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Discussions

Interactive comment on "Performance of the FMI cosine error correction method for the Brewer spectral UV measurements" *by* Kaisa Lakkala et al.

Anonymous Referee #2

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General comment:

The manuscript describes a cosine error correction method that is applied to measurements of Brewer spectrophotometers. While several cosine error correction methods have been published during the last years, I encourage publication of the manuscript by Lakkala et al. by AMT because the method is potentially important for many Brewer radiometers that are participating in EUBREWNET (COST Action 1207, see acknowledgements). However, apart from several minor issues (see below), there are four more serious problems, which I feel the authors should address before publication can be considered:

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- 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.

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.

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.

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”.

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.

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.”

P2, L34: Please explain acronym QASUME.

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).

P4, L3: Please provide confidence interval of the expanded uncertainty. I believe it is 95% or k=2.

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.

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.

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".

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.

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).

Figure 3: If the points shown in Figure 3 were connected with lines it would be easier to see azimuthal dependencies.

Figure 4a: Please also include the cosine function in this figure. In the figure caption, include spaces after each Brewer's serial number.

Figure 4b: Why has Brewer #117 such a different response than the other instruments beyond 80°? This looks like a measurement artifact. Please comment.

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.

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!

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?

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.

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?

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.

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.

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.

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.

P1, L6 and P5, L3: "travel" > "travelling"

P1, L11-12: "showed" > "shows" (two occurrences)

P1, L16: “measures” > “measure” (spectroradiometers is plural)

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.)

P2, L9: “wavelength band between” > “wavelengths between”

P2, L11: “on the division of global irradiance” > “on partitioning the global irradiance”

P2, L21: possibility > capability

P2, L27: “the near” > “near”

P3, L8: “done using” > “implemented (or applied) using”

P3, L13: “showed” > “shown”

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.)

P4, L8: “The measurement site was at the roof” > “Measurements were performed on the roof of”

P5, L1: “comparison” > comparisons”

P5, L4, and P6, L5: “done” > “performed”

P5, L9: “data was” > “data were” (“data” is plural)

P5, L10: delete “solar zenith angle” (SZA was already defined previously)

P7, L3: “to the left part of the denominator” > “in the first addend of the denominator”

P8, L20: “were close to” > “are”

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).

P12, L8: “makes possible the evaluation of” > “allows the evaluation of”

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.”

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.”

P14, L4: Delete “e.g, during changing cloudiness conditions.” (This is obvious).

P14, L6: “at midday and at 16.00 UTC on 2nd June. The SZAs” > “for 12:00 and 16:00 UTC on 2 June.”

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 ...”

P20, L27: “applicaple” > “applicable”

P21, L4: “data was” > “measurements were” (“data” is plural)

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