Validation of an improved European long-term multi-sensor global total ozone record as part of the ESA Climate Change Initiative

Koukouli M.E., Zyrichidou I., Balis D.S., Lerot C., Van Roozendael M., Loyola D., Coldewey-Egbers M., Zehner C.

The European Space Agency's [ESA] *Ozone Climate Change Initiative* [CCI] project aims at producing and characterizing a number of high quality ozone data products generated from multiple satellite sensors. Improved Level-2 total ozone data sets based on the European sensors GOME/ERS-2, SCIAMACHY/Envisat and GOME-2/MetOp-A covering more than 17 years have recently been released. GOME-type Direct FITting [GODFIT] provides consistent results for all three sensors which are manifested via a similar seasonality, albeit with reduced amplitude, and similar solar zenith angle dependency. The validation of total ozone columns hence demonstrates a high level of inter-sensor consistency and an excellent long-term stability of individual instruments. One concludes that the accuracy of the CCI total ozone data sets is at the percent level during the complete time period from 1996 until 2012.

Koukouli M.E.[1*], Zyrichidou I.[1], Balis D.S.[1], Lerot C.[2], Van Roozendael M.[2], Loyola D.[3], Coldewey-Egbers M.[3], Zehner C.[4]

1 Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece.
2 Belgian Institute for Space Aeronomy, Brussels, Belgium
3 German Aerospace Center, Remote Sensing Technology Institute, Wessling, Germany
4 European Space Agency, Frascati, Italy

***corresponding author e-mail: mariliza@auth.gr**

1 Introduction

Equally important to providing updated and improved total ozone records from existing and new satellite instruments, is their independent validation using auxiliary total ozone records. Level-2 total ozone data sets based on the European sensors GOME/ERS-2, SCIAMACHY/Envisat and GOME-2/MetOp-A covering more than 17 years have been recently released as part of the European Space Agency's [ESA] *Ozone Climate Change Initiative* [CCI] project. In this paper, we will describe the validation performed on the Level-2 total ozone columns [TOC] using independent ground and space-borne total ozone measurements. We illustrate the impact of the Level-2 algorithmic improvements on the resulting multi-sensor total ozone data focusing on the latitudinal, solar zenith angle/seasonal and cloud top pressure dependencies in the satellite/ground-based differences.

2 Data and Methodology

In this section we briefly introduce both the ground and the satellite measurements used in this report.

2.1 Ground-based observations

The validation of total ozone data products performed in CCI and other related projects has been based on archived total ozone measurements provided by the World Meteorological Organization's Global Atmosphere Watch programme [WMO/GAW]. Brewer and Dobson total ozone data records as deposited at the World Ozone and Ultraviolet Data Centre [WOUDC] in Toronto, Canada (http://www.woudc.org). The details on the quality assessment of the ground-based data as well as the final choice of stations used can be found in Lambert et al. (2011). A subset of these nominal Dobson and Brewer stations, which comprises of 18 Dobson and 12 Brewer stations, was chosen for the pre-validation exercise in order to decrease the analysis time. The stations were chosen with a dual criterion; stations were required to show a stable, long-term ozone column time series and also to provide the broadest latitudinal coverage.

2.2 Satellite observations

A beta version of the improved GOME-type direct-fitting algorithm developed for CCI [GODFIT-CCI] was applied to the GOME/ERS, SCIAMACHY/Envisat and GOME-2/MetopA time series, with the aim to perform a validation exercise on the new algorithm. The direct fitting of the measured reflectances were simulated with model LIDORT to replicate Level-1 measurements in a fitting window between 325 and 335 nm. Before the fitting, a soft-calibration technique was applied to the Level-1 reflectances. The ozone cross-sections used where those of Brion, Daumont and Malicet, (Daumont et al. 1992, Malicet et al. 1995, Brion et al. 1998) .The total-O_3 classified profile climatology employed was the well-used TOMSv8, however the tropospheric content was provided by the longitudinally resolved OMI/MLS climatology and improved between -60°N and 60°S. A T°-shift adjustment scheme was enforced where the a-priori T°-profile is shifted during the retrieval process. The cloud correction is based on the independent pixel approximation. The model FRESCOv6 provides the cloud top pressure; the effective cloud fraction is retrieved by GODFIT assuming a cloud top albedo of 0.8. The surface albedo is provided by the Kleipool climatology (Kleipool et al. 2008) and is retrieved only in the two special cases: ice/snow mode (cloud fraction = 0) and fully cloudy mode (cloud fraction = 1).

2.3 Methodology

The CCI validation exercise was performed as in previous validation studies, from individual station comparisons, to belt, to hemisphere, to global. In the following we will show global plots and statistics only. In order to assess the consistency of the new GODFIT-CCI data product in comparison to current operational data sets, to evaluate the improvements in the new settings but also to locate possible lingering issues with the new version of the algorithm we show the comparisons between the GODFIT-CCI validation results as follows:

- GOME TOC: Results are compared to GDP4.6 (Loyola et al. 2011) and GPD5 (van Roozendael et al. 2012) TOC series between 1996 and-2011.
- GOME-2 TOC: Results are compared to GDP4.6 (Loyola et al. 2011) TOC series from 2007 to 2011.
- SCIAMACHY TOC: Results are compared to SDOAS (Lerot et al. 2009) TOC series, from 2002 to 2011.

3 Results

In Fig. 1, left and right column, the latitudinal variability of the comparisons to the selected Dobson and Brewer stations are shown respectively.

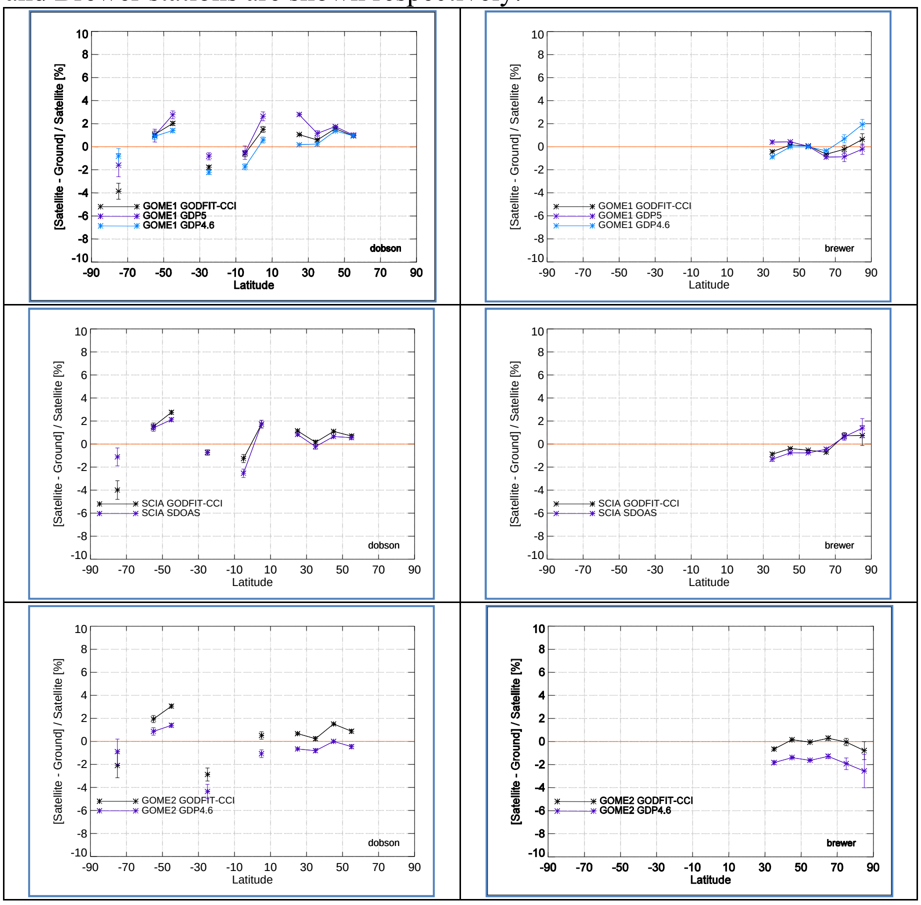

Fig. 1. Latitudinal variability of ozone differences between satellite and selected Dobson stations. Upper row: GOME; middle row: SCIAMACHY and lower row: GOME-2.

For GOME [upper row] one might say that no major differences can be observed in these mean values between the official ESA GDP5 version and the new GODFIT-CCI version of the algorithm, even though both differ from the GDP4.6 time series, as expected. The SCIAMACHY [middle left] comparisons yield no great insights at this stage. All algorithms for GOME and SCIAMACHY show a ±2% difference to selected Dobson stations and around ±1.5% to the Brewer network [middle right]. In the case of GOME-2, lower row, the new GODFIT-CCI algorithm is found to improve significantly the comparisons with the Brewers [Fig. 1, bottom right] from around -2% to 0%. The underestimation of the operational GOME-2 data is a well-known feature (Koukouli et al. 2012) related both to the currently used GOME FM cross-sections and to a larger bias after the throughput tests carried out in October 2009 impacting the Level-1 quality. However, Fig. 1 [left plots], also indicates that the Antarctica station of Arrival Heights might be problematic since the new algorithm reports larger underestimations of total ozone than previous versions.

The long-term behavior of the new CCI data set is displayed in Fig. 2, which shows the NH time series for the selected Dobson stations. Upon close inspection one might say that the peak-to-peak variability has decreased for the new CCI algorithm compared to the GDP5.0 and GDP4.6/SDOAS ones for both the GOME and SCIAMACHY comparisons. Most impressive is the improvement for GOME-2 in comparison to both types of ground-based instruments with peak-to-peak variability between 0 and 2% for the Dobson and 0 and 1% for the Brewer instruments [not shown here.]

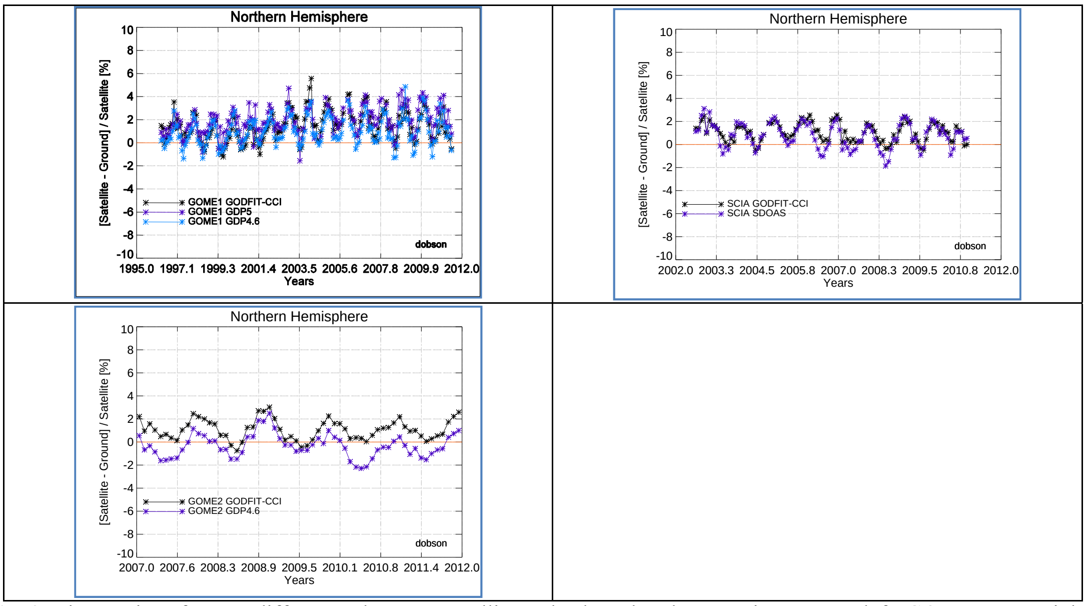

Fig. 2. Time series of ozone differences between satellite and selected Dobson stations: upper left, GOME; upper right, SCIAMACHY; and lower, GOME-2.

4 Conclusions

Summarizing the main findings of this validation exercise we can deduce that, for the total ozone column record of GOME-2/MetopA, the GODFIT-CCI algorithm is less sensitive to degradation effects and has an offset of almost 1% relative to operational GDP4.6 algorithm both in the Brewer and the Dobson comparisons. In general, the two algorithms, GDP4.6 and GODFIT, agree well. There is an almost constant bias on most of the plots that might be due to the use of different ozone cross-section in the two algorithms. For the total ozone column record of GOME/ERS-2, the GODFIT-CCI TOC is consistent with the last validated version of the official GDP5 algorithm results. However, the new GODFIT-CCI algorithm displays an under-estimation of up to ~4% for ozone hole conditions, an element not present in the official ESA GDP5 product. For the SCIAMACHY/Envisat TOC, the GODFIT-CCI results, compared to the official SDOAS TOCs, are pretty consistent, with GODFIT-CCI showing a slightly smaller amplitude in the seasonal dependence of the comparisons. However, as with GOME, there is a strong underestimation of TOC for ozone hole conditions.

As a general outcome:

- GODFIT-CCI provides consistent results for all three sensors, with a similar seasonality and reduced amplitude compared to previous versions of the data and a similar SZA dependency.
- Larger differences are observed for high cloud conditions at large SZAs (during winter/spring). It was shown that these cause most of the observed outlier points.
- GODFIT-CCI underestimates total ozone by 1-2% over Antarctica relative to GDP5 and GDOAS [based on five Antarctica Dobson stations].

A follow-up study by Koukouli et al. (2014), provides a more comprehensive and detailed description of the new long term dataset and its place in the global scientific interest for homogeneous and dependable Level-2 total ozone column records.

Acknowledgments The authors would like to acknowledge the European Space Agency Ozone-Climate Change Initiative project (ESRIN/Contract 4000101683/10/I-NB).

References

Brion J, Chakir A, Charbonnier J, et al. (1998) Absorption spectra measurements for the ozone molecule in the 350-830 nm region. J. Atmos. Chem., 30, 291-299.

Daumont, D, Brion J, Charbonnier J and Malicet J (1992) Ozone UV spectroscopy. I. Absorption cross-sections at room temperature. J. Atmos. Chem., 145–155, doi:10.1007/BF00053756.

Kleipool, QL, Dobber MR, de Haan JF, and Levelt PF (2008) Earth surface reflectance climatology from 3 years of OMI data. J. Geophys. Res., 113, D18308, doi:10.1029/2008JD010290.

Koukouli ME, Balis DS, Loyola D, et al. (2012) Geophysical validation and long-term consistency between GOME-2/MetOp-A total ozone column and measurements from the sensors GOME/ERS-2, SCIAMACHY/ENVISAT and OMI/Aura. Atmos. Meas. Tech., 5, 2169-2181, doi:10.5194/amt-5-2169-2012.

Koukouli ME, Balis DS, Zyrichidou I, et al. (2014) Validating the new GOME/ERS-2, SCIAMACHY/Envisat and GOME-2/MetOp-A homogeneous total ozone climate data record developed as part of the ESA Climate Change Initiative. In preparation for J Geophys Res.

Lambert JC, Koukouli ME, Balis DS, et al. (2011) Validation Report for ERS-2 GOME GDP 5.0 Total Ozone Column. TN-IASB-GOME-GDP5-VR / DLR-GOME-GDP5-VR, issue 1/A.

Lerot C, Van Roozendael M, van Geffen J, et al. (2009) Six years of total ozone column measurements from SCIAMACHY nadir observations. Atmos. Meas. Tech., doi:10.5194/amt-2-87-2009.

Loyola DG, Koukouli ME, Valks P, et al. (2011) The GOME-2 Total Column Ozone Product: Retrieval Algorithm and Ground-Based Validation. J. Geophys. Res., doi:10.1029/2010JD014675.

Malicet J, Daumont D, Charbonnier J, et al. (1995) Ozone UV spectroscopy. II. Absorption cross-sections and temperature dependence, J. Atmos. Chem., 21, 263-273.

Van Roozendael M, Spurr R, Loyola D, et al. (2012) Sixteen years of GOME/ERS-2 total ozone data: The new direct-fitting GOME Data Processor (GDP) version 5 — Algorithm description. J. Geophys. Res., – Atmosphere, doi:10.1029/2011JD016471.