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Retrieval of total ozone with Phaethon DOAS system

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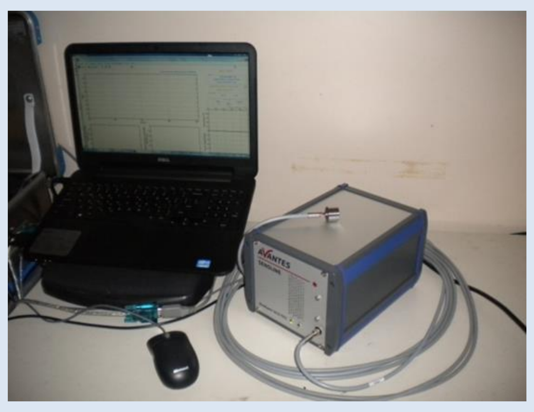
1. Introduction

- Phaethon is a mini DOAS/max-DOAS system which consists of a cooled, miniature CCD spectrograph (AvaSpec-ULS2048LTEC) and a 2-axes tracker [Kouremeti et al., 2013]. It performs spectrally resolved measurements of direct solar irradiance and sky radiance at several elevation angles in the UV-Visible region (300-450nm).
- Phaethon operates regularly on the roof of the Physics Department building of the Aristotle University of Thessaloniki, Greece (latitude 40.634ºN, longitude 22.956ºE, altitude 60m) in the center of the city of Thessaloniki.
- Measurements started at Thessaloniki, Greece in June 2013. Since then the system has undergone various modifications both in hardware and in the retrieval methodology.



2. Methodology of TOC retrieval

The total ozone column (TOC) is derived by analyzing direct radiance spectral measurements acquired by Phaethon using the QDOAS software (Version 2.108, developed by BIRA-IASB and S[&]T [Danckaert et al., 2013]). First the differential slant column density (*dSCD*) is derived relative to a selected reference spectrum. The reference spectrum has been measured during cloud-free skies with low levels of air-pollution and for small solar zenith angle (SZA).

If SCD_i is the slant column density of ozone at the time of the measured radiance spectrum (i), and SCD_{REF} is the slant column density of ozone at the time of the measured reference spectrum, then:

$$dSCD_i = SCD_i - SCD_{REF} = TOC_i \cdot AMF_i - SCD_{REF} \quad (1)$$

where AMF_i is the airmass factor. The SCD_{REF} can be derived by applying a Langley extrapolation to the *dSCDs* against *AMF* (Figure 1), during periods with fairly constant TOC, so that equation (1) is linear. Alternatively, the SCD_{REF} can be derived from a collocated instrument measuring the TOC_{REF}, as in our case the Brewer spectrophotometer #005. Note that for the same instrument the reference spectrum can be measured once and used repeatedly, irrespective of location.

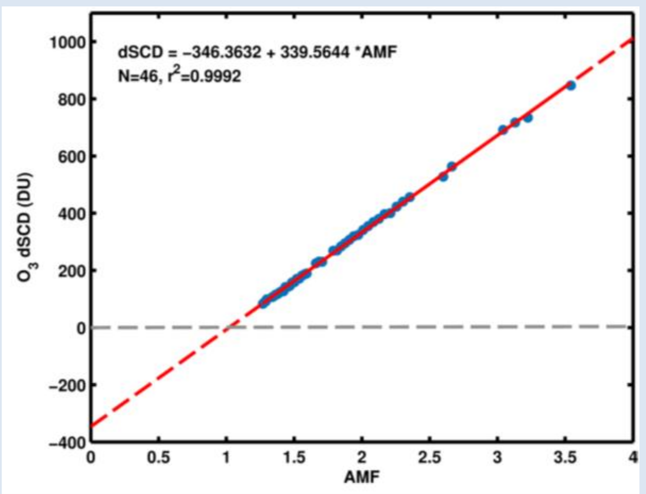


Figure 1: Example of a Langley extrapolation applied to the DSCDs derived from Phaethon direct radiance spectra recorded during 31/5/2015 at El Arenosillio, Spain. The constant term of the linear regression gives the -SCD_{REF}, while the slope corresponds to the mean TOC of this day.

Once the SCD_{REF} is known, equation (1) can be rewritten to derive the TOC from each measured direct radiance spectrum:

$$TOC_i = \frac{dSCD_i + SCD_{ref}}{AMF_i} \quad (2)$$

3. Comparison of Phaethon with Brewer

Total ozone column data retrieved by Phaethon are compared with data from a collocated MKII Brewer spectrophotometer with serial number 005. Brewer #005 has been compared in 2015 with the one Brewer of the reference triad of RBCC-E during the X Intercomparison Campaign at El Arenosillo, Spain showing an agreement to within 1%.

The agreement between Phaethon and Brewer #005 for a period of little more than 2 years is satisfactory with an average bias of 0.7± 3.2% for data with retrieval errors below 9 DU (Figures 2 and 3). Larger discrepancies appear for data at solar zenith angles larger than 80°.

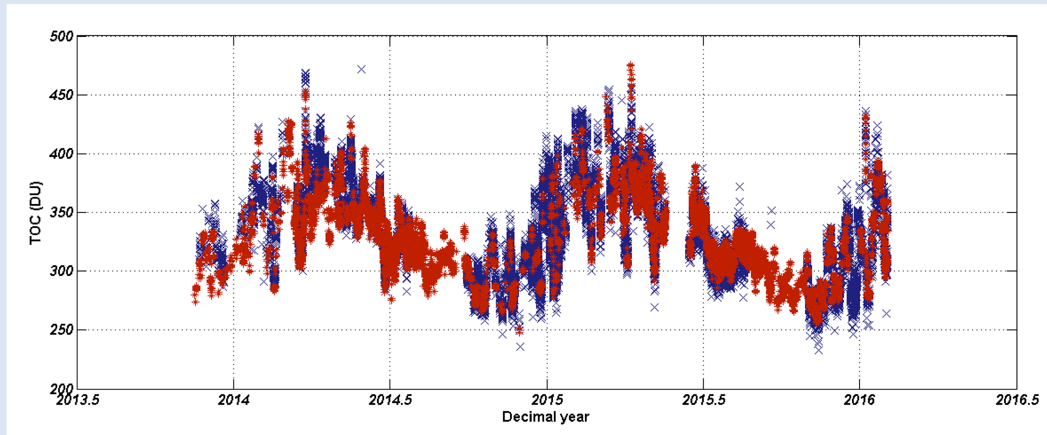


Figure 2: Total Ozone Column from Phaethon (blue) and Brewer 005 (red) measured within 30 min between November 2013 and February 2016

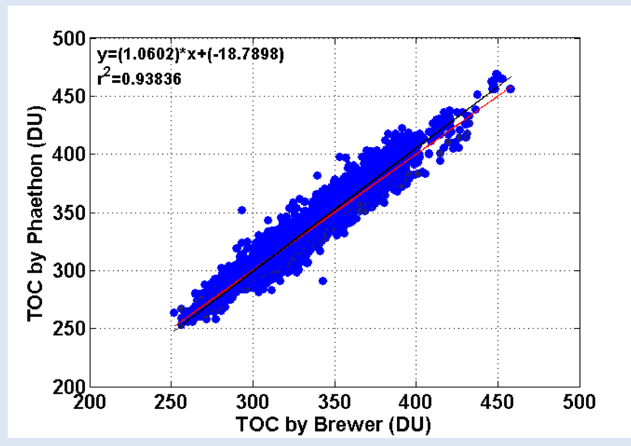


Figure 3: Scatter plot between TOC data derived by Phaethon and Brewer 005 with linear regression (black) and y=x line (red).

4. Error in TOC

The overall error in the TOC estimation (σ_{TOC}) can be derived by propagating the errors of the individual terms of (2), yielding:

$$\sigma_{TOC} = \frac{\sqrt{\sigma_{dSCDi}^2 + \sigma_{SCDref}^2}}{AMF_i} \quad (3)$$

The error in the calculation of the *AMF* is assumed negligible, being mainly a geometrical factor. The error of the *dSCD* is provided by the QDOAS analysis software, while the error of the SCD_{REF} depends on the method that is used. For the Langley extrapolation, the error can be represented by the uncertainty of the regression. When the TOC measured by the collocated Brewer is used, the uncertainty associated to this measurement can be considered. Usually it is less than 2.5 DU.

The distribution of errors in the retrieved TOC (Figure 4) reveals that for the majority of the data the errors are smaller than 9 DU, i.e. roughly 3% of the TOC, while only 20% of the data have errors smaller than 3 DU.

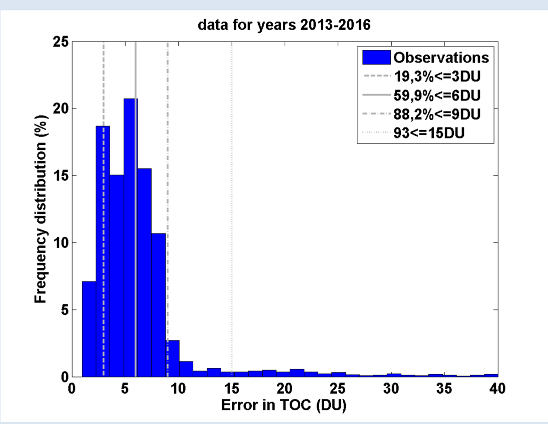


Figure 4: Frequency distribution of errors in TOC retrieval. The vertical lines mark the percentage of data with errors below 3, 6, 9 and 15 DU.

5. Improvement of error

Aiming at reducing the retrieval error, additional spectral measurements taken through a short pass filter were started in December 2015. The filter suppresses the radiance at wavelengths longer than ~370 nm allowing measurements at shorter wavelengths to performed with longer integration times; consequently with better signal to noise ratio (Figure 5).

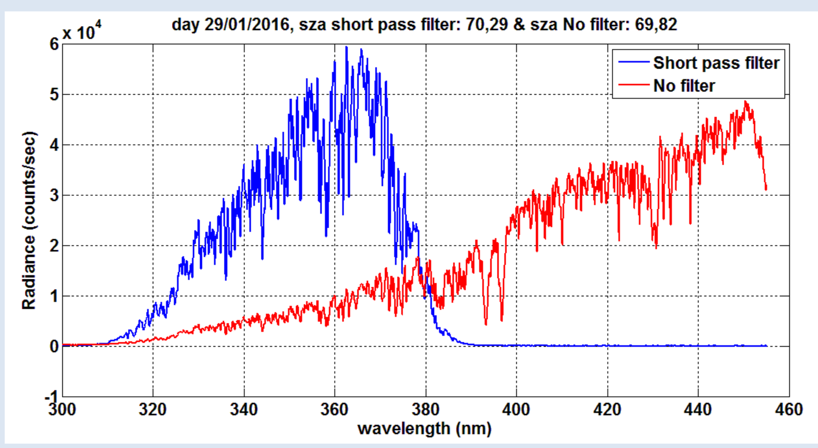


Figure 5: Example of direct-sun spectral radiance measurements recorded by Phaethon with (blue) and without (red) the short-pass filter, one after the other.

The frequency distribution for the two subsets of data for the period December 2015 – February 2016 is shown in Figure 6. The increase in the number of data with smaller error is obvious when the filter is used, with 80% of the data having errors below 3 DU compared to 40% for the spectra taken without the filter.

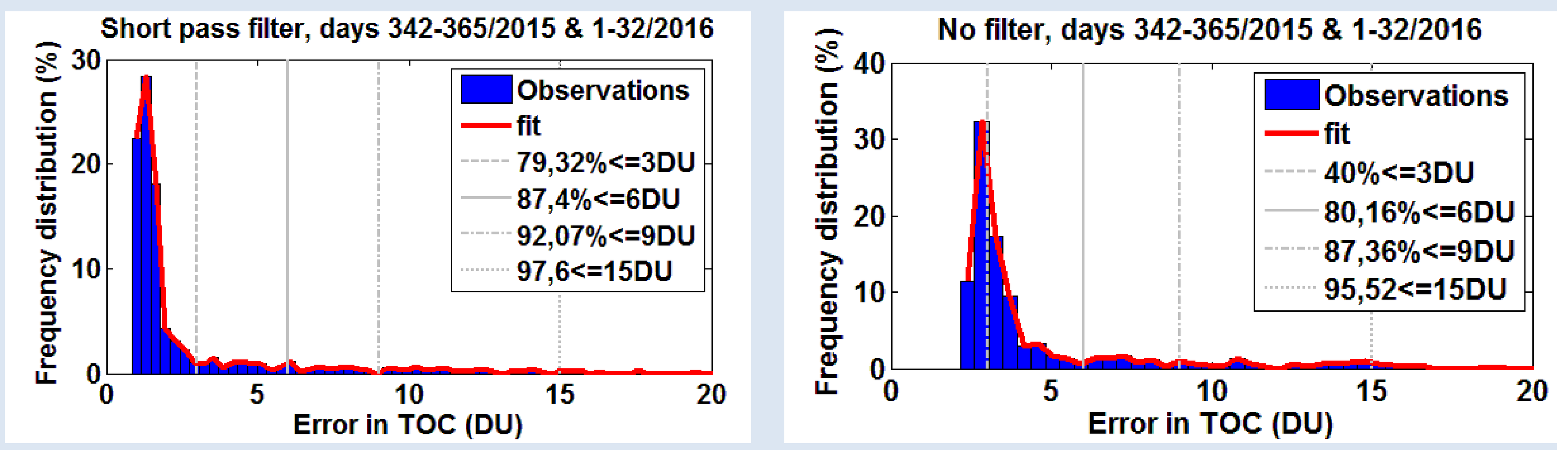


Figure 6: Frequency distribution of errors in TOC retrievals with (left) and without (right) the short-pass filter. The red line is a smoothing function fit and the vertical lines mark the percentage of data with error smaller than 3, 6 , 9 and 15 DU.

Figure 7 shows the scatter plots between the TOC values derived from Brewer #005 and Phaethon, with and without the short-pass filter. The two scatter plots are very similar with only slight differences in the statistical estimates. The correlation coefficient is practically the same, but the slope of the regression is closer to unit (0.98) for the Phaethon data taken through the filter compared to 0.91 for the data without the filter. Moreover, in the first case the offset term is smaller (about 9 DU compared to 23 DU). These results suggest an improvement in the TOC derived from the dataset with the short-pass filter, which mainly arises from the increase of the signal to noise ratio in the measured radiances. This is also confirmed by the percentage differences in TOC between Phaethon and Brewer for the two subsets of data. The mean absolute difference is 0.76±1.5% when the short-pass filter is used, compared to −1.13±1.5% without the filter.

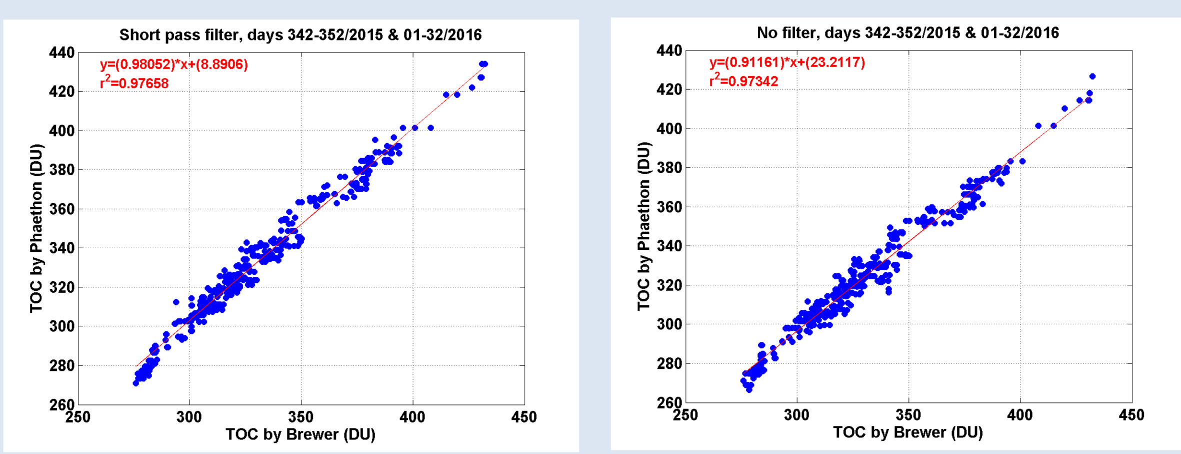


Figure 7: Scatter plot of Phaethon and Brewer derived TOC based on spectra recorded through the short-pass filter (left) and without the filter (right).

References

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Acknowledgments

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