Response to the Reviewer #1

It would be useful to obtain the original wavelength bandpasses measured for the filters for the three UV channels and compare computed weighted average alphas (for a 300 DU case with air mass equal 2) to those from the calibration analysis. Even if these cannot be obtained, the effective wavelengths for each of the three UV channels for each of the three calibrations studies should be reported in Table 1. These would give a better idea as to whether there is physical explanation related to changes in the bandpasses for the disparate results. It is not clear to this reviewer that the filters used in MicroTOPS should/would behave as the observations imply they have.

The effective wavelengths of the filters for the three calibrations are now reported in Table 1; a comment was added in section 3.2, Calibration.
The effective wavelength of the filter at 305 nm from the 2002 calibration matches those obtained in 1997 and 2010 by Solar Light. The effective wavelengths of the 312 and 320 nm filters are somewhat lower than those obtained in 1997 and 2010. It is not easy to derive a physical explanation for the differences among the various calibrations. We believe (see also the next point) that the three calibrations are reliable, and suggest non monotonous changes in the instrumental response. As it is discussed below and in the answers to the other reviewers, other effects (temperature, methodological differences in the calibrations, environmental factors) do not seem to influence the calibration results.

It would also be useful to know how much better/poorer the comparisons with Brewer and other measurements would be if the middle calibration results were discarded, that is, only the first and last were used with interpolation for the intervening years. Table 2 certainly suggest this calibration is bad.

Different tests have been carried out to analyze the reliability of the Microtops calibrations. The relative differences with respect to the Brewer measurements were calculated using different approaches: a) using the factory calibration coefficients throughout the entire time period; b) by changing the calibrations coefficients in a stepwise way (i.e., the original calibration is applied to the 2001 campaign; the 2002 calibration in the period 2002-2009; and the 2010 calibration for the 2011 measurements); c) by using a linear interpolation of the calibration coefficients in the years when the calibration was not available, taking into account the three calibrations; and d) using a linear interpolation of the calibration coefficients in the years when the calibration was not available using only the calibrations in 1997 and 2010. The results of these tests are shown in figure 1. Best agreement with Brewer measurements is found when using method c), i.e. including the 2002 calibration. It must be pointed out that, although method c) produces best results, the differences between method c) and d) are small, and suggest that there is a compensation effect in the calibration coefficients leading to similar total ozone values during the ten-year period. The differences between method c) and d) are only significant for the measurements close to the 2002 calibration.
Thus, we believe that the 2002 calibration is reliable and used it in the analysis.
An extended explanation of these tests was added in Section 4.2. Operational identification of possible calibration shifts.

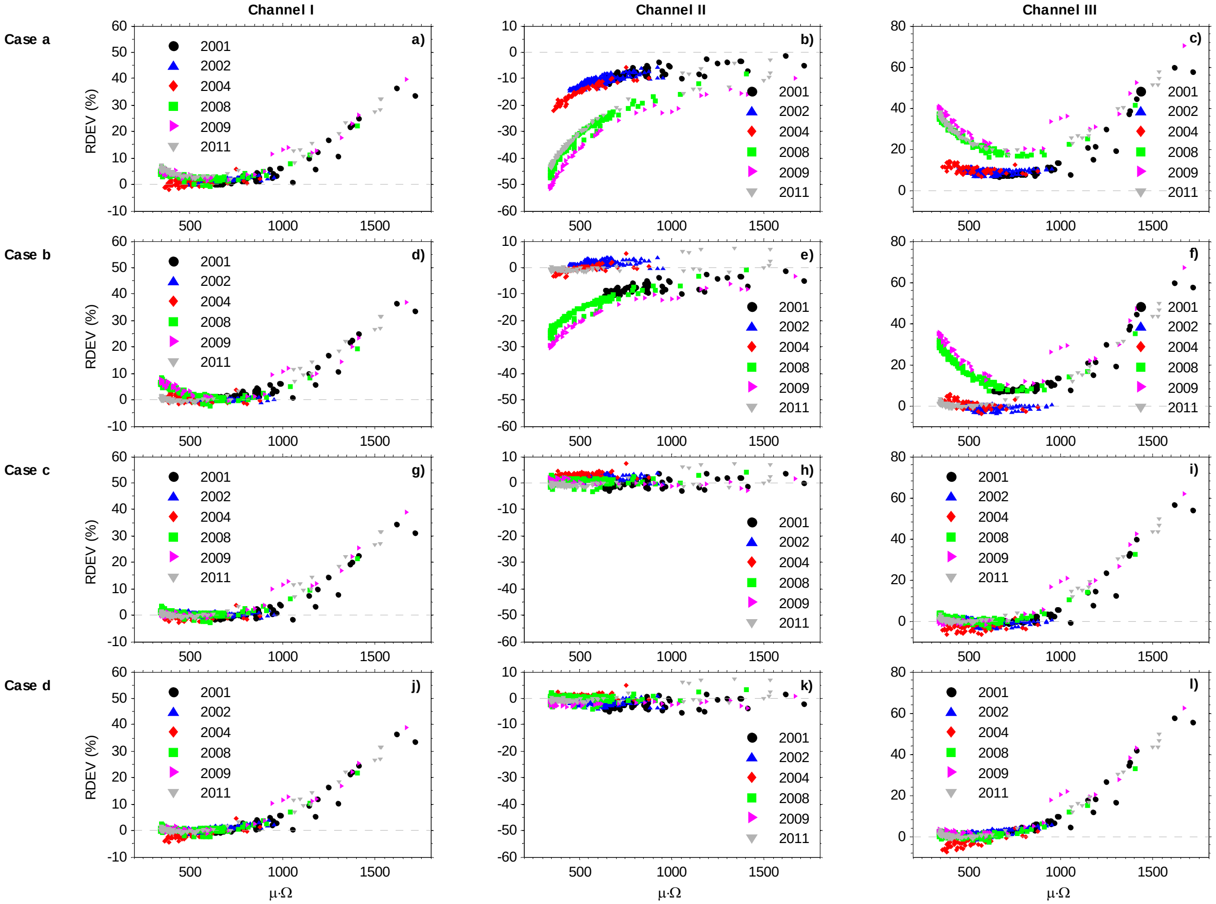


Figure 1. Relative differences between Microtops and Brewer ozone versus the prouct of airmass by total ozone using different calibration factors (see text) and retrievals (graphs a, d, g, j: Channel I; b, e, h, k: Channel II; c, f, I, l, Channel III).

Was the calibration data for the middle case taken with a much different instrument temperature than the other cases?

During the Solar Light calibrations the average temperature at Mauna Loa was around 5ºC (Chris Voth, Solar Light, personal communication). During the calibration at Veleta the temperature of the Microtops sensor was in the range 19-23 ºC. Thus, the calibrations were obtained in different temperature regimes. However, despite the difference of the calibration temperature, the performance of Microtops did not show any temperature dependence in the ten year period. For example, large instrument temperature changes (7-36°C) occurred during the campaign at Sodankylä, and no significant differences with respect to the Brewer are found. A comment clarifying this question is added in section 3.2 Calibration.

Were the absolute signal levels of the individual UV channels significantly different from those for similar expected signal levels among the three cases?

The absolute signals of the calibrations carried out by Solar Light in 1997 and 2010 are not available to us. We have tried to investigate changes in the absolute signals occurring in the 10-year period. This aspect is discusses below.

Did the ozone measurements from the other groundbased instruments show any diurnal variations during the calibration periods?

A comment clarifying this aspect was added in section 3.2 Calibrations.

The day used for the Microtops calibration at Veleta was used also for the calibration and intercomparison of other photometers (CIMEL CE-318, Estellés et al., 2008) and spectroradiometers (Brewer, Dobson and Optronic; Díaz et al., 2007). A shown in fig. 2, the ozone changes were smaller than 2% during the day of calibration.

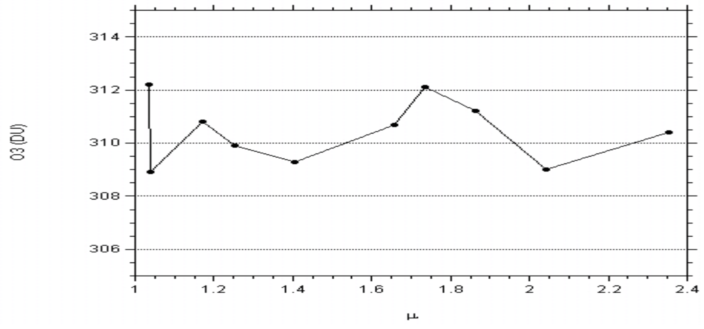
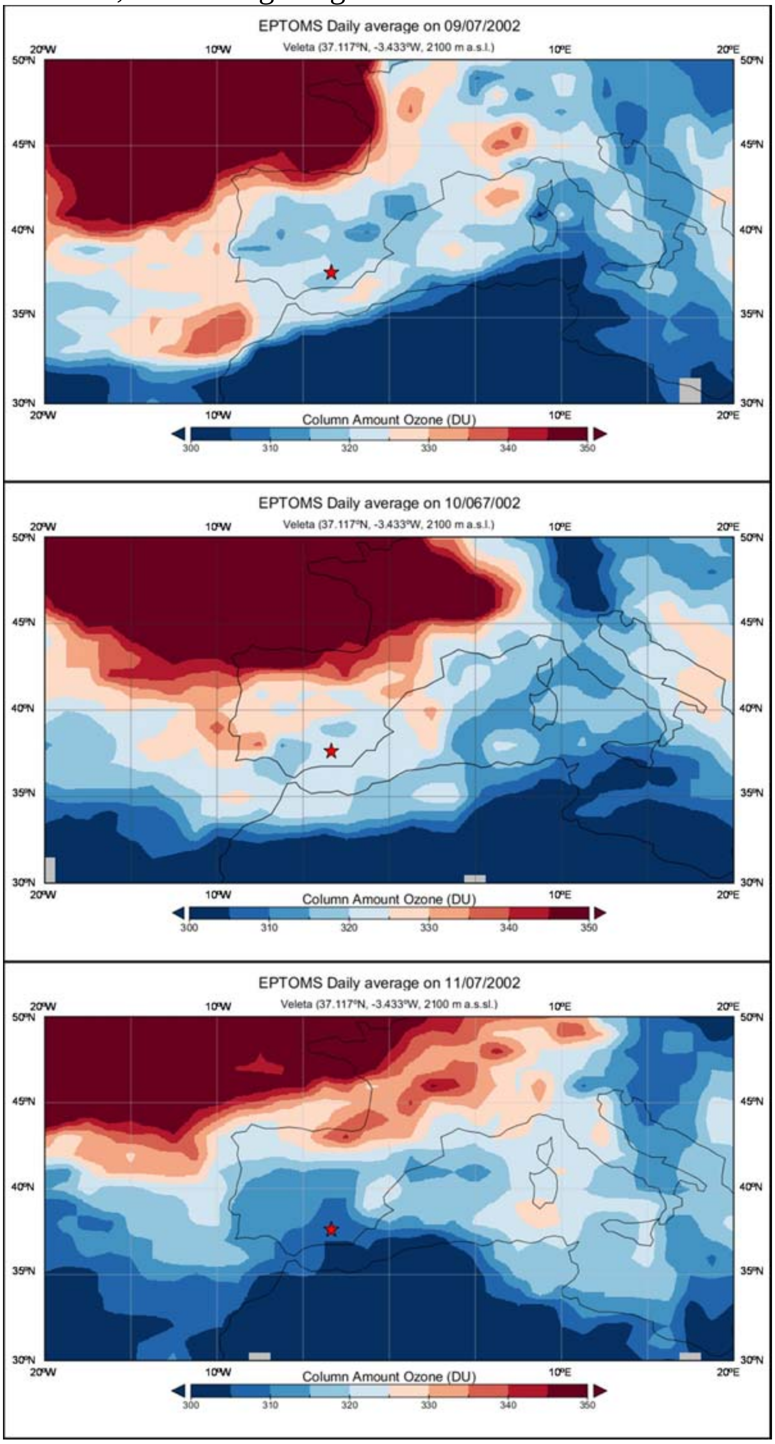


Figure 2. Total ozone measured by the Brewer during the day of the calibration in Veleta peak in 2002.

In addition, satellite data for the days closest to the calibration date on 10/07/2002 have been inspected in order to have an idea of the ozone variability during the period close to the calibration day. The following figures show the EPTOMS image for the area around Veleta from 09/07/2002 to 11/07/2002. A slight variation of the total ozone content occurs in the first two days in the region surrounding the calibration site. This variation is between 315 and 330 DU; the total ozone decreases on 11/07/2002 to 305-

310 DU. Limited spatial gradients in the ozone values have been observed in the day used for the calibration, confirming the ground-based observations.



EPTOMS Daily average on 09/07/2002

Veleta (37.117°N, -3.433°W, 2100 m a.s.l.)

EPTOMS Daily average on 10/067/002

Veleta (37.117°N, -3.433°W, 2100 m a.s.l.)

EPTOMS Daily average on 11/07/2002

Veleta (37.117°N, -3.433°W, 2100 m a.s.sl.)

Figure 3. Maps of daily total ozone measured by TOMS around the day of the calibrationa at Veleta peak in 2002.

The calibrations by Solar Light were carried out in 25/06/1997 and 31/08/2010 at Mauna Loa. Figure 4 shows the EPTOMS total ozone in the Mauna Loa area from 24/06/1997 to 26/06/1997. The calibration day (25/06/1997) was outside the satellite coverage. Despite the ozone is progressively increasing in the three days, the variation is from 265 to 280 DU and large diurnal changes are not expected.

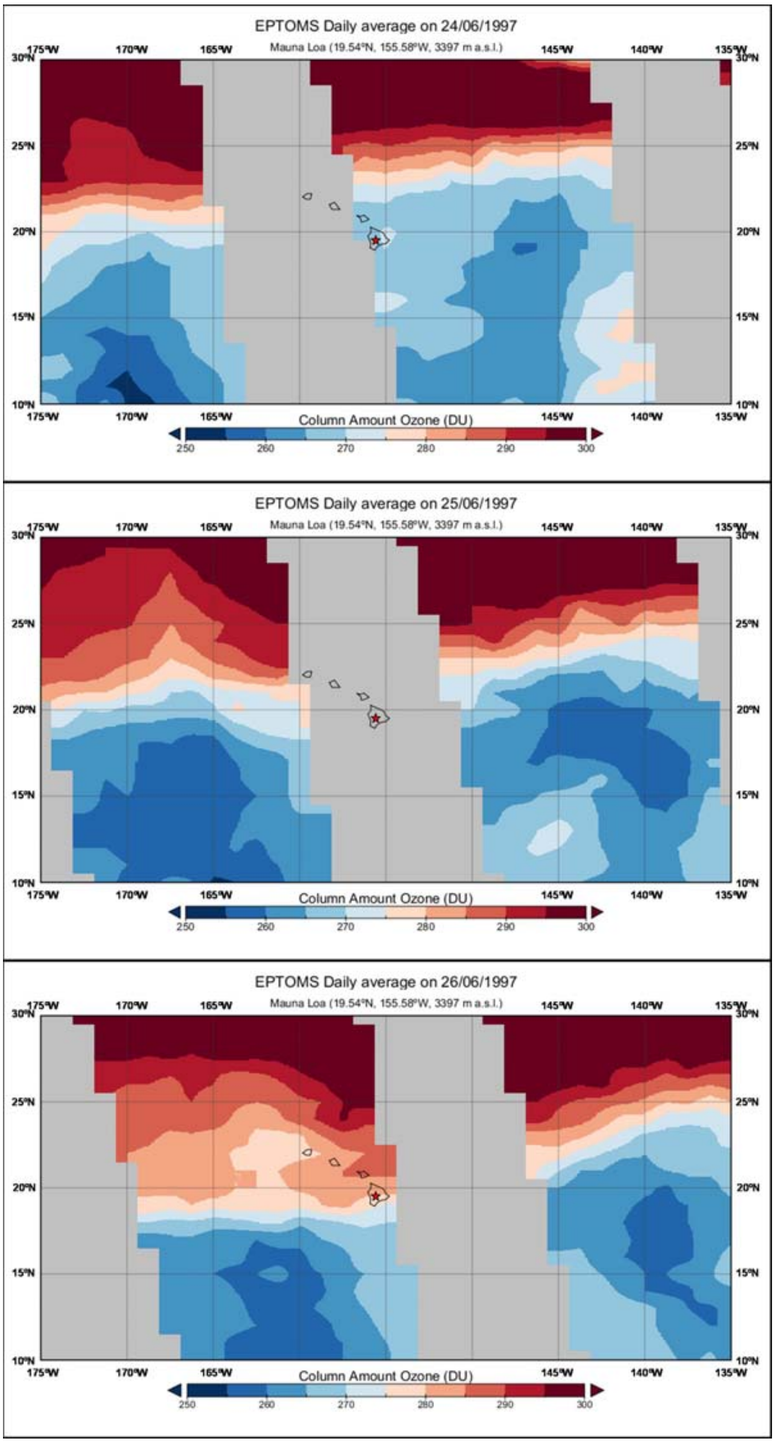


Figure 4. Maps of daily total ozone measured by TOMS around the day of the calibration at Mauna Loa in 1997.

In the case of the calibration in 2010 only the image for the calibration day (31/08/2010) is available (Figure 5). This shows also a low total ozone amount around 265-275 DU and a limited spatial variation. Daily total ozone from the Dobson spectrophotometer at Mauna Loa (courtesy of Robert Evans, NOAA/ESRL/GMD R/GMD-1), reported in table 1, show a low variability in the days close to the calibration date and corroborate the limited ozone variation during the calibration.

Day	Total ozone amount (DU)
8/31/2010	268
9/01/2010	263
9/02/2010	260
9/03/2010	267
9/04/2010	257

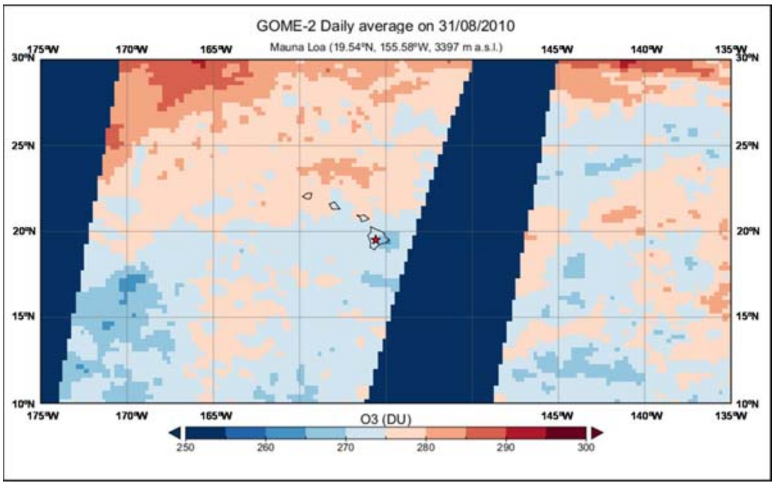


Figure 5. Maps of daily total ozone measured by GOME-2 in the day of the calibration at Mauna Loa in 2010.

Was there any screening for SO2 column amounts from the Brewer measurements?

No screening for SO2 was applied. The SO2 contribution is expected to be low in Sodankylä and Lampedusa. Larger SO2 amounts may be expected in Madrid and El Arenosillo, since both sites are located near industrial sources.

Following up on question 2 above, the absolute signal levels of individual channels can be used to help screen for aerosol, cloud, and pointing complications. Were these investigated in the comparisons with ground-based measurements?

The absolute signal levels in the UV depend on several factors: airmass, total ozone content, aerosols, altitude, etc. The Microtops measurements were carried out with different atmospheric conditions and all these factors should be taken into account when comparing absolute signal levels. Since Microtops measurements are done manually, clouds are generally avoided and all measurements are done in clear sky conditions.

We have tried to compare the absolute signal levels measured during the different campaigns. The occurrence of different conditions (mainly total ozone and solar zenith angle, due to differences in seasons and latitude) the first approach to do so was selecting a relative narrow airmass and ozone ranges available in the whole measurements period (2001-2011). Figure 6 shows the variability of airmass and ozone for the different campaigns; the figure highlights the difficulty to find sufficient data within a narrow range of ozone and solar zenith angle to investigate changes in the absolute signals occurring in the 10-year period. Due to the limited dataset, the comparison of the absolute signal levels against the Brewer observations is unpractical.

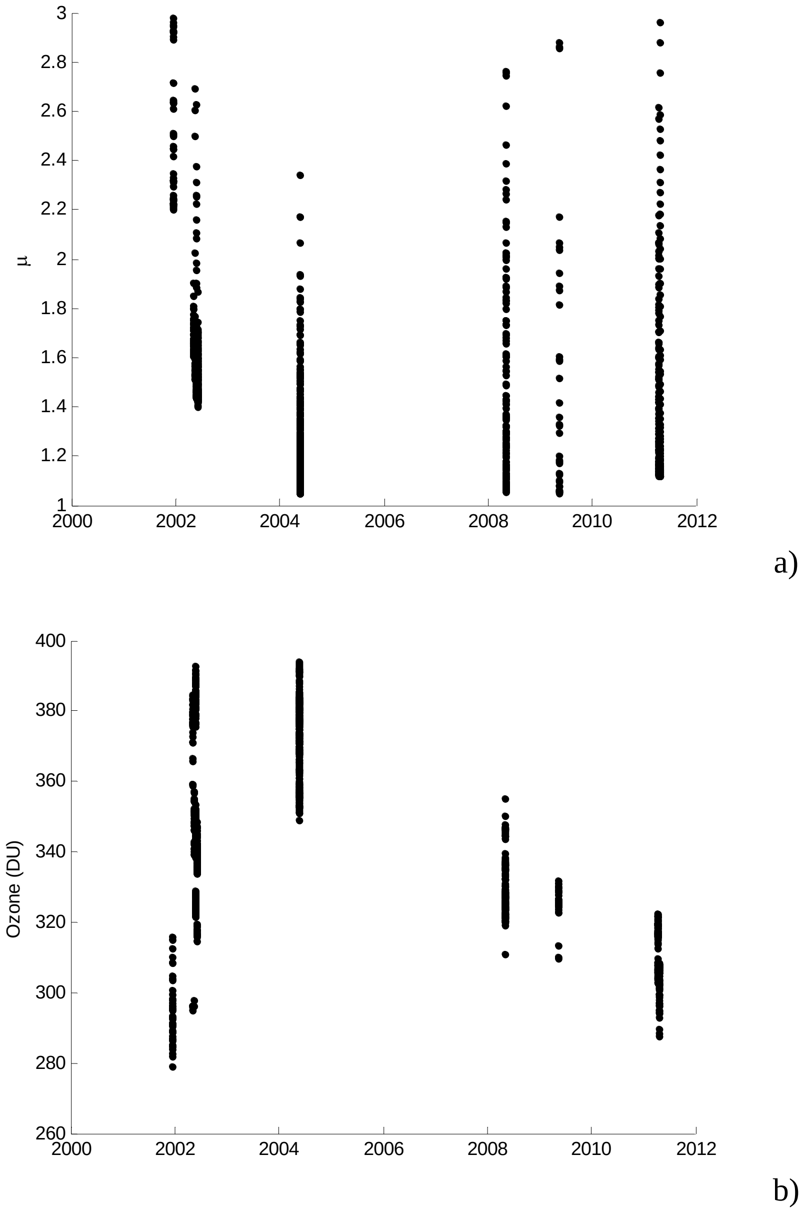


Figure 6. Airmass (a) and total ozone (b) variability during the different campaigns.

A second approach was developed to investigate the long-term behaviour of the Microtops. The signals were reported to the average Earth-Sun distance in order to compare the signals measured in different days of the year; all measurements were reported to the signals which would be obtained at O3 = 300 DU; a relatively small solar zenith angle interval was selected , and signals were scaled to the expected signal at 60º solar zenith angle. In that way, the signal levels might provide indications on the Microtops performance and changes with time. To this purpose the evolution of the signals (at the same Earth-Sun distance, for total ozone of 300 U, and at 60° solar zenith angle) at the three UV wavelengths (single values and averages over the different campaigns) was plotted versus time in figure 7.

It must be emphasized that no correction for varying aerosol conditions was applied, and part of the variability may be due to changing aerosols. It is interesting to note that the different channels display a similar overall evolution; moreover, despite the relatively large variability, the different latitudes and seasons, and the varying aerosol conditions, it is possible to identify a single average signal value which falls within the error bars for the whole measurements period. Although it provides useful indications on the Microtops performance, this analysis does not allow unequivocally identifying changes in the instrument and assessing the validity of the calibrations.

The evolution of the ratios between signals of the different filters used in the ozone retrieval has been analyzed. The ratios between signals at 305 and 312, and between signals at 312 and 320 nm are shown in figure 5. The vertical bars show one standard deviation.

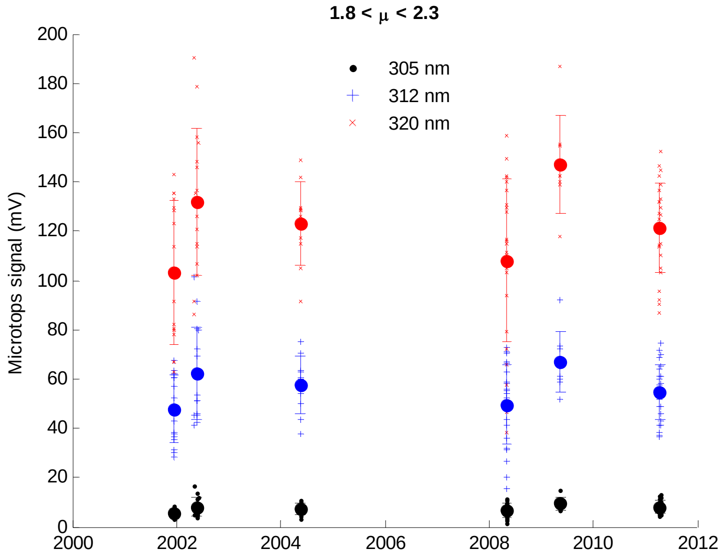


Figure 7. Signal level for the three Microtops UV filters reported to the solar zenith angle of 60°, O3 = 300 DU, and mean Earth-Sun distance. Large dots are average values for each campaign, and vertical bars are one standard deviations of the values obtained in each campaign.

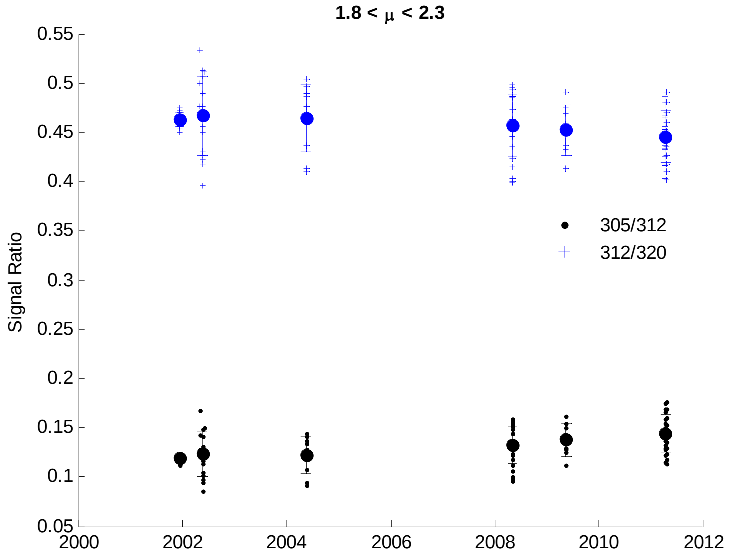


Figure 8. Evolution of the ratio of the absolute signal levels reported in figure 7.

The variability of the signal level show in figure 4 is reduced in the case of signal ratios. It is interesting to note that it is reasonable to assume an almost linear change of the ratio with time (decreasing for the 312 to 320 nm ratio, increasing for the 305 to 312 nm ratio) between 2002 and 2011. The same evolution between the 2002 and 2010 calibrations is found for the coefficients LNV_{12} and LNV_{23} (see table 1 of the paper). This result, in addition to the good agreement observed against the Brewer for the three UV filters, supports the conclusion that the calibration carried out in Veleta 2002 is reliable and can be used in the analysis.

The relative signal sizes between the three UV channels can also be used to investigate when stray light may start to be a significant error in the shortest channel. That is, one assumes that the stray light in the shortest channel has sources similar to the longer channels signals and sees how much more rapidly the shorter channel signal decreases than the longer ones. These changes will be related to the airmass, mu, times the ozone amount, Omega, (with additional smaller effects from the Rayleigh term) so the errors in Channel I retrievals (or Channel III) should be plotted against this product, not just airmass. (E.g., in Figures 5 and 6 where Omega may vary for the different data sets, make the x-axis Omega*mu.)

The relative deviations have been plotted also against the product Omega*mu (see figure 1 in this report). The figures do not vary substantially from those plotted against the airmass “mu” and the same conclusions were extracted.

We have preferred to leave the graphs with the airmass in the paper because it is operatively easier to define an airmass limit for the Microtops measurements. From the operational point of view, we believe that it can be more useful to the Microtops user community,

Following up on question 3 above, global daily ozone maps from satellites can prove useful to compare the biases of ground based stations as the same satellite instrument will view two locations and statistics may be collected over extended periods and a range of conditions. Have the different Brewer/ground stations in this study participated in such intercomparisons? The daily ozone map at the time of a calibration sequence can also be checked to see if there are large gradients in the ozone field surrounding a ground site. If there are, then this suggests that there may be systematic changes in the ozone over the site during the time period of measurements.

The Brewers from Sodankylä, Madrid and El Arenosillo have participated in several comparisons with satellite (GOME, GOME-2 and OMI and TOMS) on total ozone measurements. There are no indications of anomalous offsets for any of the used sites in the various reports (e.g. Balis et al., 2007a; 2007b; Antón et al., 2008; 2009a; 2009b).

Total ozone data from Lampedusa were compared with TOMS and OMI data (Casale et al., 2009), and revealed no anomalous bias.

The four Brewers used in this paper are well maintained and calibrated even two years. In most cases the calibration was done in the same year of the campaign. Comparison with satellite data during the campaigns did not reveal any significant site-dependent difference. There is no evidence of possible systematic site-dependent differences in the Brewer ozone.

Figure 3 provides very limited information except for the ten cases with the largest aerosol optical depth variations.

We think that is useful to retain Figure 3, since it illustrates that the large deviations of the AOD at 1020 nm are associated with large deviations in the UV signals, and the channel at 1020 nm may be used as for the data selection. In addition, that figure allows defining the data quality criteria.

References

Antón, M., D. Loyola, B. Navascúes, and P. Valks (2008), Comparison of GOME total ozone data with ground data from the Spanish Brewer spectroradiometers, *Ann. Geophys*., 26, 401–412.

Antón, M., D. Loyola, M. López, J. M. Vilaplana, M. Bañón, W. Zimmer, and A. Serrano (2009a), Comparison of GOME-2/MetOp total ozone data with Brewer spectroradiometer data over the Iberian Peninsula, *Ann. Geophys.*, 27, 1377–1386.

Antón, M., M. López, J. M. Vilaplana, M. Kroon, R. McPeters, M. Bañon, and A. Serrano (2009b), Validation of OMI-TOMS and OMI-DOAS total ozone column using five Brewer spectroradiometers at the Iberian peninsula, *J. Geophys. Res.*, *114*, D14307, doi:10.1029/2009JD012003.

Balis, D., J.-C. Lambert, M. Van Roozendael, R. Spurr, D. Loyola, Y. Livschitz, P. Valks, V. Amiridis, P. Gerard, J. Granville, and C. Zehner (2007), Ten years of GOME/ERS2 total ozone data—The new GOME data processor (GDP) version 4: 2. Ground-based validation and comparisons with TOMS V7/V8, *J. Geophys. Res.*, 112, D07307, doi:10.1029/2005JD006376.

Balis, D., M. Kroon, M. E. Koukouli, E. J. Brinksma, G. Labow, J. P. Veefkind, and R. D. McPeters (2007b), Validation of Ozone Monitoring Instrument total ozone column measurements using Brewer and Dobson spectrophotometer ground-based observations, *J. Geophys. Res., 112*, D24S46, doi:10.1029/2007JD008796.

Casale, G. R., A.M. Siani, I. Ialongo, A. G. di Sarra, and D. Meloni (2009), Ozone nd UV radiation at the stations of Ispra, Rome, an Lampedusa, *Proceedings of the XXV Environment ay "Ozone hole and radiation", Accademia Nazionale dei Lincei*, **245**, 27-38 (in italian).

Díaz, A. M., O. E. García, J. P. Díaz, F. J. Expósito, M. P. Utrillas, J. A. Martínez-Lozano, L. Alados-Arboledas, F. J. Olmo, J. Lorente, V. Cachorro, H. Horvath, A. Labajo, M. Sorribas, J. M. Vilaplana, A. M. Silva, T. Elias, M. Pujadas, J. A. Rodrigues, and J. A. González. (2007), Aerosol radiative forcing efficiency in the UV region over southeastern Mediterranean:VELETA2002 campaign, *J. Geophys. Res.*, 112, D06213, doi:10.1029/2006JD007348.

Estellés, V., M. P. Utrillas, J. A. Martínez-Lozano, A. Alcántara, L. Alados-Arboledas, F. J. Olmo, J. Lorente, X. de Cabo, V. Cachorro, H. Horvath, A. Labajo, M. Sorribas, J. P. Díaz, A. M. Díaz, A. M. Silva, T. Elías, M. Pujadas, J. A. Rodrigues, J. Cañada, and Y. García. Intercomparison of spectroradiometers and Sun photometers for the determination of the aerosol optical depth during the VELETA-

2002 field campaign, *J. Geophys. Res., 111*, D17207, doi:10.1029/2005JD006047. 2006.