



LuftBlick Report 2016003

OMI validation support

Brewer-OMI UV AOD calibration report

	Name	Company	Date
prepared by	Alberto Redondas	RBCC-E	31 March 2016
	Javier López-Solano	RBCC-E	31 March 2016
checked by	Alexander Cede	LuftBlick	31 March 2016
	Katherine Cede	LuftBlick	31 March 2016
approved by			

Contents

Document Change Record	2
Acronyms and Abbreviations	3
1 Introduction	4
1.1 Applicable Documents	4
1.2 Reference Documents	4
2 Method	6
2.1 AOD equation for Brewer spectrophotometers	6
2.2 Calibration by the Langley plot method	7
2.3 Calibration by transfer from a reference instrument	8
3 Validation	9
3.1 AOD during the VIII RBCC-E	9
3.2 AOD during the X RBCC-E	12
3.3 AOD after the X RBCC-E	14
4 Concluding remarks and future work	15

Document Change Record

Issue	Date	Page	Observations
1	31 March 2016	All	First draft version.

Acronyms and Abbreviations

AOD	Aerosol Optical Depth
AVDC	Aura Validation Data Center
EUBREWNET	European Brewer Network, COST action 1207
IZO	Izaña Atmospheric Observatory
OMI	Ozone Monitoring Instrument
PFR	Precision Filter Radiometer
PMOD/WRC	Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center
RBCC-E	Regional Brewer Calibration Center
VIII RBCC-E	Eighth Intercomparison of the RBCC-E
X RBCC-E	Tenth Intercomparison of the RBCC-E

1 Introduction

This report is deliverable TD3370-2.4 of the contract "OMI validation support" [1] within Task 3 of the ESA IDEAS+ project.

In this document we describe the calibration method of Brewer spectrophotometers currently in use at the RBCC-E to determine the Aerosol Optical Depth(AOD). To test this method, we have calibrated several Brewer spectrophotometers taking part in two different campaigns:

- The “Eighth Intercomparison of the RBCC-E” (VIII RBCC-E), held at El Arenosillo (Huelva, Spain), from June 10th to 20th 2013, [13] in which two Brewer reference instruments from the RBCC-E were present.
- The “Tenth Intercomparison of the RBCC-E”(X RBCC-E), held at El Arenosillo (Huelva, Spain), from May 25th to June 5th 2015, in which a Precision Filter Radiometer (PFR) from the PMOD/WRC (Davos, Switzerland) operating in the UV range was present together with one RBCC-E reference Brewer spectrophotometer.

The calibration methodology has been implemented using the information available in the EUBREWNET database. It has been further used to define the calibration parameters needed to be available on the database for the AOD product of the network.

The following pages are organized as follows. In Sec. 2 we outline the calibration process, both for the RBCC-E reference instruments and for the other Brewers present at the intercomparison campaigns. In Sec. 3 we test our calibration method. Subsec. 3.1 is devoted to the comparison of the AOD determined by the instruments present at the VIII RBCC-E. In Subsec. 3.2 we compare the AOD of the Brewer and PFR instruments during the X RBCC-E. Finally, in Section 4 we provide some concluding remarks and discuss our plans to improve our AOD calibration and determination method.

1.1 Applicable Documents

- [1] OMI Validation Support - Contract Description, Contract Number: 4000111304/14/I-AM, LuftBlick Proposal 201504A, 2015.

1.2 Reference Documents

- [2] Technical Coordination for Better Integration of a Global Network: Recommendations of Working Group II. In *WMO/GAW experts workshop on a global surface-based network for long term observations of column aerosol optical properties*, number 162 in WMO/GAW Reports. World Meteorological Organization, 2005. URL <ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw162.pdf>.
- [3] A. Cede, S. Kazadzis, M. Kowalewski, A. Bais, N. Kouremeti, M. Blumthaler, and J. Herman. Correction of direct irradiance measurements of Brewer spectrophotometers due to the effect of internal polarization. *Geophysical Research Letters*, 33(2), 2006. ISSN 0094-8276. doi: 10.1029/2005GL024860. URL <http://doi.wiley.com/10.1029/2005GL024860>.
- [4] H. Diémoz, K. Eleftheratos, S. Kazadzis, V. Amiridis, and C.S. Zerefos. Retrieval of aerosol optical depth in the visible range with a Brewer spectrophotometer in Athens. *Atmospheric Measurement Techniques*

- Discussions*, pages 1–41, January 2016. ISSN 1867-8610. doi: 10.5194/amt-2015-328. URL <http://www.atmos-meas-tech-discuss.net/amt-2015-328/>.
- [5] J. Gröbner and C. Meleti. Aerosol optical depth in the UVB and visible wavelength range from Brewer spectrophotometer direct irradiance measurements: 1991–2002. *Journal of Geophysical Research*, 109 (D9), 2004. ISSN 0148-0227. doi: 10.1029/2003JD004409. URL <http://doi.wiley.com/10.1029/2003JD004409>.
 - [6] J. Gröbner, R. Vergaz, V. E. Cachorro, D. V. Henriques, K. Lamb, A. Redondas, J. M. Vilaplana, and D. Rembges. Intercomparison of aerosol optical depth measurements in the UVB using Brewer spectrophotometers and a Li-Cor spectrophotometer. *Geophysical Research Letters*, 28(9):1691–1694, 2001.
 - [7] M. Iqbal. *An Introduction to Solar Radiation*. Academic Press, 1983. ISBN 978-0-12-373750-2.
 - [8] S. Kazadzis, I. Veselovskii, V. Amiridis, J. Gröbner, A. Suvorina, S. Nyeki, E. Gerasopoulos, N. Kouremeti, M. Taylor, A. Tsekeri, and C. Wehrli. Aerosol microphysical retrievals from precision filter radiometer direct solar radiation measurements and comparison with AERONET. *Atmos. Meas. Tech.*, 7(7):2013–2025, July 2014. ISSN 1867-8548. doi: 10.5194/amt-7-2013-2014. URL <http://www.atmos-meas-tech.net/7/2013/2014/>.
 - [9] J. B. Kerr. The Brewer Spectrophotometer. In *UV Radiation in Global Climate Change*, pages 160–191. Springer, 2010. URL http://link.springer.com/chapter/10.1007/978-3-642-03313-1_6.
 - [10] N. Kouremeti, J. Gröbner, and A. Redondas. Aerosol optical depth in the UV spectral region retrieved by filter sunphotometers and a Brewer spectroradiometer. In *12 International Conference of Meteorology, Climatology and Physics of the Atmosphere, Heraklion, Crete, 28 – 31 May 2014*. Crete University Press, 2014. ISBN 978-960-524-430-9. URL http://comecap2014.chemistry.uoc.gr/COMECAP-ISBN-978-960-524-430-9-vol_2.pdf.
 - [11] F. Marengo, A. di Sarra, and J. De Luisi. Methodology for determining aerosol optical depth from Brewer 300-320-nm ozone measurements. *Applied Optics*, 41(9):1805–1814, March 2002.
 - [12] A. Redondas. Ozone Absolute Langley Calibration. In *The Tenth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting*, number 176 in WMO/GAW reports. World Meteorological Organization, 2008. URL ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw176_10thbrewer.pdf.
 - [13] A. Redondas and J. Rodriguez-Franco. *Eighth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E)*. Number 223 in WMO/GAW Reports. World Meteorological Organization, December 2015. URL http://www.wmo.int/pages/prog/arep/gaw/documents/FINAL_GAW_223.pdf.
 - [14] A. Redondas, R. Evans, R. Stuebi, U. Köhler, and M. Weber. Evaluation of the use of five laboratory-determined ozone absorption cross sections in Brewer and Dobson retrieval algorithms. *Atmospheric Chemistry and Physics*, 14(3):1635–1648, February 2014. ISSN 1680-7324. doi: 10.5194/acp-14-1635-2014. URL <http://www.atmos-chem-phys.net/14/1635/2014/>.
 - [15] O. Torres. OMAERUV readme file, 2011. URL http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/documents/v003/OMAERUV_README_V003.pdf.

2 Method

In this section we describe the AOD calculation currently used at the RBCC-E. As shown later in this report, the results obtained with this calculation method are in reasonable agreement with reference data. Regardless, we plan to continue improving our AOD algorithm in the upcoming months.

2.1 AOD equation for Brewer spectrophotometers

The well known Beer-Lambert-Bouguer equation (see e.g. [7]) can be used to describe the attenuation of the solar radiation as it travels through the Earth's atmosphere:

$$I = I_0 e^{-\tau m} \quad (1)$$

where I is the solar irradiance after being attenuated by the atmosphere, I_0 is the extraterrestrial (i.e., before the effect of the atmosphere is taken into account) irradiance, τ is the so-called optical depth, and m , the optical mass. The two latter variables describe the effect of the different components of the atmosphere on the solar radiation. Note that, instead of absolute irradiances, we can use any other proportional magnitudes.

In the UV operational range of the Brewer instruments, the main contributions to the exponent of Eq. 1 are the ozone, SO_2 , Rayleigh scattering, and aerosols. Following previous authors (e.g. [11]) we currently do not consider the contribution of the SO_2 to the optical depth. The product of the optical depth and mass can thus be written as

$$\tau m = \tau_o m_o + \tau_R m_R + \tau_a m_a$$

where the o subscript makes reference to the ozone terms, R to the Rayleigh ones, and a to those corresponding to the contribution of aerosols. Solving for the AOD τ_a term, Eq. 1 then becomes

$$\tau_a = \frac{1}{m_a} \{ \log I_0 - \log I - \tau_o m_o - \tau_R m_R \}$$

For Brewer spectrophotometers, and taking also the approximation $m_a = m_R$, this equation can be written as

$$\tau_a = \frac{1}{m_R} \left\{ \log f_0 - \log f - D_o \frac{k_o \log 10}{1000} m_o - \frac{p}{1013} \frac{k_R \log 10}{10000} m_R \right\} \quad (2)$$

Note that this expression is valid for each of the UV wavelengths measured by the Brewer spectrophotometers, usually six between approx. 300 and 320 nm. The terms in Eq. 2 are

- f_0 : calibration constant for each wavelength, determined by any of the two procedures described in the next sections
- f : counts per second¹ for each wavelength, obtained taking into the account the effects on the raw counts produced by the dark counts, dead time, temperature, filters, and seasonal change of the Earth-Sun distance. Unlike the standard Brewer ozone algorithm, filter attenuation coefficients used here include the

¹For efficiency reasons, the standard Brewer algorithm works in a base-10 logarithmic space further scaled by 10000, and are stored as such in the EUBREWNET database. In this report the counts are used in the standard, non-logarithmic and non-scaled space

dependence with the wavelength, as determined during the calibration process for each specific Brewer spectrophotometer. We also apply to these data the filters corresponding EUBREWNET's ozone level 1.5 product, as described next

- D_o : measured ozone, in Dobson units. We use EUBREWNET's ozone level 1.5 product, which includes the following data filters and corrections:
 - standard deviation (cloud) filter: used to remove groups of measurements with large standard deviations (above 2.5 DU) and thus likely affected by fast-moving clouds
 - optical mass filter: used to remove measurements taken under conditions of high ozone optical mass (above 3.5), unreliable due to the fast Sun speed and with large Stray Light effects
 - Hg filter: used to remove measurements likely affected by a wavelength shift
 - Standard lamp correction: applied if the analysis of historical data determines that changes in the ozone calibration constant are related to those of the standard internal lamp
 - Filter correction: applied to correct for the dependence with the wavelength of the filter attenuation coefficients
 - Stray Light correction: applied to remove the effects of scattering on the single grating of MK II and IV Brewer spectrophotometers
- k_o : Bass and Paur ozone absorption cross sections for each wavelength in $(\text{atm cm})^{-1}$, as determined during calibration process for each specific Brewer spectrophotometer (see Ref. [14] for further details on the ozone cross sections used by Brewer spectrophotometers)
- m_o : ozone optical mass, $1./\cos\{\arcsin[k\sin(sza)]\}$, $k = 6370/(6370 + h)$, and $h = 22$ Km
- p : climatological pressure at the observation site in millibars
- k_R : Rayleigh coefficients for each wavelength, as used in the standard Brewer algorithm
- m_R : Rayleigh optical mass, calculated with the same expression as the ozone optical mass but with $h = 5$ Km

After the AOD has been calculated, we remove groups of five measurements with a standard deviation of the AOD greater than 0.02, as suggested by Gröbner and Meleti. [5]

2.2 Calibration by the Langley plot method

If the Brewer spectrophotometer is being calibrated under stable atmospheric conditions, the total optical depth τ can be considered constant. Equation 1 for the Brewer instrument can then be rewritten as a linear equation with the optical mass m as the independent variable and $\log f_0$ as the intercept:

$$\log f = -\tau m + \log f_0 \quad (3)$$

The determination of the calibration constant f_0 then just requires fitting a linear equation to the data of a $\log f$ vs. m plot, commonly known as a Langley plot.

During a large part of the year, the Izaña Atmospheric Observatory (IZO), located at 2367 m.a.s.l. in Tenerife (Canary Islands, Spain) presents the stable atmospheric conditions required by the Langley calibration method.

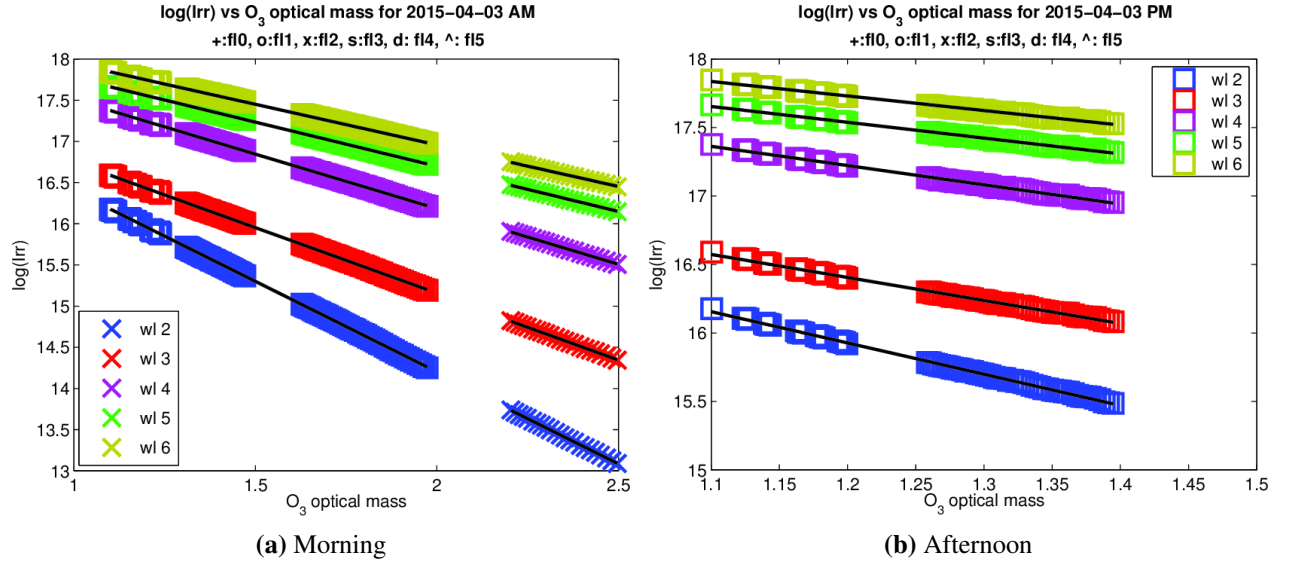


Figure 1: Langley plots for Brewer #185 operating at IZO during the morning and afternoon of April 3rd 2015. Wavelengths are plotted in different colors, filters with different symbols. In this case, there is only data for filters 2 (crosses) and 3 (squares).

Following the usual ozone calibration procedure for Brewer spectrophotometers (see e.g. [12]), we do separate Langley plots for each half day, if there are at least 20 observations taken with the same filter, and consider optical masses between 1.1 and 2.5-2.75.

Although the characterization of optical masses larger than 2.75 might be necessary for Brewers operating at extreme latitudes (e.g., at Sodankyla), these data might be also affected by internal polarization issues [3]. At this time our data does not include corrections for the internal polarization effects, although we plan to examine the issue early in April 2016 in collaboration with researchers of the PMOD/WRC.

Figure 1 shows two examples of Langley plots for all the wavelengths measured by Brewer #185 during its standard operation. Measurements with each filter are marked with different symbols, wavelengths by different colors. Since the counts are compensated for filter attenuation, the data for each wavelength are almost on a single regression line. Nevertheless, to ensure the maximum precision, filters are used as dummy variables in our linear regression, and we obtain a calibration constant for each filter. The result of each half-day Langley calibration is thus a matrix of calibration constants f_0 , one for each filter and wavelength. Note that in the case of ozone the effect of the filters in the calibration is introduced via a separate “filter correction” vector. We will evaluate the possibility of doing the same for the AOD calibration.

As the final step in the calibration, we average the calibration constants obtained over a period of 1-2 months, discarding those corresponding to linear regressions with r^2 coefficients of determination below 0.9985, or above/below 1.20 times the average.

2.3 Calibration by transfer from a reference instrument

If the Brewer spectrophotometer being calibrated is operating on the same place and simultaneously with a reference instrument already producing correct AOD values, Eq. 2 can be solved for the calibration constant

$$\log f_0 = \tau_a^{ref} m_R + \log f + D_o \frac{k_o \log 10}{1000} m_o + \frac{p}{1013} \frac{k_R \log 10}{10000} m_R \quad (4)$$

Here, the τ_a^{ref} AOD value is provided by the reference instrument, and the remaining data is measured by the Brewer being calibrated. Eq. 4 is valid for each simultaneous measurement, with a specific wavelength and filter position. The complete calibration matrix can thus be determined solving this equation for multiple simultaneous measurements taken under different conditions.

The last days of the intercomparison campaigns of the RBCC-E, after the Brewer instruments have received maintenance and their ozone calibrations have been updated or confirmed, provide the necessary time span to carry out this calibration procedure. Measurements within 1 minute are considered simultaneous, and the average of multiple calibration constants for each wavelength and filter provides the final AOD calibration matrix.

3 Validation

In this section we test the calibration method just described. We have calibrated several Brewer spectrophotometers taking part in the VIII RBCC-E and X RBCC-E.

3.1 AOD during the VIII RBCC-E

In this section we present results of AOD calculated during the El Arenosillo 2013 campaign. Brewers #183 and #185 operated by the RBCC-E where both present at this campaign. Both instruments have been calibrated independently by the Langley method, using data measured at IZO before the campaign, from April to June for Brewer #183, and from May to June for the #185. An ozone optical mass range between 1.1 and 2.75 was used in the Langley plots, allowing for the determination of the calibration constants of filters 2 and 3 at all wavelengths.

Figure 2 shows the AOD difference with respect to Brewer #185 for the all the instruments considered. We have only plotted the longest wavelength, 320 nm, since this is the closest to the lowest one available in the OMI overpass data at the AVDC, 354 nm.[15]

A good agreement between the AOD of Brewers #183 and #185 is found for all days of the campaign, with days 165 and 166 showing a larger difference than the others. The calibration of Brewer #185 was transferred to selected Brewers taking part in the campaign. We followed the method described in Sec. 2.3 using all the days where the ozone calibration was stable and the instrument was not under maintenance, except days 165 and 166.

Overall, the AOD difference is within ± 0.03 , with the exception of days 165 and 166. For comparison, Gröbner *et al.* found differences within ± 0.02 for 7 Brewer spectrophotometers during an intercomparison at El Arenosillo in year 1999. [6]

Table 1 summarizes the comparison between selected Brewers at the VIII RBCC-E and the reference instrument #185. Overall, there is a good correlation between all datasets, with 0.97 as the average correlation coefficient and a rather small intercept of 0.004. There are however noticeable differences among the Brewers considered. At least part of this difference might be attributed to wrong data included in the datasets analyzed. The filters mentioned in Sec. 2.1 remove many data outliers, and furthermore we have removed some of the most notable remaining ones. Still, the maintenance work being carried out during the campaign, which requires access to the Brewer setup area, is likely to disturb the measurements and introduce erroneous data. Further filters and outlier detection methods should be developed to improve the quality of the data.

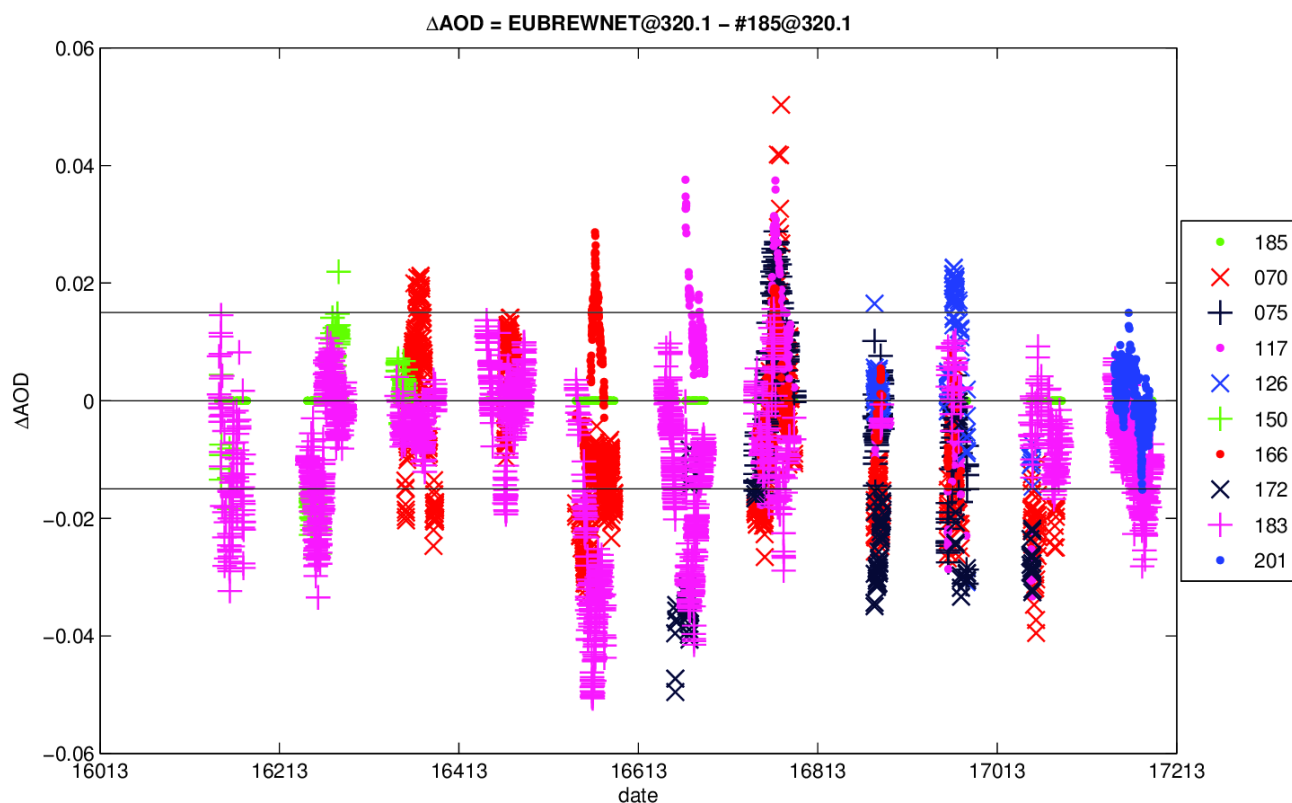


Figure 2: AOD difference with respect to Brewer #185 during the VIII RBCC-E. Dates are written as *jjjyy*, where *jjj* is the number of the day in the year, and *yy* is the last two digits of the year.

Table 1: AOD from selected Brewers compared to reference Brewer #185 during the VIII RBCC-E, for a wavelength of 320.1 nm. The table includes the number of simultaneous observations with the reference instrument, the Pearson's correlation coefficient, the slope and intercept of a linear fit to the two data series, and the percentage of measurements within the *U* limit (Eq. 5)

Brewer ID	observations	correlation	linear fit slope	intercept	% within <i>U</i> limit
070	869	0.942	0.998	-0.008	52.7
075	246	0.973	0.874	0.019	70.7
117	400	0.945	0.848	0.024	67.2
126	125	0.988	1.122	-0.017	75.2
150	124	0.954	0.886	0.015	53.2
166	389	0.977	1.014	0.001	82.8
172	118	0.996	1.018	-0.003	100.0
183	1875	0.980	0.993	-0.008	65.8
201	308	0.977	0.933	0.015	100.0
mean	495	0.970	0.965	0.004	74.2

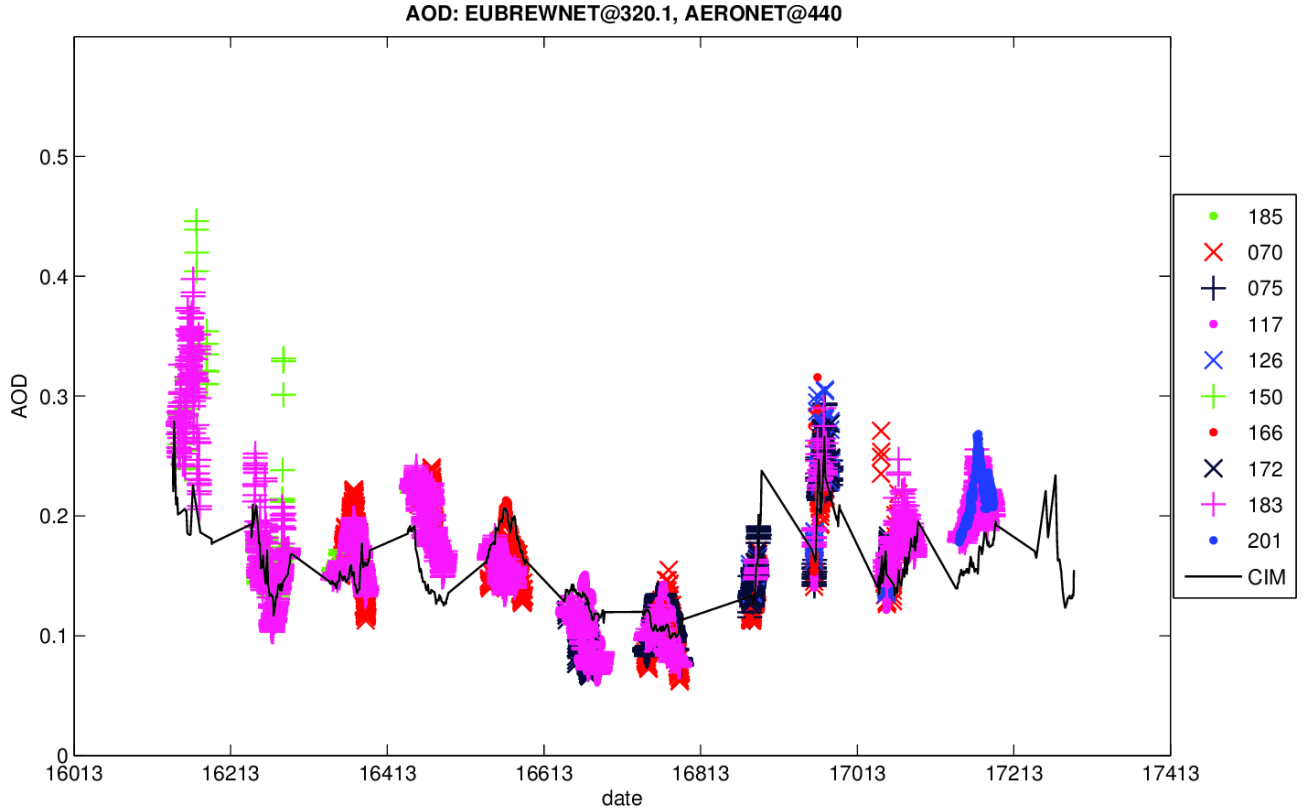


Figure 3: AOD measurements during the VIII RBCC-E from Brewer spectrophotometers and the CIMEL sun photometer operating at the Huelva AERONET site. CIMEL data corresponds to 440 nm and has been shifted up by 0.07 to allow for a better comparison with the Brewer AOD in the 320 nm wavelength.

The column labeled as “ U limit” in Table 1 shows the percentage of measurements whose AOD difference with respect to the reference is within the limit

$$U = \pm(0.005 + 0.010/m_a) \quad (5)$$

The WMO traceability criteria for finite field-of-view instruments requires at least 95% of the observations to be within the U limit. [2] Here we find that 74% of the observations are within the U limit on average. For comparison, Kouremeti *et al.* found percentages ranging from 50 to 88% when comparing Brewer and extrapolated CIMEL data between 306 and 320 nm. [10] More recently, Diémoz *et al.* compared CIMEL and Brewer AOD at 437 nm, finding that 60% of the observations were within the U limit, although the percentage increased to 90% once a temperature correction for the Brewer NiSO_4 filter was included. [4]

Figure 3 further shows the AOD at 320 nm for the 10 Brewer spectrophotometers considered together with the AOD measured by a CIMEL sun photometer at 440 nm, the lowest wavelength available. The wavelength difference between the Brewer and CIMEL measurements results in a bias in the AOD, and we have shifted up the CIMEL data by 0.07 to allow for an easier comparison. Once the data is shifted, a reasonable agreement between the data from most Brewer instruments and the CIMEL can be observed, and indeed the correlation coefficients range from 0.6 to 1.

From the data presented in this section, we can conclude that the current calibration method of Brewer spectrophotometers, either by the Langley plot method or by calibration transfer, allows for the determination of the

AOD with a reasonable precision. In the next section we will compare our AOD results to an independently-operated PFR instrument.

3.2 AOD during the X RBCC-E

We now discuss the AOD results for the last days of the X RBCC-E. Brewer #185 was used as reference to calibrate all the other Brewer instruments at the campaign. The AOD calibration for this instrument was performed by the Langley plot method using data from April to late May 2015, just before the beginning of the campaign. The maximum optical mass considered was 2.5, and allowed to characterize the filters 2, 3, and 4 of Brewer #185.

Further present at the campaign was an UV-PFR operated by the PMOD/WRC. This instrument measures the AOD at the 305.3, 311.3, 317.5, and 332.2 nm wavelengths (for further details on the PFR instrument, see e.g. [10] and [8]). In the comparisons with the PFR below, we have compared the AOD from the Brewer at 316.8 nm with that of the PFR at 317.5 nm.

From the comparison between the Brewer #185 and PFR instruments, we found that days 151, 152, and 154 presented a larger difference than the others. Hence, these days were not used to transfer the calibration of the RBCC-E reference #185 to the other Brewer instruments present at the campaign.

Table 2 summarizes the comparison between the Brewer and PFR AOD. The overall agreement is quite good, with a 0.98 average correlation coefficient and a very small average intercept. A 73% of the measurements are within the U limit.

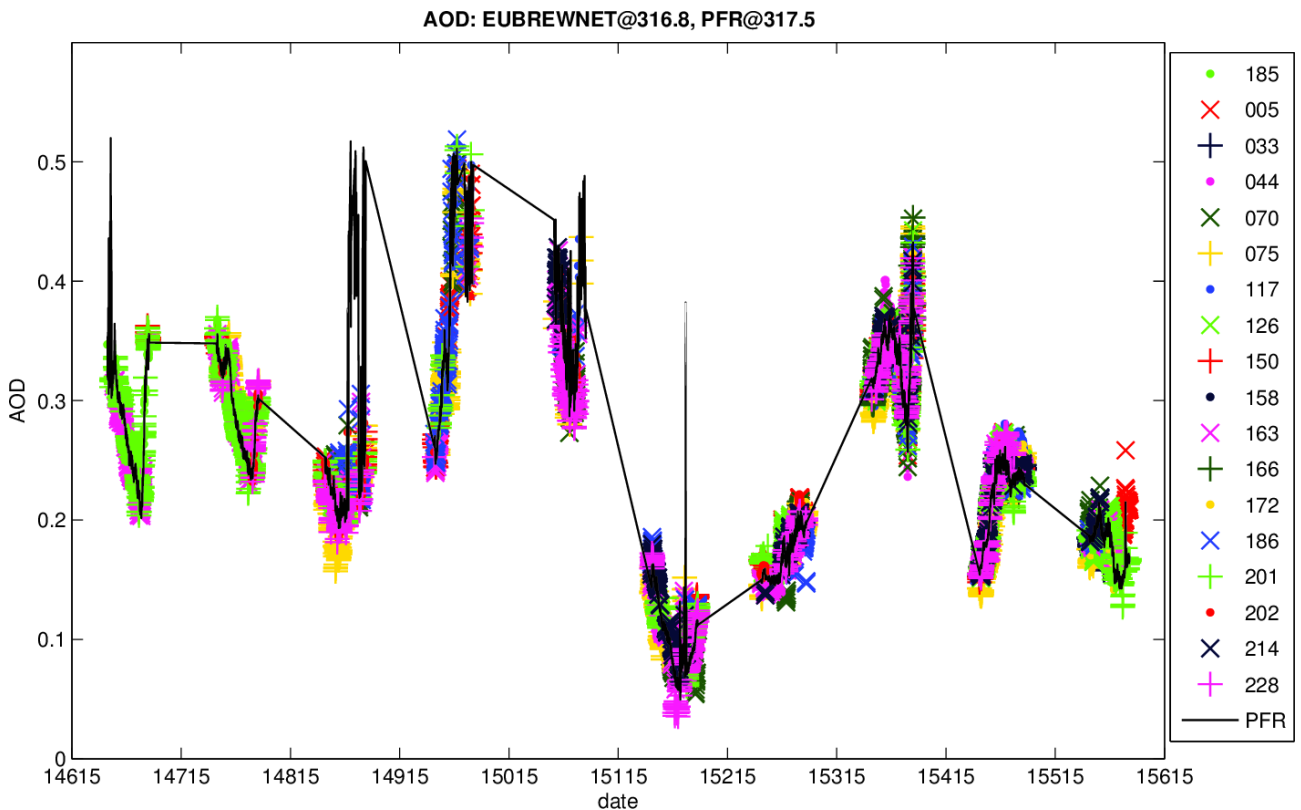


Figure 4: AOD from Brewer and PFR instruments during the X RBCC-E. The Brewer AOD corresponds to a wavelength of 316.8 nm, and that of the PFR to 317.5 nm.

Table 2: Comparison of the AOD from the Brewer (at 316.8 nm) and PFR (at 317.5 nm) instruments during the X RBCC-E. The table provides values of the number of simultaneous Brewer-PFR observations, Pearson's correlation coefficient, the slope and intercept of a linear fit to the two data series, and the percentage of measurements within the U limit (Eq. 5).

Brewer ID	observations	correlation	linear fit slope	intercept	% within U limit
005	754	0.985	0.933	0.024	67.0
033	335	0.979	1.151	-0.035	80.9
044	246	0.983	1.030	-0.008	58.5
070	827	0.986	0.973	0.004	62.4
075	1329	0.974	0.963	0.008	37.5
117	762	0.982	0.967	0.013	50.7
126	838	0.986	0.990	0.006	68.5
150	173	0.991	0.972	0.007	60.7
158	342	0.998	0.993	0.004	99.1
163	1503	0.996	0.996	0.000	94.2
166	228	0.913	1.103	-0.034	64.5
172	431	0.988	0.971	0.007	74.2
185	1343	0.994	1.022	-0.007	95.8
186	456	0.989	1.003	0.000	79.6
201	1354	0.994	0.987	0.004	85.4
202	807	0.993	0.991	0.004	89.0
214	520	0.997	0.987	0.007	87.1
228	590	0.989	0.987	0.000	64.6
mean	713	0.984	1.001	0.000	73.31

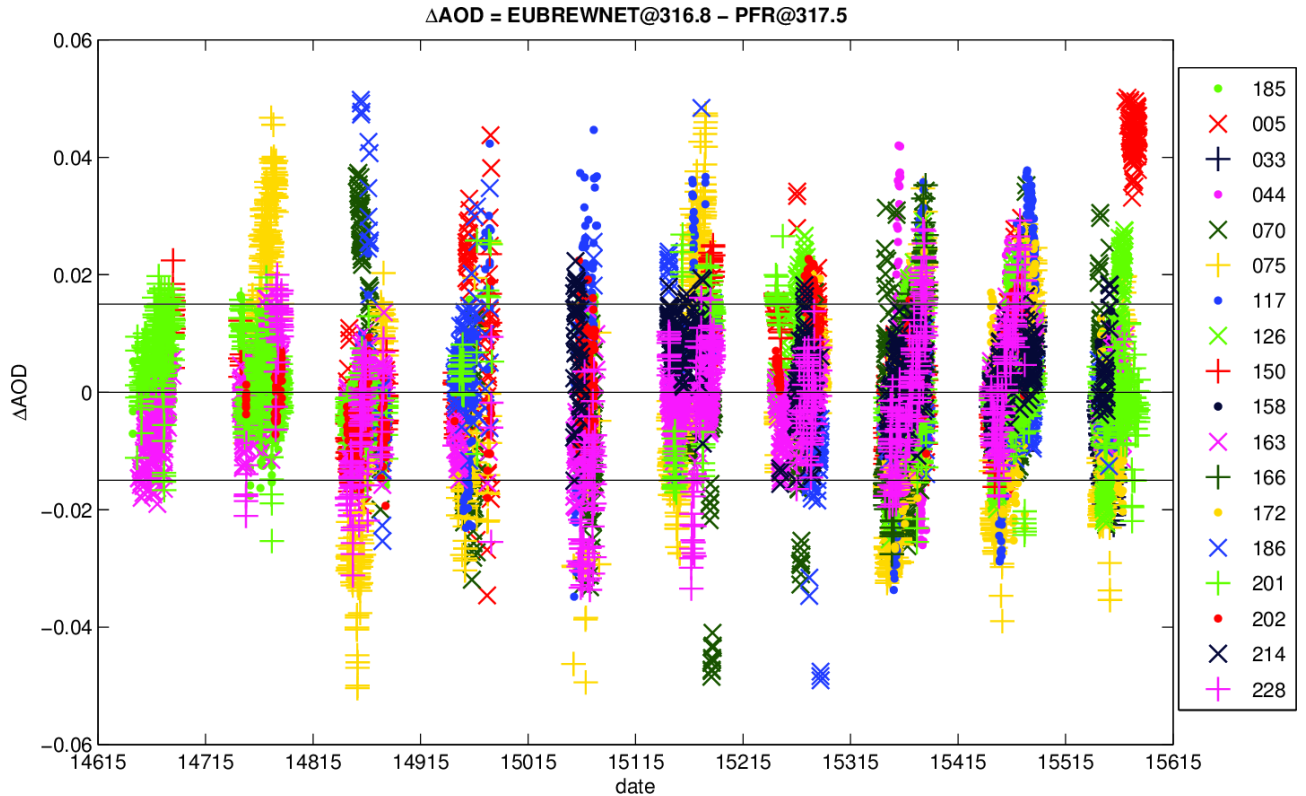


Figure 5: Difference between Brewer and PFR AOD during the X RBCC-E.

Fig. 4 further shows the good correlation within the Brewer and PFR AOD, and Fig. 5 shows that the AOD difference is below 0.03 on average. All this seems to indicate that most Brewer instruments taking part in the X RBCC-E were correctly calibrated and can be currently used to measure AOD at their respective observation sites. We briefly discuss this point in the next section.

3.3 AOD after the X RBCC-E

In this section we briefly compare the AOD from selected Brewers operating at the observation sites with co-located CIMEL photometers. We have used all the simultaneous data available at the AERONET and EUBREUNET databases since the end of the X RBCC-E up to March 1st, 2016. The AOD was determined using the calibration obtained in the last days of the X RBCCE, already checked in the previous section.

Fig. 6 shows AOD plots for the Brewer instruments operating at Sodankyla (ID #214) and Davos (ID #163). We compare the Brewer 320.1 nm to CIMEL data extrapolated to 320 nm from 340 nm using the Angström exponent between 340 and 440 nm. As can be seen, there is quite a good correlation between the Brewer and CIMEL data, and this indeed confirmed by the Pearson's correlation coefficients: 0.978 for the AOD at Sodankyla, and 0.993 for Davos. The percentage of observations within the U limit is 22% for Sodankyla, and 45.6% for Davos. Despite the extrapolation used in the CIMEL data, there might still be a bias between the AOD of both instruments, so the previous percentages should be taken with some caution.

Overall, we can conclude from this brief comparison with CIMEL data that the Brewer AOD calibration is stable in time and can be used at observation sites with very different characteristics. In deliverable TD3370-2.5, dedicated to the Brewer-OMI AOD validation, we will analyze the stability of the Brewer AOD calibration in more detail.

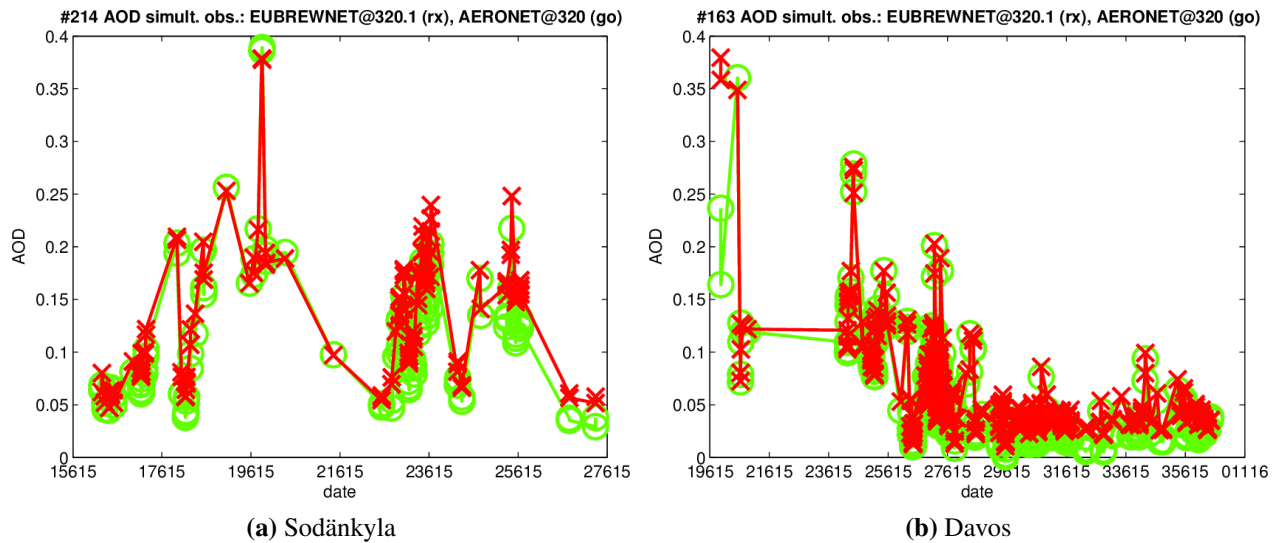


Figure 6: AOD from Brewer (red crosses) and CIMEL (green circles) instruments operating at Sodankylä and Davos. The Brewer AOD corresponds to a wavelength of 320.1 nm, CIMEL data has been extrapolated from 340 nm to 320 nm using the Angström exponent between 340 and 440 nm.

4 Concluding remarks and future work

The AOD calculation analyzed in this report are based on the standard Brewer ozone measurement process, which uses all the operative wavelengths shown in the first column of Table 3. For the validation with the OMI instrument, we have analyzed the highest wavelengths, 316.8 and 320 nm, which are still below the lowest one included in the OMI overpass files at the AVDC, 357 nm. A new AOD measurement method is being implemented in the EUBREWNET network, and will allow for the AOD retrieval on the full spectral range of the Brewer spectrometer, at all the wavelengths shown in Table 3. This will allow for a direct comparison with the OMI OMIAERUV product at 357 nm, and with the 340 nm channel of CIMEL sun photometers.

Overall, the Brewer-Brewer, Brewer-PFR, and Brewer-CIMEL comparisons in previous sections show a good agreement for the AOD. Correlation coefficients are on average above 0.97 and there is a very low bias. The WMO traceability criteria requires 95% of the observations within the U limit (Eq. 5), which is quite far from the 73% obtained in our comparisons. The WMO might be too restrictive for the UV range AOD retrieval. Regardless, it should be noted that none of the reported studies reach the required 95% level, see [10] and [4].

Table 3: Wavelengths of the AOD-specific Brewer measurement process. The process combines the six slits (rows) and grating positions (columns) available in Brewer spectrophotometers.

Slit/Grating	0	1	2	3	4
1	303.2	311	325.6	339.3	348.9
2	306.3	314	328.5	342	351.5
3	310.1	317.6	332	345.3	354.7
4	313.5	321	335.2	348.4	357.7
5	316.8	324.2	338.2	351.2	360.4
6	320.1	327.3	341.1	354	363.1

Within this work, we have also defined the set of required characterization parameters for the AOD calculation. Some parameters should have to be adapted for the AOD determination, as is the case of the temperature coefficients, which are calculated to minimize the ozone ratio rather the individual wavelength measurements. Other parameters are completely specific to the AOD determination and require additional characterization and calibration not performed during the standard ozone and UV calibration, like for example the spectral filter attenuation coefficients.

There are three main improvements to our current AOD algorithm that we will explore in the next months:

- Rayleigh coefficients are taken from the standard ozone configuration, and are thus the same for all the Brewer instruments [9]. Likewise, we also use a climatological value for the pressure, as in the standard Brewer algorithm, and the already-mentioned temperature coefficients. We will evaluate if it is necessary to improve these parameters.
- The current outlier detection is based on the standard cloud screen method for ozone measurement and the criteria of the standard deviation of the AOD proposed by Gröbner and Meletti [5]. However, these two criteria do not seem enough, and evident outliers are revealed when the AOD is compared with another instruments.
- Polarization effects might have a noticeable effect on the AOD, specially for measurements taken at high solar zenith angles. We plan to examine this issue in the upcoming weeks in collaboration with Thomas Carlund from the PMOD/WRC, which will perform a Short Term Scientific Mission at IZO in April 2016.

An updated AOD algorithm can be expected for deliverable TD3370-2.5 in June 2016. In that report, we will extend our study of the AOD calibration stability and compare the Brewer and OMI AOD products.