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Interactive Comment

Interactive comment on "Improving the solar zenith angle dependence of broadband UV radiometers calibration" *by* M. L. Cancillo et al.

M. L. Cancillo et al.

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We thank the referee for his comments and suggestions which helped us to improve the paper.

RC– *Referee comment*

RES– Our response

Page and line numbers are referred to the previous version of the paper.

With reference to the general comments we would point out these aspects:

RC–*In the paper two different calibration methods are distinguished: the one step and the two step method. In the later all the specific properties of the radiometer are directly taken into account. Next to the absolute calibration factor, the spectral and the angular* *response functions are obtained. From the former a conversion function, f, is derived which is a function of both, the solar zenith angle and the total ozone column. The second is used to calculate another correction function, coscor, which accounts for the imperfection of the angular response. This calibration method is recommended and gives the lowest uncertainties. In the one step method first only the absolute calibration factor is obtained. Further on the variability of C during the calibration period is studied. In the past the variability of the calibration factor was neglected. However, several one-step-attempts to treat this variability have been published, as stated in the paper. One described approach is, to run first a regression analysis over the data, to derive additional coefficients (C1 and C2) and to convert the data using a second order polynomial. This mathematical solution does of course neglect the physical reason behind the variability of C. A further development of this method is to explicitly account for the strong diurnal dependence on the solar zenith angle by introducing the cosine function into the regression analysis. This method is the new calibration method, called angular method presented by the authors.*

RES–The new one-step method proposed in this paper (angular method) doesn't try to be an alternative to the two-steps method but a significant improvement of the widely used one-step methodology. Although the two-steps method is the only one that takes into account explicitly all the factors that have an influence on the calibration function (total ozone, solar zenith angle, cloud amount, ...) nowadays the majority of broadband radiometers are still calibrated using a one-step method. One main reason for not using the more suitable two-step method is that it needs the spectral response of each instrument and this can only be provided by a well characterized laboratory that, nowadays is not available to the great majority of broadband instruments. Accordingly, the new method proposed means a notable improvement to the one-step methods used previously and, from a practical point of view, has a significant value.

RC– *For the test of the new calibration method three broadband radiometers where used;all three are radiometers from Scintec. One of the advantages of these instru-*

ments is their nearly ideal cosine response. In addition the deviation from the spectral response function to the erythemal weighting functions lead to a very low dependence of the conversion function f on the solar zenith angle and thus, the dependence of the absolute calibration factor on the solar zenith angle is very small. Using these instruments for the validation of the new angular method is therefore the weakest possible test of the method. To illustrate the usability of the new calibration approach a validation with data from the widely used Yankee UVB-1 and Solar Light 501 radiometer is needed. It is likely that the proposed advantage of the angular method will vanish during these tests. Data from these instruments should be available from either the calibration campaign in the year 2005 or 2007.

RES–The proposed new methodology was applied to three Scintec-Kipp & Zonen broadband radiometers which were the instruments belonging to our research group. All our three radiometers were used in order to account for differences between the individual instruments. We agree with the referee that in the future it could be very interesting to validate the performance of the proposed improved one-step method also with other broadband radiometers' families, such as Yankee or Solar Light.

RC– *The variability of the total ozone column during the test period is given with +-25 DU. This covers only 48% of the usual days at the measurement side. The transferability of the calibration to measurements under different ozone conditions is not discussed.*

RES– It is true that the total ozone column values range from 255 DU to 312 DU and this interval doesn't cover all possible values. However, this is the usual situation in all the calibration campaigns because they have a limited duration (a few weeks). In a future work, we plan to study the dependence of the calibration coefficients of our model with total ozone values measured during a longer period. Indeed, this is a general limitation intrinsic to any calibration campaign: since they are performed during a short period of time, not all atmospheric conditions are represented. However, our calibration campaign lasted 27 days, which is much longer that intercomparison periods in usual

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campaigns. Additionally, it was performed in October, when the atmosphere is very variable and covers very different conditions regarding ozone amount and cloudiness. To cover the 48% of the whole range of ozone values with only 27 days confirms the suitability of this period of the year for a calibration campaign.

RC– *No information and discussion is given on the atmospheric conditions (cloud amount).*

RES– In the intercomparison campaign carried out in 2005, no ground instrument to measure cloud amount was available. The campaign lasted for 27 days and different cloud conditions occured. Considering the reflectivity data given by TOMS instrument as an indicator of atmospheric conditions, 14 days were clear (reflectivity$<$10%), and 13 were cloudy, of which 6 had reflectivity between 10% and 30%, 2 between 30% and 50% and 5 higher than 50%

This comment has been included in Section 2, page 17877, line 11.

RC– *The transferability of the calibration coefficients, which are strongly influenced by the specific situation present at the calibration period, will always be a major problem with the presented calibration method, because the obtained calibration factors strongly depend on the conditions of the calibration period used for the regression analysis.This is the reason why the two step method has been developed.*

RES– As mentioned before, the atmospheric situations occurred during the duration of a calibration campaign influence the coefficients obtained and limit their usability. This is a general limitation intrinsic to any calibration campaign based on outdoors intercomparison. Therefore, our calibration campaign was held in October (variable atmospheric conditions for the calibration site), in order to account for as many different atmospheric conditions as possible. Although the dependence exists, the new proposed method means an interesting improvement to the other one-step methods, which are also based on specific calibration campaigns and, therefore, also suffer from the mentioned limitation. In order to extend the range of atmospheric situations, the two-step method uses radiation transfer models. This is a different approach which has also its particular drawbacks: dependence on the specific radiation transfer code used, initial values given to the large number of variables needed to run the model, etc. However, it must be noted again that the proposed new method doesn't attempt to be an alternative to the two-step method, but a very interesting improvement to the one-step methodology. This methodology is still the most widely used method for calibrating broadband radiometers since the two-step methodology requires information that is usually not available. In this sense, the new proposed method still suffer from the dependence on range of atmospheric situations occurred during the campaign, but highly improves the one-step methodology mainly for the solar zenith angle dependence.

RC– *An "mathematical" approach cannot identify the intrinsic properties of the radiometers in test and can therefore only conceal the imperfection of the measurements instead of the careful treatment provided by the two step method. One can conclude that the angular method is probably only useful to convert data for instruments with a negligible cosine error and a very small dependence of the conversion function on the SZA and TO3. The only advantage of the proposed method is that no spectral and angular response of the radiometer must be obtained.*

RES– We agree with the referee that the angular method can't identify the intrinsic properties of the radiometers as the two-step method does. However, the advantage mentioned by the referee of our new proposed method concerning the no need of measuring the spectral and angular response is such important that the great majority of the broadband UV radiometers are nowadays calibrated using a one-step method. The main reason of this fact is the non availability of the spectral and angular response of the radiometers, that can only be measured by a few well equipped laboratories. In this sense, even being a "mathematical" approach, the improvement of the one-step methodology is a valuable contribution.

RC– *The presented quality tests of the different methods are based on statistical numbers, i.e. the standard errors of the calibration factors. A figure showing the diurnal* *variability of the calibration factor would visualize the uncertainty of each calibration method for the full angular range. Such plots are very interesting for the analysis of the calibration factor for instrument with a larger cosine error like the Yankee UVB-1 radiometers. The discussion of the calibration uncertainty should result in an expanded uncertainty. It is composed of the points listed above and most of all the uncertainty of the reference measurement itself (>2%). For the two-step method an expanded uncertainty of 7% is expected for Scintec radiometers.*

RES– Except for the ratio model, the calibration coefficients are not obtained for each instant of measurement, but by means of a regression analysis with all the data. Therefore, no diurnal variability can be plotted. The statistical parameters of the fitting (standard errors, MBE, MABE, etc.), although not showing the total uncertainty of the calibration procedure, give interesting information to compare the models since the reference measurements used are the same for the different models.

Regarding to the uncertainty in measurements and its propagation, we have included several sentences in the revised paper:

Page 17876, line 23 The average differences between Brewer #150 and QASUME measurements were around a 8% in 2005 campaing (Hülsen and Gröbner, 2007). However, after aplying cosine response correction to Brewer data, these differences have been reduced aproximately by a factor 2.

Page 17876, line 27 Instrumental errors in the diurnal measurements (raw data) of broadband radiometers are lower than 1.7%.

Page 17881, line 12 From a statistical point of view, the uncertainty in the calibration coefficients for one-step methods is stated as the standard error (SE) multiplied by a coverage factor k=2 which for a normal distribution will give a level of confidence of approximately 95%.

Specific comments:

17875, 13: *Ozone measurements of very good quality are available from satellite data for all possible stations.*

According to the comment of the referee, we have modified the expression excluding the reference to the total ozone data in this point, as follows:

Although the two-step method is recommended by several organizations responsible for calibration protocols, because of its higher accuracy, it has the disadvantage that needs to know the actual spectral response function of the broadband radiometer and its angular response function which are often not available.

17876, 16: *In respect to ozone measurements the calibration against Brewer #015 will be performed from IOS. However, the calibration for UV measurements will have been performed against the transportable reference spectroradiometer QASUME. The corresponding statement, result and reference are missing.*

Certainly, the spectrophotometer Brewer #150 that has been the reference instrument in all the calibrations of our broadband instruments, has been calibrated in 2005 campaign against the transportable reference spectroradiometer QASUME for UV measurements. This information has been added to the text:

Page17876, line 16. Has been changed as follows: Brewer #150 spectroradiometer is calibrated every two years by its comparison to the travelling standard (Brewer #017) from the International Ozone Services (IOS, Canada). Moreover, in this campaign, Brewer #150 UV measurements have been calibrated against the transportable spectroradiometer QASUME (Quality Assurance of solar Spectral Ultraviolet irradiance Measurements in Europe), which is an European irradiance reference (Gröbner et al., 2006). Thus, the reliability of Brewer #150 is highly guaranteed.

17877, 16: *The uncertainty of calibration introduced by the extrapolation of the Brewer data to the full UV-range should be discussed.*

The range between 363 and 400 nm represents only about 5% in the UV erythemal

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irradiance (280-400 nm). Thefore, the uncertainty introduced in the calibration coefficients by the extrapolation of the Brewer data to the full UV range is negligible.

17879, 24: *Definition and reference for CIE should be added.*

This reference has been included and we have added the cite in the following paragraph (section 2 Instrumentation and data, page 17876, line 1):

They are UV-S-E-T model, manufactured by Scintec- Kipp & Zonen, which spectral response simulates the CIE erythema action spectrum of the human skin, defined by McKinlay and Diffey (1987).

17879, 26: *The conversion function Ci(SZA,TO3) is normalized to its value at SZA=40deg and TO3=300 DU (recommendation from "A practical guide to operating broadband instruments measuring erythemally weighted irradiance" by Webb et al.)*

In this paper, the conversion function has not been normalized The absolute calibration factor K_A includes implicitly the normalization factor (K_A=(C/f(40ž,300DU), in notation of Webb et al.)

17880, 8, *Equation 6: Incomplete cited (coscor etc).*

The reference to Webb et al., 2006 has been introduced. The description of two-steps method has been modified as follows (we omit equation 5) (page 17880, line 4):

Finally, the erythemally weighted irradiance is obtained as:

$\mathrm{UVER}=(V_i - V_{offset})K_A C_i([O_3], \theta)$,

where V_{offset} is the average dark signal.

Equation 5 is stated in its most general form as defined by Webb et al., 2006. In this work the cosine correction has been not applied to the broadband radiometers (Coscor=1). This fact could cause that the absolute calibration factor becomes a function depending on SZA. However, the UV broadband radiometers manufactured by

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Kipp & Zonen present a very low angular deviation and thus, the dependence of the absolute calibration factor on SZA is negligible.

17885, *Table 1-4: Summarize the tables into one; the accurate listing of the result of all three radiometers is redundant.*

It is not possible to summarize the tables 1-4 into one because the information recopiled in each one refers to coefficients corresponding to different one-step calibration model, so they are not comparables.

17889, *Table 5: Does not give any information, because no comparison is possible.*

To our opinion table 5 is informative because it summarizes the regression results comparing the behaviour of angular method contrasted with the two-step method for the three broadband studied. It can be seen there how close is the slope to the expected value (1.0).

17891, *Figure 2: More interesting than the relative differences would be a plot showing relative the ratios.*

According to the referee suggestion, we have changed the figure 2 including the ratio (Broadband/Brewer) values instead of the relative differences. The comments to the figure (page 17881) have been modified according to the new version of figure:

Figure 2 shows the variation with the solar zenith angle of the ratios between the irradiance measured by Brewer spectrophotometer and the irradiance estimated by broadband radiometer #1. Results using the four one-step calibration methods and the two-step method are depicted. The points represented correspond to the averaged ratios obtained for SZA intervals of 1°. It is observable that, for the one-step methods, the best results are obtained by the angular method, which presents ratios very close to 1.0 (bounded by 0.96 and 1.07 values) in the whole range of solar zenith angles. These results are also very close to those obtained by the two-step method, which ratios are bounded by 0.98 and 1.11 values. Radiometers #2 and #3 (not shown), present very similar behaviour to radiometer #1.

17892, *Figure 3: Add this information into the ratio plot of Fig. 2.*

The ratios corresponding to the two-steps method have been included in the new version of figure 2.

Technical corrections:

17874, 11: *"In the last" - missing "the" (very frequent error throughout the paper)*

The expression has been corrected.

17875, 4: *Change numbering (First,... Second,... Third,...)*

The numbering has been changed.

17875, 7: *"to determine a matrix calibration", change to: "to calculate a conversion function"*

The suggested change has been included.

17875, 19: *"Although a second-order method improving this angular characterization was proposed, certain dependence with the solar zenith angle still remains for those cases with low solar elevations."; - consider restructuring of the sentence.*

We have changed the sentence as follows: In the previous paper was proposed a second-order method that improved the dependence with solar zenith angle of one-step methodology. However, certain dependence with the solar zenith angle still remained for those cases with low solar elevations.

17879, 4: *"Erythematic irradiance" change to: "erythemally weighted irradiance"*

17880, 14: *"obtained applying..." change to: "obtained by applying".*

The corrections have been made.

17882, 6-7: *Double declaration of MABE and MBE.*

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It is true that MABE and MBE definitions were duplicated. We have suppressed the second one (pag. 17882).

17880, 24 and 17885, *Table 1-4: Units W/m2 V should be W/m2/V.*

Units have been corrected in tables 1 to 4.

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