

## Responses to Reviewer # 2

We thank the referee for providing the constructive comments on our paper.

### *General comments*

**Comment #1:** The authors should make a comment on the usefulness of the total ozone products as an integral from the ozone profile products, in comparison to the direct total ozone products. Is the consistency with the long-term series of the SBUV an objective of such a study and if yes, the authors should provide some relevant information. There are studies in the literature that compare column products with SBUV so the comparison of SOE and KOE with SBUV would be very interesting.

**Response #1:** There are several purposes to compare integrated total ozone from ozone profile with directly retrieved total ozone. First, as total ozone column is the just the sum of our retrieved partial ozone columns at each layer, the quality of integrated total ozone is generally considered as a prerequisite to the quality of ozone profile retrieval, and we have not validated the retrieved SOE total ozone against ground-based measurements as mentioned in the ACPD manuscript P4054 lines 4-6. Second, as we have mentioned this in the ACPD manuscript P4054 lines 23-29, the ozone profile algorithms have the potential to provide more accurate retrievals of total ozone than the two total ozone algorithms due to the use of broader spectral ranges than those used for the total ozone retrievals. However, the successful performance of ozone profile retrieval algorithms can be accomplished only when accurate calibration and forward model simulations and good knowledge of measurement errors and the a priori covariance matrix are available. This still need to be verified. So we compare the total ozone retrieval performance of two profile algorithms and two total ozone algorithms from the same OMI observations, minimizing the instrument and sampling differences. Although evaluating the consistency of long-term series between SBUV (a series of different type of instruments, different spectral and spatiotemporal sampling from OMI, different time periods of availability) and OMI SOE retrieval is very interesting, it is beyond the scope of this study (focus on the evaluation of OMI retrievals).

To clarify the motivation of this study, we have added at the beginning of third paragraph in the introduction session, “In Liu et al. [2010a], profile of partial ozone columns is retrieved at 24 layers and total ozone column is just the sum of partial ozone columns at all layers. Although high quality of the integrated total ozone does not guarantee the high quality of retrieved profile, the total ozone quality is generally an important prerequisite to the overall quality of the retrieved profile.”

**Comment #2:** I agree with the other reviewer that the impact of the use of different absorption cross sections when comparing different total ozone data sets should be discussed in more detail and respective comments should be included in the manuscript, especially concerning the observed biases.

**Response #2:** We have already answered about the similar comment in the response to the first reviewer’s general comment as follows. We added two paragraphs to address this issue, 1 in section 2.2 (describing Brewer total ozone data) and 1 at the end of the paper.

In section 2.2, we added after “Absorption coefficients based on Bass and Paur (1985) data are used in the standard Brewer algorithm” the following:

Several studies have evaluated the effects of using newer high-resolution ozone cross section datasets and accounting for temperature dependence on Brewer total ozone retrievals and its consistency with

the Dobson retrievals (Fragkos et al., 2013; Redonas et al., 2014). These two newer datasets are the BDM dataset (used in SOE, KOE, and DOAS algorithms) and the dataset by Institute of Environmental Physics, Bremen University (IUP dataset, Gorshelev et al., 2014; Serdyuchenko et al., 2014). Using both BDM and IUP datasets removes the seasonality of the Dobson/Brewer differences after accounting for the temperature dependence. However, using the BDM dataset produces Dobson/Brewer biases of ~2-3% as the Brewer total ozone is reduced by ~3.2% (Redonas et al., 2014), while using the IUP dataset reduces the Dobson/Brewer differences to within 1%. Therefore, the IUP dataset has been recommended for ground-based Brewer and Dobson measurements. According to Fragkos et al. (2013), using the recommended IUP dataset and accounting for its temperature dependence reduces the Brewer total ozone at a mid-latitude station (Thessaloniki, Greece) by ~-0.7% on average with a seasonal dependence of ~0.2% and a trend change on the order of 0.05%/decade, compared to the operational Brewer total ozone. These studies imply that the operational total ozone, despite the deficiencies in the standard Brewer algorithm, is close to that from the improved algorithm with a positive bias of ~0.7% and a very small seasonal dependence of ~0.2%.

We also added at the end of paper:

It is important to discuss the possible impacts of cross sections on the evaluation of algorithm performances as different cross sections are used in the OMI and Brewer algorithms. In 2009, WMO/GAC-IO3C has established the ACSO (Absorption Cross Sections of Ozone, <http://igaco-o3.fmi.fi/ACSO/>) Committee to review the current ozone cross sections and determine the impacts of changing ozone cross sections on retrievals from different satellite and ground-based instruments. According to the activities from ASCO members, switching from BP to newer BDM and IUP datasets has different impacts on retrievals from different instruments/retrieval algorithms due to the use of different wavelengths/spectral regions and the quality of ozone cross sections in the used wavelengths/spectral regions. The BDM cross section dataset is recommended for use in our ozone profile retrieval algorithm and the TOMS algorithm (Liu et al., 2013; Bhartia, 2013, [http://igaco-o3.fmi.fi/ACSO/presentations\\_2013/satellite/WS\\_2013\\_Bhartia.pdf](http://igaco-o3.fmi.fi/ACSO/presentations_2013/satellite/WS_2013_Bhartia.pdf)) and is used in all OMI algorithms except for the TOMS algorithm. If it is used in the TOMS algorithm, the OMTO3 would increase by ~1.5%. However, using BDM reduces the Brewer total ozone by ~3.2% and produces Dobson/Brewer differences of 2-3% (Fragkos et al., 2013; Redonas et al., 2014). On the other hand, the IUP dataset is recommended for ground-based Dobson and Brewer measurements as it minimizes the Dobson/Brewer differences to within 1%; using the IUP dataset and accounting for its temperature dependence would reduce the Brewer total ozone by ~-0.7 % with a small seasonal dependence (Fragkos et al., 2013). If using the recommended cross sections for different algorithms (i.e., switch to the BDM dataset for the TOMS algorithm and to the IUP dataset for the Brewer algorithm), the SOE and TOMS total ozone would show positive biases of ~0.5-0.7%, DOAS total ozone would show negative biases of ~1% and KOE total ozone would show positive biases of 3-4%. Because the very small change in seasonal dependence and trend of Brewer total ozone and the systematic bias in TOMS total ozone, the evaluation of algorithm performance with respect to different geophysical variables should not change much. Overall, the main conclusions of this study are not affected much except for the mean OMI/Brewer biases.

**Comment #3:** A summary table with the main characteristics of the four algorithms (e.g. wavelength window, cross-sections, principle, calibration etc) would be very useful for the reader to follow the discussion and the figures.

**Response #3:** According to Reviewer, the indicated summary table is newly included as Table 1 in the revised manuscript.

Table 1. Main Characteristics of SOE, KOE, TOMS, and DOAS ozone algorithms.

	SOE	KOE	TOMS	DOAS
<b>Retrieval Method</b>	Optimal Estimation	Optimal Estimation	TOMS	DOAS fitting and SCD to VCD conversion
<b>Algorithm Version</b>	X*	1.1.1 (1.1.0 before 2 January 2006)	8.5	1.2.3.1
<b>Fitting window</b>	270-330 nm	270-330 nm	312.6, 317.6, 331.3 nm	331.1-336 nm
<b>Ozone cross section</b>	BDM	BDM	Bass and Paur	BDM
<b>Ozone A Priori</b>	Mean and a prior error from LLM	Mean from LLM, 20% a priori error	TOMS V8 climatology (mean)	TOMS V8 climatology (mean)
<b>Soft Calibration</b>	Yes	No	Yes	No
<b>Cloud Pressure</b>	O <sub>2</sub> -O <sub>2</sub> algorithm	O <sub>2</sub> -O <sub>2</sub> algorithm	RRS algorithm	O <sub>2</sub> -O <sub>2</sub> algorithm

\*No official version, the first version is provided in Liu et al. (2010) and then some updates are described in Kim et al. (2013).

### *Specific comments*

**Comment #1:** Page 4054, line 8, correct “Would” to “World”

**Response #1:** We have corrected “Would” to World”.

**Comment #2:** Page 4056, line 8. Although the authors cite the paper by Liu et al., it would be very useful here to provide briefly some more information on the soft calibration since this is a major factor that affects the quality of the SOE data.

**Response #2:** We have added a few sentences to provide more information on the soft calibration.

- Added text (p.5, line 25-28): This first-order correction is derived using the average percent difference between measured and simulated radiance derived from 2 days of MLS data in the tropics (shown in section 2.3 and Figure 1 of Liu et al. [2010a]).

**Comment #3:** Page 4056, line 23. Please mention briefly what concerns the updates described by Kim et al.

**Response #3:** The main updates are mainly to improve radiative transfer calculations and address the retrieval impacts of correcting the OMI L1b random-noise error overestimate by ~2-5 times [Braak, 2010]. We have removed the sentence “It should be noted that the SOE algorithm used in this study has several updates from the version presented by Liu et al. (2010a), which are described in Kim et al. (2013)”, and changed the last sentence in the previous paragraph “Details can be found in Liu et al. (2010a) and Kroon et al. (2011)” to “Details about the SOE algorithm can be found in Liu et al. [2010a], with several updates described in Kim et al. [2013] to improve radiative transfer calculations and address the retrieval impacts of correcting the OMI L1b random-noise error overestimate by ~2-5 times [Braak, 2010]. Detailed about the KOE algorithm can be found in Kroon et al. [2011].”

**Comment #4:** Page 4057, line 13. I guess that the soft calibration mentioned here has no connection with the SOE one mentioned before, but as it is written can be very confusing for the Reader, so please avoid using the same term for different corrections.

**Response #4:** We have revised the manuscript to provide more detail on soft calibration done in the TOMS algorithm according to both reviewer #1 and reviewer #2.

- Revised text (p.6, line 20-26): OMTO3 total ozone measurements are tied closely to OMI's pre-launch radiometric calibration at nadir described by Dobber et al. (2006) and validated by Jaross and Warner (2008). Small residual errors in the Collection 3 radiances (Dobber et al., 2008) are further reduced using soft-calibration techniques where biases and irregularities that vary with viewing angle and wavelength are estimated and reduced by comparing the measured radiances with theoretical forward model radiance calculations. This approach is applied only to select data where the variability in ozone is low and therefore the radiances can be simulated reliably.

**Comment #5:** Section 3.1. Stations that seem problematic (and there are references for that) should be removed. The authors do that any way in a second step, but their inclusion in the discussion and then the exclusion can be confusing.

**Response #5:** We mainly followed the methodology used in Balis et al. [2007]; those excluded stations were not mentioned in that study. In addition, we have indicated that “the filled and opened symbols represent stations selected and rejected, respectively” in the caption of figure 1 to avoid confusing. We think that it is useful for readers (especially who have no experience in this kind of validation study) to provide how to select the good reference.

**Comment #6:** Page 4063. Line 6. Please write “trend of the differences”, since as it is written it can be confusing meaning trend in total ozone.

**Response # 6:** We have corrected “trend” to “trend of the differences” on p.12, line 10 in the revised manuscript.

**Comment #7:** Page 4063, Line 13. Please write “the average difference of trends”. As it is written one can easily wrongly conclude that the average difference in total ozone is only 0.02%!

**Response #7:** The indicated value of 0.02 % (presented in Table 2 in previous manuscript and in Table 3 in the revised manuscript) represents the average difference between SOE and Brewer in the Northern Hemisphere. Therefore, we did not change it.

**Comment #9:** Section 5. The main conclusion from this comparison seems to be that the large

KOE/SOE differences are mainly caused by other implementation details. I think that here the authors should try to be more specific. Which could be the other variables used in the fitting, what could be the source of differences in the RT simulations etc., and if there are plans to investigate these in more detail?

**Response #9:** As we specified in Section 2.1, the fitting variables of SOE algorithm include ozone values at 24 layers from the surface to ~0.087 hPa, surface albedo, cloud fraction, scaling parameters for the Ring effect, radiance/O<sub>3</sub> cross section wavelength shift, radiance/irradiance wavelength shift, and a scaling parameter for mean fitting residual. In other hand, the fitting variables of the KOE algorithm include ozone profiles at 18 layers from the surface to 0.3 hPa, surface albedo, cloud albedo, and straylight correction parameters. There are the sources of differences in the RT simulations: different RT models, forward spectroscopic/atmospheric/surface inputs. The investigation of all kind of sources is very worth and interesting, but we think that it is out of scope in this paper, as it requires close coordination with the KOE developers or access to the KOE source code. However, the first author (Juseon Bak) of this paper has a plan to investigate the effect of each implementation on ozone retrieval to get a better understanding on the SOE algorithm. As the first step, Juseon Bak and her co-worker are preparing a paper to show the effect of the cloud variables on the ozone profile, total ozone, and tropospheric ozone from the SOE algorithm.

**Comment #8:** (a) Section 4. This short paragraph could be merged with the section 3 when discussing the comparison results for the high latitudes as a confirmation. As it is written it hardly justifies to be considered a different section in the manuscript. (b) A comment on possible differences between double and single Brewer comparisons should be added.

**Response #8:**

(a) According to Reviewer #1, the paragraph of Section 4 has been moved to Section 3.1

(b) According to Reviewer #2, we have compared total ozone difference between OMI and Brewer as function of SZA at single (blue) and double (red) brewer stations, respectively in five figures below. Except at UCCLE station, there is no station where both single and double brewers are installed and thereby other brewer stations are compared with latitudinally adjacent single brewer stations. In most cases, we can see generally less scatter at double Brewer stations, but did not see significant SZA-dependence reduction in the differences with double Brewer measurements. According to Figure 2, a smaller trend of the differences between OMI and Brewer is also observed at double brewer stations. The revision to include this result is followings.

- Added text (13p., line 7-14): In Figure 3, both single and double Brewer measurements at Uccle station are compared with the four OMI datasets. This comparison with double Brewer measurements shows less scatter, but insignificant SZA-dependent reduction of OMI/Brewer differences although it is known that the performance of single Brewer instruments has a distinct dependence on SZA especially at large SZA due to the influence of stray-light [Bais and Zerefos, 1996]. In addition, comparisons at other double Brewer stations also show less scatter and even smaller trend of the OMI/Brewer differences compared to those latitudinally adjacent stations with single Brewer instruments (Figure 1 and Figure 2).

- Added new figure 3: Comparison between OMI and Brewer total ozone measurements as a function of solar zenith angle at single (blue) and double (red) Brewer Uccle stations, respectively. We also give the mean biases and  $1\sigma$  standard deviations for relative differences in the legend.







