Aerosol optical depth in the European Brewer Network: Reply to V. Savastiouk, RC4, 4 Dec 2017

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We thank the referee for his detailed comments on our manuscript. Below we include in italics a copy of his comments in RC4 and address his questions and suggestions.

Review of "Aerosol optical depth in the European Brewer Network"

by Javier López-Solano et al.

Vladimir Savastiouk

The paper, as I see it, is intended to present a near-real time aerosol optical depth (AOD) product based on the Brewer spectrophotometer direct-sun observations as it will be implemented in EUBREWNET. This is an extremely useful and scientifically important product.

The AOD calculations within the Brewer community have evolved in the last 25 years and are well documented in scientific publications. These include numerous publications showing comparisons with other instruments.

Indeed, the AOD retrieval by Brewer spectrophotometers is not a new topic, as stated in the Introduction just after the importance of aerosol studies is mentioned. Note also that the paper includes many references and comparisons to previous Brewer AOD studies, some of them written by coauthors of the present work.

What is new for Europe and what should be the focus of the paper in my opinion is the idea of harmonization of the data through consistent, centralized processing and quality control at the EUBREWNET data centre.

We agree with the referee and note that, to reach this goal of "harmonization of the data through consistent, centralized processing and quality control at the EUBREWNET data centre", we believe it is key to describe in a detailed and concise manner the algorithm implemented to retrieve the data. It's also important to demonstrate that this implemented algorithm produces results of a reasonable quality.

A brief description of a very well known algorithm would be appropriate, however calling this "our algorithm" is a little misleading unless the paper clearly shows what is new in this implementation of the AOD calculations.

We apologize for any confusion caused by the expression "our algorithm" – we just used it as a short way to refer to the specific implementation of the AOD algorithm implemented at the RBCC-E and presented in this work. To avoid further confusion, we now use "the AOD algorithm implemented at the RBCC-E" or similar expressions.

The paper describes very well the criteria for data selection and the corrections that will be implemented to the data. It also nicely shows how the RBCC-E calibrates their reference Brewers. I have some questions about this process though (these are listed below). The paper confirms previously published findings that well-maintained and properly calibrated Brewers will provide reliable AOD data. Having EUBREWNET centralized data processing and quality control will be a great contribution to the scientific community.

Some general comments:

The authors should choose to either present the future AOD from Brewers that calibrated by RBCC-E only, and this would be a sub-set of the data in the EURBEWNET database; or present and refer to all Brewers in the EUBREWNET but then clearly state that RBCC-E is only one of several agencies that provide calibrations for the Brewers in question. In fact, RBCC-E regularly reaches only about a half of the Brewers in the database, the rest are calibrated by others.

To make clear which instruments within EUBREWNET are considered in the present work, the following text has been added to the Abstract:

"In this work we present and discuss results of an aerosol optical depth (AOD) algorithm applied to instruments of the European Brewer Network. This network is comprised by close to 50 Brewer spectrophotometers, mostly located in Europe and adjacent areas, although instruments operating at e.g. South America and Australia are also members. Although we only show results for instruments calibrated by the Regional Brewer Calibration Center for Europe, the implementation of the AOD algorithm described is intended to be used by the whole network in the future."

Furthermore, a new paragraph (no. 5) has been added to the Introduction:

"It should be noted that the RBCC-E provides calibration data for approximately half the Brewer spectrophometers integrated in EUBREWNET, and this paper is focused on these instruments. However, the present implementation of the AOD algorithm is intended to run directly on EUBREWNET's dataserver using any measurements and calibration data available. This would allow to extend the applicability of the present implementation of the AOD algorithm, with minor modifications as needed, to the whole EUBREWNET network, because any other calibration data could be used besides that supplied by the RBCC-E. This includes calibrations transferred from other Brewer reference spectrophotometers, such as the one operated by International Ozone Services (Toronto, Canada, http://www.io3.ca/). Furthermore, preliminary work on the feasibility of using an Ultraviolet Precision Filter Radiometer (UVPFR) from the Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center (Davos, Switzerland, https://www.pmodwrc.ch/) to calibrate Brewer instruments has also been carried out (Carlund et al., 2017)."

For the network to be reliable some comments on sustainability of funding for RBCC-E and EUBREWNET database centre might be useful.

Rather than provide our own predictions on the future of the RBBC-E and EUBREWNET's dataserver, we have added a sentence on the background of the RBCC-E, so that the readers can draw their own conclusions:

"It should be noted that EUBREWNET's dataserver is currently maintained by the RBCC-E, which itself operates uninterruptedly since 2003 under the auspices of the WMO/GAW and the Spanish Agencia Estatal de Meteorología (http://www.aemet.es/)."

Following are line-by-line comments

Abstract: please be consistent in the usage of verb tenses: "algorithm to be used" means it is not yet used, "provides" means it is already working.

This part of the Abstract has been rewritten (see above)

P1 L7 the uncertainty does not include that from the air mass factor calculations, which can be significant. Please address this.

As stated in Sect. 2.4, the analytic derivation of the uncertainty presented in this paper is just an approximation, taking into account just three sources of uncertainty. The effect of the optical air mass has not been included because we only consider measurements up to a value of 3.5 in the optical air mass, and the uncertainty it introduces in this range is expected to be quite small, except perhaps for the shortest wavelength measured by the Brewer instrument, see Carlund et al. (2017) and the new reference Savastiouk and McElroy (2004).

We have added this explanation to Sect. 2.4 (see below).

P1 L8 Some of the "future improvements" can be easily implemented. Can you comment why you have decided not to do this now?

The current implementation of the AOD algorithm presented in this paper is intended to provide a base data level of reasonable quality, using calibration data which is immediately available, and in agreement with what has been discussed at meetings of EUBREWNET community.

P2 L17 "we have developed" is more like "we have implemented", no?

Changed.

P2 L21 to know that the accuracy is increasing you would have to know the true answer for TOC. How do you assess the accuracy?

We apologize for using the work "accuracy" incorrectly. The sentence has been changed to

"an increasing number of corrections to improve data quality"

P2 L23 this implies that RBCC-E is the only organization that provides calibration to the Brewers that are part of EUBREWNET. Please address this. This comment applies to many parts of the paper and will not be repeated every time RBCC-E is mentioned.

This sentence has been rewritten as

"Also needed for the determination of the AOD is the data provided by the calibration of the Brewer instruments."

Furthermore, as already mentioned, a new paragraph (no. 5) with further information on the calibration providers has been added to the Introduction.

P2 L30 The wording suggests that calibration is transferred every year to all participating Brewers, while this is not the case. Please be more precise.

This sentence has been changed to

"This absolute calibration is transferred to participating instruments at international intercomparison campaigns"

P3 L10 suggest adding "by" between "section" and "providing"

Done.

P3 L24 it may not be extremely important, but there is another Brewer type, MK V, that has an 1800 l/mm grating with a FW3 and measures in the UV and the visible 600-650 nm range.

We thank the referee for pointing this out. Since there are no Mk V Brewers in EUBREWNET, to avoid confusion we have decided not to mention it. The sentence in P3 L24 has been thus changed to

"There are three types of Brewer instruments currently in use at the EUBREWNET network"

P3 L25 suggest removing "the effect of" since the double monochromator actually reduces the stray light, not just effects of it

Done.

P3 L28 suggest "made up of" instead of "made up by". Also, suggest wording the rest of this sentence differently since it is only FW2 that adjusts the intensity, not both FW1 and FW2. Besides, you clearly say this in the next sentence.

Text has been changed to

"The light subsequently passes through the fore-optics, which consists in a set of lenses to adequately focus the beam, an iris diaphragm, and two filter wheels. A ground quartz diffuser is located on the first filter wheel. The second filter wheel consists of a set of five neutral density filter attenuators"

P3 L31 suggest "passing through the filter wheels". Also replace "spectrometer" with "monochromator"

Done.

P4 L2 some of the characterization are obtained without a calibration campaign, e.g. DT, potentially TC, filters...

This sentence has been rewritten as

"The Brewer retrieval of the TOC requires instrument characteristics which in some cases can only be determined by calibration experiments performed at intercomparison campaigns (see e.g. the GAW reports of the Seventh, Eighth, and Ninth Intercomparison Campaigns of the RBCC-E, Redondas et al., 2015; Redondas and Rodriguez-Franco, 2015a, b)"

Since the TOC is not the main point of this paper and we provide references with further details, we don't think it's necessary to be more specific with regard of which calibration constants can only be determined at intercomparison campaigns.

P4 L7 functions must be plural

Changed.

P4 L8 Is it just one ETC that is determined?

Yes, for the ozone retrieval, a single ETC is determined. Its value can then be further modified by filter and stray light corrections, which are also determined during calibration.

P4 EQ1 - this equation from 1983 is a concept that is impossible to use in practice: what is m? Some effective air mass factor? Using one variable for the product of tau and m that represents the slant total optical depth is better I think and can be expanded into its components with corresponding AMFs. Also, this equation is only valid for monochromatic light, but the Brewer measurements are clearly not that. Please either address this or reduce this whole description of the algorithm that is published elsewhere and only highlight your contribution (what is new).

We could indeed remove the Beer-Lambert-Bouguer equation, because it is the basis for the operation of the Brewer (both for the AOD and ozone retrieval) and many other instruments, and as such it is very likely that this equation will be very familiar to the reader. However, we believe that introducing it helps to establish the notation and makes the derivation of all the expressions in Sects. 2.2 and 2.3 easier to follow. Furthermore, removing it would save almost no space – most of Sect. 2.2 is devoted to the description of the parameters used in the equations and how they are obtained, which we find is completely necessary to avoid any confusion when dealing with an algorithm used by many instruments.

Regarding the other comments of the referee, Eq. 1 is indeed valid for each of the wavelengths measured by the Brewer, which thus allows to retrieve the AOD in the whole wavelength range. To make it clear, in Sect. 2.2 we have added the explicit dependence on the wavelength in both text and equations, e.g.:

" [...]the well known Beer-Lambert-Bouguer equation (see e.g. Iqbal, 1983):

$$I(\lambda) = I_0(\lambda) e^{-\boldsymbol{\tau(\lambda) m}}$$

where $I(\lambda)$ is the direct solar irradiance of wavelength λ measured at the ground[...]"

Regarding using a single variable in the exponent of Eq. 1, note that although we introduce two factors ($\boldsymbol{\tau}$ and $\boldsymbol{m}$) in this equation, we only expand their product in multiple contributions in Eq. 2, after we explain why we don't consider some other contributions.

Finally, regarding the meaning of m, it should be noted that, to avoid any confusion with the nomenclature used, we provide the specific mathematical expression used for the calculation of each of its components m_o, m_R, and m_a a bit later on the same section, see Eq. 5 and the accompanying text.

P5 L20 What is your rationale for using instrument-specific Rayleigh coefficients (which is not the standard now), but not improve the AMF calculations?

Rayleigh coefficients specific for each instrument are routinely obtained in the calibrations performed at the RBCC-E, and we have found that for some instruments they can have a noticeable effect on the TOC retrieval. Hence, it is natural that we also use them for the determination of the AOD.

We believe that changes on the expression of the optical air mass are indeed important, but should be discussed first by the whole EUBREWNET community – or perhaps even the whole world-wide Brewer community. In any case, our measurements are limited to a maximum optical air mass of 3.5, so we don't expect large errors in this range of air masses. See also the answers to further air mass-related questions below.

P5 L20 (continuation) Also, the formula for AMF is missing the instrument altitude, it's a lucky coincidence for IZO to have the ozone layer above the station close to 22km, but for Brewer #033, that is not far away, that is not true.

We currently only use measurements up to maximum optical air mass value of 3.5, so the error introduced by the omission of the instrument altitude in Eq. 5 is rather small. See also the answer to the next question.

P5 L28 this assumes that most of aerosol is in the troposphere. Is this a correct assumption?

We only include measurements up to an optical air mass value of 3.5, so the difference in altitude has a rather small effect. We have added the following text to the manuscript:

"Note that we only consider measurements up to a maximum optical air mass value of 3.5, so the exact altitude of the aerosol layer has a small effect on the the optical air mass. Thus for example, in the case of aerosols at sea level, the approximation $m_a \approx m_R$ introduces at most a $\sim$1% error in the aerosol optical air mass."

P6 L4 suggest removing "one" from "each one of"

Done.

P6 L7 suggest using "separately" instead of "by separate"

Done.

P6 L18 "criteria" instead of "filters"

Changed.

P6 L22 Will it be appropriate to apply location-specific criteria for the AMF cutoff? Many Brewers are in high latitudes and if they are MKIII they canlikely successfully measure at higher SZA, no?

Yes, this is indeed a good suggestion that should be take into consideration by the members of the European Brewer Network. We have added the following text to the future improvements, see the first paragraph of Sect. 4:

"Furthermore, optical air mass limits specific to each Brewer model could be implemented. This would specially benefit Mk III instruments (which are largely free from stray light issues) operating at high latitudes."

P6 L25 suggest adding "test" between "lamp" and "filter"

Done.

P7 L3 "our Brewer" is, I assume, an IZO Brewer. Since not authors are from IZO I suggest refer to the reference Brewer as RBCC-E reference or similar

This part of the text has been hanged to

"with the RBCC-E reference Brewer"

P7 L5 Please describe what stable conditions are and how you objectively decide they are stable

The fourth paragraph in Sect. 2.3 describes the conditions in which the half-day Langley calibrations are performed, and which conditions they have to meet to be included in the final average. In particular, there are two conditions we use to determine if the Langley has provided good results and, thus, has been performed in stable conditions: the linear regression must

have a r^2 coefficient of determination above 0.995, and the resulting calibration constant must be within 1.20 times the median of the whole ensemble of calibration constants for the whole period. The results presented in the paper seem to indicate that these conditions produce a good selection of Langley results, in a rather objective way.

P7 EQ7 - again, you cannot use EQ1 literally and make it linear before explaining what m is. Same in line 16.

We use the same notation through all the paper, so the meaning of m in Sect 2.3, and in particular in Eq. 7, is the same as in Sect. 2.2. As mentioned above, we believe that Eqs. 1, 2, and 5, plus the accompanying text, provide a good definition of m.

P7 L25 Do you (and how) monitor stability of the Brewer during the 1-2 months of calibration? If you average the results you assume the Brewer didn't change.

The Brewer instruments of the RBCC-E Triad are continuously and rigorously checked to ensure an optimal operational behaviour for the measurement of the TOC. This includes checks of each Brewer spectrophotometer individually (by means of internal tests on the standard and mercury lamp, and checks on dead time and operational voltages) and also comparisons between the three instruments. At this time, we rely on this TOC-specific checks to track the AOD stability, even though (as stated in the paper) we are aware that there are possibly some events that affect the AOD calibration but not that of the TOC. Furthermore, since we remove Langley results that deviate from the median value of the whole set of results (see one of the previous questions), we expect the resulting average to be a good representative of the whole period.

P7 L25 (continuation) Also, most points are collected at noon and only a few at larger SZA. Do you bin the data for Langleys?

There are different ways to solve the problem of the uneven distribution in time of the measured data. In our case, in the fit we introduce dummy variables associated to each filter position (which are in turn related to the SZA). We can then perform a fit with data from all filters but obtain a single, common slope – the AOD, which is indeed assumed to be stable during the whole time. Note that the solution specific for each filter is then characterized by a different independent term, which we found to be negligible thanks to the filter correction performed before the fit, as mentioned in the paper.

P7 L28 and other places: please avoid using the word "usually". Try to either describe the conditions when this is true and/or provide frequency of this.

Indeed, the sentence in question does not clearly the describe this part of the calibration process, because in all the cases presented in the paper we have always performed the second, less-demanding calibration to characterize filter positions #0 and #1. The sentence has been rewritten as follows:

"Performing this Langley calibration procedure at IZO, we can only obtain calibration constants for just two filter wheel positions (#2 and #3), leaving another 4 positions without characterization due to a lack of measurements at this filter wheel positions."

We have also checked other occurrences of the word "usually" through the manuscript and made changes where necessary, retaining the cases where we don't expect any confusion.

P7 L29 maybe "filter wheel" is better here than "filter"

This part of the text has been changed to

"two filter wheel positions (#2 and #3), leaving another 4 positions without characterization. This includes filter wheel positions #0 and #1"

P8 L1 It is not clear why the difference will have lower uncertainty. If I take two measurements with same uncertainty then the difference between them will likely have double the uncertainty, no?

In the case of completely uncorrelated quantities, the uncertainty of the difference would indeed be the sum of the two uncertainties. However, in the case of correlated quantities, extra terms are included in the mathematical expression of the uncertainty (see e.g. GUM (2008)), and they might reduce the uncertainty. In the present case, there is certainly a correlation between the results of the calibration constants of two different filter positions, because they have been performed with the same data and method. The uncertainty of the difference is then expected to be reduced due to a cancellation of systematic errors associated with the two calibration constants (see e.g. Dunn, P.F.: Measurement and Data Analysis for Engineering and Science, CRC Press, 2010)

P8 L5 Why not use a matrix-based solution for all filters? It is described in cited literature and can easily be further improved.

In the ozone calibration, the calibration constant is split in two parts – the ETC and the so-called filter correction. In the AOD calibration procedure described in the paper, we obtain just one matrix of calibration constants, with one value for each filter and wavelength. We have considered splitting this matrix in the same way as in the case of the ozone, but there does not seem to be any clear advantage in doing it.

P8 L25 Uncertainty from AMF calculations is missing in the analysis.

As discussed in the question above, the analytic derivation of the uncertainty presented in this paper is just a simplification, as stated in the text. Its results are complemented by the uncertainty obtained from the comparison with other instruments, particularly the UVPFR. Regardless, we have modified the first paragraph of Sect. 2.4 as follows:

"We also assume no correlation between variables, and work within the approximation $m_a \approx m_o \approx m_R$. This latter approximation is reasonable within the maximum optical air mass value of 3.5 used in the present work, in which case the differences between the various optical air mass terms is $\sim 1\%$ at most. A more careful examination of the optical air mass is required in other cases, see Savastiouk and McElroy (2004)."

P17 L5 the TC are not always relative, especially in recent years' calibrations

This sentence is indeed specific to the RBCC-E calibrations, and it has been modified as follows:

"Finally, it should be noted that currently the temperature correction coefficients provided by the RBCC-E for the ozone are also used in the present implementation of the Brewer AOD algorithm."

P17 L19 How do you plan to address the difficult question of objectively assessing whether the Brewers are "well maintained and calibrated"?

This is indeed a difficult question, but a strategy that could work thanks to the large collaborative effort established by EUBREWNET would be roughly as follows. First, more long-term AOD comparative studies, both between Brewer spectrophotometers and also with other independently-calibrated instruments such as Cimels and UVPFR, should be produced. Then, from the correlation of these AOD series with the maintenance records kept at the observation sites and the results of internal tests (standard lamp, dead time, ...), we expect it should be possible to determine which events result in a degradation of the AOD calibration. From there, guidelines for the maintenance of the Brewer instruments for AOD measurements could be established. For this strategy to produce reasonable and objective guidelines, a large amount of data should be analyzed and we believe EUBREWNET provides the necessary framework.

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