ATMD-2019-467

Interactive comment on "Characterization of an EKO MS-711 spectroradiometer: aerosol retrieval from spectral direct irradiance measurements and corrections of the circumsolar radiation" by Rosa Delia García-Cabrera et al.

Referee #2

The current work presents AOD retrievals form EKO MS-711, compared with CIMEL retrievals at Izaña Observatory and most importantly proposes an approach to correct DNI in respect to different FOV of the instruments using CSR. The paper fits perfectly the purposes of AMT and the proposed correction could find greater use in a number of instruments. Details of the approach are well presented and described sufficient in order to be repeatable. Results presented fortify the validity of the approach and are a guide for future studies of other spectroradiometers. The structure of the presentation is very steady and bibliographical review of the subject is more than sufficient. I suggest the acceptance of the article for publication at AMT, after some minor corrections and clarifications.

Authors: We acknowledge the referee's positive and constructive comments. Below we respond to his/her general comments.

General Comments:

More specifically

L22. This sentence seems a little poor and inadequate. I suggest to restate.

Authors: We have modified the sentence as follows:

> *"One of the most important elements that governs the Earth's climate, and its processes, is the presence of atmospheric aerosols, **which produce a significant radiative forcing resulting from light scattering and absorption, and radiation emission. Moreover, they act as cloud condensation nuclei, modifying cloud properties (IPCC, 2013).** Aerosols effect on the Earth Radiation Balance has been quantified as a cooling of -0.45 W m^{-2}, and -0.9 W m^{-2} when considering the combined effect of both aerosols and clouds…"*

Paragraph 2.2 1) I think some information on the measuring schedule should be added. 2) There is one spectral per minute or they are multiple spectra averaged and stored per minute? 3) Exposure time is steady or it is changed according to the intensity of the irradiance? 4) Are there oversaturation problems? 5) Are there any filters used?

Authors:

1) and 2) The EKO MS-711 spectroradiometer measures one spectrum per minute.

3) The exposure time is not constant. The setting changes automatically according to the intensity of the irradiance, and varies from 10 ms to 5 s.

4) As a result of the optimized exposure time for the irradiance and the instrument measurement dynamic range, no saturated measurements are experienced.

5) This instrument does not use filters.

Followings the recommendations of the referee, we have added this information as follows:

Section 2.2

> *"An EKO MS-711 **grating** spectroradiometer used in direct sun measurement mode has been tested (Figure 1) within the CIMO Testbed program from April to September 2019 (14706 datapoints) …"*
> *"…This spectroradiometer has been mounted on an EKO sun-tracker STR-21G-S2 (accuracy of <0.01°). **This setup performs one spectrum per minute, with an exposure time that changes automatically according to the intensity of the irradiance that varies from 10 ms to 5 s.** The main specifications of the EKO MS-711 spectroradiometer are shown in Table 1…"*

L105 Level 1.5 are automatic cloud screening and the quality assured data are L2.0. Please restate to be clear.

Authors: The authors have not used Level 2.0 because it is not available for the study period (April and September 2019) in AERONET. We have modified the sentence as follows:

> ***"…In this study, we have used AERONET Version 3.0 Level 1.5 AOD data…"***

L155 Have you used O3 in the calculations? There is nothing about it and at least for 340nm is important. If you have not calculated ozone absorption probably it could explain a part of the differences at 340 nm.

Authors: Yes. We have taken into account ozone column in the AOD retrievals at 340, 500 and 675 nm (see Table 2 of the manuscript). The ozone values used have been measured with a reference double Brewer spectroradiometer at Izaña station, therefore it does not explain the differences found at 340 nm.

This information is given in the Section 3.1, however, the authors have added this information in the Section 3.2 as follows:

> *"…In this work, we have calculated the EKO AOD at the same nominal wavelengths as those of the Cimel (340, 380, 440, 500, 675 and 870 nm) following the methodology used by AERONET (Holben et al. (2001); Giles et al. (2019), and references herein). **For each wavelength**, we have taken into account the spectral corrections shown in Table 2. **All wavelengths have been corrected by the Rayleigh scattering (see Sect. 3.1). Furthermore** the 340, 380, 440 and 500 nm are corrected from nitrogen dioxide (NO_2) absorption, being the optical depth calculated using the OMI total column NO_2 climatological monthly averages, and the NO_2 absorption coefficient from Burrows et al. (1999).**The 340, 500 and 675 nm channels are corrected of ozone, using the ozone values from the Izaña WMO-GAW reference Brewer spectroradiometer..."***

L166-167 Please restate this sentence because it is not clear.

Authors: We have modified the sentence as follows:

*"... This CSR has a high dependence **on the particle size (Räisänen and Lindfors, 2019), thus large particles (such as desert dust) produce a higher scattering on the incident beam than the smaller particles (e.g., rural background aerosols), leading this contribution to overestimate the DNI..."***

Paragraph 3.2 The measured spectrum has a resolution of 0.4nm with FWHM of 7 nm. When referring to monochromatic retrievals of AOD, have you used just one channel(which?) or do you have convoluted multiple channels to a slit function? Please clarify this because it is crucial for understanding the differences with AERONET. For example lines 293-295 confused me on this matter. Also, I think it should be cleared if there any other difference with AERONET calculations (air masses, Rayleigh etc).

<u>Authors:</u> For determining the AOD with the EKO MS-711 spectroradiometer, we have considered the same nominal wavelengths and bandwidths (Filter Bandpass) as those of the Cimel (340: 2 nm, 380: 4 nm, 440: 5 nm, 500: 5 nm, 675: 5 nm and 870: 5 nm) as indicated on Table 2 of the manuscript. Centred on each wavelength and with its corresponding bandwidth, we have performed the integration of the irradiance on the considered spectral range. For example, in the AOD retrieval at 500 nm, the range 495-505 nm is used to perform the integration:

$$DNI(\lambda) = \int_{495\ nm}^{505\ nm} DNI(\lambda)_{EKO-MS711} d\lambda$$

This integrated value is the one used in equations of paragraph 3.2.

We have modified this paragraph as follows:

*"...In this work, we have calculated the EKO AOD at the same nominal wavelengths as those of the Cimel (340, 380, 440, 500, 675 and 870 nm), **by integrating the measured irradiance on the considered bandpass (see Table 2),** following the methodology used by AERONET (Holben et al. (2001); Giles et al. (2019), and references herein). **For each wavelength**, we have taken into account the spectral corrections shown in Table 2. **All wavelengths have been corrected by the Rayleigh scattering (see Sect. 3.1). Furthermore** the 340, 380, 440 and 500 nm channels have been corrected from nitrogen dioxide (NO_2) absorption, being its optical depth calculated using the OMI total column NO_2 climatological monthly averages, and the NO_2 absorption coefficient from Burrows et al. (1999). **The 340, 500 and 675 nm channels have been corrected of ozone, using the ozone values from a GAW reference Brewer spectroradiometer sited at Izaña Observatory..."***

Regarding the Lines 293-295, maybe the confusion arises in the sentence "some additional radiation contribution from the adjacent wavelengths". The considered range on each channel are those explained before and, in the paragraph, we tried to highlight that for the UV channels the contribution of the stray-light is important, therefore we have modified the paragraph as follows:

*"...Since the 340 nm and 380 nm channels have 2 nm and 4 nm bandpass, respectively, and the EKO MS-711 FWHM is 7nm (Table 1), these two UV channels have some additional radiation contribution from the adjacent wavelengths **due to stray-light**, increasing their uncertainty and causing an AOD overestimation..."*

The equations of air masses and optical depths used are the same to those used by AERONET, and they have been included in the final manuscript.

L248 There is no equation 15 in the manuscript

Authors: Thank you. The equation of the CR has been added in the final manuscript as follows:

$$CR(\%) = \frac{CSR}{DNI_{SUN} + CSR} \cdot 100$$

Paragraph 3.4 I understand that dust aerosols are the main in Izaña, but I think it is important to add some discussion of potential differences for other aerosol types.

Authors: We have only used dust since at Izaña Observatory only two very contrasting situations are normally present: clean atmosphere with almost no aerosols, or dusty conditions under Saharan intrusions, mainly in summer. So, the correction factor has been specifically determined for dust aerosol.

Any way, we have included in the paper the following information from LibRadtran simulations that can be used for other types of aerosols. Apart from the graph, we have included in the Appendix B, a table with simulated CR values as a function of AOD for different types of aerosols.

We have added this information in the final manuscript as follows:

> ***"… These results have been simulated considering the typical conditions of IZO where mineral dust is practically the only aerosol present (Berjón et al., 2019; García et al., 2017). Simulations of the effect on CR of the eight OPAC mixture aerosols available in LibRadtran model, continental (clean, average and polluted), urban, maritime (clean, polluted and tropical) and desert aerosols (Hess et al., 1998), and for a FOV=5°, are shown in Figure 6. For SZA=30°, with an AOD_{500nm} range between 0 and 2 at sea level, two defined groups are distinguished: the continental and urban aerosol mixtures, and the maritime and desert dust mixtures. It should be noted that for stations located in urban or continental (clean and contaminated) environments, which are the majority, the correction that would have to be made to the AOD for a very high aerosol load (e.g., AOD = 1) would be much lower, between 1/3 to 1/6, than the correction that would have been performed in the case of dust aerosol. (Figure 6 and Appendix B) …"***

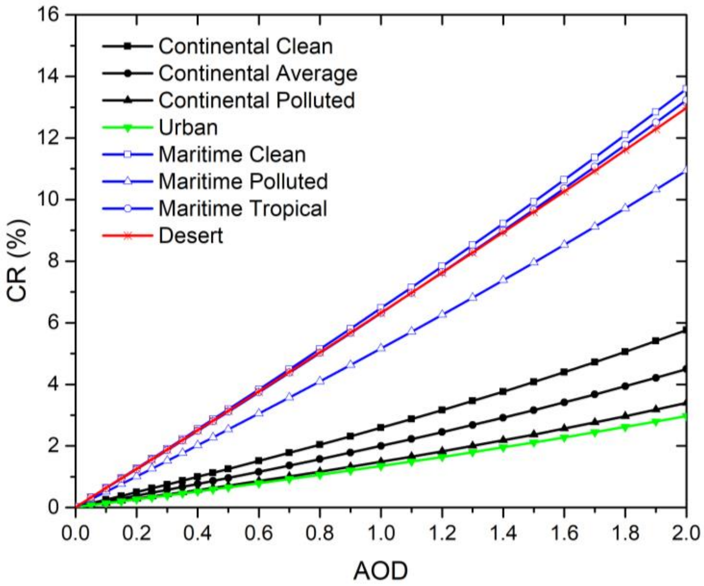

Figure 6. Simulations of CR (%) for SZA 30° at sea level for AOD values between 0 and 2, at 500 nm, for different types of aerosols for FOV of 5°.

The following references have been added:

Berjón, A., Barreto, A., Hernández, Y., Yela, M., Toledano, C., and Cuevas, E.: A 10-year characterization of the Saharan Air Layer lidar ratio in the subtropical North Atlantic, Atmos. Chem. Phys., 19, 6331-6349, https://doi.org/10.5194/acp-19-6331-2019, 2019.

García, M. I., Rodríguez, S., and Alastuey, A.: Impact of North America on the aerosol composition in the North Atlantic free troposphere, Atmos. Chem. Phys., 17, 7387-7404, https://doi.org/10.5194/acp-17-7387-2017, 2017.

Hess, M., Koepke, P., and Schult, I.: Optical properties of aerosols and clouds: The software package OPAC, B. Am. Meteorol. Soc., 80, 831–844, 1998.

We have added the following table in the Appendix B with the numbers plotted in Figure 6.

(Table of Appendix B) ***Numerical values of the CR (%) simulations for SZA 30° at sea level for AOD values between 0 and 2, at 500 nm, for different types of aerosols for FOV of 5°.***

AOD	Continental Clean CR (%)	Continental Average CR (%)	Continental Polluted CR (%)	Urban CR (%)	Maritime Clean CR (%)	Maritime Polluted CR (%)	Maritime Tropical CR (%)	Desert CR (%)
0.1	0.3	0.2	0.1	0.1	0.6	0.5	0.6	0.6
0.2	0.5	0.4	0.3	0.3	1.3	1.0	1.2	1.3
0.3	0.7	0.6	0.4	0.4	1.9	1.5	1.9	1.9
0.4	1.0	0.8	0.6	0.5	2.5	2.0	2.5	2.5
0.5	1.3	1.0	0.7	0.7	3.2	2.5	3.1	3.1
0.6	1.5	1.2	0.9	0.8	3.8	3.1	3.7	3.8
0.7	1.8	1.4	1.0	0.9	4.5	3.6	4.4	4.4
0.8	2.0	1.6	1.2	1.1	5.1	4.1	5.0	5.0
0.9	2.3	1.8	1.3	1.2	5.8	4.6	5.7	5.7

1	**2.6**	**2.0**	**1.5**	**1.3**	**6.5**	**5.2**	**6.3**	**6.3**
1.1	**2.9**	**2.2**	**1.7**	**1.5**	**7.1**	**5.7**	**7.0**	**7.0**
1.2	**3.2**	**2.4**	**1.8**	**1.6**	**7.8**	**6.3**	**7.6**	**7.6**
1.3	**3.5**	**2.7**	**2.0**	**1.8**	**8.5**	**6.8**	**8.3**	**8.3**
1.4	**3.8**	**2.9**	**2.2**	**2.0**	**9.2**	**7.4**	**9.0**	**8.9**
1.5	**4.1**	**3.2**	**2.4**	**2.1**	**9.9**	**8.0**	**9.7**	**9.6**
1.6	**4.4**	**3.4**	**2.6**	**2.3**	**10.6**	**8.5**	**10.4**	**10.3**
1.7	**4.7**	**3.7**	**2.8**	**2.4**	**11.4**	**9.1**	**11.1**	**10.9**
1.8	**5.1**	**3.9**	**3.0**	**2.6**	**12.1**	**9.7**	**11.8**	**11.6**
1.9	**5.4**	**4.2**	**3.2**	**2.8**	**12.8**	**10.3**	**12.5**	**12.3**
2	**5.8**	**4.5**	**3.4**	**3.0**	**13.6**	**10.9**	**13.2**	**13.0**

Table 4. There is typo and all columns seem to be uncorrected.

Authors: Done. The final table is the following:

Wavelength (nm)	*R*		*Slope*		*RMS*		*MB*	
	CSR Unc.	***CSR Corr.***	***CSR Unc.***	***CSR Corr.***	***CSR Unc.***	***CSR Corr.***	***CSR Unc.***	***CSR Corr.***
340 nm	*0.960*	*0.973*	*1.063*	*0.994*	*0.017 (28.9%)*	*0.007 (16.9%)*	*0.015 (24.5%)*	*<0.001 (-1.4%)*
380 nm	*0.981*	*0.986*	*1.071*	*1.001*	*0.009 (20.2%)*	*0.005 (12.9%)*	*0.007 (14.8%)*	*<0.001 (1.2%)*
UV-Range	*0.971*	*0.979*	*1.067*	*0.997*	*0.013 (24.6%)*	*0.006 (14.9%)*	*0.011 (19.7%)*	*<0.001 (1.3%)*
440 nm	*0.984*	*0.987*	*1.041*	*0.997*	*0.101 (22.4%)*	*0.005 (13.5%)*	*0.009 (18.7%)*	*0.001 (0.6%)*
500 nm	*0.988*	*0.991*	*1.075*	*1.018*	*0.007 (18.2%)*	*0.005 (12.9%)*	*0.004 (12.1%)*	*0.002 (0.4%)*
675 nm	*0.989*	*0.991*	*1.057*	*1.013*	*0.006 (19.7%)*	*0.006 (10.7%)*	*0.003 (11.2%)*	*<0.001 (0.5%)*
870 nm	*0.998*	*0.999*	*1.039*	*1.009*	*0.004 (18.8%)*	*0.003 (7.3%)*	*<0.001 (0.3%)*	*<0.001 (0.2%)*
VIS-Range	*0.989*	*0.992*	*1.053*	*1.009*	*0.029 (19.5%)*	*0.005 (11.1%)*	*0.004 (10.6%)*	*<0.001 (0.4%)*

***Table 4**. Statistics of the comparison between EKO AOD, with no CSR corrections **(CSR Unc.)** and implementing CSR corrections **(CSR Corr.)**, and Cimel AOD at 340, 380, 440, 500, 675 and 870 nm at IZO between April and September 2019. R: correlation coefficient, slope of the least-squares fit between EKO AOD and Cimel AOD, RMS: root mean square of the bias and MB: mean bias. The results of the relative bias are in brackets (in %).*

L296-298. Please refer the number of datapoints used for each of the two periods.

Authors: We have added the number of datapoints used for each of the two periods as follows:

> *"… The linear AOD-correction equations were determined by using data measured from April 1st to July 31th 2019 **(69% of the data)** at Izaña Observatory (Table 5). The validation of these linear AOD-correction equations was performed using an independent period of data (between August 1st and September 30th 2019) **(31% of the data)**…"*

L.3131 Also refer the number of data with AOD>0.1

Authors: *We have added the number of AOD>0.1 as follows:*

> *"When focusing the analysis on relatively high AOD (AOD> 0.10), we found that the percentage of AOD differences out of the WMO U_{95} limits were ≈ 3.5% (**0.8% of de data**) at 380 nm and 0.6% (**0.3% of the data**) at 870 nm…"*