Retrieval of AOD in the UV-B from Brewer#001 and integration of the new product to EUBREWNET

Action number: CA21119

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1. Introduction

Currently, measurements of the aerosol optical depth (AOD) in the UV-B are sparse. Few instruments provide direct sun spectral measurements in the UV-B region, from which very few are calibrated properly to provide reliable AOD retrievals. Furthermore, to retrieve AOD in the UV-B it is necessary to use accurate measurements of the total column of ozone. Brewer spectroradiometers are among the instruments that provide automated spectral UV-B direct sun measurements that are routinely used to retrieve the total column of ozone. The same measurements can be also used to retrieve the AOD. In the context of this STSM the Brewer spectrophotometer with serial number 001 (Brewer#001) that is regularly operating in Athens, Greece, was transferred to El Arenosillo, Spain, to participate in the 20th Brewer intercomparison campaign. At the campaign, the instrument went through maintenance and upgrade of its optical parts, and it was calibrated. During the campaign, the grantee worked closely with the host to retrieve the AOD in the UV-B, and to provide the necessary constants for automatic retrieval of the AOD in the EUBREWNET database. The steps that were followed to achieve the goals of the STSM, as well as the technical work that was carried out are described below.

2. Processing raw data from the Brewer

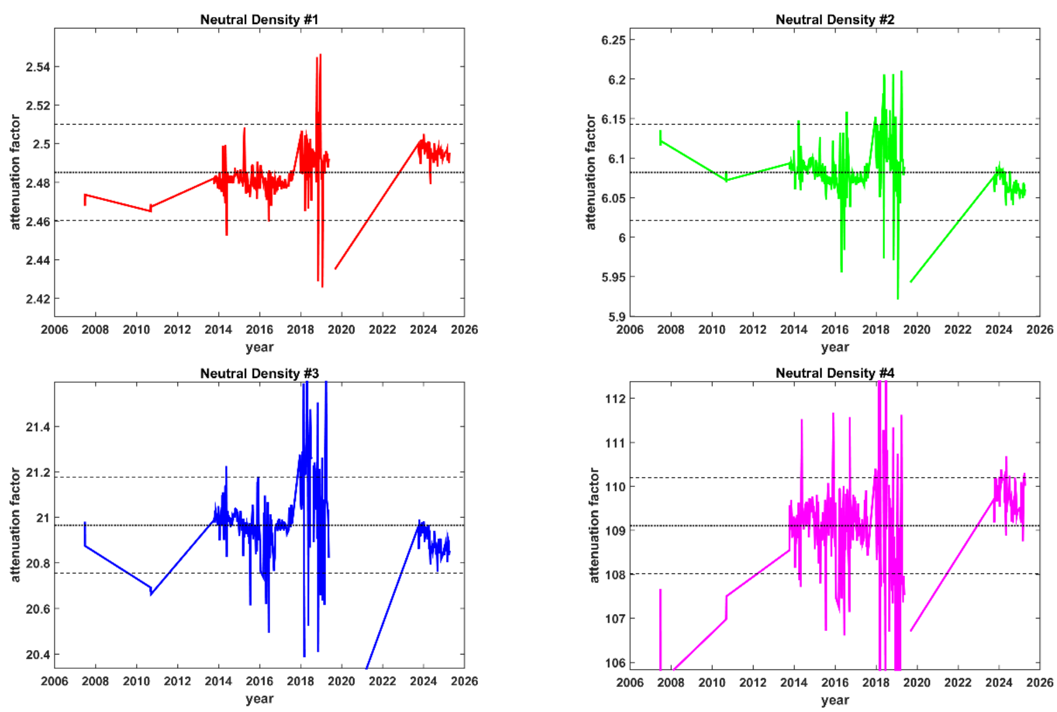
Light enters the Brewer through the entrance optics, it is then analyzed to different wavelengths in the spectrometer, and finally the irradiance at specific wavelengths reaches the photomultiplier. The Brewer measures the number of photons that reach the photo-multiplying tube per sampling time. These raw counts must be converted in counts per second (since different sampling times may be used depending on the sensitivity of the instrument and the type of the measurement) prior to using the data for Langley calibration and/or for AOD retrieval. Although the conversion from counts to counts per second is straightforward, the instrument characteristics (which are specific for each Brewer) must also be considered.

1.1. Dead time

Dead time represents the time after a photon reaches the PMT when the PMT cannot measure a second photon. Dead time is instrument-specific (differs for different Brewers) and may change with time. A statistical correction is applied to compensate for the effect of dead time. Accuracy of the order of 1% is desirable in the correction (e.g., Fountoulakis et al., 2016). A test to determine the correct dead time value is applied daily using the instrument internal standard lamp. From the beginning of 2023 until the RBCCE campaign the dead time was 40 ns. After the campaign a dead time value of 39 ns is used for the correction.

1.2. Neutral density filters

Five neutral density filters are used to regulate the signal at the desired levels where the instrument's response is linear. The attenuation of the Neutral Density (ND) filters is measured using an internal lamp. These measurements were analyzed for the whole period of the instrument's operation. To present the long-term changes in the ND filters attenuation we averaged the attenuation over the five wavelengths and the results are shown in Figure 1.



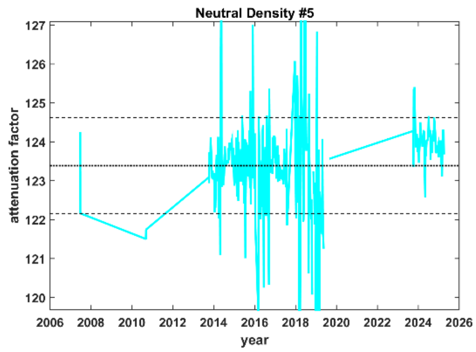
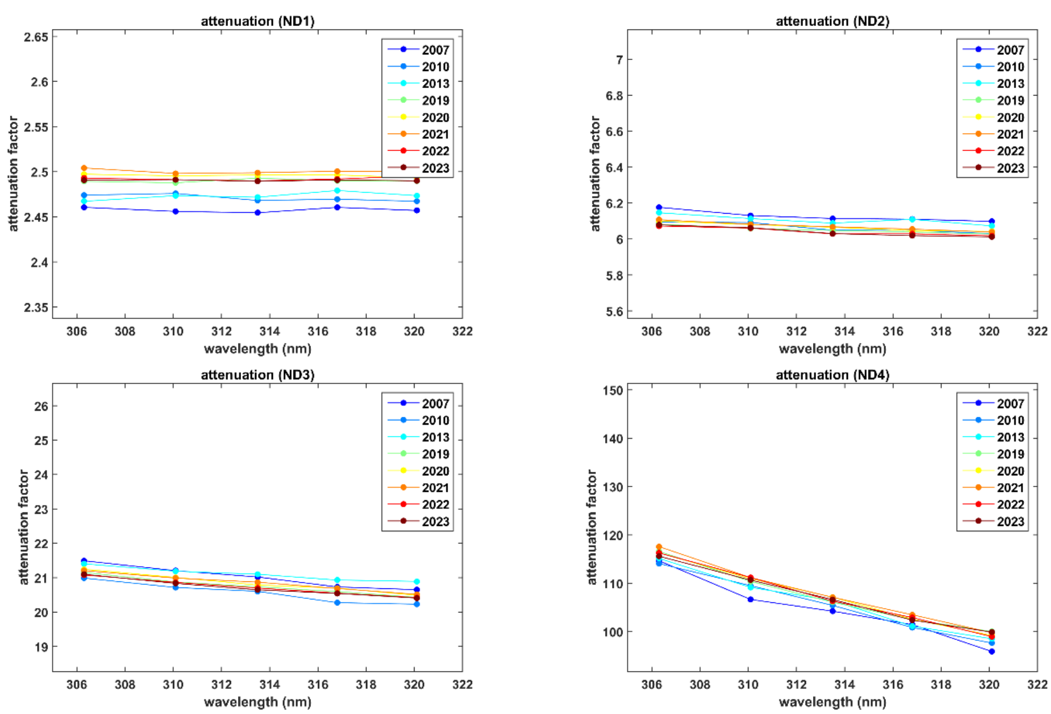


Figure 1. Change in the ND filter attenuation with respect to time. Dotted line represents average values. Dashed lines represent ± 1% around the average. The presented results are averages over the five ozone wavelengths.

As shown in Figure 1, for as long as the attenuation of the ND filters is measured (nearly 20 years), differences are generally within 1%. Occasionally, differences from the average value can be of the order of 2-3%, which however has to do with the stability in the signal of the standard lamp that is being used to measure the attenuation, rather than with real variations in the ND filters properties.

<u>Spectral ND filter attenuation</u>

Measurements of the ND filter attenuation that were performed during the instrument calibration/maintenance activities in different years are presented in Figure 2.



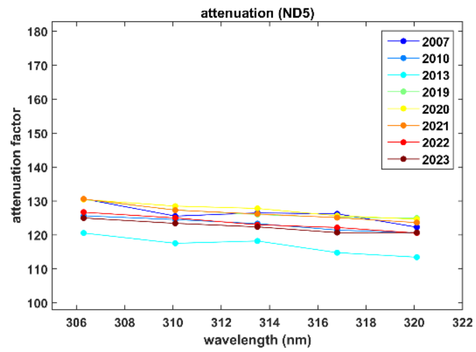


Figure 2. Spectral ND filter attenuation as it was measured during calibration in different years.

While some filters are "more neutral" (e.g., ND1, ND2), for other, attenuation changes significantly with wavelength (e.g., ND4).

Based on this analysis we decided to use different correction factors for each wavelength, that are considered invariant for the whole period of the instrument's operation. The correction factors used are presented in Table 1.

Table 1. Correction factors for the effect of the Neutral Density filters

Filter/wavelength	306.3 nm	310.1 nm	313.5 nm	316.8 nm	320.1 nm
1	2.480	2.484	2.484	2.486	2.486
2	6.109	6.085	6.070	6.058	6.044
3	21.254	21.014	20.846	20.698	20.558
4	116.286	110.921	106.553	102.794	99.437
5	125.992	124.045	122.674	121.512	120.387

1.3. Compensation for the effect of temperature

Ideally, to measure the effect of temperature we should measure the signal from an external lamp that is operating at a fixed temperature (so that lamp's emitted signal is not affected by temperature variations). Since this was not possible, we derived the temperature correction factors from the measurements of the signal from the internal lamp. Using the internal 12V lamp introduces uncertainties since its signal is affected by the variations in temperature. The temperature correction factors have been used to derive past AOD data but are not used in EUBREWNET for AOD retrieval. Temperature correction factors were found to be wavelength independent, and thus the 320.1 nm results that are presented in Figure 3 are representative for all wavelengths,

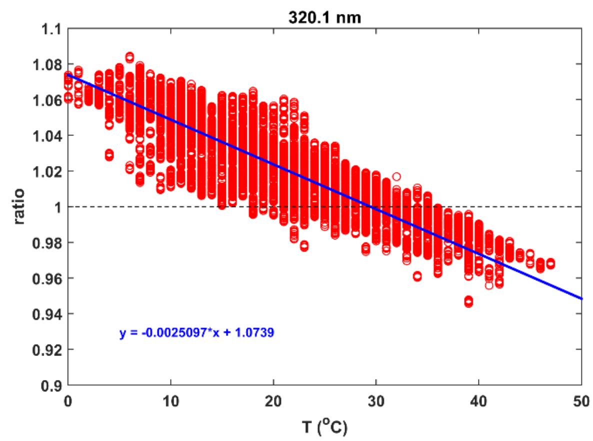


Figure 3: Temperature dependence of the Brewer#001.

1.4. Ozone cross sections

The Brewer#001 slit function was calculated using the methodology described in Gröbner et al., (1998). Then the ozone cross sections that were used for the retrieval of the AOD were derived by weighting the fine resolution cross sections by Paur and Bass, (1985) with the slit function for the five wavelengths.

1.5. Polarization

The average polarization correction factors proposed by Cede et al., (2006) have been used to correct the measurements.

1.6. Stray light

The effect of stray light has been corrected using the methodology described in Savastiouk et al., (2023).

2. Langley calibration

The Extra-Terrestrial Constant (ETC) for EUBREWNET is derived according to the methodology described in López-Solano et al., (2018). For the past Brewer dataset we applied.

After applying all the above corrections, we derived the Extra Terrestrial Constant (ETC) as follows:

- Direct sun (DS) measurements are performed in groups of five consecutive measurements. When total ozone within each group varies by more than 1% measurements are rejected
- For each morning or evening at least five groups of DS measurements must be available
- Air mass range corresponding to the available measurements must be at least 3
- The R^2 of the Langley fit must be at least 0.999

- If $R^2 < 0.999$, measurements are removed iteratively (in each iteration, the measurement that deviates most from the Langley fit is removed), until either the aforementioned criteria are not fulfilled (the derived ETC is rejected) or $R^2 \geq 0.999$ (the derived ETC is used).

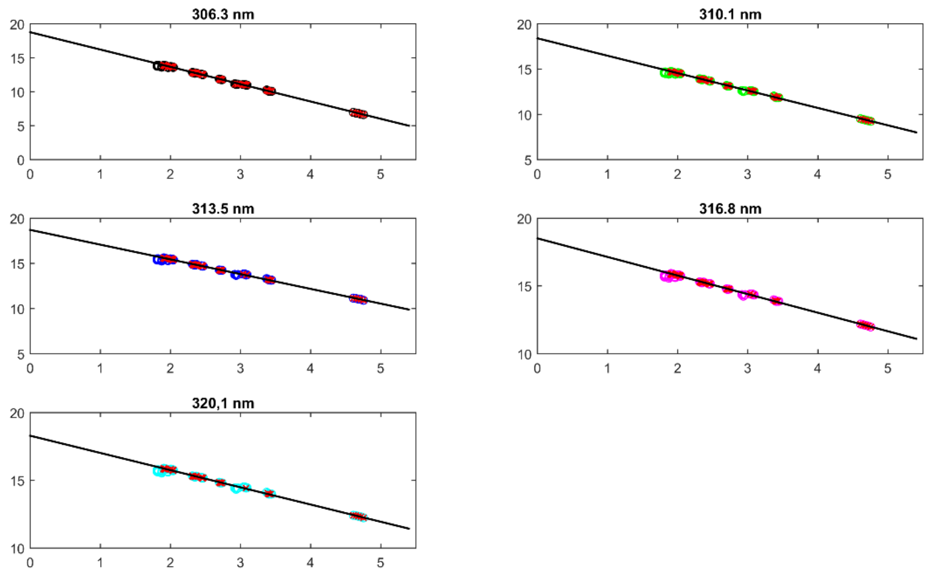


Figure 4. Example of Langley for DOY 26 of 2025. Only the points marked with red "x" have been used to derive the ETC.

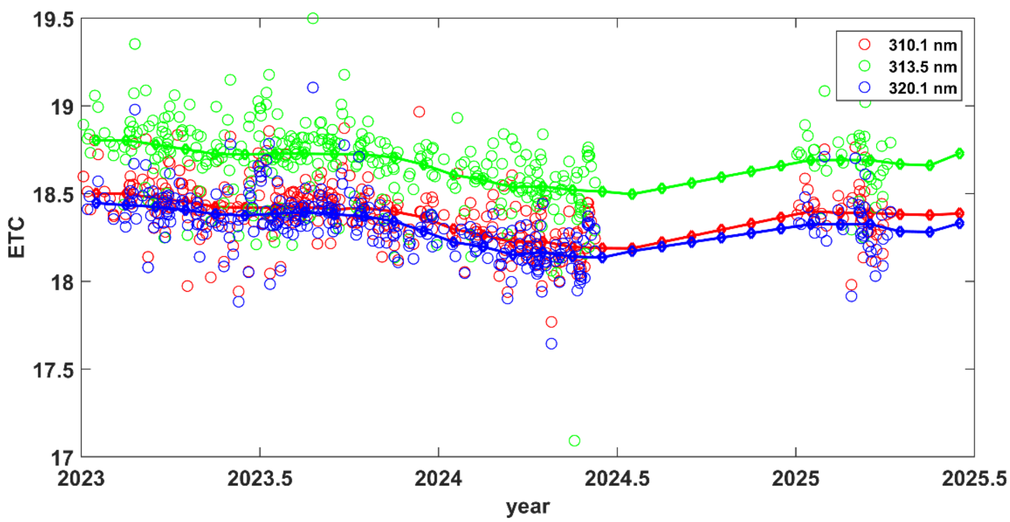


Figure 5. ETC for different wavelengths for the period 2023 – 2025.

The ETC used for each month has been derived as the median for a period of ± 2 months around the middle of the month. The retrieved ETC for three wavelengths is shown in Figure 4.

3. AOD calculation and Comparison with AOD from the CIMEL sun-photometer

The AOD for 2023 – 2025 has been retrieved using the calculated ETCs. To evaluate the accuracy of the new product we scaled the 340 nm AOD from AERONET (level 1.5 direct sun product, version 3) to the Brewer wavelengths using the 340 – 440 nm Angstrom Exponent. The results of the comparison are shown in Figures 6 – 8 (indicatively for 306.3 nm, 313.5 nm, and 320.1 nm).

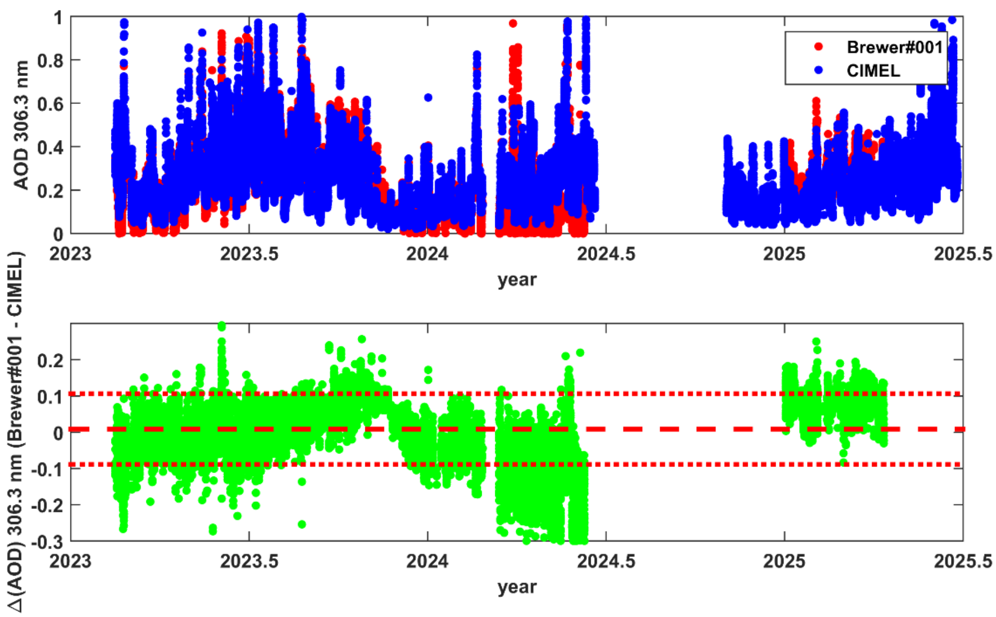


Figure 6: AOD at 306.3 nm from the Brewer and CIMEL.

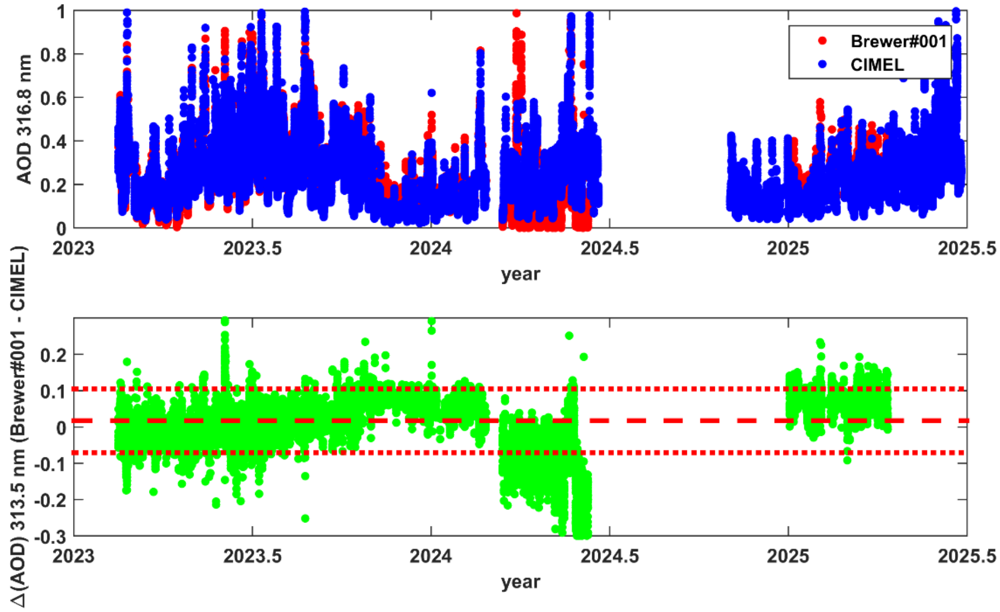


Figure 7: AOD at 3130.5 nm from the Brewer and CIMEL.

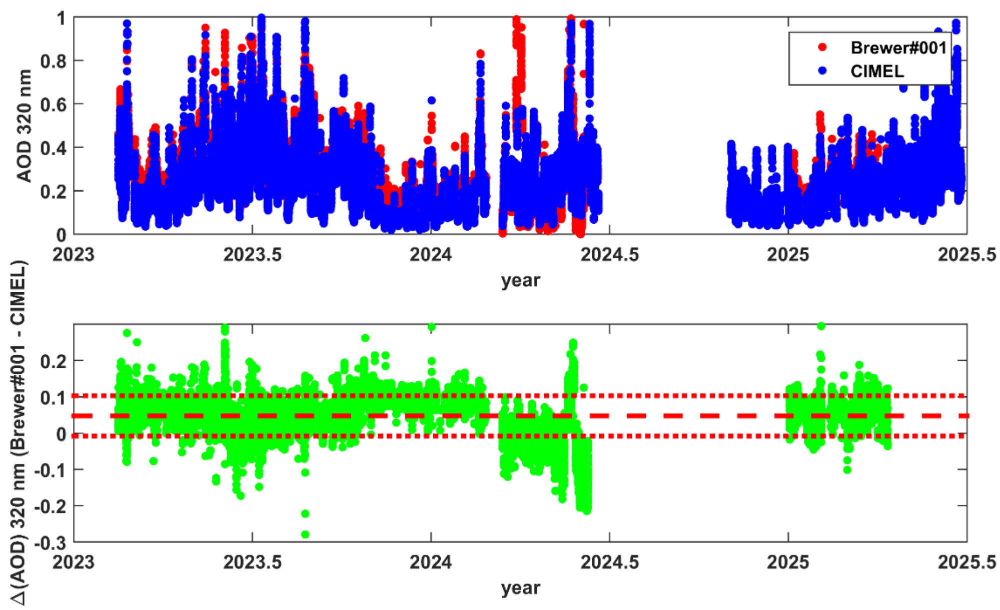


Figure 8: AOD at 320.1 nm from the Brewer and CIMEL.

It must be noted that conversion of the CIMEL AOD from 340 nm to the Brewer wavelengths does not guarantee that the calculated AOD is accurate. AOD at 340 nm is however the only available dataset for comparison.

The average agreement is within 0.05 and the standard deviation decreases with increasing wavelength from ~0.1 at 306.3 nm to ~0.05 at 320.1 nm.

4. Summary and future actions

During the STSM we calculated all necessary constants from the Brewer#001 to calculate AOD at the UV-B wavelengths that are regularly used to retrieve columnar ozone. Furthermore, the Brewer#001 has been maintained and calibrated during the campaign. The UV-B AOD product from EUBREWNET will be soon freely available on the EUBREWNET web-page.

Based on the work that was carried out, the direct sun measurements that were performed in the last three years were processed to retrieve the AOD. The AOD from Brewer was compared to the AOD from CIMEL, and the average agreement was better than 0.05. We expect that the upgrade of the optics may give better results after the campaign, although this data has not been processed yet.

The next steps include provision of the AOD from the EUBREWNET web-page, as well as "in-house" retrieval of the AOD. We also intend to inter-compare the AOD that is derived using the EUBREWNET algorithm, the AOD from CIMEL, and the AOD that is derived using the "in-house" algorithm that was developed and has been described above. This way we will evaluate the effect of differences between the two methodologies (i.e., using temperature correction or not, differences in Langley, etc.). The AOD from the Brewer#001 will be also compared to the AOD from other Brewer spectrophotometers that participated in the campaign.

References

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