Dear Editor,

With regard to the manuscript:

MS-NR: acpd-2010-0522
Title: NDACC UV-visible total ozone measurements: improved retrieval and comparison with correlative satellite and ground-based observations
Author(s): F. Hendrick, et al.

Please find below the replies to Referee #3 comments.

Sincerely yours,

F. Hendrick (**franch@oma.be**)

Anonymous Referee #3

First, we would like to thank Anonymous Referee #3 for his/her helpful comments.

1 ***Introduction***

This paper reports on a standardisation of groundbased DOAS retrievals of total ozone within NDACC. This is a very important and relevant topic since so far very different approaches are used to derive total ozone from DOAS type measurements which makes them less suitable for long-term trend assessment than the more conventional Brewer/Dobson network (with highly standardized retrievals) and the suite of satellite measurements. The ground DOAS retrieval is a two step procedure with slant column derived in a first step from spectral inversion and conversion to vertical column amounts using radiative transfer models and a priori knowledge of atmospheric profiles, in particular ozone, in a second step. This paper focuses more on the use of a standardized air mass factor (amf) tables for the slant column conversion to total ozone, which is believed to be the largest source of errors in the DOAS retrieval so far.

For satellite retrievals the use of a seasonal and meridional dependent ozone profile climatology (used in the AMF caluclation) is very common and has been here specified for the ground DOAS retrievals within NDACC as well. Significant improvements are obtained with the new AMF tables reducing seasonal variations with respect to other correlative data. This paper investigates in details the various error sources in the new retrieval version. Comparisons with other data show that still some seasonal variations remain in the differences and possible sources for this are discussed in detail. This paper is very well written and suitable for publication in AMT after clarifying some issues as raised below.

2 Major issues

p. 20409, l. 27: The authors should make it more clear that SAOZ is part of the world wide DOAS network, which in parts is also part of NDACC. I do not think that every DOAS station is within NDACC. It would be also very helpful for the reader to know more about what is the distinction of SAOZ from other DOAS stations apart form the organization. Are their instrumental differences? For instance, some SAOZ instruments are not temperature stabilized which could lead to different type of errors.

On one hand, we agree with Referee #3 that not every DOAS station is within the NDACC network. On the other hand, it should be noted that the ground-based zenith-sky UV-visible spectrometers measuring routinely ozone at twilight are largely dominated by SAOZ instruments which are all part of the NDACC network. So, in the revised version of the manuscript, we have rephrased line 27 page 20409 as follows:

"….by a comparison between total ozone measurements made by a selection of SAOZ (Système d'Analyse par Observation Zénithale, Pommereau and Goutail, 1988) spectrometers belonging to the NDACC uv-visible network and collocated observations performed by other instruments."

We don't think it is relevant to discuss the instrumental differences between the SAOZ and other DOAS instruments and related errors here. These issues are discussed in the papers on the past NDACC blind intercomparison campaigns (Hofmann et al., 1995, Vaughan et al., 1997, Roscoe et al., 1999, Vandaele et al., 2005, Roscoe et al., 2010) to which SAOZ instruments were always participating. All the details on UV-Vis instruments and performances can be found in there.

p. 20416, l. 18: Regarding the neglect of seasonal and longitude dependence of tropospheric ozone in the ozone profile climatology, one should remind the reader that the TV8 climatology is per definition a stratospheric climatology. I would rather say here that tropospheric ozone changes are "not accounted for" rather than "not implemented" here. It would be tricky to combine total ozone and tropospheric ozone classification, although from the work by Lamsal et al. (2004) it is evident that there is some linkage between stratospheric and tropospheric ozone variation revealed in a total ozone classified profile climatology. A zonal mean monthly mean climatology may be better suited to represent seasonal variation in tropospheric ozone. For this reason the WFDOAS approach described by Coldewey-Egbers et al. (2005) uses the McPeters et al. zonal mean climatology to determine the ghost column to be added to the retrieved satellite columns. However, a zonal mean climatology will still neglect the longitude dependence (e.g. wave-1 pattern).

According to McPeters et al., JGR (2007), the TV8 climatology includes a contribution of the troposphere derived from ozonesondes observations. However, this contribution must be considered as a ghost column and the longitude dependence (e.g. wave-1 pattern) is neglected as Referee #3 noted. In the revised manuscript, we have replaced “not implemented” by “not accounted for” as suggested above.

p. 20418, l. 22: Here the authors claim that there are little differences in the AMFs when using different ozone profile climatologies (TV8, IUP, and Fortuin and Kelder climatologies). If the use of Fortuin Kelder (1998) does not make a large difference then a total ozone classified climatology would be not needed, since FK is a zonal mean monthly mean climatology. My impression was that a total ozone classified climatology is important like TV8 or Lamsal et al. (2004). Please discuss this.

We fully agree with Referee #3 on the fact that significant differences exist in the AMFs when using TV8 and IUP on one hand (total ozone classified climatologies) and simple zonal mean monthly mean climatology as Fortuin and Kelder (1998) on the other hand. In contrast to a simple zonal mean climatology, a total ozone classified climatology captures the short-term variations of the ozone profile. In the revised version of the manuscript, we have removed this paragraph on the impact of the ozone climatology, which was based on inappropriate sensitivity test results.

In Lamsal et al. (2004, 2007) the impact of different O3 climatologies on satellite retrievals were investigated and at large solar zenith angles it has an impact on satellite retrievals. Please discuss this.

Lamsal et al. (2004 and 2007) have shown that the impact of the O3 climatology on the satellite nadir retrievals is larger at high SZA. Since SAOZ retrievals are always performed around 90°SZA, we can expect a similar feature as for satellites although less marked since SAOZ observations are made in the visible region. We have added the Lamsal et al. (2007) and Weber et al. (2005) references on page 9 of the revised manuscript.

p. 20419, l. 11: Here the V1 of SAOZ retrieval is mentioned. Are the AMF changes the only modfication in the new version 2. Please clarify.

We have added in the beginning of the Section 4 a paragraph on the changes in the DOAS settings between V1 and V2 of the SAOZ data sets, with focus on the Ring and ozone cross-sections, and the ozone fitting spectral window. The impact of these three parameters is now discussed. Overall, the main change between V1 and V2 after applying the NDACC UV-Vis working group recommendations for DOAS settings is a decrease of ozone vertical column at twilight by 0.5%, which is not significant.

p. 20424, l. 19: The correlation of total ozone with analysis temperatures is in my opinion not a true temperature correction, since the seasonal variation is a superposition of the seasonalities of many errors, of which stratospheric T (or cross-sections) is one of them. In a sense the ECMWF/NCEP temperature are used more like a proxy for seasonally varying errors. Even though the temperature corrections derived from Dobson comparisons seem to agree with the inferred numbers from Komhyr et al. (1993), but sometimes the seasonal variations are even larger (e.g. OMI-DOAS). Although SAOZ has no temperature dependence due to the use of Chappuis ozone bands, they may have still a seasonal dependent error source. It should be more stressed in the conclusion that seasonal varying errors in many of the auxiliary parameters used can cause seasonal dependence in the comparisons between data sets that are beyond the stratospheric temperature issue.

Indeed there are several possible sources of errors showing a seasonality, but very few of them display a systematic summer maximum and winter minimum. In addition to the temperature of the stratosphere and the TV8 climatology already studied in the Discussion paper, another parameter, the SZA at the location of the satellite measurement, has been added in the revised paper. The SZA has an impact in some satellite retrievals, which is particularly large on SCIA-TOSOMI. We also looked at the total ozone column itself known to show a maximum in spring but the correlation was found not significant. We also found a mistake in the comparisons with satellites in Dumont d'Urville: since the station is located at 140°E, the dates of the GOME and SCIA overpasses were shifted by one day compared to SAOZ measurements in the morning because of their earlier equatorial crossing at 10:30 and 10:00 local time respectively. But this has resulted only in a noise reduction. We agree that other sources of errors might exist but we did not succeed in identifying them.
We also agree that the large temperature correction required for TOMS and OMI-TOMS is quite surprising since it is expected to be corrected in their respective retrieval, but we did not find any idea to correct it with another proxy.

Overall, we think that these sources of errors are better discussed now than in the first version of the manuscript.

3 Minor issues
Abstract/Section 4.1: Why did the authors did not use SCIAMACHY-OL3 which has about the same data version as GOME-GDO4 for comparisons to SAOZ? this would highlight how different satellite algorithms impact differences to SAOZ.

The revised version of the manuscript now includes the SCIAMACHY-OL3 O_3 column product.

p. 20409, l. 2: spell out acronym NDSC

Done

p. 20409, l. 2: "However, despite", better start sentence with "Despite" only

Corrected.

p. 20411, l. 12: "provision of homogeneous tools for calculating appropriate latitude and seasonal dependent AMFs". "Homogenous tools" sounds a bit awkward, I suggest to say "provision of an standardized AMF data base that accounts for latitude and seasonal dependence of the climatological ozone profiles"

In the revised version of the manuscript, this line has been changed into: “provision of standardized DOAS settings and O_3 AMF look-up tables (LUTs) that account for the latitudinal and seasonal dependence of the O_3 vertical profile.”

p. 20412, l. 16: "average all available measurements between 86deg and 91deg SZA". To make it less ambigous, say "average of all retrieved vertical ozone columns" to distinguish this from averaging spectral data.

Corrected.

p. 20412, l. 25: The McPeters et al (2007) paper describes a monthly mean zonal mean climatology which is different from the total ozone classified (TV8) used in the OMITOMS retrieval. The same profile data pool was apparently used in both climatologies. This should be clarified here.

Right. The TV8 climatology is the McPeters et al. (2007) climatology with in addition a total ozone dependence. We have modified the paper accordingly: we have replaced “These are based on the TOMS version 8 (TV8) ozone and temperature profile climatology (Bhartia et al., 2004; McPeters et al., 2007). TV8 is a monthly mean climatology for 10° latitude bands between 90°S and 90°N, covering altitudes from 0 to 60 km, and including a total O_3 column dependence (225-325 Dobson Unit (DU) in the tropics, 225-575 DU at mid-latitudes, and 125-575 DU at high-latitudes, with a 50 DU step)

by

“These are based on the TOMS version 8 (TV8) ozone and temperature profile climatology. TV8 is similar to the climatology of McPeters et al. (2007), i.e. a monthly mean climatology for 10° latitude bands between 90°S and 90°N and covering altitudes from 0 to 60 km, with in addition a total O_3 column dependence (225-325 Dobson Unit (DU) in the tropics, 225-575 DU at mid-latitudes, and 125-575 DU at high-latitudes, with in all cases a 50 DU step). A total ozone column classification allows reproducing the short-term variation of the ozone profile.”

p. 20413, l. 7: "for the eighteen TV8 latitude bands" –> for eighteen zonal bands"

Corrected.

p. 20413, l. 21: "the Pinatubo" –> "Mt. Pinatubo"

Corrected

p. 20413, l. 25: "global monthly climatology" –> "global monthly mean climatology"

Corrected

p. 20414, l. 3: Please add a reference which describes the SAOZ AMFs as used in the V1 retrieval.

Done. The reference is: Sarkissian, A., Roscoe, H. K., Fish, D., Van Roozendael, M., Gil, M., Chen, H. P., Wang, P., Pommereau, J.-P., and Lenoble, J.: Ozone and NO_2 AMF for zenith sky spectrometer: Intercomparison of calculations with different radiative transfer model, Geophys. Res. Lett., 22, 1113-1116, 1995.

p. 20416, l. 2: "Lidar" –> "lidar"

Corrected.

p. 20416, l. 12: "in average" –> "on average"

Corrected.

p. 20416, l. 16: "here is of -1%" –> "here is -1%" (omit "of")

Corrected.

p. 20416, l. 18: "that the zonal dependence of the tropospheric ozone seasonality is not implemented in the TV8 climatology" –> "that the tropospheric ozone seasonality is not accounted for in the TV8 climatology." (omit: "the zonal dependence of", change "implemented" to "accounted for", see also discussion above)

Corrected.

p. 20417, l. 7: "is of 0.6%" –> "is 0.6

Corrected.

p. 20417, l. 26: I would stress by adding a sentence that in the new AMF tables for DOAS ground retrieval clouds are not accounted for.

Page 20417, line 9: We have replaced the sentence “The impact of clouds on O_3 AMFs has also been investigated using the water clouds model included in UVSPEC/DISORT.”

by

“Clouds are not accounted for in our O_3 AMF calculations but their impact has been investigated using the water clouds model included in UVSPEC/DISORT.”

p. 20418, l. 20: "the University of Bremen atmospheric model for trace gases". Is this the same as the Lamsal et al. (2004) ozone profile climatology, called "IUP" in SCIATRAN settings for ozone profiles, then please add the reference here! All other trace gases are from the Bremen CTM. Please clarify.

As this paragraph on the influence of the ozone climatology has been removed from the revised version of the manuscript, this comment is not significant anymore.

p. 20420, l. 22 (Table 6): What is the explanation that OMI-DOAS shows a larger seasonal cycle in the differences to SAOZ V2 than V1. Almost all satellite retrievals so far I know account for stratospheric temperature changes. From this is clear that the seasonal dependence in total ozone retrieval differences must have other origins than ozone temperature issues. This should be discussed here in some more details.

a) There was an error in the calculation of these seasonal cycles. Although some satellites data (TOMS, SCIA, OMI-TOMS) are limited to SZA<84° in their respective databases, others like GOME and OMI-DOAS are including measurements at all SZA (also those during the pm descending orbit at high latitude in the summer). These data sets are showing large uncertainties at large SZA in the winter at high latitude (note that DDU, missing in the discussion paper, is now added). In the revised manuscript, all measurements SZA>84° are now ignored, reducing the amplitude of the seasonal cycle with V1 as well as V2 for GOME and OMI-DOAS.
b) However there are still satellites for which the change from V1 to V2 increases the amplitude of the seasonal cycle, particularly with SCIA-TOSOMI and OMI-DOAS at high latitude. This comes again from measurements at large SZA at the beginning and the end of the winter period, for which large deviations are observed, compared to SAOZ. It is not clear that all satellites (or retrieval

algorithms) can perform correctly up to 84° but for homogeneity reason we decided to take the same SZA limit for all.

p. 20421, l. 10: "the average bias of each station is normalize to zero at 210 K". A bias cannot be normalised, better to say: the bias of each station is set to zero at 210 K"

Corrected.

p. 20422, l. better: "Since these features are not present with all satellites, they can not be attributed to the SAOZ retrievals alone". (remove "hardly" and add "alone") I think that the issue here is that many of the auxillary data (albedo, cloud, O3 climatology and associated errors) as well as stratospheric temperature (or error in cross-sections) have a distinct seasonal pattern and this varies among all retrievals (see earlier discussion).

See above. We think that the sources of errors and their seasonality are now better discussed now in the revised version of the manuscript.

p. 20423, l. 28. "zonal profile climatology" –> "zonal mean profile climatology"

Corrected.

p. 20425, l. 25: "although an underestimation of the temperature sensitivity of the Dobson AD pair cannot be ruled-out" If this point is not discussed further in the paper, I suggest to remove this subphrase.

We have replaced:

“In summary, the 3.2% apparent seasonal amplitude of difference Dobson-SAOZ V2 could be largely explained by the temperature dependence of the absorption cross sections not corrected for in the Dobson measurements, the seasonal variation of the tropospheric column to which SAOZ is little sensitive, and internal stray light in the Dobson instrument, although an underestimation of the temperature sensitivity of the Dobson AD pair cannot be ruled-out.”

by

“In summary, the 3.2% residual seasonal amplitude of the Dobson-SAOZ V2 difference at OHP can be partly explained by a known temperature dependence of the absorption cross-sections at Dobson wavelengths, varying between 0.11-0.13%/°C according to laboratory measurements and 0.18%/°C in the present study, not taken into account in the Dobson retrievals, and by uncertainties in the ozone profile seasonal variation, particularly in the troposphere, in the TV8

climatology. The mean 1% low bias of the SAOZ compared to Dobson is within the uncertainties of absolute cross-sections used by both instruments”

p. 20428, l. 13: "mean zonal profile climatology" –> "zonal mean profile climatology"

Corrected.

Table 1: I suggest to add in Table 1 references to the solar atlases (Kurucz and/or Chance, is there a preference?) also use a reference to the Chance paper for the Ring effect (remove "NDACC source(?)")

These two references (Kurucz, 1984; Chance and Spurr, 1997) are mentioned in the text but not in Table 1. They have been added in Table 1 in the revised version of the manuscript.

Table 2: Spell out the climatology TV8, i.e. "TOMS V8 climatology (TV8, Bhartia et al., 2004)". Is a representative AMF wavelength or several wavelengths are used for slant column conversion into VCD. No details are given here nor in the main text. Please do so.

Done. AMF is computed at a single representative wavelength chosen at 500 nm (middle of the 450-550 nm wavelength range). We have clarified this on page 5 line 11 in the revised version of the manuscript. We have removed the Barthia et al. (2004) reference since the TV8 climatology is mostly based on McPeters et al. (2007) climatology.

Fig. 5: Mention "OHP" in figure caption.

OHP is already mentioned in fig 5 caption.