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Correcting Stray Light in Single-monochromator Brewer Spectrophotometers

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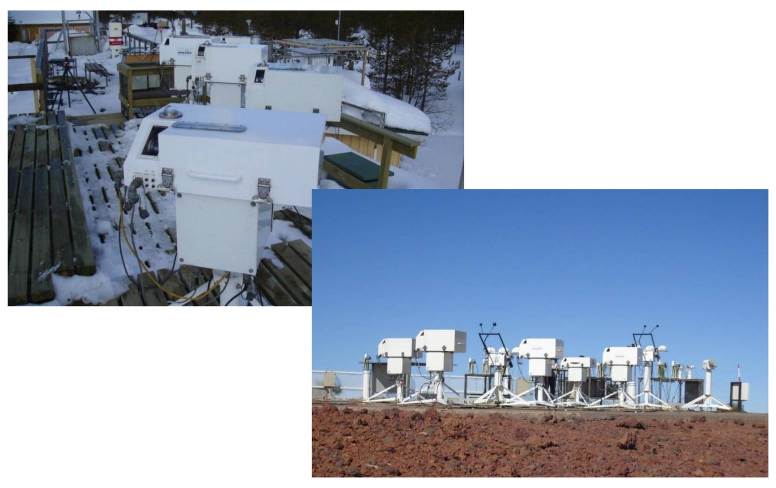
CEOS Intercal campaigns 2011



The CEOS Intercal long ozone slant path Intercomparison/Calibration campaign for Nordic Brewers and Dobsons was held at Sodankylä March 8.-24., 2011. The follow up mini-campaign to extend calibrations to shorter ozone slant paths took place at Izaña observatory, Tenerife between October 28 and November 18, 2011.

These campaigns were part of the ESA funded project “CEOS Intercalibration of Ground-based Spectrometers and Lidars”, that aims to homogenize the European ozone ground-truthing network. During the active intercomparison periods, sky measurements were taken only when good conditions for sun or moon observations existed. The laboratory measurements with calibration lamps and helium-cadmium (HeCd) lasers were an essential part of both campaigns. The campaigns produced a high-quality data base of total ozone and UV measurements and an accurate and up-to-date calibration and characterization of participating Brewers and Dobsons against the European standard instruments from RDCC-E and RBCC-E.

Brewer ozone retrieval

Brewer spectrophotometer total ozone retrieval is based on calculating ratios of powered photon count rates that relate to spectral intensities on four wavelengths: F3(λ_3~310.0 nm), F4(λ_4~313.5 nm), F5(λ_5~316.8 nm) and F6(λ_6~320.0 nm). The ratio denoted as MS9 is calculated as

$$MS9_{sd} = 10^4 \times \log_{10}\left(\frac{F_5^{2.2} \times F_4^{0.5}}{F_6^{1.7} \times F_3}\right)$$

Total ozone column, MS11, is calculated from MS9 trough equation

$$MS11 = \frac{MS9 - ETC}{\alpha\mu},$$

where μ is airmass factor and ETC and α are calibration constants and individual properties of each Brewer.

Stray light effects on ozone measurements

During earlier intercomparison campaigns it was noticed that compared to double Brewers a single Brewer total ozone tends to ”dip” at early morning and late evening when the solar zenith angle is high – especially when total ozone was high.

The dip is caused by light ”leaking” from other wavelengths to measured wavelength because of device imperfections. Characterizing and correcting this stray light problem was one of the major tasks of the CEOS campaigns.

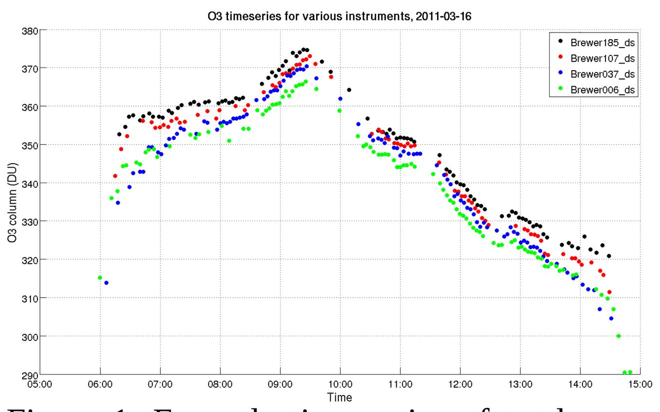


Figure 1. Example time series of total ozone measurements during the CEOS campaign at Sodankylä.

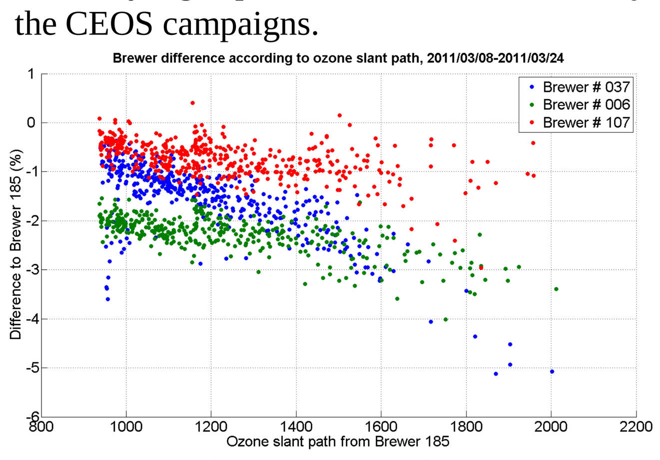


Figure 2. Difference of total ozone retrieved by other Brewers compared to the Brewer #185

Characterizing the spectrophotometer

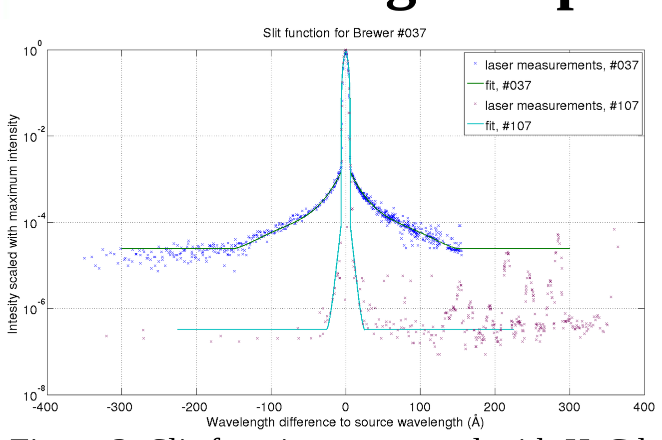


Figure 3. Slit functions measured with HeCd-laser for single and double Brewers at Izaña 2011.

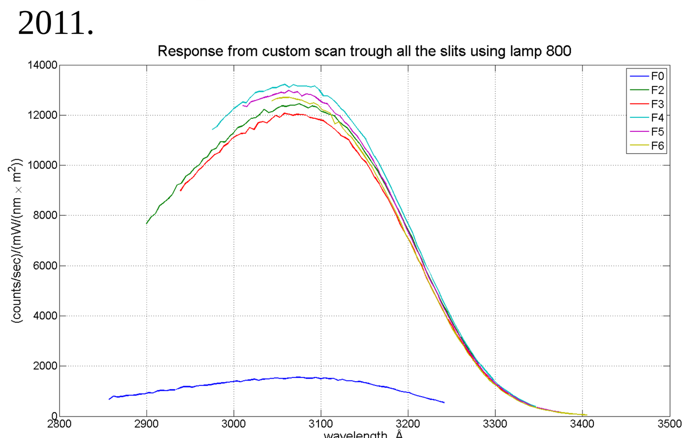


Figure 4. Global response of the Brewer #037 measured through all the exit slits.

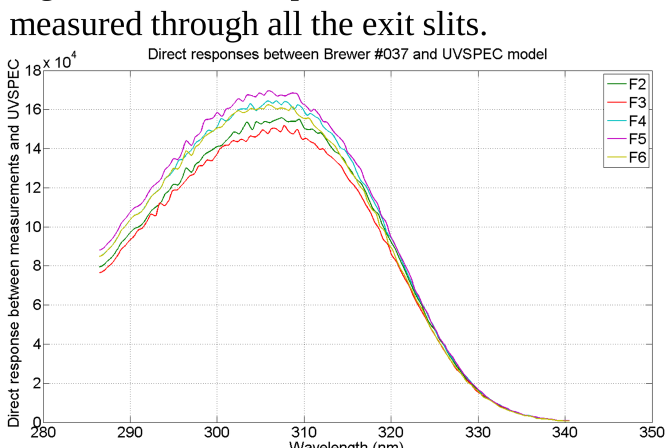


Figure 5. Brewer #037 direct response constructed by modeling the Brewer direct sun measurements. See explanation in the next chapter.

Laboratory measurements were important part of CEOS campaigns. When characterizing stray light properties of a Brewer the most important one is the slit function measurement. It is made by measuring thin spectral line of HeCd –laser at 325 nm through all wavelengths. Result gives out the spread of light at certain wavelength to other wavelengths called slit function, S(Δλ). In this work it is considered to be the same for all the slits.

The other important characterization is response measurement. It represents how the instrument signal corresponds with irradiances at certain wavelengths. The global response is measured through UV-port using calibrated spectral lamps, which have a known irradiance spectrum. Response is the ratio between the signal given by the spectrometer and the irradiance of the lamp. In total ozone measurements the intensities are measured through different exit slits making it important to characterize every slit individually.

All the responses are constructed to start from 286.5 nm. This is done by scaling the slit 0 response, R_0, for wavelengths, λ_-, between the 286.5 nm and the beginning wavelength, λ_{st}, of the measurements for the slit number n response, R_n.

$$R_n(\lambda_-) = R_0(\lambda_-) \times R_n(\lambda_{st}) \div R_0(\lambda_{st})$$

From the end wavelength, λ_{end}, the response is continued to longer wavelengths, λ_+, by slit #6 response.

$$R_n(\lambda_+) = R_6(\lambda_+) \times R_n(\lambda_{end}) \div R_6(\lambda_{end})$$

The transformation from global to direct response is explained in the next chapter.

LibRadtran modeling the direct sun measurements

Brewer measured photon count rate through exit slit n, F_n, is integral of spectral intensities on all wavelengths weighted by slit function, S, and device response, R_n

$$F_n(\lambda_0) = \int_{-\infty}^{\infty} S(\lambda_0 - \lambda) \times R_n(\lambda) \times I(\lambda) d\lambda$$

To create intensities, I, and thus to model the measurements, F, we used LibRadtran 1.6-beta package and UVspec sdisort version (code is freely available from http://www.libradtran.org).

As we don't have direct response and we want our modeling to be close the real measurements we assume the shape of the response to be the same as with global response but scale it to match real measured count rates, $F_{measured,n}$, and model intensities for a clear day. So for the 31. October 2011 with the help of real count rates at low zenith angles we calculate a scaling factor, r_n, for slit n to construct direct response from global response

$$r_n = \frac{F_{measured,n}(\lambda_n)}{\int_{-\infty}^{\infty} S(\lambda_n - \lambda) \times R_n(\lambda) \times I(\lambda) d\lambda}$$

For the modeled count rates scaled response $r_n \times R_n$ is used as direct response.

Model based corrections

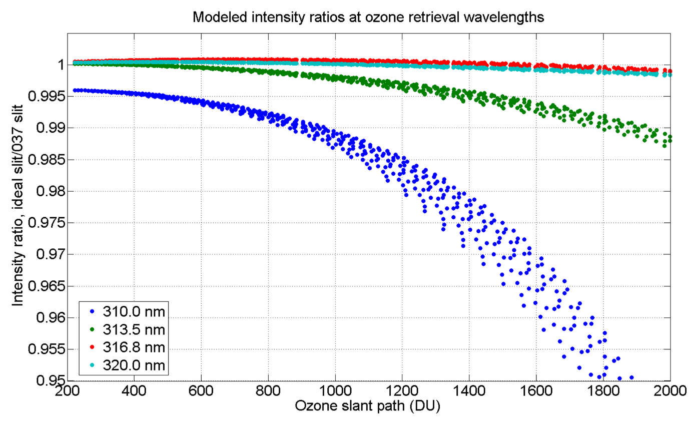


Figure 6. Ratios, a_n, of modeled count rates on ozone retrieval wavelengths between Brewers with ideal slit function(triangle, FWHM 0,6 nm) and with Brewer #037 slit. function

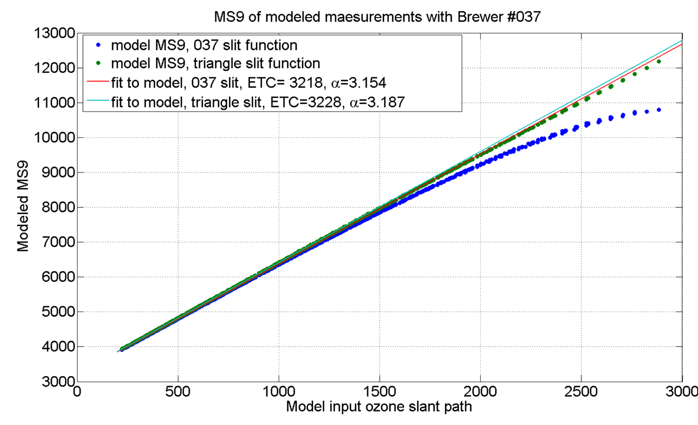


Figure 7. Calibration plots for modeled ideal and Brewer 037 measurements.

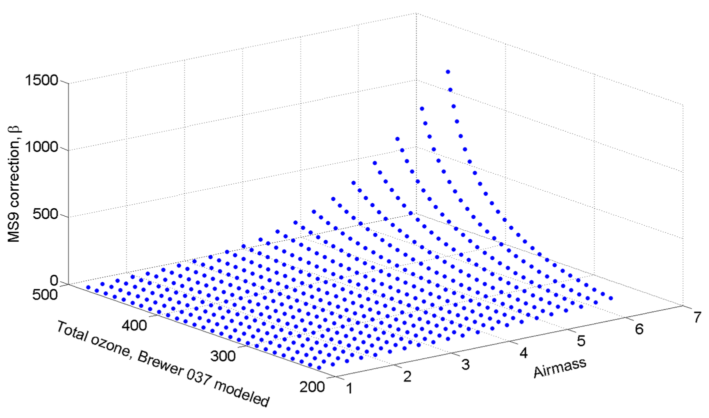


Figure 8. Additive stray light correction, β, for MS9 presented as three dimensional surface as function of Brewer 037 total ozone and airmass.

In model based correction we assume that due to stray light we get an ozone and airmass dependent ratio, a_n, between double Brewer (ideal slit) count rates and single Brewer (037 slit) count rates, F_n, making the double Brewer $MS9_{do}$

$$MS9_{do} = 10^4 \times \log_{10}\left(\frac{a_5 F_5^{2.2} \times a_4 F_4^{0.5}}{a_6 F_6^{1.7} \times a_3 F_3}\right)$$

With some logarithm algebra we end up with a single additive correction coefficient β to single Brewer $MS9_{si}$

$$MS9_{do} = 10^4 \times \left[\log_{10}\left(\frac{F_5^{2.2} \times F_4^{0.5}}{F_6^{1.7} \times F_3}\right) + \log_{10}\left(\frac{a_5^{2.2} \times a_4^{0.5}}{a_6^{1.7} \times a_3}\right)\right]$$

$$= MS9_{si} + 10^4 \times \log_{10}\left(\frac{a_5^{2.2} \times a_4^{0.5}}{a_6^{1.7} \times a_3}\right) = MS9_{si} + \beta$$

As there are no simultaneous double Brewer measurements outside campaigns the correction should not be characterized according to model input ozone or double Brewer measurements. Therefore β has been characterized dependent on airmass and single Brewer (037) ozone.

Single Brewer MS9 is calculated from the model and calibrated against model input ozone slant path. To avoid stray light effects on calibration constants only slant paths under 800 DU have been used. From calibration constants and model MS9 the model $MS11_{si}$ for single Brewer are calculated.

Running the model with a large number of airmasses, μ, and ozone values MS11 we can create a lookup table of β($MS11_{si}$, μ) from which to interpolate to all values within ozone-airmass -space.

Correcting real data

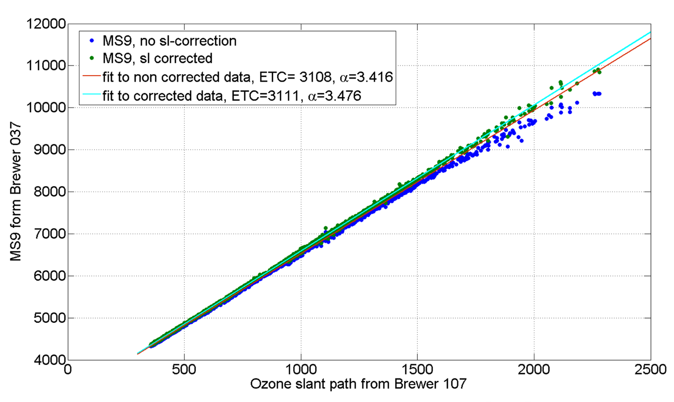


Figure 9. Brewer #037 ETC and absorption coefficients fitted for original and sl—corrected data to match Brewer #107. at low airmasses.

As an example the dataset from CEOS campaigns has been stray light –corrected with the method described above. First Brewer 037 MS9 was calibrated against simultaneous Brewer 107 total ozone.

$$MS11_{107} \times \mu \times \alpha + ETC = MS9_{037}$$

Using these constant MS11 was calculated and correction β(MS11, μ) was applied to MS9. Corrected $MS9_c$ was again calibrated against Brewer 107;

$$MS11_{107} \times \mu \times \alpha_c + ETC_c = MS9_c$$

Finally the ozone is calculated with corrected MS9 and new constants:

$$MS11_c = \frac{MS9_{037} + \beta(MS11_{037}, \mu) - ETC_c}{\mu \times \alpha_c}.$$

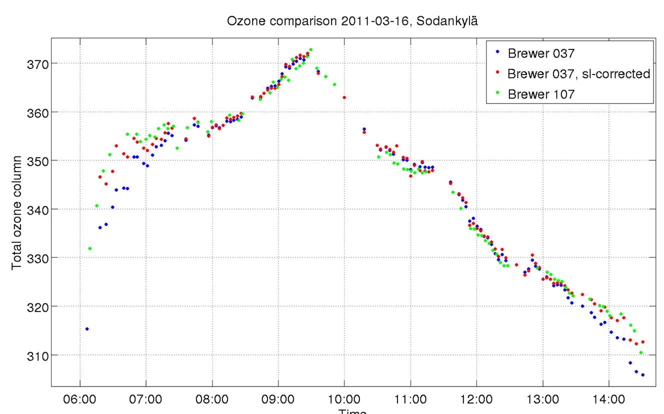


Figure 10. Example time series of corrected and non corrected data measured in Sodankylä during CEOS campaign.

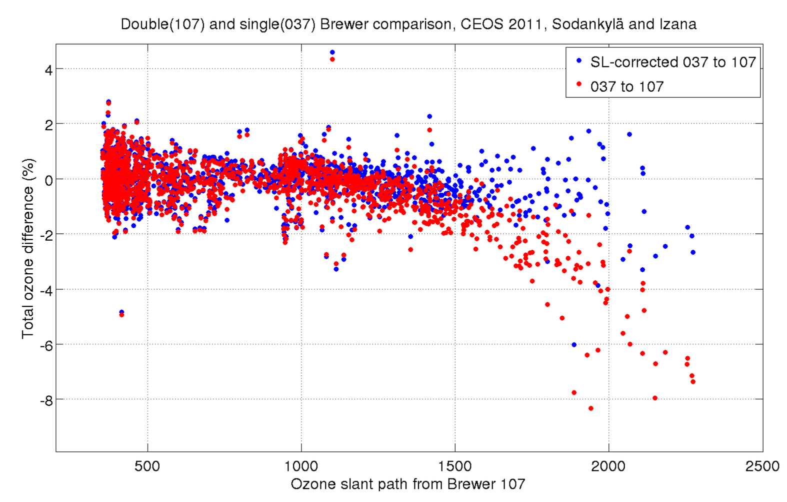


Figure 11. Ratio of Brewer 037 total ozone column to 107 total ozone column before and after stray light correction.

Summary

•Stray light leads to under-estimation of total ozone in Brewer measurements during high ozone and high zenith angle measurements,a common scene especially in arctic spring conditions.

•We are developing a method to correct stray light in Brewer measurements using instrument characterization and modeling.

•Method has been developed and tested using CEOS 2011 campaign data and Libradtran software.

•With the campaign data method improved single Brewer #037 measurements in comparison with double Brewers.

Future work

•Improve the model Brewer; calibration coefficients differ greatly from real measurements.

•Measure real direct response; current is rather robust construction from global response.

•Study the effect of stray light on the ozone absorption coefficient; the modeling suggests unexpected change in absorption coefficient due to stray light.