**Final Author comments**

Authors' response to **Referee #2** comments on "Performance of the FMI cosine error correction method for the Brewer spectral UV measurements" by Kaisa Lakkala et al.

The authors thank the Referee for constructive comments and reply to all comments here below. The answer is structured as follow: (1) comments from Referee, (2) author's response, (3) author's changes in manuscript

(1) 1-The algorithm described in Section 2.4 starts by "multiplying the whole measured spectrum with the first guess cosine correction", which is defined as "the cosine correction coefficient assuming all radiation to be diffuse, eq. (10)." (see P8, L30). Cloud optical depth is then estimated by comparing the so-corrected measurements with model results that were calculated for different cloud optical depths using a look-up table. This method is rather crude, in particular at long wavelengths during clear-sky and thin-cloud periods when the true cosine error correction factor may deviate considerably from the diffuse correction factor defined by eq. (10). As a result, the retrieved cloud optical depths may be in error. It would be more accurate if the look-up table were to take the cosine error of the Brewers into account. For example, results of the radiative transfer model could be multiplied with the inverse of the cosine error correction factor that takes the direct/diffuse ratio calculated by the model into consideration. In other words, the model would simulate measurements under clouds that are affected by the cosine error. These modified model spectra would then be compared with the measured global irradiances (without applying a cosine error correction) to estimate the atmospheric transmittance from which the cloud optical depth can be determined. So instead of comparing "first guess corrected" measurements with model results that do not consider the cosine error, my suggested approach is to compare measurements affect by the cosine error with model results that are scaled by this error.

In addition, the method does not seem to take into account that there may be a systematic bias between measurement and model. For example, it is unlikely that cosine-corrected measurements and model agree ideally during clear sky conditions. If true, a bias would likely also apply to cloudy conditions. Such a model bias would introduce a bias into the cloud optical depth used in the final correction.

Ideally, the authors should modify their method to take the issues described above into account. The alternative is to leave their algorithm unchanged but add a paragraph to the manuscript discussing and quantifying the effects of their approximations used by their method, for example by providing an uncertainty budget of the correction procedure considering different cloud conditions (e.g., clear sky, scattered clouds, overcast).

(2) The authors thank the Referee for the constructive comment. The method proposed by the Referee was tested with one Brewer, the Brewer #214. The maximum difference of these two methods in the final cosine correction coefficient was 2%. The authors think the method suggested by the Referee is a good approach, but it also includes problems: As model results and real world differ, it might be difficult to find clear skies. This is due to the mostly positive bias between measurement and model (model calculated higher irradiances that what was measured). In the method presented in this paper

clear skies are found in most cases, as the method easily over-correct. But as the method suggested by the Referee doesn't over correct, clear skies are more easily interpreted as thin cloud situations.

We calculated that the assumption made in step 1 that all radiation is diffuse leads to an overestimation of the global irradiance of up to 5% for SZA less than 20 degrees and cloudless skies. This has an impact on the calculated cloud optical depth and on the model retrieved direct to diffuse ratio. For cloudless conditions and for cloud optical depths >= 2 the effect on the cosine correction is in the order of 0 to 1.2% for all solar zenith angles and all Brewers. In the case of thin cirrus clouds (e.g. cloud optical depth =1) the relative error is 0 to 1.5%, where 1.5% is the under correction for the Brewer with the worse cosine response for SZA 15 º and for 320 nm. Results for the Brewers with the best cosine response presented in this study are in the order of 0-1% for the same conditions.

We found biases of around 5% between the QASUME measurements and model calculations for atmospheric conditions of the Huelva 2015 comparison campaign. The model calculations were in most conditions higher than the QASUME measurements. During the campaign, this lead to results, in which, even under clear skies, the cosine error correction algorithm found thin clouds, and yield to over correct the irradiances. The effect was the highest during mid day, at SZA 15, when over corrections of even 3% were seen. The effect diminished towards higher SZA, and was less than 1% at SZA 50.

One have to keep in mind that the main point of the method is that the instrument should know itself if the sky is cloudy or not. It's true that very thin clouds (cloud optical depth (COD) less than 1) may be not caught. However, even thin clouds, cloud optical depth 3-5, makes the radiation distribution to be near all diffuse at UV wavelengths. For those conditions, the cosine error correction factor is calculated right.

(3) The following text was added in the text:"

Chapter 3.1.2 : "The small scale wavelength to wavelength changes, which can be seen especially at midday, are due to the method in which the direct to diffuse radiation is calculated for each wavelength separately. As here there was clear sky, the cosine error correction factor should vary smoothly with wavelength. The small scale features seen in the plot, are signs that the measurements and model differed from each other so that the retrieved cloud optical depths erroneously corresponded to that of thin cloud conditions. For the Brewer #214 there was error of even 2-3% at around 360 nm due to problems in wavelength setting of that Brewer at those wavelengths."

Chapter Discussion:
"The lookup table is also a source of error: The model calculations do not entirely correspond to the atmospheric conditions at which the UV measurements are performed. E.g., the lookup table of the Brewer #214 was generated for Finnish atmospheric conditions but the measurements were performed in Spain where e.g. the ozone profile is different. For the Brewers of AEMET, the lookup tables were generated using the slit function of Brewer #117, even if all Brewers had instrument specific slits, however the impact due to these assumptions was less than 1%. The largest error source was found to be the bias between model calculations and measurements. For conditions of the Huelva 2015 campaign, the model overestimated irradiances by an average of +5%. For some Brewers this led to retrieve cloud optical depth values corresponding to thin cloud cover, even if there was clear sky conditions. At the Huelva 2015 campaign, the effect was the highest during midday, at SZA 15º, when

over corrections of the cosine error of up to 3% were found for cloudless cases. The effect diminished towards higher SZA and was less than 1% at SZA equal or larger than 50.

Another error source was the first step of the correction procedure in which the irradiance was corrected assuming all radiation is diffuse. The assumption leads to an overestimation of the global irradiance of up to 5% for sza less than 20 degrees and cloudless skies. This has an impact on the calculated cloud optical depth and on the model retrieved direct to diffuse ratio. For cloudless conditions and for cloud optical depths >= 2 the effect on the cosine correction is in the order of 0 to 1.2% for all solar zenith angles and all Brewers. In the case of thin cirrus clouds (e.g. cloud optical depth =1) the relative error is 0 to 1.5%, where 1.5% is the under correction for the Brewer with the worse cosine response for SZA 15 º and for 320 nm. Results for the Brewers with the best cosine response presented in this study are in the order of 0-1% for the same conditions. This under correction compensated completely or partially to the overcorrection of the same magnitude and under the same conditions (thin clouds, low szas) due to the bias between model calculations and measurements, discussed above. However, the study showed that possibility to see thin clouds, i.e. cirrus with cloud optical depth less than 1 (Giannakaki et al., 2007) was challenging.

One possibility to improve the method could be to correct the lookup table irradiances with the theoretical cosine error correction factor of each Brewer. Then the effect of the bias between model and measurements should be taken into account by multiplying the irradiances with the bias. The additional challenge using this approach, is that the bias between model and measurements vary as a function of wavelength and depends on the atmospheric conditions."

2- Figure 6a shows variation in the order of 2.5% or about 1/3 of the total correction of about 7% even though the sky was free of clouds. For these conditions, the cosine correction factor should vary smoothly with wavelength. I feel that the algorithm should be improved to avoid this artifact before the manuscript is published.

(2) The authors agree. The variation is due to the bias between the measurements and the modeled irradiances. As explained in the answer to comment #1, the original method retrieved cloud optical depths corresponding to thin clouds at some wavelengths, even if the real conditions were clear skies. As the bias was found to be on average around 5%, one possibility is to improve the method by including a multiplication of the irradiances with the bias found between the model and the measurements, when comparing measurements with irradiances in the lookup tables. For the comparison campaign held in Huelva, that improved the method, and clear skies were retrieved for most of the spectra.

(3) The following text has been included in the manuscript: "The small scale wavelength to wavelength changes, which can be seen especially at midday, are due to the method in which the direct to diffuse radiation is calculated for each wavelength separately. As here there was clear sky, the cosine error correction factor should vary smoothly with wavelength. The small scale features seen in the plot, are signs that the measurements and model differed from each other so that the retrieved cloud optical depths erroneously corresponded to that of thin cloud conditions. For the Brewer #214 there was error of even 2-3% at around 360 nm due to problems in wavelength setting of that Brewer at those wavelengths."

and in Discussion: “One possibility to improve the method could be to correct the lookup table irradiances with the theoretical cosine error correction factor of each Brewer. Then the effect of the bias between model and measurements should be taken into account by multiplying the irradiances with the bias. The additional challenge using this approach, is that the bias between model and measurements vary as a function of wavelength and depends on the atmospheric conditions. “

(1) 3- The structure of the manuscript is confusing. After introducing Brewer instruments, Section 2 presents results of the Huelva campaign and site audits in Finland, then presents the cosine error correction method, followed by angular response measurements. In Section 3, more results from Huelva and Finland are presented. Why are results from the campaign and audits separated by Sections 2.3 and 2.4? A more logical order would be: introduction of Brewer Instruments, angular response measurements, cosine error correction method, results from Huelva, results from Finland. The result sections could first show results without cosine error correction and then results with cosine error correction.

(2)Section 2 includes Material and Methods, not results of this study.

The Section 2.2. describes the UV comparison campaign of Huelva in 2015. We understand that the text of the Section 2 was confusing. The results presented in the section were already published, and they have now been moved the Chapter 1: Introduction.

The Section 2.3 describes when and how the site audits have been performed in Finland, not the results.

(3) The text in the Section 2.2. has been modified and the Figure 2 deleted.

According to the comment of the Referee, the text in the Introduction has been changed to “Even if the above mentioned methods exist, the Brewer UV measurement comparison campaign held in El Arenosillo, Spain, in 2015, showed that irradiances of most Brewers were not corrected for cosine error. The comparison results showed that only 5 out of 18 Brewers were within ±5% of the reference, while 6 Brewers were outside of the 10% band (Gröbner, 2015). Most Brewers had significant diurnal variations due to uncorrected temperature dependence and cosine error. A lack of easily applicable cosine error correction algorithm was obvious. This paper studies if the FMI cosine error correction method (Lakkala et al., 2008) could be used to respond to this need. The method was applied for five Brewers of the El Arenosillo 2015 comparison campaign. In addition, results from three Brewers during site audits with the portable reference spectroradiometer QASUME in Finland were studied. “

The places of the sections have been changed and are now:

2.1 Spectroradiometers
2.2 (old 2.5) Angular responses of the Brewers
2.3 (old 2.4) Cosine error correction method
2.4 (old 2.2) Comparison campaign in Huelva
2.5 (old 2.3) UV comparisons during site audits in Finland

(1) 4- The font size used in all figures, and in particular Figures 7-9, is far too small for reading axis titles and legends with ease. Please improve readability in accordance with AMT guidelines.

(2) The authors agree.

(3) The font size has been enlarged for Figures 7-9.

Minor comments:

P1, L3: The correction does not take the “actual sky radiation” into account. Instead, it assumes that sky radiation is isotropic and only considers the ratio of direct (solar beam) to diffuse (sky) irradiance. I suggest to replace “actual sky radiation” with “ratio of direct and diffuse irradiance”.

(2) The authors took into account the comment and changed the abstract to be more clear:

(3) The sentences in the abstract are now: “Ideally, the correction depends on the actual sky radiation distribution, which can change even during one spectral scan due to rapid changes in cloudiness. The FMI method has been developed to take into account changes in the ratio of direct to diffuse sky radiation and derives a correction coefficient for each measured wavelength.”

P2, L4: Regarding: “The cosine error of a Brewer varies between instruments and is typically 5-15%”. At what angle? By definition, the error is 0% at 0◦ for any instrument.

(2) The 0% is for vertival direct beam. Such conditions can be achieved only in laboratory. For solar radiation, there is always a contribution of diffuse light. The sentence has been changed to:

(3) “The cosine error of a Brewer varies between instruments and is typically 5-15% for solar UV irradiance measurements.”

P2, L16: Regarding: “and when the cloud cover is not high enough to assume all radiation to be diffuse.” I would say: “and when the cloud cover is thin and the contribution from the direct component is significant.”

(2) The authors agree.

(3) The text has been changed as suggested by the Referee: “and when the cloud cover is thin and the contribution from the direct component is significant.”

P2, L34: Please explain acronym QASUME.

(2) The portable Quality Assurance of Spectral UV Measurements in Europe (QASUME)

(3) The text has been changed to:” This portable reference spectroradiometer is referred as QASUME, which comes from “Quality Assurance of Spectral UVMeasurements in Europe”.”

Figure 1: Because of noise in the measurements, which also affects the normalization wavelength, the slit functions shown in Figure 1 appear to be shifted against each other. I suggest to calculate the normalization wavelength differently, for example as the centroid wavelength, defined as Integral (slit function times wavelength) / Integral (slit function).

(2) The slit functions and central wavelengths have been calculated following common practices (slit function value 1 at the central wavelength) For some Brewers, the slit function is not symmetrical. Following the comment of the Referee #1, the Figure has been plotted using logarithmic scale.

(3) Figure 1 has been updated and plot changed to logarithmic scale.

P4, L3: Please provide confidence interval of the expanded uncertainty. I believe it is 95% or k=2.
(2) The confidence interval has been added to the text.
(3) The text is now: "The expanded relative uncertainty (coverage factor k=2) of solar UV irradiance measurements with QASUME for solar zenith angles smaller than 75_ is 3.1% (Hülsen et al., 2016), which corresponds to a confidence interval of 95%, assuming a normal distribution."

P5, L5: Regarding: "The data was delivered using both data processing and configuration provided by the operator and the standard UV processing." If I understand this sentence correctly, two data versions were submitted by each operator, one using the data processing method typically used by the instrument operator and the "standard UV processing" method. What is the difference between the two processing methods? Did data provided by the operators include a cosine error correction? Please clarify.
(2) Yes, two different data sets were submitted for the campaign. The first data set was processed by the operators of the instrument, using the UV processing they typically use at home. The second data set was calculated using the standard UV processing algorithm of the EUBREWNET. In the first data set, the cosine correction was either done or not, depending on the UV processing algorithm of the operator. In practice, the data of only two Brewers were cosine corrected (FMI, following the method described in Lakkala et al. 2008 and the Brewer of the University of Thessaloniki, following the method described in Bais et al. 1998). The standard UV processing algorithm of EUBREWNET didn't include cosine correction.

In this manuscript we didn't use neither of the two data sets described above. We studied the data sets of five Brewers calculated using the FMI's cosine error correction algorithm (Lakkala et al. 2008).

The text in the manuscript has been clarified.

(3) The text is now: "During the campaign, the operators of the instruments submitted the data, which were processed using their own calibration and UV processing algorithms. These algorithms differed, e.g., by how the temperature dependence or angular dependence was taken into account. For most Brewers, no temperature or cosine error correction was performed. In addition to irradiances submitted by the operators, the spectral UV irradiances were calculated using the standard UV processing (Lakkala et al., 2016a; León-Luis et al., 2016) of the COST Action 1207, EUBREWNET (Rimmer et al., 2017) and a calibration perfomed with a common lamp during the campaign (Gröbner, 2015).

In this work, the UV irradiances measured by five Brewers were calculated using the routine UV processing algorithm of FMI (Mäkelä et al., 2016; Lakkala et al., 2008). The cosine error correction was applied, but the temperature correction was not applied in order not to mix the effects of different corrections."

P5, L16: Regarding "less than 50◦and 90◦.": I am not sure what this range means. Were there two sets of comparisons, one where the mean (=average), and the 5th and 95th percentiles were calculated taking only measurements at SZAs less than 50◦into account, and one where the three statistics were based on measurements with SZAs up to 90◦ ? Please clarify.

(2) There was only one set of comparison, but two different averages were calculated. In the first one, only measurements at SZAs less than 50◦ were taken into
account. In the second average, all measurements up to SZA 90 were taken into account. The 5$^{th}$ and 95$^{th}$ percentiles were calculated from the whole data set (SZA up to 90).

(3) The text has been clarified and is now:"The irradiance measurements of the five studied Brewers were compared with the irradiances measured by the QASUME. The mean differences from QASUME, and 5th and 95th percentiles were calculated. For each Brewer, the mean difference was calculated separately for datasets including irradiances measured when the SZAs were 1) less than 50 ◦ and 2) less than 90 ◦ . The percentiles were calculated for the dataset including all spectra."

P5, L17: Please clarify whether the cosine error of the measurements shown in Figure 2 was corrected. The text "cosine characterization provided by the operators", (P5, L8) suggest that a cosine error correction was applied, which conflicts with "uncorrected temperature and angular response problems".

(2) Taking into account the comments of the Referee about the srtucture of the manuscript, the Figure 2 has been deleted. The results have been moved to the Chapter 1 Introduction, as they are results of earlier work. The UV irradiances which were used to produce the Figure 2, were submitted by the operators. Depending on the operator, the cosine correction was either done or not: in most cases not.
(3) Figure 2 was deleted and results moved to Chapter 1: Introduction.

P6, L16: If the Brewer measurements at Huelva, Sodankylä, and Jokioinen were cosine error corrected with the method described in Section 2.4., it would be better to move Section 2.4. before Sections 2.2. If a different method (e.g., the method described by (Lakkala et al., 2008)) was used in Section 2.2, this should be clarified. As mentioned earlier, the structure of the manuscript is confusing.
(2) Yes, the Brewer measurements at Huelva, Sodankylä and Jokioinen were cosine error corrected with the method described in Section 2.4.
(3) The sections 2.4 and 2.5 have been moved before sections 2.2 and 2.3.

P9, L4: Section 2.5. would better fit before Section 2.4., or even before Section 2.2, if section 2.4 is moved up (see my previous comment).
(2,3) We agree, and the Sections have been moved as suggested by the Referee.

Figure 3: If the points shown in Figure 3 were connected with lines it would be easier to see azimuthal dependencies.
(2) We preferred to keep the single measurements not connected with lines, as there as for some angles two measurements (one performed on when moving towards higher angles and the second when coming back towards lower angles.) This would mix the plot even more than what it is now. We think it is easier to see the scattering of the measurements, when leaving them as such.
(3) Figure: X-axis explanation was added. The size of the markers were enlarged.

Figure 4a: Please also include the cosine function in this figure. In the figure caption, include spaces after each Brewer's serial number.
(2,3) Cosine function has been added. Spaces have been included in the figure caption.

Figure 4b: Why has Brewer #117 such a different response than the other instruments beyond 80◦? This looks like a measurement artifact. Please comment.
(2) Based on the measurements of the Brewer #117 at four azimuth planes we concluded that the specific instruments show relatively increased inhomogeneity among the 4 planes' measurements, especially for measurements in high (>80°) angles). However, we have no proof that this is an artifact, despite the fact that measurements on such high angles in the lab become more uncertain due to the low measurement signal.

(3) The text is nowt:"The angular response of the Brewers of AEMET were measured during the first Regional Brewer Calibration Center –
Europe (RBCC-E) Campaign in Huelva in 2005 with a portable device developed within the European Commission funded project QASUME. A detailed uncertainty analysis of the laboratory measurements using the angular response measurementdevice is presented in Bais et al. (2005).

For the cosine error correction algorithm, the mean of the four azimuth angles at one measured wavelength was calculated and used as the angular response of the instrument (Figure 3). From Figure 3b it can be seen that the cosine error of most Brewers exceeded 10% at angles higher than 70 ◦ . The angular response of the Brewer #117 differed from the others at 85 ◦ ,which was due to relatively increased inhomogeneity among the measurements over the four planes, for such high measurement angles. However, laboratory measurements at such angles become more uncertain due to the low measurement signals (Bais et al., 2005)."

Figure 5: Data shown in the graph change in 0.01 increments. Why? This would result in unnecessary 1% step-changes in the cosine error corrected data.
(2) The authors think the 1% accuracy in the plot is enough, even if the cosine error correction coefficient is calculated with 4 decimals (0.01%).
(3) The plot is kept unchanged.

P14, L8: See my general comment above. Figure 6a indicates that the algorithm does not work as intended. There should be no variation with wavelength of the magnitude shown in Figure 6a during clear sky conditions!
(2) The authors agree. As mentioned in the earlier answers, the problem is the bias between the model and the measurements. The problem was solved by multiplying the measured irradiances by the average bias found for Huelva measurements.
(3) The cosine error correction coefficients have been recalculated taking into account the average bias between the measurements and the model. The Figure has been updated.
The text is now: "The small scale features seen in the plot, tell that the measurement and model differed from each other so that the retrieved cloud optical depth erroneously corresponded to that of thin cloud conditions. For the Brewer #214 there was error of even 2-3 % at around 360 nm due to problems in wavelength setting of that Brewer at those wavelengths."

Figure 7: For the uncorrected data (panel a), the mean is about in the middle of the range. For the corrected data, the mean is much closer to the lower envelope of the range, indicating that the distribution is skewed after the correction. Why is this the

case?
(2) After the cosine correction, the diurnal dependence which is related to the cosine error has disappeared. The remaining effect is the temperature dependence of the instrument: we know that the sensitivity decreases with increasing temperature, and most spectra are measured at high temperature, so the average will be biased to a lower irradiance. At high SZAs and short wavelengths the effect of stray light is important.
(3) This is discussed in the text: “One reason is that the Brewer UV measurements have a temperature dependence, and measurements were not corrected for it. As the campaign days were sunny days, during which the inner temperatures of the Brewers ranged between 25° in the morning and 48° in the afternoon, the effect of the temperature dependence can be up to 3-4% depending on the wavelength and the instrument (Fountoulakis et al. 2017).”.

Figure 8: Here the skewness of the distribution is even more apparent than in Figure 7. It seems that the correction is too large for a good portion of the distribution. This points to a problem in the algorithm, which should be clarified.
(2,3) See the answer above. We included also the non cosine corrected results for the two Brewers in Figure 8. From that figure it can be seen that the highest ratios compared to the QASUME were found at SZAs, at which the radiation field is near all diffuse radiation. For those SZA:s, as radiation was near all diffuse, the method worked right, which suggest that the remaining error was due to other reasons than problems in the cosine correction method.

P18, L10: I don’t understand “and that of FMI’s Brewer from Aalto University, Finland, and was traceable to SP, Sweden (Lakkala et al., 2008).” in the context of the previous sentence. Does this imply that the radiometric reference in 2014 was different than in the other years, explaining why the Brewer/QASUME results in 2014 were an outlier?

Also, what does the acronym “SP” stand for?

(2) SP stands for Swedish National Testing and Research Institute (*SP*). The sentences were misleading and have now been corrected. The meaning was that from a general point of view, one reason for the differences between the QASUME and Finnish Brewers was the traceability of the irradiance scale.

(3) The text has been changed to “ The Finnish Brewers overestimated the irradiance compared to the QASUME during all years except the Brewer #107 in 2014. A possible explanation for differences between the QASUME and the Finnish Brewers was the difference in the traceability of the irradiance scale of the instruments. The irradiance scale of the QASUME was traceable to PTB, and that of FMI's Brewer was traceable via the Aalto University, Finland, to the Swedish National Testing and Research Institutes (SP), Sweden (Lakkala et al. 2008).

P18, L14: Regarding: “
...
under cloudy conditions was almost constant.” “With respect to what variable? The SZA? Also, I don’t understand how the results by Webb and Kylling lead to the conclusion that the systematic error due from the isotropy assumption is in the order of 1.5 to 2.5%. It would be nice to include these calculations here or as a supplement.

(2) Under cloudy conditions the correction is almost constant with respect to wavelength and solar zenith angle. This is because the diffuse errors shown in table 2 are solar zenith angle and wavelength independent and they are equal with the cosine correction that is applied when the direct to global ratio of the solar irradiance is very low.
The calculations are explained in the Appendix 1 of this response.
(3) The text has been changed to:"...under cloudy conditions was almost constant with respect to wavelength and SZA."

P20, L10: I also don't understand why "the errors in the cosine correction of the diffuse component would increase." Why would the cosine error correction for the diffuse component necessarily increase in case of a significant azimuth angle dependence? The magnitude of the correction should depend on the specific features of the azimuthal asymmetry. Since the Brewer window moves with the solar azimuth, I would think that the correction of the direct beam should be based on the cosine error measured in the direction of the window while the diffuse correction factor should be bases on the average of measurements at all azimuth angles. Perhaps this should be mentioned.
(2) The authors agree that the correction of the direct beam should be based on the cosine error measured in the direction of the the window. The authors also agree that the diffuse correction factor should be based on the average of measurements at all azimuth angles. But in case there are large differences between azimuth angles, and as in reality the diffuse radiation is not isotropic, the average angular response would not correspond to conditions at all azimuth angles. "Why would the cosine error correction for the diffuse component necessarily increase in case of a significant azimuth angle dependence?" - That is not mentioned in the manuscript. The cosine error correction could increase or decrease, but the error in the cosine correction would certainly increase in case of azimuthal dependency of the angular response.
(3) The text has been changed to: "The method uses the average of angular responses measured at four different azimuth angles to calculate the error related to both direct and diffuse component of solar radiation. Averaging introduces errors in case angular responses differ from each other. Then, the correction of the direct component should be based on the angular response measured in the direction of the quartz window of the Brewer, as the Brewer window follows the sun. As the radiation field in real world is not isotropic, errors in the cosine correction of the diffuse component would increase if large differences exist between angular responses of different azimuths but the average is used."

P20, L17: 2% may sound small, but this number does not preclude a much larger difference for the direct component, in particular at large SZAs. Differences in the direct component should be specified also.

(2) Differences in the direct component are specified and added to the text.
(3) The text is now: "The maximum difference in the error related to the direct component was 3% at angle 85°, being less than 1.6% for angles lower than 70° . Bais et al. (2005) found that reproducibility of the angular response measurements was better than ±2% for the angular response measurement device used within the QASUME project."

Technical corrections:
The English should be improved before the paper is published by AMT. Since AMT provides copy-editing service, I only suggest improvements below that may not be

obvious to the copy editor. I also encourage the authors to ask a native English speaker to improve the English before submitting the final version to AMT.

(2) The corrections suggested by the Referee have been made and the English has been improved in the new version of the manuscript.

P1, L6 and P5, L3: “travel” > “travelling” (2) Done.

P1, L11-12: “showed” > “shows” (two occurrences) (2) Done.
P1, L16: “measures” > “measure” (spectroradiometers is plural) (2) Done.
P2, L2: “The deviation from the ideal angular response, the one that is proportional to the cosine of the incident angle that, is” > “The deviation from this ideal angular response is” (it is not necessary to repeat the definition of the preceding sentence.) (2) Done.
P2, L9: “wavelength band between” > “wavelengths between” (2) Done.
P2, L11: “on the division of global irradiance” > “on partitioning the global irradiance” (2) Done.
P2, L21: possibility > capability (2) Done.
P2, L27: “the near” > “near” (2) Done.
P3, L8: “done using” > “implemented (or applied) using” (2) Done.
P3, L13: “showed” > “shown” (2) Done.
P3, L15 - L19: Use present tense instead of past tense when describing general attributes of the Brewer. (e.g., were > are, had a > have a, etc.) (2) Done.
P4, L8: “The measurement site was at the roof” > “Measurements were performed on the roof of” (2) Done.
P5, L1: “comparison” > comparisons” (2) Done.
P5, L4, and P6, L5: “done” > “performed” (2) Done.
P5, L9: “data was” > “data were” (“data” is plural) (2) Done.
P5, L10: delete “solar zenith angle” (SZA was already defined previously) (2) Done.
P7, L3: “to the left part of the denominator” > “in the first addend of the denominator” (2) Done.
P8, L20: “were close to” > “are” (2) Done.
P8, L27: “in a 6 dimention lookup table” > “in a 6 dimensional lookup table” (dimension is spelled with an “s”). Also, delete “which dimentions were 26 x 1250, containing” or state hat the lookup table has 26 * 1250 = 32500 elements (not dimensions). (2) Done.
P12, L8: “makes possible the evaluation of” > “allows the evaluation of” (2) Done.
P12, L17: “The cosine error correction factor is shown as function of time in Figure 5 for the five studied Brewers at 308 nm.” > “Cosine correction factors at 308 nm are shown in Figure 5 as a function of time for the five Brewers included in this study.” (2) Done.
P12, L22: Start new sentence after 7:30 UTC: “The cosine correction factors peaks at this SZA because of the large cosine error of 20% and the relative large contribution of the direct component to the global irradiance at this SZA.” (2) Done.
P14, L4: Delete “e.g, during changing cloudiness conditions.” (This is obvious). (2) Done.
P14, L6: “at midday and at 16.00 UTC on 2nd June. The SZAs” > “for 12:00 and 16:00 UTC on 2 June.” (2) Done.
P18, L12: “Another reason can be uncertainties related to the assumption of isotropic” > “Another potential reason for the systematic bias is the assumption of isotropic ...” (2) Done.
P20, L27: “applicaple” > “applicable” (2) Done.
P21, L4: “data was” > “measurements were” (“data” is plural) (2) Done.

Appendix 1:
Under cloudy conditions the correction is almost constant in respect of the different wavelengths and the different solar zenith angles. This is because the diffuse errors shown in table 2 are solar zenith angle and wavelength independent and they are equal with the cosine correction that is applied when the direct to global ratio of the solar irradiance is very low.
Kylling et al. is describing the ratio

$$A = \frac{\int_0^{2\pi}\int_0^{\pi/2} I(\lambda,\theta,\phi)\ \sin(\theta)\ d\theta\ \ d\phi}{\int_0^{2\pi}\int_0^{\pi/2} I(\lambda,\theta,\phi)\cos(\theta)\ \sin(\theta)\ d\theta\ \ d\phi} \qquad (1)$$

Where I is the diffuse solar irradiance at a wavelength λ received by an azimuth angle φ and zenith angle θ.

In Kylling et al., equation 8 and under cloudy condition in the case that the direct sun component tends to zero A is the ratio of the diffuse actinic flux divided by the diffuse irradiance measured by a flat diffuser.

In Kylling et al, figure 3 and in Webb et al., figure 7, modeling and actual measurements have been used to determine this ratio A that was found in the order of 1.75±0.1. In addition, one year of simultaneous actinic flux and global irradiance spectroradiometer measurements at Thessaloniki, Greece (S. Kazadzis personal communication) have shown similar results on a number of days under overcast conditions.

Using these results we tried to understand the differences of the diffuse irradiance coming from the direction closer to the horizon $\theta > 45^o$ ($I_b$) and the one closer to the zenith $\theta < 45^o$ ($I_a$). That is because in case of a difference in $I_a$ and $I_b$ which leads to a non isotropic distribution assumption, the diffuse cosine error in the cosine correction is affected.

In the case of an isotropic diffuse radiation A can be solved as $I(\lambda,\theta,\varphi) = I$ and A=2. However, as mentioned, Webb, Kylling and the long term Thessaloniki measurements showed that under overcast conditions this ratio A is 1.75±0.1.

Assuming that the isotropy assumption is valid for the azimuth (φ) only and separating the I(θ) το $I_a$ and $I_b$ and defining $I_a = K * I_b$ then A can be written

$$A= \frac{\int_0^{\pi/4} K*Ib\sin(\theta)\,d\theta + \int_{\pi/4}^{\pi/2} Ib\sin(\theta)\,d\theta}{\int_0^{\frac{\pi}{4}} K*Ib\cos(\theta)\sin(\theta)\,d\theta + \int_{\frac{\pi}{4}}^{\frac{\pi}{2}} Ib\cos(\theta)\sin(\theta)\,d\theta}$$

in this case if we assume the isotropy assumption then A = 2 and K=1 ($I_a = I_b$). Then assuming the isotropy assumption separately for $I_a$ and $I_b$ and since A=1.75 then K = 1.87.
That means that $Ia = 1.87 * I_b$ and if this is inserted in the diffuse cosine error calculations then we end up with the mentioned overcorrection, due to the isotropy assumption in overcast (direct component tend to zero) situations.