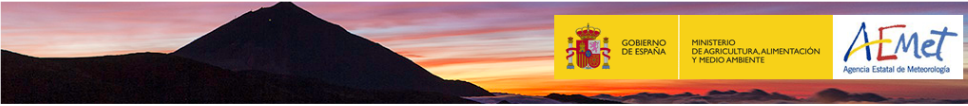
Brewer AOD Calibration and Retrieval in the UV-B

J. J. Rodríguez-Franco

Short Term Scientific Mission COST-ES1207-140215-055087

April 22, 2015



Underlying Goal

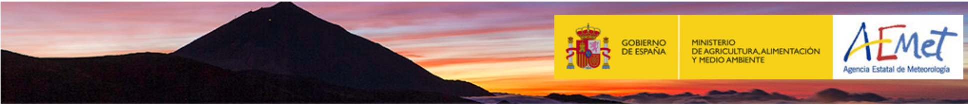
A Short Term Scientific Mission (STSM) was conducted at the Physical Meteorological Observatory / World Radiation Centre (PMOD/WRC), Davos, Switzerland, from 15th to 22th February, 2015, with the goals:

- Continue and complete the development of a standard methodology to transfer optical depth (AOD) calibration factors between Brewer spectrophotometers
- The establishment of a common algorithm applicable to the EUBREWNET network to compute AOD

This will contribute to standardize the Brewer aerosols measurements within the scope of the Eubrewnet network.

Outline

- Aerosol Optical Depth algorithm
  - Algorithm description
  - RBCC-E Langley
  - Comparing World Optical Depth Research and Calibration Center (WORCC – PMOD/WRC) and Regional Brewer Calibration Center for Europe (RBCC-E – AEMet) AOD algorithms
- Solar zenith angle (sza) dependence. Quartz Window (QW)
  - Brewer's polarization effect
  - Comparing Brewer AOD with co-located Cimel data
- AOD Calibration Transfer: first results



Introduction
- Motivation
- Outline

Aerosol Optical Depth Algorithm
- Algorithm Description
- RBCC-E Langley Methodology
- WORCC – RBCC-E Algorithms

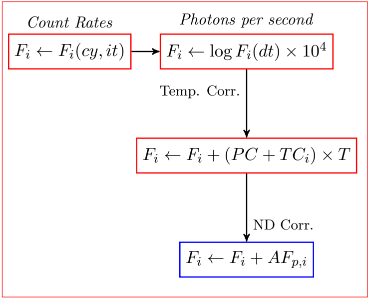
Polarization Sensitivity
- Methodology
- Polarization Results
- Cimel Comparison

AOD Calibration Transfer

Conclusions

Algorithm

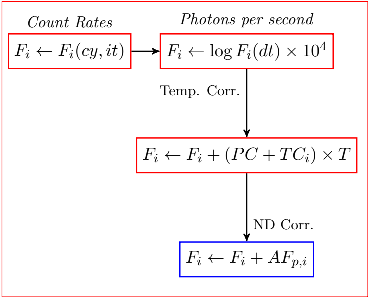
Working with individual DS measurements



1. Standard Data Reduction
2. ND filters correction: attenuations calculated from the fi routine
3. Remove the Earth–Sun distance annual cycle (eccentricity)
4. Airmass factor
5. Calculate the atmospheric extinction due to Ozone
6. Calculate the atmospheric extinction due to Rayleigh scattering
7. Outliers rejection: standard deviation for the five ozone and AOD values are below 2.5 DU and 0.02, respectively

Algorithm

Working with individual DS measurements



Count Rates

$F_i \leftarrow F_i(cy, it)$

Photons per second

$F_i \leftarrow \log F_i(dt) \times 10^4$

Temp. Corr.

$F_i \leftarrow F_i + (PC + TC_i) \times T$

ND Corr.

$F_i \leftarrow F_i + AF_{p,i}$

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Algorithm

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$$\boxed{\begin{aligned} D =& 1.000110 + 0.034221\cos(T) \\ &+ 0.001280\sin(T) \\ &+ 0.000719\cos(2T) \\ &+ 0.000077\sin(2T) \end{aligned}}$$

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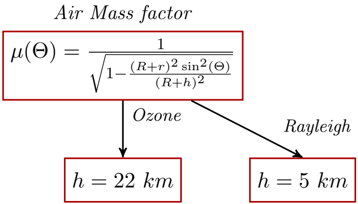

Air Mass factor

$$\mu(\Theta) = \frac{1}{\sqrt{1-\frac{(R+r)^2\sin^2(\Theta)}{(R+h)^2}}}$$

Ozone

$h = 22\ km$

Rayleigh

$h = 5\ km$

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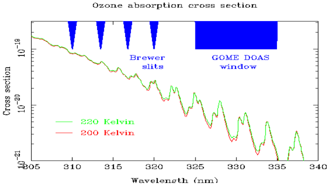
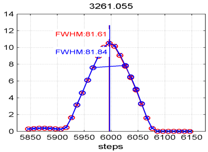
$$O_3(\lambda)_{Ext} = O_3 \times O_3(\lambda)_{XSec} \times \mu_{O_3}(\Theta)$$





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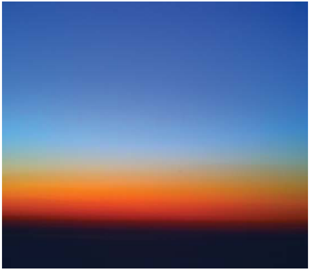
$$R(\lambda)_{scatt} = R(\lambda)_{coeff} \times \frac{p}{1013.25} \times \mu_R(\Theta)$$



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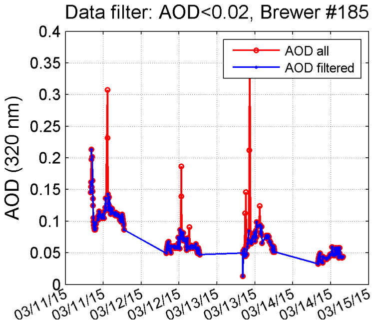

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Algorithm

Finally, we compute the Aerosol Optical Depth as follows (we are not taking into account the atmospheric extinction due to SO_2. As well, we assume that $\mu_{aod} = \mu_R$):

Aerosol Optical Depth Equation

$$\begin{aligned}\tau_{aod}(\lambda) =& \frac{1}{\mu_{aod}}\{[\log(I_0(\lambda)) - \log(I(\lambda))] - \\ &- \frac{O_3(\lambda)_{Ext}}{1000} \times \log(10) - \\ &- R(\lambda)_{scatt} \times \log(10)\}\end{aligned}$$

Langley Method

Several steps are taken to reduce known variations from the Langley data:

- The ozone column and standard deviation are computed on groups of five individual DS measurements. Data is accepted if the standard deviation is lower than 2.5 DU (Brewer cloud-screening method).
- The number of such individual DS for a langley event must be at least 100 (i.e. 20 summaries).
- We removed ozone values lower (greater) than 100 DU (600 DU) from the data set.
- We limit the analysis to half-days (airmass range 1.15-3.75) with stable Ozone and little AOD variability ($std(AOD) < 0.02$).
- We use robust linear regression by means of an iterative linear-fit (Harrison and Michalsky [1994])

Langley Method

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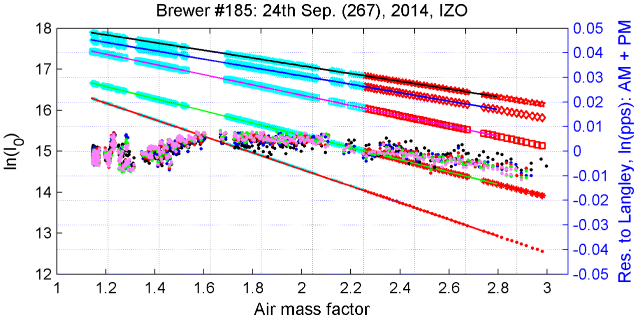
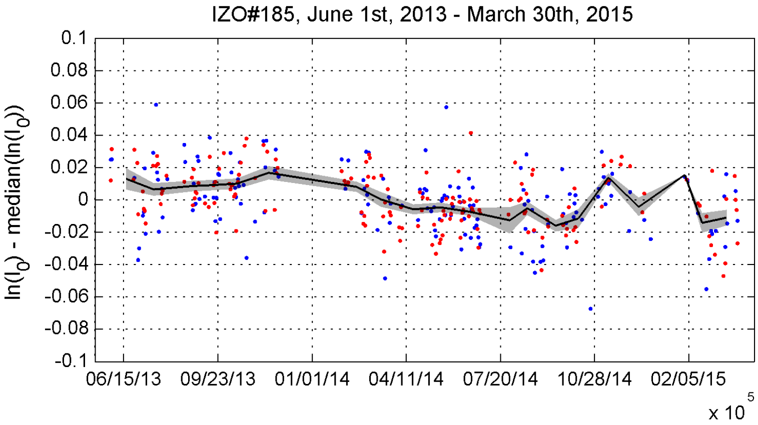
- We applied a physically-based method to screen cloudy half-days (since March 2009) from the data set based on a modified Long and Ackerman [2000] clear sky detection algorithm (Garcia, R.D., [2014]).
- We define (reject) sample outliers as those ETC_λ values more than 1.5 standard deviations from the sample mean.



Langley Method

The Brewer spectrophotometer shows a good stability in time of the AOD calibration, within ±2% (0.02 in AOD).



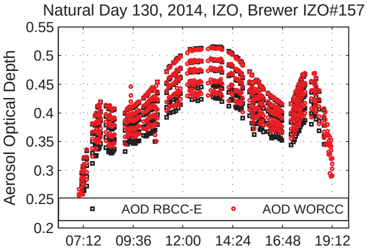
WORCC – RBCC-E

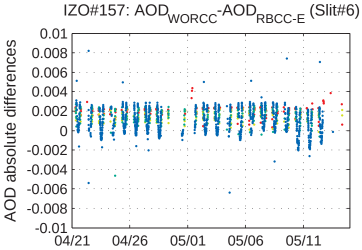
Next we compare the AOD as obtained from both the RBCC-E and the WORCC algorithm. The first step was to select a good day for independently ETC determination through the zero-air mass extrapolation method.

- We look for clear days matching the following conditions:
  - total ozone half-day variation less than 2.5 DU
  - low aerosol optical depth (AOD at 340nm $<$ 0.1) and a diurnal $STD(AOD) < 0.05$
- The linear regression is performed on the [1.1 - 3.0] air mass range

WORCC – RBCC-E

Different degrees of agreement between the RBCC-E and the WORCC algorithms are observed, depending on which instrument we analyze.





A possible cause for the observed discrepancies would be different calibration constants used for data-processing, including the calibration factors independently calculated through the Langley method.

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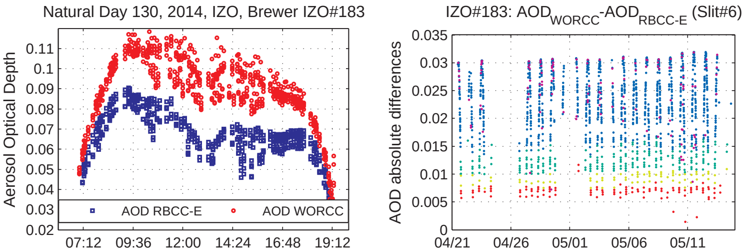

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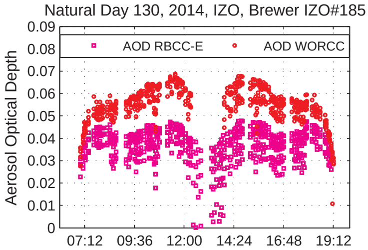
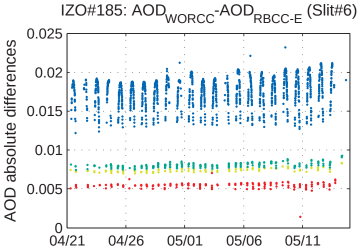

Natural Day 130, 2014, IZO, Brewer IZO#185


IZO#185: AOD$_{WORCC}$-AOD$_{RBCC-E}$ (Slit#6)

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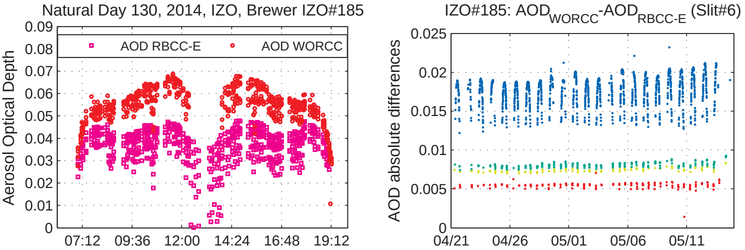
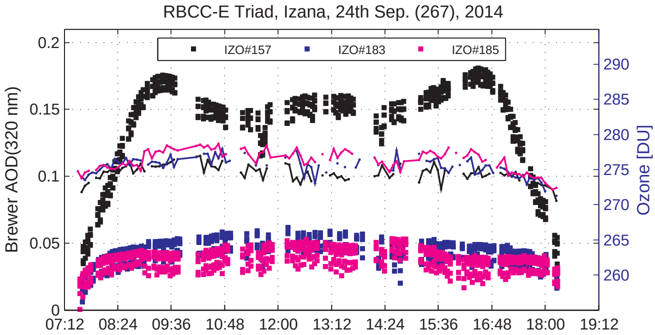


A possible cause for the observed discrepancies would be different calibration constants used for data-processing, including the calibration factors independently calculated through the Langley method.

We found large AOD discrepancies for the Brewer #157, independently of the AOD algorithm used.



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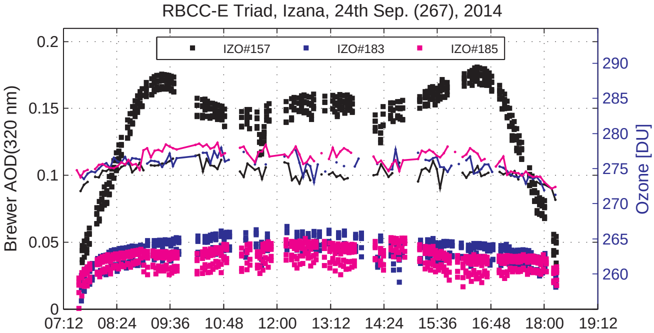
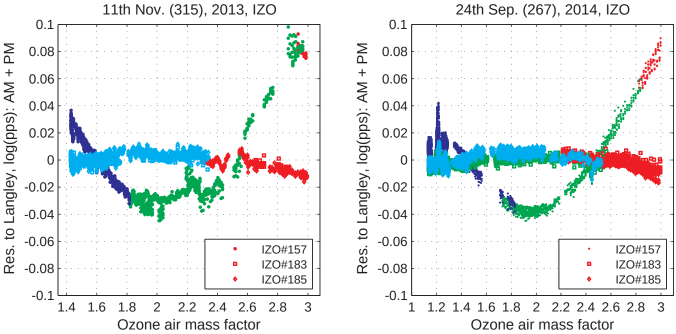
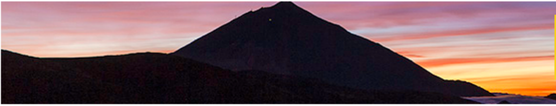


We will not be able to ensure an AOD calibration unless we can take all the instruments into a reasonably agreement (within less than 0.02 in AOD).

After analyzing the Langley residuals data, we thought of the Brewer polarization sensitivity as responsible for AOD discrepancies.



The next step was to analyze the polarization curve for each triad member.



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  - **Polarization Results**
  - **Cimel Comparison**
- AOD Calibration Transfer
- Conclusions

Brewer Polarization

Two polarization sensitive elements were found in the Brewer:

1. The flat quartz window (QW) as the first optical element, mounted at an angle of 35° with respect to the horizontal plane
2. The internal diffraction grating

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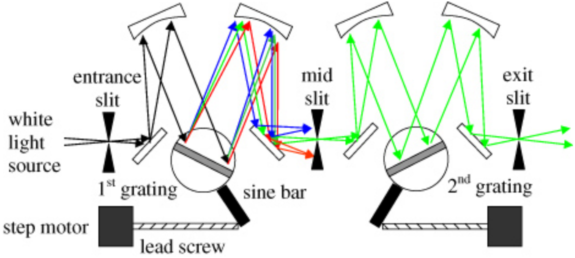

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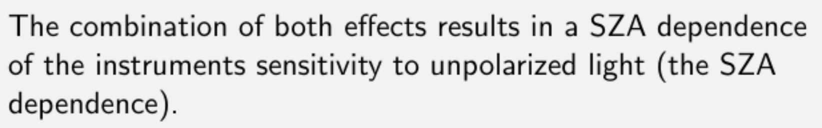


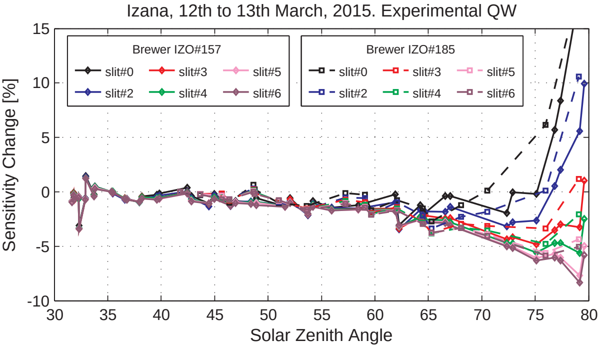
The combination of both effects results in a SZA dependence of the instruments sensitivity to unpolarized light (the SZA dependence).

Methodology

- Solar direct irradiance measurements at several UV wavelengths were collected for solar zenith angles (SZA) 80° to 30° with and without the quartz window (QW)
- We used a normal DS measurement for measurements through the QW, while the same routine renamed to DK was used to retrieve solar direct irradiance measurements without the QW.
- We followed the same procedure described in [Cede et al., 2006] to obtain the polarization curve (field measurements, method 4)
- We tested an experimental setup designed to characterize the Brewer polarization sensitivity during routine Brewer intercomparisons.
- This allowed us to get some insight into the differences between different QWs

Polarization Results

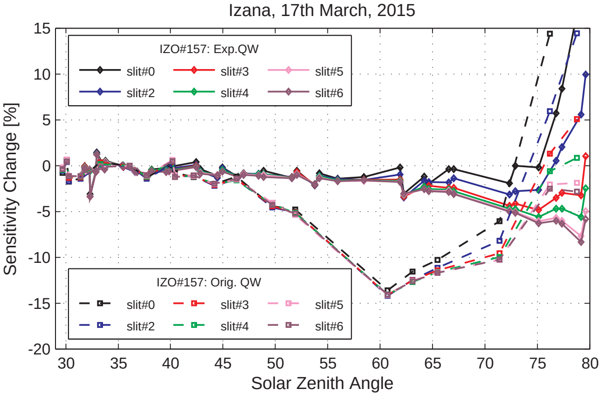
We observed a similar change in Brewer spectrophotometer sensitivity with SZA as in previous studies (Bais et al, 2005, Cede et al, 2006).



On the contrary, we observed a clear wavelength dependence in the SZA dependence for $SZA > 65°$.

Polarization Results

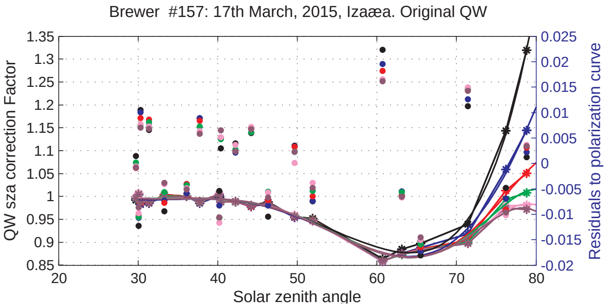
Large differences are found between different QW's, which, in principle, invalidate the experimental setup designed to characterize the instrument's polarization sensitivity during routine Brewer intercomparisons.



Polarization Results

We correct solar direct irradiance measurements for SZA dependence and calculate new calibration factors from the corrected data set.

- Fit the polarization data to a 6-degree polynomial
- Calculate the zero air mass factor
- Using the new calibration factors we achieved a very good agreement between the RBCC-E Brewer Triad


Brewer #157: 17th March, 2015, Izaæa. Original QW

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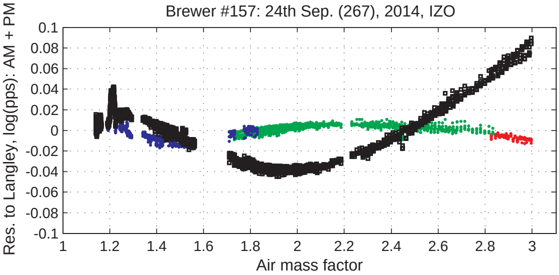

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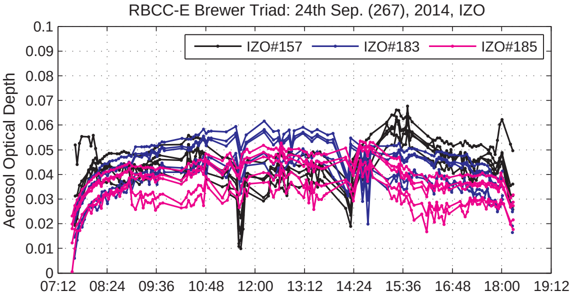
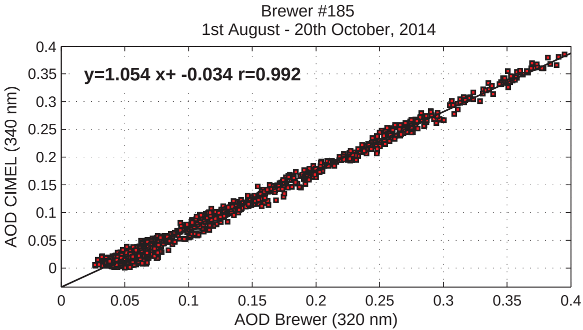


Cimel Comparison

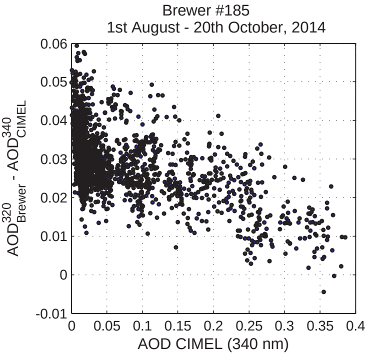
The AOD measurements at 320 nm derived with the Brewer spectrophotometer were compared with the AOD at 340 nm from a Cimel sun-photometer.

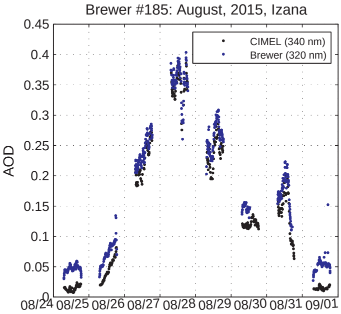


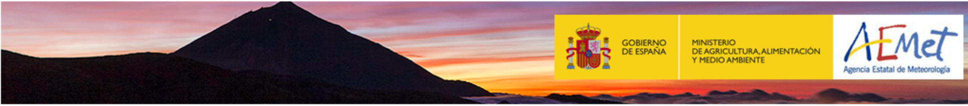
- The two data sets are highly correlated (r=0.992)
- An offset of 0.03 is observed.

Cimel Comparison

- The AOD differences between the Brewer and the Cimel appear to be correlated to the AOD measured by the Brewer.
- The better agreement is found for high AOD levels (about AOD $>$ 0.02).







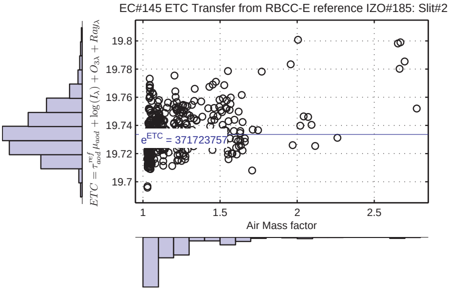
Calibration Transfer

The Aerosol calibration transfer method is done similar to the ozone one: the (espectral) extraterrestrial constants are obtained by comparison with the reference brewer using near-simultaneous AOD measurements. By doing $\tau_{aod}^{ref} = \tau_{aod}^{inst}$, and after solving for $\log(I_0(\lambda))$, we get

$$\begin{aligned}\log(I_0(\lambda)) = & \log(I(\lambda)) + \tau_{aod}^{ref}(\lambda) \times \mu_{aod}^{inst} \\ & + \frac{O_3(\lambda)_{ext}}{1000} \times \log(10) \\ & + R(\lambda)_{scatt} \times \log(10)\end{aligned}$$

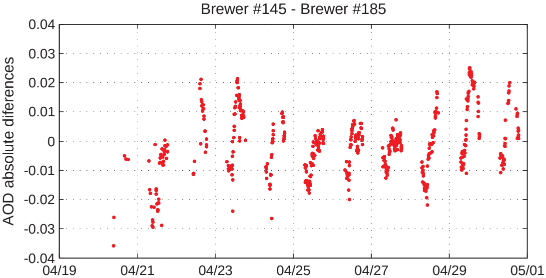
Using the simultaneous AOD data from the reference instrument, the spectral ETCs can be derived for each near-simultaneous $[\tau_{aod}^{ref}, \mu_{aod}^{inst}]$ pair and then averaged.

- We have used a time window of 5 minutes for near-simultaneous AOD measurements
- μ_{aod} range to be used is an input to the algorithm
- Measurements such that $|sza_{ref} - sza_{inst}| > sza'$ will be removed from the analysis

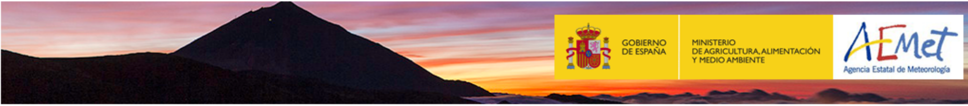


Data from Brewer #145 collected at the Izaña Observatory during the period from 20th to 30th April, 2014 were chosen to test the calibration transfer algorithm, using the Brewer #185 as a reference.

- $\mu_{aod}^{inst} < 3$
- $sza_{sync} = 0.003$



Using the transferred AOD calibration factors we achieved a good agreement between both spectrophotometers, within ± 0.02.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Conclusions

- We found some inconsistencies when checking the RBCC-E AOD algorithm against the WORCC algorithm. AOD deviations were of the order of 0.025 in the worst case
- A possible cause for the observed AOD discrepancies should be different calibration constants used for data-processing
- The Brewer quartz window does not necessarily show the same SZA dependence for different instruments. Correcting for the polarization effect can be a key factor to obtain reliable AOD measurements
- A preliminary methodology to transfer the absolute calibration of direct spectral irradiance measurements from a reference standard to other instruments has been developed.