AOD data does not make sense. The deviation between Aeronet and SAM data is claimed to be caused by circumsolar radiation. This is only one contribution to the error. Also the data suggests that this is not likely, as the highest overestimations of AOD by Aeronet occur for low AOD. Correcting Aeronet data in the proposed way with an instrument that has a higher uncertainty is not acceptable. Furthermore, the SAM is calibrated with Aeronet data by the manufacturer so that the calibration of Aeronet data with the SAM does not make sense. The idea to use the SAM's disk camera calibration to reduce the effects of a wrong aureole camera calibration on the validation of RTM results is also not useful. The SAM's two cameras are calibrated independently. If possible you should repeat the RTM calculations with the original Aeronet data (see marker ** in specific comments).

REPLY:

We thank you, and the other reviewers, for shedding light on this point. In the revised manuscript we only compare SAM and AERONET AODs, no corrections or filtrations based on the uncertainties applied in the comparison. To remove possibly contaminated measurements, we have filtered out the coinciding samples if their difference is greater than three time the standard deviation of these differences. 150 pairs out of 5024 pairs of samples were excluded. The data sets, figures, text, and tables have been revised in the manuscript accordingly.

Another point brought to our attention by Reviewer #5 is that $\ln(\tau_{a,\lambda})$ versus $\ln(\lambda)$ is not necessarily linear under conditions where the fine mode pollution aerosol prevail. Therefore, in the revised text the following is the method to compute the AERONET reference AOD at 670 nm:

CHANGES IN MANUSCRIPT:

"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:

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

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 $\tau_{a,670\ \mathrm{nm}}$ is greater in average than the AERONET $\tau_{a,670\ \mathrm{nm}}$. 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 $\tau_{a,670\ \mathrm{nm}}$. 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."

Another example is that the entrance window of the SAM instrument was exchanged on November 23rd, 2012 because it was apparently damaged (Wilbert, 2014). This should be mentioned when discussing the temporal variation of the deviations between SAM, Aeronet and RTM results.

REPLY:

This is now mentioned in the text wherever applicable.

Other references that must be linked to the work are Reinhardt, 2013 and Reinhardt et al, 2014. There, libRadtran was used to derive sunshapes and circumsolar ratios.

CHANGES IN MANUSCRIPT:

We add the following in the introduction:

"Reinhardt (2013) and Reinhardt et al. (2014) use cirrus cloud properties derived from Meteosat satellite imagery to estimate the broadband circumsolar radiation by the use of look-up-tables established with the Monte Carlo radiative transfer solver available in libRadtran (Mayer and Kylling, 2005; Mayer et al., 2012)."

And the following in the conclusion:

"A further step may then be to integrate the model of Reinhardt (2013) and Reinhardt et al. (2014) to devise a model which works under both cloud-free and cirrus cloudy conditions."

Specific comments:

-7699, 1-3. This statement is misleading. WMO states a range of frequently used opening angles, but only one geometry is recommended. Please change to: TheWorld Meteorological Organization (WMO) recommends slope angles of 1° and aperture (or opening) half-angles of 2.5° for all new instrument designs, equivalent to solid angle apertures of 6 msr.

REPLY:

Text has been revised, but we do not mention the slope angle here, to avoid confusion to the reader in the first paragraph of the introduction.

CHANGES IN MANUSCRIPT:

“In modern instruments the aperture (or opening) half-angles range between 2.5° and 5°, respectively equivalent to solid angle apertures of 6 msr and 24 msr. The World Meteorological Organization (WMO) recommends that all new designs of DNI measuring instruments to have an aperture half-angle of 2.5° (WMO, 2010).”

-7699, 15: The term circumsolar contribution is defined as a specific parameter in Blanc et al 2014 and Wilbert, 2014. Please do not use the term for something else.

REPLY:

The term “circumsolar contribution” is no longer used.

-7700, 7: Comment to “not further specified”. The modifications of SMARTS are small and described in Wilbert et al., 2013: “The modifications of the SMARTS code allow the usage of user-defined values for the single scattering albedo, the asymmetry factor and Angström’s wavelength exponents aAng,1 and aAng,2 together with the selection of a phase function model.” More information on the processing is also published in Wilbert, 2014.

CHANGES IN MANUSCRIPT:

Text has been revised as:

“Wilbert (2014) and Wilbert et al. (2013) propose a method to convert the SAM monochromatic measurements of the profile of solar radiance to broadband profiles using a modified version of the radiative transfer model (RTM) SMARTS (Simple Model of the Atmospheric Radiative Transfer of Sunshine, Gueymard, 1995, 2001).”

-7700, 7: Please also mention that the method applies further modelling with the diffraction approximation for sunshapes measured when clouds mask the sun.

REPLY:

This provides too much details in the introduction. Those interested may refer to the applicable references.

-7701, 19: \xi is not the scattering angle, but the angular distance of the given point in the sky to the center of the sun.

REPLY:

ξ is now defined as "the angular distance from the center of the Sun".

-7703, 7: Please mention that more data is available now.

CHANGES IN MANUSCRIPT:

Text has been revised as:

"Coinciding AERONET and SAM measurements were performed from June 2012 to May 2013, the instruments are ~55 m apart and measurements are still ongoing."

-7706, 16: The data from the aureole camera close to the disk is not useable because of artifacts in the signal that are caused by the roughness of the screen (see Wilbert et al. 2013). This is not noise. Also the angular limit that you use is for the 300 series of the instrument and not for the 400 series. The screen of this 400 series is different from that of the 300 series.

REPLY:

We revised the text where applicable and update the validations to be in the interval [0.52°, 6°]:

CHANGES IN MANUSCRIPT:

"For the SAM 400 series, as the one in Masdar City, measurements from the aureole camera for $\xi < 0.52$ are discarded (Wilbert, 2014)."

-*7706, 22: The angles in the h files are the distance from the center of the sun. This is quite different from the angles in an almucantar file which are azimuthal deviations (see Tonna et al., 1995).

REPLY:

Thank you again for pointing this out. We have revised the manuscript accordingly as stated in our third reply from the top.

-7706, 26. Please clarify that the SAM OD file contains the particle optical depth, not the AOD. Explain that you can use this particle OD as AOD for clear sky cases which you filter out as explained in the following.

CHANGES IN MANUSCRIPT:

We revise the text as:

"The last file includes the particulate optical depth at 670 nm and θ_S. In this study the matching of AERONET and SAM data is only performed under cloud-free conditions, hence the particulate optical depth is basically $\tau_{a,670\ \mathrm{nm}}$."

-7707 –7708 points 1 and 3 to 5: These criteria are not quality criteria. Hence, the list should first of all have a different name, e.g. sort out criteria. Points 3-5 help to remove measurements during cloud passages. However, when clouds are present such measurement might be perfectly correct. Point 5 furthermore restricts your dataset to specific aerosol conditions. It is difficult to quantify how strict your criterion is. However, it is possible that two very different slopes occur in a sunshape if a particle mixture with particles of different sizes is present. Please discuss the effect of these sort out criteria.

REPLY:

We understand your point and we partly agree. Actually, what we did is to set up a series of tests that permit to retain the high quality measurements. Some tests are more general than the others, some are maybe specific to our work.

CHANGES IN MANUSCRIPT:

We have softened the tone and changed the text from

"Therefore, a set of quality control procedures are defined herein to retain only the high quality measurements:"

into

"A series of tests have been applied herein to retain only the high quality measurements and possibly remove cloud-contaminated ones:"

We also changed the text in the Conclusion (Page 7721 – Line 20) from

"This article presents several tests that may contribute to a well-accepted quality control procedure."

into

"Several elements were developed here that may further contribute to a quality control procedure, whose design requires more work."

-*7708, 19: Please describe in more detail how you derived the SAM radiances for the Aeronet radiances. This could clarify the deviation of the results from Fig. 1 on the one hand and and Fig. 6 and Wilbert, 2014 on the other hand.

REPLY:

Covered in our third reply from the top.

-7709, 4: Please add the distance between the two instruments for both positions of the SAM.

REPLY:

~55 m. It has been added in the text, we refer you to our third reply from the top.

-7709, 5: Here you should also discuss the calibration results from Wilbert, 2014.

REPLY:

Added in the discussion, again we refer you to our third reply from the top.

-*7709, 5: Please explain which data set you used in more detail.

REPLY:

This data set is now clearly described, see the revised text from our third reply from the top. We do not give it an acronym though, that is to avoid any confusions since we do not used this data set in the validations.

-**7710, 2. Why should one perform a correction of the AOD as a linear fit in AOD? Calibration errors affect the irradiance and are hence not linear in vertical column AOD.

REPLY:

No more correction to AOD in the study.

-**7710, 9: Change “is due to the field of view” to “is partially due to the field of view“. You do not at all investigate other effects that might cause errors of both AOD data. Calibration errors are typically the most important ones and hence a comparison should be based on irradiance. Another interesting aspect is that errors due to circumsolar radiation would be higher for high slant AODs. It is not completely straight forward to see in your graph, but I see the highest overestimation for low AOD <0.2. This indicates that your conclusion is wrong. Please add a discussion of other errors or remove the section on the AOD comparison as this is irrelevant for your RTM validations. The SAM OD is not relevant for the SAM’s aureole measurements.

REPLY:

Comparison has been updated, please refer to the fourth reply from the top.

-7711, 16. Clarify if DS1 is the dataset with the AOD “correction”.

REPLY:

DS1 is the one used for the AOD comparisons, no more correction.

CHANGES IN MANUSCRIPT:

This is stated in the revised text:

“data set 1, abbreviated as DS1, already used in Fig. 2 for the AOD comparison. It comprises 4874 observations of the SAM beam and circumsolar radiance measurements along with their corresponding AERONET $\tau_{a,\lambda}$ and total column content in water vapor, extracted from the DSA Level 2.0 product. There is no data for August 2012 and May 2013. The number of samples varies from a minimum of 102 in July 2012 to a maximum of 809 achieved in September 2012. DS1 is used in the following when modelling the monochromatic $\mathrm{DNI_S}$ with the RTMs;”

-7712, 10. Here would be a place to discuss the differences between your version of libradtran and the one used by Reinhardt, 2013. Also, Reinhardt, 2013 and Reinhardt et al 2014 should be discussed in more detail in the introduction and/or the theoretical back ground.

CHANGES IN MANUSCRIPT:

We add the following text:

“It is worth noting that Monte Carlo radiative transfer solver MYSTIC is also available in libRadtran, and was used by Reinhardt (2013) and Reinhardt et al. (2014). It has several advantages over the DISORT solver: it assumes 3-D geometry, it assumes the Sun is an extended source with a finite diameter, and it more accurately handles the phase functions with extremely sharp peaks. However, in the public version of libRadtran the MYSTIC solver assumes 1-D geometry, and assumes the Sun as a Dirac function. Moreover, it can only compute the radiance at one viewing direction at a time, whereas DISORT can model the radiance at multiple directions using one input file. Besides, the DISORT solver is significantly faster than the MYSTIC solver. Finally, the modelling of the radiance when using a desert aerosol model is practically the same from the MYSTIC and DISORT solvers, the same is not true though under cirrus cloud conditions (Reinhardt, 2013). Therefore, in this work DISORT was the selected solver when using libRadtran.”

-7715, 17 – 21: Clarify that you only describe other options that are available in libRadtran.

REPLY:

We do not understand what is meant by the Reviewer.

-7716, 18. Do you derive the AOD from the Angström coefficients and AOD at 670nm? If you apply the “correction” from Eq. 10 to the AOD for 500nm this is not ok. Or did you apply your correction to the AOD at 670nm and then applied the Angström coefficients? In the latter case the AOD you specify in SMARTS and libradtran at 670nm is the same and your discussion (7717, 23) doesn’t make sense to me.

REPLY:

No more corrections. Also, for the SMARTS inputs we are now providing the AERONET AOD at 500 nm directly, that is to avoid any errors we may induced by computing the 550 nm, which will then be scaled again in SMARTS to 670 nm. The input of AOD 500 nm to SMARTS has been updated in the text wherever applicable.

-7717, 18: Here, in table 1 and in figures 4 and 5 you should specify the bias with one digit after the comma. Otherwise it is hard to follow your discussion between the two biases of 1%.

REPLY:

The relative values are rounded in the whole text because one digit does not bring more information. Because we have updated the comparison, SMARTS and libRadtran do not show the same relative bias for the updated datasets with no AOD correction. For DNI_S, SMARTS exhibits a relative bias of −1% and that from libRadtran is +2%.

-7718, 5: The SAM's window was exchanged in November 2012 (see Wilbert, 2014).

REPLY:

Mentioned whenever applicable, see our third reply from the top.

-7718, 21. No. You can also specify AOD at 1000nm, meteorological range and prevailing visibility.

REPLY:

The discussion here is on AOD only.

CHANGES IN MANUSCRIPT:

The text has been revised as:

"One is that SMARTS does not give the flexibility to input $\tau_{a,\lambda}$ at a user-defined wavelength except at 500 nm, 550 nm or 1000 nm (although compensated for by the Ångström exponents), whereas this flexibility is available in libRadtran."

-*7719, 22. No. The angles in the almucantar files are azimuthal deviations from the solar position. Hence, 3° at solar zenith angle of 40° results in an angular distance of 1.9° from the center of the sun. (see Tonna et al., 1995).

REPLY:

Again you are right. But in the AERONET Version 2 Inversion products only almucantar radiance measurements for $\xi \geq 3.2°$ are considered.

CHANGES IN MANUSCRIPT:

We add the following text:

"in the AERONET Version 2 Inversion products only almucantar radiance measurements for $\xi \geq 3.2°$ are considered (Holben et al., 2006)"

-7719, 25. Discuss the change of SAM's entrance window

REPLY:

Done.

-*7719, 20 The accuracy of the manufacturer's aureole calibration must appear much earlier in the discussion.

REPLY:

We prefer to keep in its locations. We discuss possible sources of errors and then at the end we mention that even with all these possible errors the validations are still good, considering the uncertainty in the SAM aureole measurements.

-7721, 21. It seems to be exaggerated to call your sort out a quality check as only one of the tests is a quality check.

REPLY:

We changed the text in the Conclusion (Page 7721 – Line 20) from

"This article presents several tests that may contribute to a well-accepted quality control procedure."

into

"Several elements were developed here that may further contribute to a quality control procedure, whose design requires more work."

-**7721, 24-26: The conclusion concerning the sun photometers field of view is wrong.

REPLY:

Removed from conclusion. No more correction, the text in the manuscript has been revised accordingly.

-7722, 8: Discuss that your next step would be to apply the model to broadband clear sky data. Then the work must be extended to all sky conditions e.g. following the approach by Reinhardt, 2013, and Reinhardt et al. 2014.

CHANGES IN MANUSCRIPT:

The last paragraph of the conclusion now reads:

"The next step is to apply this approach to model the broadband DNI_S and CSNI. This would directly contribute to the recommendation of Blanc et al. (2014) to report the sunshape and circumsolar ratio with the standard DNI measurements. A further step may then be to integrate the model of Reinhardt (2013) and Reinhardt et al. (2014) to devise a model which works under both cloud-free and cirrus cloudy conditions."

-7722, 8: Furthermore, it should be noted that you did not investigate at all what happens in the region from the solar disk angle to 0.62°. So your conclusions must always be given stating the angular restriction. Here, your argument about extrapolation of the Aeronet data for the derivation of the phase functions to small scattering angles has to be included in the discussion.

REPLY:

The angular limits of the monochromatic CSNI validations of this study are clearly stated throughout the manuscript.

We prefer not to go into too much details in the future studies appearing in the final paragraph of the conclusion.

-7729: Figure 1: The part of the dataset from Figure 6 that overlaps with Almucantars should be shown in the same way as Figure 1.

REPLY:

We do not understand what is meant by the Reviewer.

-7733: Did you use Desert_Max or the User option for the graph?

REPLY:

User defined for this graph.

CHANGES IN MANUSCRIPT:

To clarify, the last paragraph in Sect. 6.2 now reads:

"When using the user-defined aerosol model in SMARTS, it requires the broadband asymmetry parameter and the broadband aerosol single scattering albedo, but such broadband values were not available. Therefore, to model the monochromatic CSNI $g_{675\ \mathrm{nm}}$ was used from data set DS2, and to model the monochromatic DNI$_{\mathrm{S}}$ the mean value of $g_{675\ \mathrm{nm}}$ from the AERONET data was used. In both cases the mean value of $\omega_{a,675\ \mathrm{nm}}$ was used. Also, it is not possible to specify $P_{a,\lambda}(\xi)$ in the SMARTS version 2.9.5 which is automatically selected from tables when selecting the aerosol model."

Technical corrections

-7700, 3: (state the date of last visit)

REPLY:

Done.

-7700, 17: New line after CSNI.

REPLY:

Done.

-7703, 9: Change AOD -> vertical column AOD to avoid confusion.

REPLY:

Done.

-7704, 12: changes: between 8% and -> from 8% to; 491 from -> 491 of

REPLY:

This comment is not too clear. The text looks fine.

-7704, 14: Add full stop after 2012.

REPLY:

Done.

-7704, 16: add “a” between offer and statistically

REPLY:

Text modified to:

“The five remaining months offer larger numbers of samples.”

-7704, 17 - 19: Change: If an atmosphere containing aerosols only is assumed, Eq. (4) becomes “EQ 6” since the aerosol optical properties contributes the most to the radiance for clear sky conditions (Dubovik and King, 2000)

REPLY:

These Eqs. have been removed from the text.

CHANGES IN MANUSCRIPT:

The revised analysis now reads:

“Table 1 presents the mean, minimum, maximum and standard deviation of $\tau_{a,675\text{ nm}}$, $\omega_{a,675\text{ nm}}$ and $P_{a,675\text{ nm}}(\xi)$ for both the 1068 samples (excluding $\omega_{a,675\text{ nm}}$) and the 491 samples. These statistics are presented for $P_{a,675\text{ nm}}(\xi)$ for the three ξ smaller than 6° reported in the AERONET Version 2 Inversion product, i.e. 0°, 1.71°, and 3.93°.

The relative standard deviation of $\tau_{a,675\text{ nm}}$ for the 1068 samples is very large at 69% of the mean value, indicating its great temporal variability and its significance in modelling both the monochromatic DNI_S and diffuse radiance. The relative standard deviation of $P_{a,675\text{ nm}}(\xi)$ is also large, ranging between 18% and 24% for the three smallest ξ for the 1068 samples, again implying its significance in modelling the diffuse radiance.

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 $\omega_{a,675\text{ nm}}$. However, this is a rare situation. Indeed, 67% of the $\omega_{a,675\text{ nm}}$ samples lie within the mean ± 1 standard deviation and 96% lie within the mean ± 2 standard deviations.”

-7709, 25 & 27: Replace accuracy with uncertainty

REPLY:

This text no longer appears in the manuscript.

-7713, 6: change final CSNI to “finally investigated CSNI”

REPLY:

Done.

-7735: Use different plot method to increase readability.

REPLY:

The figure has been split in to two separate figures, one showing Oct to Dec 2012, and another for the rest of the months. Crosses are now used in both figures.

References

R. Reinhardt. 2013. On the retrieval of circumsolar radiation from satellite observations and weather model output. PhD thesis, LMU München.

Reinhardt, B., R. Buras, L. Bugliaro, S. Wilbert, and B. Mayer. 2014. "Determination of circumsolar radiation from Meteosat Second Generation." Atmos. Meas. Tech. no. 7 (3):823-838. doi: 10.5194/amt-7-823-2014.

G. Tonna, T. Nakajima, and R. Rao. Aerosol features retrieved from solar aureole data: a simulation study concerning a turbid atmosphere. Applied Optics, 34(21):4486{4499, 1995.

S. Wilbert. 2014. Determination of Circumsolar Radiation and its Effect on Concentrating Solar Power. PhD thesis, Fakultät für Maschinenwesen, Rheinisch-Westfälische Technische Hochschule Aachen, DLR.

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