<u>We thank the reviewer for the thoughtful and constructive review.</u>

<u>RC1</u>

Review of:

Comparison of total ozone measurements in Melbourne, Australia, performed with a low-cost micro spectrometer and a Brewer MK-III

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General comments:

This paper provides a description of the methods to derive total column ozone (TCO) from a very low-cost instrument measuring global ultra-violet irradiance. The paper is well written, well structured and the methods are clearly described. It is recommended for publication after addressing the comments below.

The paper focuses rather on the method of TCO retrial rather than a sound analysis of the performance of TCO compared to a reference instrument. Therefore, the general comments are divided into two following parts:

Method:

Commonly, TCO is derived best by direct sun measurements. The paper uses global UV measurements, which implicate parameters of uncertainty such as clouds in front of the sun, clouds in the sky, effective albedo from the surrounding terrain and cosine response of the diffusor. All these effects would not occur when using direct sun measurements. The authors argue that in many places worldwide cloud coverage hinder direct sun measurement for TCO. Are there so many places with such conditions? Maybe the performance of the low-cost instrument would be much better when using direct sun measurements. Has this ever been tested with the instrument?

This is a fair question but would have to be the subject of future work. The GI configuration was chosen in part to keep the design as simple as possible, and to assess what performance could be achieved with the least complexity. Many locations around the world experience very persistent cloud cover in certain seasons or synoptic conditions, so in principle an instrument that could only measure ozone in sunny conditions will lead to bias in the ozone record.

The method includes many parametrizations based on empirical functions. I have lost the overview. Maybe the authors can provide a summary of all the empirical parametrizations, the number of measurements needed for the parametrization and, if possible, an estimation of the uncertainty of the parametrization and its implication of TCO.

The parametrization also arises the question if the method is also suitable for other placed world wide, once it has “calibrated” with a Brewer at a specific site. Or must the method be “calibrated” for each location worldwide separately with a Brewer?

The method used on the micro spectrometer data (STS GI) is not based on parametrizations of empirical functions, like the Brewer “zenith sky” method. TOC retrieval from GI measurements is based on the multi-stream discrete ordinates radiative transfer equation solver (see line 135 and on). The model (LibRadtran) simulates the instrument’s response to the global irradiation $I_{321.9\ nm}$ and $I_{312.2\ nm}$ and the TOC is derived from when the measured ratio $R_{me} = \frac{I_{321.9\ nm}}{I_{312.2\ nm}}$ fits the model ratio R_{mod} for the same global irradiance ratio with TOC as the model input variable.
The method does not need a calibration for each new location once the instrument is “calibrated” with a Brewer. However, this requires that other significant UV sensitive parameters are accounted for (albedo, aerosols etc). For the wavelengths used, other UV sensitive parameters than ozone, have an almost equal effect on the two wavelengths, so they cancel out in the ratio.

The results reported here are based on only one location.

However, the very same method is in use by the Norwegian UV and ozone measurement network. This network consists of two Brewers and eight Biospherical GUV instruments measuring ozone from Olso (60 N) to Ny-Alesund (78 N) with similar results (line 80 and on).

Performance:

It is not clear if the authors have compared daily averages with quasi synchronous measurements for STS GI and Brewer DS. I suggest comparing synchronous measurements within e.g. 10 minutes intervall and also show the individual measurements to indicate the variation of TCO.

Daily means are based on all available data for each instrument within the Solar Zenith Angle limits the Brewer was measuring TOC within, so there is no filtering for quasi synchronous measurements. The micro spectrometer recorded data continuously with a time resolution of one minute, and synchronous measurements are shown in figure 4 (Brewer data is red, STS data in black and green), but this is only for one day where the TOC seem stable. The TOC does not vary very much at this latitude (less than 10 DU 95 % of the days), but we have added figure 6 that indicates the variation of the TOC when the variation was 22 DU, and some comments (line 270-275 in the revised manuscript.)

Commonly these small low cost spectrometers suffer from straylight, which biases TCO at low solar zenith angles or high ozone slant columns. In order to assess the performance of the instrument the comparison between the Brewer and STS GI depending on ozone slant column (airmass * TCO) should be provided.

Yes, the method certainly breaks down at high solar zenith angles (we are sure the reviewer means <u>high solar zenith angles rather than low).</u> We have added figure 7 which shows this clearly. This issue was not discussed in detail because the Brewer's schedule during the

campaign did not include any TOC measurements with higher zenith angles than ~65 degrees, as the Brewer making Umkehr measurements at these times.

Temperature dependency. Indeed, the dependency of the small array spectroradiometer is a crucial issue of these instruments. Ambient temperature causes wavelength shifts, linearity and detectability problems (signal to noise ratio etc.). I am surprised that a simple parametrization (Eq. 2) can account for that. It would be worthful to calculate the uncertainty of TCO based on the parametrization and its applicability for other instruments and other locations.

We did not attempt to conduct a full uncertainty analysis for this work.

A very useful property of this particular spectrometer is that the detector is sensitive all the way down to around 190nm, and the noise in the detector can be established from the blind area of 180 – 280 nm continuously. Then the only major thing left is to find the temperature effect on the TOC calculations, which turned out to be quite simple in this case. The temperature correction is further elaborated well described in section 2.5 with added plots (page 8)

Furthermore, the model includes the ozone absorption cross section, which depends on the effective ozone temperature (basically stratospheric temperature). How sensitive is the algorithm and resulting TCO on effective ozone temperature?

We did not attempt to calculate the sensitivity of the results to effective stratospheric ozone temperature. This is a relatively small effect at mid-latitudes even for reference ozone instruments (Voglmeier et al.). For the very simple, low cost instruments being studied, we have focused on the major issues such as clouds and ambient temperature. We agree though that in in principle a small seasonal and latitudinal error would be expected from this cause.

Specific comments:

Page 2: line 32: How significant is the fraction of the price of the Brewer. To my estimate it is about 10% of a Brewer, which is already low cost.

Prices vary of course with time, delivery costs, currency conversions etc, but in broad terms an instruments such as the Pandora or BTS would cost at least 20-30% of the price of a Brewer. This instrument is more than an order of magnitude cheaper so we feel the statement is quite reasonable.

Page 2, line 47: Is the MK II Brewer a double monochromator with insignificant stray light impact?

The Brewer was Mk III with a double monochromator and low stray light.

Page 2, line 60: Can the method be described as a cloud correction?

No, the alternating DS and ZS measurements establish a pure statistical relationship by solving for the nine coefficients (a -k) in equation (1) regardless of clouds.

Page 3 line 89: The reference is missing

Thanks. It has been added in the revised version.

Page 4 line 95: What is the slit function and full width half maximum of the instrument, resulting from 25 micron slit?

The manufacturer claimed 4 pixels FWHM (~1.5 nm) slit function from a lab test (Hg 253.6 line), but the instrument simulations from the LibRadtran model predicted a complete instrument function of ~3.0 nm FWHM at 312 nm, which was used in the calculations. This information has been added to the manuscript.

Page 5 line 126: Do you mean ozone slant column (=airmass * TCO) - > see comment above.

No, ozone slant "path" was intended – (μ) refers to the path length through the atmosphere, relative to the vertical path length (often referred to as "air mass factor" in the Brewer community).

Page 5: 132: and EQ 1 is this parametrization also applicable at other locations

Equation (1) is for the Brewer ZS measurements used in absence of Brewer DS measurements, and should be calculated for each Brewer at each site.

Page 5, line 146. Again, what is the full width half maximum of the slit function?

It is described according to the question above.

Table 1: It would be worthful to indicate the performance in percent

The table now includes the percentage.

Caption Figure 2: SZ -> ZS

It is corrected.

Figure 4. The ratio between Brewer and STS would be more helpful

A ratio plot for the same data as fig 4 is presented in fig 8.

Page 11 line 280: Why is TCO increasing with temperature? Wavelength shift?

Yes, we would expect wavelength shift, which is in general related to instrument temperature, to be the major cause.

Page 11 line 286: I suggest using quasi simultaneous measurements.

Thanks for the suggestion. We have chosen instead to add a new figure 2 (panel a) clearly demonstrating the temperature effect on the measurements, and how well the correction works after being applied (panel b and c). We hope this addresses the concern.

Page 12 line 310: At what conditions is STS comparable to the Brewer? What are the limitations?

As mentioned already in the abstract, clouds and temperature is the main contributor to the rejection of measurements. The cloud limitation is outlined in section 2.4 lines 181 – 192 in the revised manuscript, and the temperature limitation in section 3.4.1 lines 349 – 362.

Page 13: line 324. The conclusion should not end with a bullet list. Maybe a closing sentence would help.

Thanks, yes, the bullet list has now been replaced with a closing sentence.