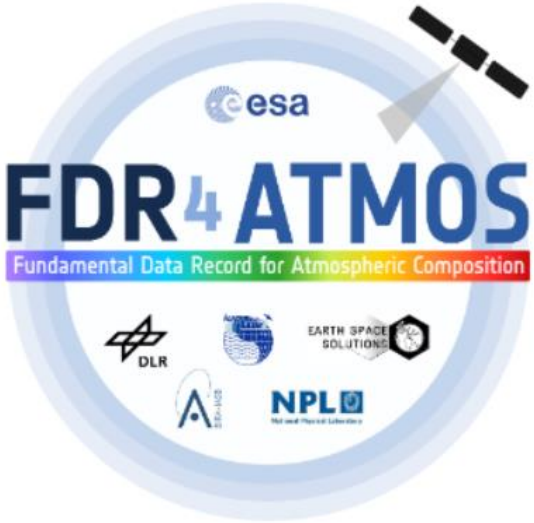


Validation report

SCIAMACHY SGP V7.1 Level-2 Total O_3 Data Product



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Issue	Rev.	Date	Section	Description of Change
1	A	2022/10/28	All	First publication of this document
	B	2022/12/7	Summary and SCIA data sets	Explicit mention of absence of L2 processor changes (as requested after 1st review by ESA).

Executive summary

Over the past few years the SCIAMACHY Quality Working Group and the FDR4ATMOS team have developed updated SCIAMACHY Level-1 and Level-2 processors. This validation report has two objectives. The first is to document the data quality of the SCIAMACHY Level-2 processor SGP V7.1 used for the reprocessing of the total O_3 product for the entire mission (August 2002 to April 2012, about 46000 orbits). The second is to compare the data quality to that of the current, publicly released SGP V6.1 data record. The difference between both Level-2 data versions only stems from the update of the Level-1 used for the retrieval. The paragraphs below and Table 1 give an overview of our main observations and conclusions. The SCIAMACHY total ozone columns were evaluated through extensive comparison to correlative reference observations collected from ground-based instruments in the framework of WMO's Global Atmosphere Watch (GAW) and its contributing networks Network for the Detection of Atmospheric Composition Change NDACC. The reference instruments of choice are the direct-sun Dobson and Brewer instruments, and the zenith-scattered-light (ZSL-DOAS) instruments measuring in the UV-Vis during sunrise and sunset twilight.

Table 1 presents an overview of our observations and conclusion. **Overall, the data quality of SGP 7.1 data is very similar to that of SGP 6.1, with a bias <2% and a comparison spread of the order of 4%. There is little dependence on influence quantities besides a minor underestimation at the highest SZA (-4% at SZA>85°). The long-term drift w.r.t. ground-based data is within 1%/decade. As such, the new processor produces data of equal, if not slightly better quality than its predecessor.** No unexpected changes were found for the overall bias and spread of the comparisons, and their dependence on geophysical parameters (latitude, altitude, season, year, solar zenith angle, cloud fraction…).

Table 1: Overview of the quality of Envisat SCIAMACHY's full-mission SGP V7.1 total O_3 data record, and changes with respect to the previous version SGP V6.1.

	Correlative data sets	Coverage validation	Main conclusions V7.1 data quality	V7.1 changes relative to V6.1
O3 nadir column	• 36 Dobsons • 32 Brewers • 17 NDACC ZSL-DOAS UV-visible spectrometers	Representative global sample.	Bias mostly within +/- 1% and well within +/- 2% over the entire networks, from pole to pole. Spread on the comparisons typically of the order of 4%. Long-term drift well below 1%/decade. A slight dependence of bias on SZA beyond 80° (total ozone underestimation of up to 4%) but no dependence on fractional cloud cover.	No significant change in bias or comparison spread at any latitude. Minor change in long-term drift of +0.5%/decade, representing a net improvement in the Northern hemisphere. No changes in dependence on influence quanities.

Acknowledgements

The validation work presented in this report was funded by the European Space Agency through the ESA Contract 4000128410/19/I-NS. The work relies on the versatile multi-platform validation system Multi-TASTE, its correlative measurement database CORR-2, and its observing systems metrology simulator OSSSMOSE, which all were developed at BIRA-IASB within several ESA and BELSPO/ProDEx heritage projects and refined within the recent EC FP7 project Quality Assurance for Essential Climate Variables (QA4ECV), grant no. 60740. The ground-based reference data used in this publication – Brewer, Dobson, and DOAS UV-visible spectrometers – were obtained as part of WMO's Global Atmosphere Watch (GAW) and one of its main contributors, namely, the Network for the Detection of Atmospheric Composition Change (NDACC). The authors acknowledge the meticulous and sustained work of the PIs and staff at the stations to acquire and maintain long-term data records of high quality.

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I Introduction

This document reports on the ground-based, geophysical validation of the Envisat SCIAMACHY total O_3 column data records reprocessed with the latest version V7.1 of the operational Level-1-to-2 data processor (SGP). The SGP V7.1 data record covering the entire SCIAMACHY mission was evaluated through extensive comparison to well-documented and controlled correlative observations collected from ground-based instruments certified for WMO's Global Atmosphere Watch (GAW) and contributing networks like NDACC (ZSL-DOAS UV-visible spectrometers and Brewer and Dobson UV spectrophotometers). This work was carried out by the Atmospheric Data Synergies group at BIRA-IASB, in the framework of the FDR4ATMOS activities under ESA Contract 4000128410/19/I-NS.

The primary objective of this report is to document the data quality of SGP V7.1 reprocessed data records spanning the full Envisat mission (August 2002 – April 2012). Target audience are users of SGP V7.1 products and the SCIAMACHY Quality Working Group (QWG). Key results of the ground-based validation analyses are incorporated in the Product Quality Readme file associated with the data sets.

Sections II and III give a brief overview of the SCIAMACHY and ground-based reference data sets considered in this report. Section IV presents concise evaluations of the geophysical data quality of this Level-2 data product, differentiated by latitude where sensible and feasible. Specific attention is given to the evolution of SGP V7.1 data relative to the earlier SCIAMACHY SGP V6.1 data processing version.

II SCIAMACHY data sets

The quality of the Level-2 data products retrieved by operational processor SGP V7.1 is the main subject of this report. When possible, the data quality is compared to that of the earlier processor version SGP V6.01/Y. Two full datasets are therefore under consideration in this report:

- SGP V7.1: complete data set, Aug 2002 – Apr 2012, retrieved from IPF 10.0 Level-1 data.
- SGP V6.01/Y: complete data set, Aug 2002 – Apr 2012, retrieved from IPF 8.02/Y Level-1 data.

It is important to note that the different Level-2 data sets were retrieved from different Level-1 data sets but using identical Level-2 processors. Changes in the Level-1 processor may therefore impact Level-2 data quality. The Product Quality Readme file for the SGP V7.1[1] dataset provides information on the retrieval set-up, the product characteristics and some known problems and features of each data product.

Note that ground-based validation of SCIAMACHY ozone column data retrieved at DLR with SGP V3.01 and V5.02 was reported in detail in the Multi-TASTE reports (Hubert et al., 2012; Keppens et al., 2016), which provided estimates of SCIAMACHY uncertainties as well as dependences on solar zenith angle, time, latitude, and cloud parameters.

III Reference data and validation methodology

The SCIAMACHY ozone column data set is compared to correlative observations collected from ground-based Brewer and Dobson UV spectrophotometers and ZSL-DOAS UV-visible spectrometers performing network operation in the framework of WMO's Global Atmosphere Watch (GAW) and its contributing Network for the Detection of Atmospheric Composition Change (NDACC); see Figure 1. The comparison methodology is described in Lambert et al. (1999, 2000), with updates in Balis et al. (2007). Correlative data undergo first quality checks and filtering procedures, e.g., only direct-sun Brewer and Dobson data are considered, and among those obtained by single monochromator instruments, only data at solar elevation higher than 15° are kept to avoid data affected by stray-light and consequently showing an air mass dependent bias.

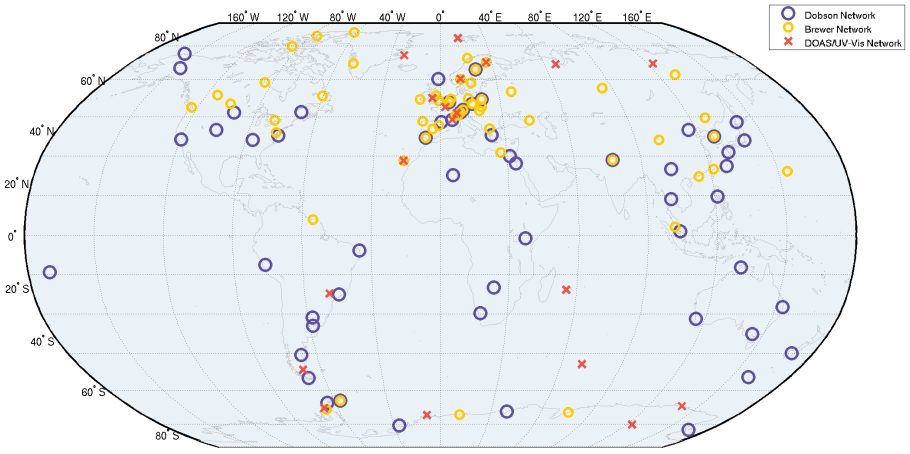


Figure 1: Global distribution of ground-based Brewer and Dobson UV spectrophotometers and ZSL-DOAS UV-visible spectrometers that have provided data for the total ozone column validation presented in this work.

[1] https://earth.esa.int/eogateway/instruments/sciamachy/products-information

Comparison studies like the one reported by Van Roozendael et al. (1998) show that mutual agreement between Dobson, Brewer and UV-visible data can reach the "percent" level when major sources of discrepancy are properly accounted for. For Dobson instruments, temperature dependence of the ozone absorption coefficients used in the retrieval can account for a seasonal variation in the error of ±0.9% in the Alps and ±1.7% at Sodankylä (Finland, 67.4 N), and for systematic errors of up to 4 % (Bernhard et al., 2005). The effect can dramatically increase in extremely cold conditions (winter polar vortex). The effect is smaller for Brewer instruments thanks to their use of wavelength pairs with reduced ozone absorption dependence on the temperature. Unattended Dobson and Brewer instruments might also suffer from long-term drift associated with calibration changes. Assuming that the Dobson and Brewer instruments are well-calibrated regularly, and that data are filtered to avoid air mass dependence, values of 1% on the Brewer and 2% on the Dobson total ozone data can be considered as indicative of their measurement uncertainty.

Zenith-sky DOAS UV-visible spectrometers measure ozone in the Chappuis band, where the use of differential spectroscopy (DOAS) minimizes uncertainties associated with the temperature dependence of the absorption cross-sections (Burkholder and Talukdar, 1994). The uncertainty on the vertical ozone column arises mainly from the air mass factor-based (AMF) calculation used to convert spectrally derived slant ozone columns into vertical ozone columns. Real-time data can be based e.g. on a standard AMF calculated with ozone, pressure and temperature single profiles measured at 60°N in winter and at sea level (SAOZ standard AMF, Sarkissian et al., 1995). Seasonal changes of the ozone profile and scattering geometry are then responsible for a systematic bias of about 5–6 % amplitude at 67 N, falling to 3–4% at 44 N. This is in addition to the ±1% scatter that might result from short-term fluctuations. The use of the standard SAOZ AMF, e.g., also introduces an average meridian dependence of 3% at 67 N to +2.8% at the tropics. In recent years the SAOZ sub-network of the NDACC UV-VIS network has undergone a reprocessing at all stations with the new version 3 of the algorithm, which includes now climatological air mass factors for the conversion of ozone slant column data into ozone vertical column data, plus several other improvements. The use of climatological air mass factors instead of the standard air mass factor changes DOAS/SAOZ total ozone data by at least one percent in the Southern middle latitudes. According to recent work by Hendrick et al. (2011), a total uncertainty of 4.7%, of which a systematic bias lower than 2.5%, can be used as indicative values of the uncertainty of UV-visible total ozone measurements.

Co-location between SCIAMACHY and ground-based observations is defined according to geographical and temporal criteria depending on the type of validation data: for Brewer and Dobson direct sun measurements there is a maximum distance of 300 km between the SCIAMACHY footprint centre and the station and a time difference of maximum 3 hours where possible; for UV-visible DOAS zenith-sky observations at twilight, the footprint of the SCIAMACHY field-of-view must intercept the ground-based air mass estimated with a ray tracing model for the dawn and dusk of the same day.

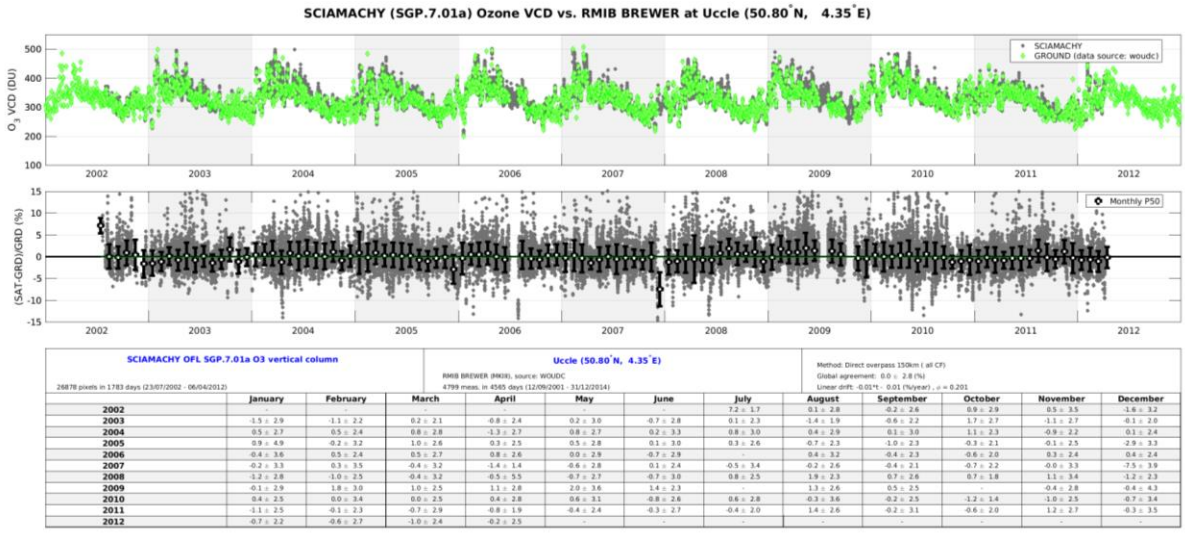
IV Validation results

After a few case studies at individual stations, demonstrating the high quality of both the V6.1 and V7.1 data, network-wide analyses are reported here for:

- the bias, i.e., the mean difference between satellite and ground-based data),
- the comparison spread, i.e., a proxy for more random errors, which also includes the random errors in the ground-based data and some natural variability due to imperfect spatio-temporal co-location,
- the stability as estimated using a linear regression on the differences between satellite and ground-based data, and
- the dependence of the bias and comparison spread on two key influence quantities, known to be critical elements in the retrieval of total ozone: solar zenith angle and cloud fraction.

IV.1 Illustrative examples

As illustrations, Figure 2 and Figure 3 provide detailed information on the comparison between SCIAMACHY total ozone column measurements and the corresponding observations with Brewers at Uccle, Belgium, and Hohenpeissenberg, Germany, respectively. They demonstrate the small bias (well below 1%) and comparison spread (<3-4%) for most months at these sites with well-calibrated Brewer instruments. Figure 3 also demonstrates the very small differences between V6.1 and V7.1.



	January	February	March	April	May	June	July	August	September	October	November	December
2002	-	-	-	-	-	-	7.2 ± 1.7	0.1 ± 2.8	-0.2 ± 2.6	0.9 ± 2.9	0.5 ± 3.5	-1.6 ± 3.2
2003	-1.5 ± 2.9	-1.1 ± 2.2	0.2 ± 2.1	-0.8 ± 2.4	0.2 ± 3.0	-0.7 ± 2.8	0.1 ± 2.3	-1.4 ± 1.9	-0.6 ± 2.2	1.7 ± 2.7	-1.1 ± 2.7	-0.1 ± 2.0
2004	0.5 ± 2.7	0.5 ± 2.4	0.8 ± 2.8	-1.3 ± 2.7	0.8 ± 2.7	0.2 ± 3.3	0.8 ± 3.0	0.4 ± 2.9	0.1 ± 3.0	1.1 ± 2.3	-0.9 ± 2.2	0.1 ± 2.4
2005	0.9 ± 4.9	-0.2 ± 3.2	1.0 ± 2.6	0.3 ± 2.5	0.5 ± 2.8	0.1 ± 3.0	0.3 ± 2.6	-0.7 ± 2.3	-1.0 ± 2.3	-0.3 ± 2.1	-0.1 ± 2.5	-2.9 ± 3.3
2006	0.4 ± 3.6	0.5 ± 2.4	0.5 ± 2.7	0.8 ± 2.6	0.0 ± 2.9	-0.7 ± 2.9	-	0.4 ± 3.2	-0.4 ± 2.3	-0.6 ± 2.0	0.3 ± 2.4	0.4 ± 2.4
2007	-0.2 ± 3.3	0.3 ± 3.5	-0.4 ± 3.2	-1.4 ± 1.4	-0.6 ± 2.8	0.1 ± 2.4	-0.5 ± 3.4	-0.2 ± 2.6	-0.4 ± 2.1	-0.7 ± 2.2	-0.0 ± 3.3	-7.5 ± 3.9
2008	-1.2 ± 2.8	-1.0 ± 2.5	-0.4 ± 3.2	-0.5 ± 5.5	-0.7 ± 2.7	-0.7 ± 3.0	0.8 ± 2.5	1.9 ± 2.3	0.7 ± 2.6	0.7 ± 1.8	1.1 ± 3.4	-1.2 ± 2.3
2009	-0.1 ± 2.9	1.8 ± 3.0	1.0 ± 2.5	1.1 ± 2.8	2.0 ± 3.6	1.4 ± 2.3	-	1.3 ± 2.6	0.5 ± 2.5	-	-0.4 ± 2.8	-0.4 ± 4.3
2010	0.4 ± 2.5	0.0 ± 3.4	0.6 ± 2.5	0.4 ± 2.8	0.6 ± 3.1	-0.8 ± 2.6	0.6 ± 2.8	-0.3 ± 3.6	-0.2 ± 2.5	-1.2 ± 3.4	-1.0 ± 2.5	-0.7 ± 3.4
2011	-1.1 ± 2.5	-0.1 ± 2.3	-0.7 ± 2.9	-0.8 ± 1.9	-0.4 ± 2.4	-0.3 ± 2.7	-0.4 ± 2.0	1.4 ± 2.6	-0.2 ± 3.1	-0.6 ± 2.0	1.2 ± 2.7	-0.3 ± 3.5
2012	-0.7 ± 2.2	-0.6 ± 2.7	-1.0 ± 2.4	-0.2 ± 2.5	-	-	-	-	-	-	-	-

Figure 2: Comparison between SCIAMACHY V7.1 total ozone vertical column density (VCD) and the corresponding measurements made with the Brewer at Uccle, Belgium. Top panel shows the time series of both the satellite (black) and ground-based (green) measurements. The middle panel contains the corresponding relative differences. The bottom panel contains summarizing numbers: bias and comparison spread for each month of the mission and a linear drift estimate (top-right box).

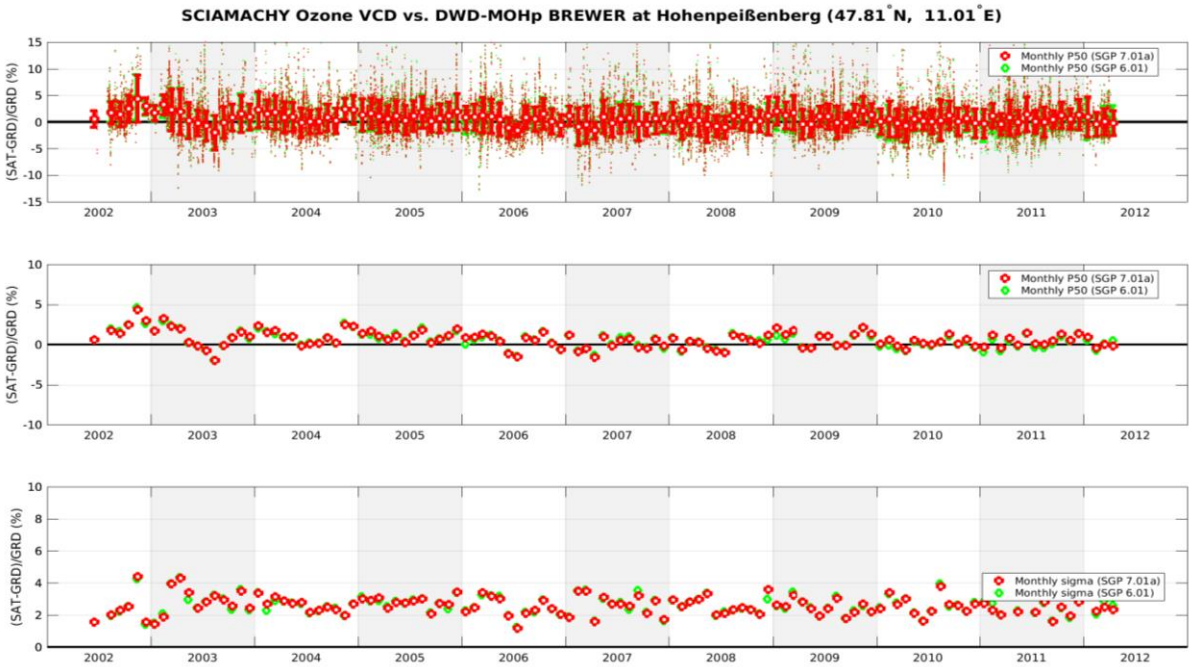


Figure 3: Comparative analysis between SCIAMACHY V7.1 (red) and V6.1 (green) at Hohenpeissenberg, Germany. Top panel contains the relative differences w.r.t. the Brewer at Hohenpeissenberg, both for individual days (dots) and per month (circles with error bars). The middle panel contains only the monthly median differences, the bottom panel the spread on the differences within each month.

IV.2 Network results: Bias and comparison spread

Figure 4 summarizes the per-station results in pole-to-pole graphs per type of ground-based instrument. For the better part of the Dobson and Brewer networks, biases are below 1-2%, with no significant dependence on latitude and no discernible difference between V6.1 and V7.1. Outliers can in general be related to issues with the ground-based instruments, e.g., the unexpectedly large negative mean difference (-4.2%) in the comparisons to the Brewer at New Delhi (28.65°N) comes from a poorly sampled time series and is not confirmed by the Dobson also located in New Delhi. The comparisons to ZSL-DOAS measurements lead to somewhat larger mean differences at several sites, but one must keep in mind the more difficult co-location, both in space and in time due to the ZSL-DOAS measurements being obtained in twilight. The comparison spread is typically of the order of 4%, a number which is to be considered an upper limit for the uncertainty in the SCIAMACHY data as it also includes measurement uncertainty from the ground-based data and atmospheric variability through co-location mismatch (Verhoelst et al., 2015).

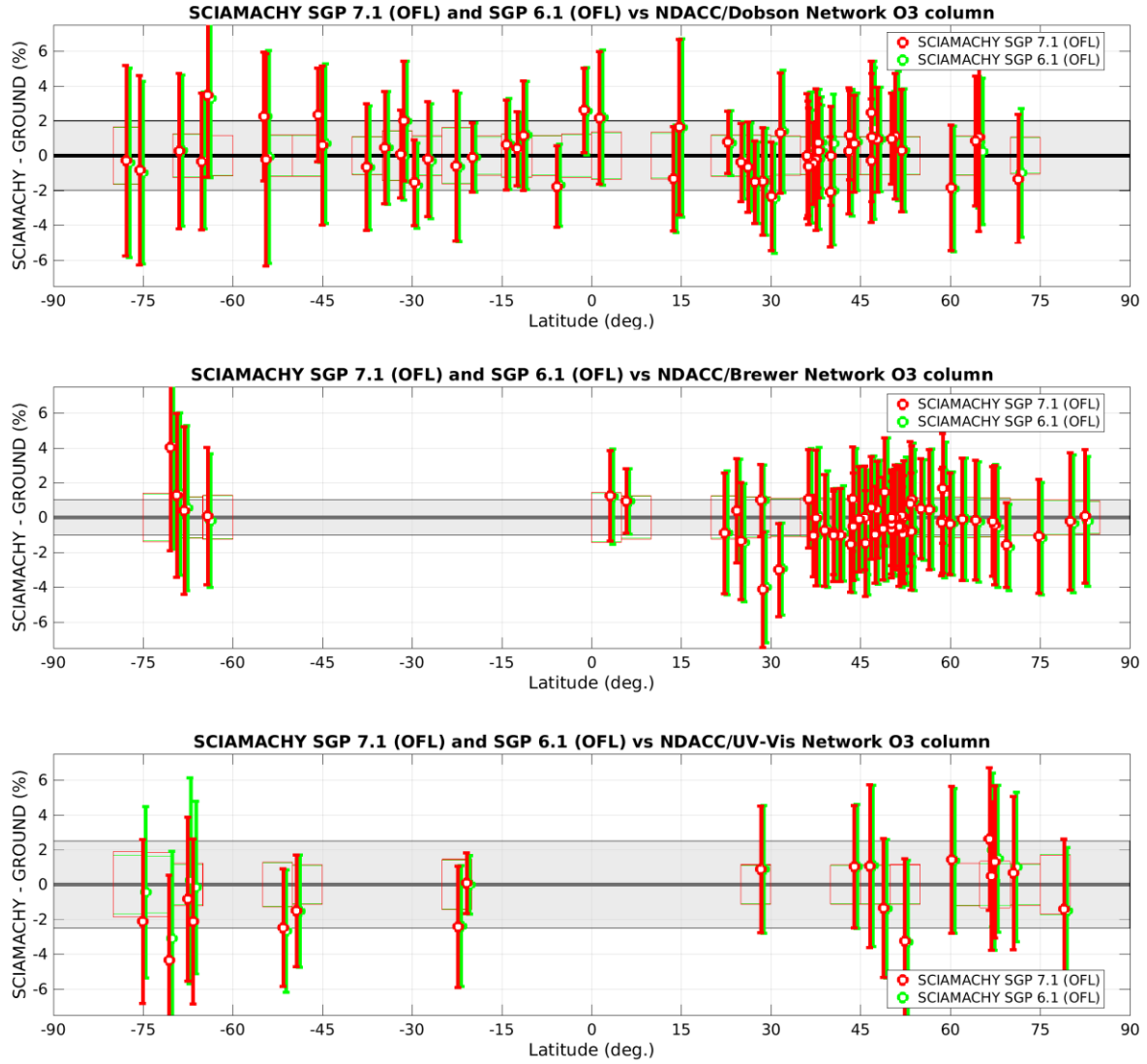


Figure 4: 10-year mean value (bullet) and 1σ spread (error bar) of the percent relative difference between SCIAMACHY SGP data and ground-based network total ozone data, as a function of latitude. SGP 6.1 results are depicted in green and new SGP 7.1 results in red. Upper graph: SGP vs. Dobson network; middle graph: SGP vs. Brewer network; lower graph: SGP vs. ZSL-DOAS UV-visible network. The shaded area represents the indicative

uncertainty (1 sigma) of2%, 1% and 2.5% on the Dobson, Brewer and ZSL-DOAS ozone column measurement, respectively. Green and red square contours represent the median value of the uncertainty on SCIAMACHY total ozone data as reported in SGP 6. 1 (green) and 7.1 (red) data files, respectively, though these are virtually identical and thus impossible to differentiate in the graph.

IV.3 Network results: Long-term stability

For the earlier version SGP 3.01, a negative drift in SCIAMACHY ozone column values was noticed at numerous but not all stations, resulting from a transitory decrease in total ozone values in the first couple of years of the mission, followed by a more stable behaviour after 2004. The introduction of a degradation correction for the Level-1 data fed to SGP 5.02 reduced this negative drift in the latter part of the mission. As further improvements have since been implemented in the SCIAMACHY Level-1 data, also improvements in both the SGP 6.1 and SGP 7.1 data sets can be expected. In Figure 5 we show the long-term evolution of the relative difference between SCIAMACHY and Northern hemisphere Brewer data. A regression analysis was performed for the period 2005-2011 on the time series of the difference using a purely linear model and accounting for the autocorrelation in the fit residuals in the calculation of the confidence interval. Both V6.1 and V7.1 show a small (negative) drift of less than 1%/decade, with V7.1 (-0.3%/decade) apparently performing somewhat better, though in fact neither V7.1 nor V6.1 exhibit a drift that is significant at the 2-sigma levelFigure 6 shows similar results but the Southern hemisphere Dobson network (which has much better coverage in the Southern hemisphere than the Brewer network). It exhibits the known seasonality of about ±2.5% expected from the temperature dependence of the ozone absorption coefficients, but as the regression uses 7 years of comparisons, its impact is negligible. Neither for V6.1 nor for V7.1 do we detect a significant drift at the 2%/decade level. Differentiating the analysis per station for the Dobson network (Figure 7) shows some stations with larger values for the drift estimates, but perusal of the time series at these sites reveals poor temporal coverage and perhaps questionable calibration of the ground-based data. That is in particular the case for several tropical sites just below the equator.

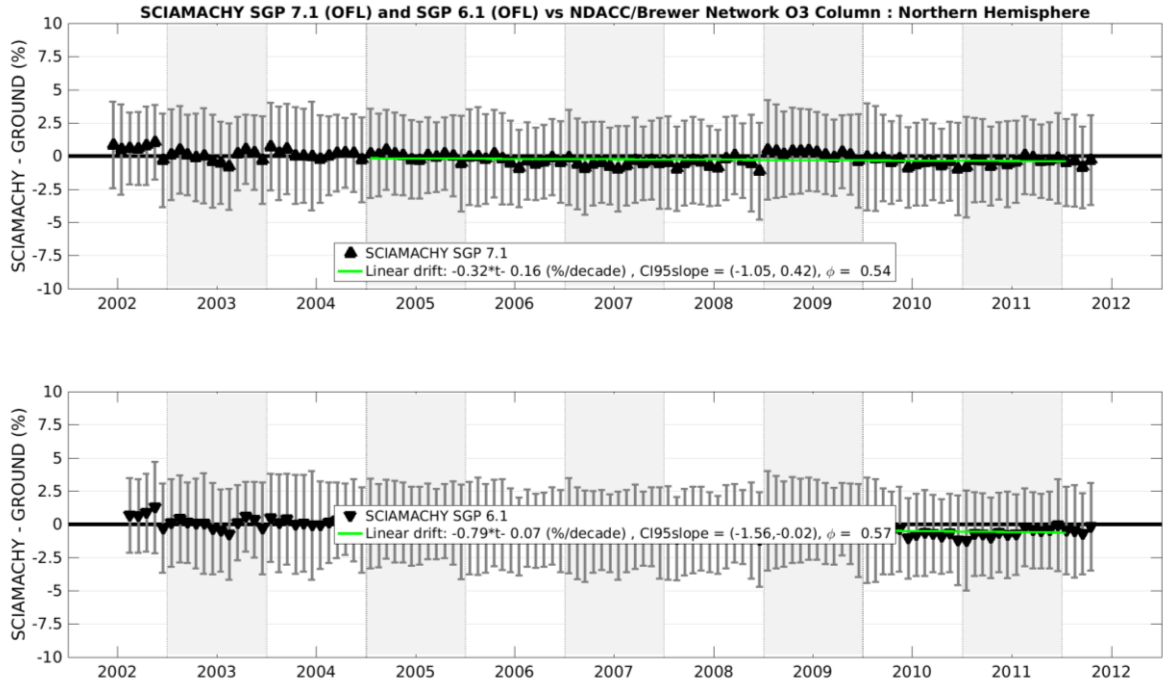


Figure 5: 10-year time series of the monthly mean value (triangle) and 1σ spread (error bar) of the percent relative difference between SCIAMACHY SGP and Brewer network total ozone data averaged in the Northern hemisphere. For clarity, SGP 7.1 results are depicted separately in upper graph and SGP 6.1 results in the lower graph.

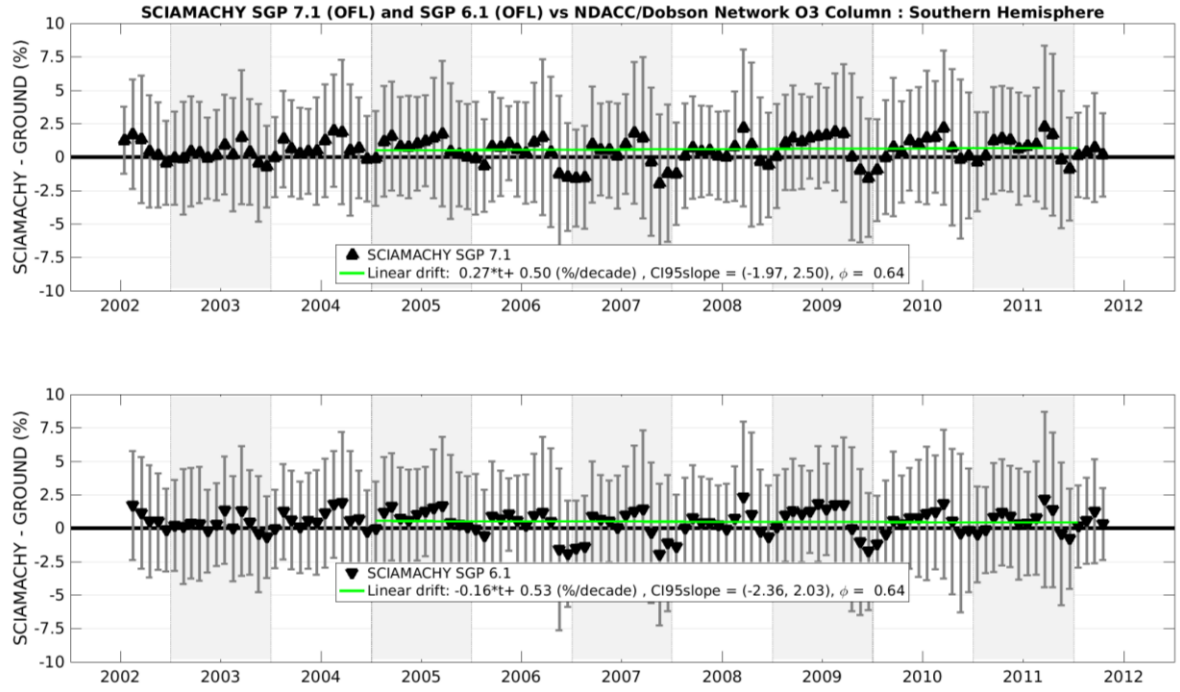


Figure 6: Same as Figure 5 but for the Southern hemisphere Dobson network.

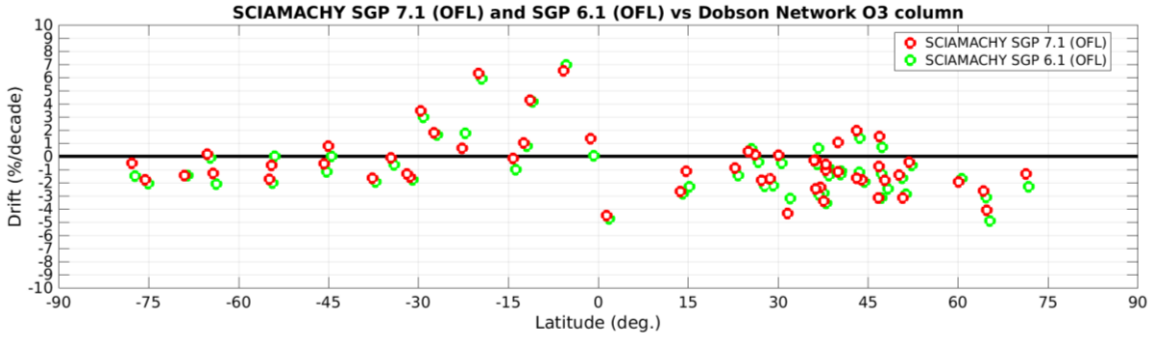


Figure 7: Drift in the SCIAMACHY total ozone column data as derived from a linear regression to the relative differences between SCIAMACHY SGP data and Dobson ground-based network total ozone data, as a function of latitude. SGP 6.1 results are depicted in green and new SGP 7.1 results in red.

IV.4 Network results: Dependence on influence quantities

A permanent caveat for the application of single-wavelength-AMF DOAS in the 325-335 nm spectral range, thus within an optically thick atmosphere due to strong ozone absorptions, is the dependence of the retrieved ozone value on the solar zenith angle (SZA) associated with the measurement. This dependence usually shows up in the form of an artificial decrease of ozone values at large SZA (typically beyond 80°). Figure 8 shows this to be the case to a small extent, with SCIAMACHY underestimating the ground-based columns by up to 4% at the highest SZA (>85°) at mid and high latitudes. No difference can be observed between V7.1 and V6.1.

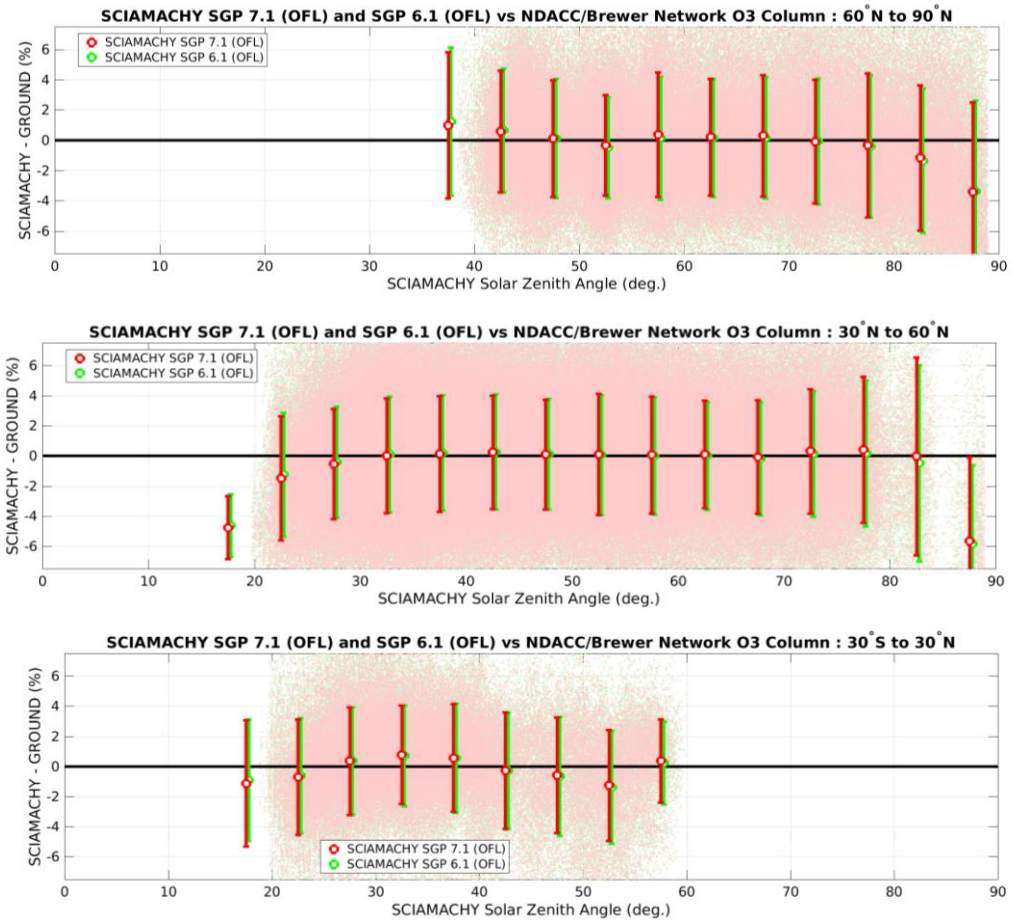


Figure 8: Percent relative difference between SCIAMACHY SGP datasets and ground-based network total ozone data, as a function of the SCIAMACHY Solar Zenith Angle for three latitude bands: Northern high latitudes (top panel), Northern mid latitudes (middle panel) and (sub-)tropical latitudes (bottom panel).

Clouds are also an important source of uncertainty in total ozone retrievals from nadir measurements. The SGP data files contain the fractional cloud cover over the SCIAMACHY ground pixel, the cloud top pressure, and the cloud optical depth. Figure 9 demonstrates that in fact, neither V6.1 nor V7.1 show any significant dependence of the bias or comparison spread on the cloud fraction. Again, no difference between V6.1 and V7.1 can be observed.

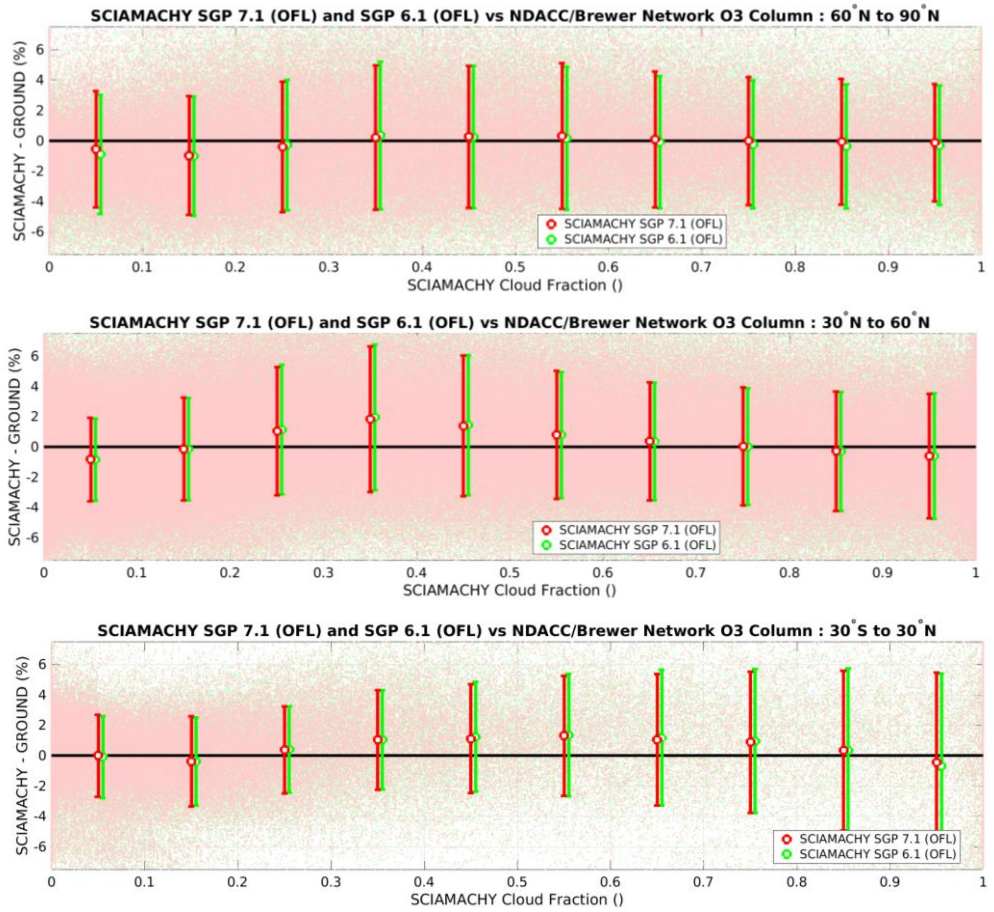


Figure 9: Percent relative difference between SCIAMACHY SGP datasets and ground-based network total ozone data, as a function of SCIAMACHY Cloud Fraction for three latitude bands: Northern high latitudes (top panel), Northern mid latitudes (middle panel) and (sub-)tropical latitudes (bottom panel).

V Summary and conclusions

Table 2 summarizes the findings of the validation study on the SCIAMACHY SGP V7.1 total ozone columns. While V7.1 represents the best SCIAMACHY total ozone column processing available in terms of bias, comparison spread, long-term stability, and dependence on influence quantities, differences with the previous SGP V6.1 are actually negligible bar perhaps some slight (but statistically not significant) improvement in the long-term stability.

Table 2: Summary table of the nadir vertical ozone column validation results.

SGP 7.1	
Bias	Below 2% at virtually all sites with direct-sun instruments. Largely below 1% for the comparisons to Brewers. Almost identical to SGP V6.1.
Spread	Typically 3-4%. No changes w.r.t. to SGP V6.1. This spread contains a combination of random measurement uncertainties and atmospheric noise (irreducible co-location mismatch uncertainties). Virtually no seasonal effects in the Brewer comparisons.
Drift	No statistically significant drift at the 1%/decade level in the Northern hemisphere, and no significant drift at the 2%/decade level in the Southern hemisphere. Actual drift numbers below 0.5%/decade at the global level but with significant station-to-station scatter (to some extent due to poor temporal coverage by the ground-based instrument at several sites).
Other	Minor dependence of bias on Solar Zenith Angle beyond 80°-85° (total ozone underestimation of up to 4%). No significant dependence on fractional cloud cover.

VI References

Balis, D., J.-C. Lambert, M. Van Roozendael, R. Spurr, D. Loyola, Y. Livschitz, P. Valks, V. Amiridis, P. Gerard, J. Granville, C. Zehner, 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, 2007.

Burkholder, J., and Talukdar, R., Temperature dependence of the ozone absorption spectrum over the wavelength range 410 to 760 nm, Geophysical Research Letters, v21, issue 7, 1994.

De Mazière, M., A. M. Thompson, M. J. Kurylo, J. Wild, G. Bernhard, T. Blumenstock, J. W. Hannigan, J.-C. Lambert, T. Leblanc, T. J. McGee, G. Nedoluha, I. Petropavlovskikh, G. Seckmeyer, P. C. Simon, W. Steinbrecht, S. Strahan, and J. T. Sullivan, *The Network for the Detection of Atmospheric Composition Change (NDACC): History, status and perspectives*, Atmos. Chem. Phys., Vol. 18, 4935-4964, https://doi.org/10.5194/acp-18-4935-2018, 2018.

Hendrick, F.; Pommereau, J.-P.; Goutail, F.; Evans, R. D.; Ionov, D.; Pazmino, A.; Kyrö, E.; Held, G.; Eriksen, P.; Dorokhov, V.; Gil, M. & Van Roozendael, M. NDACC/SAOZ UV-visible total ozone measurements: improved retrieval and comparison with correlative ground-based and satellite observations Atmos. Chem. Phys., 11, 5975-5995, 2011

Hubert, D., N. Kalb, J.-C. Lambert et al.: *Multi-TASTE: Technical Assistance to Multi-mission Validation by Sounders, Spectrometers and Radiometers*, TN-BIRA-IASB-MultiTASTE-FR, Multi-TASTE Final Report / October 2008 – October 2011, 157 pp., http://earth.eo.esa.int/pcs/envisat/calval_res/2012/TN-BIRA-IASB-MultiTASTE-FR-iss1revC-Oct2012.pdf, 8 October 2012.

Keppens, A., Hubert, D., Granville, J., Hendrick, F. and Lambert, J.-C.: Validation Report : SCIAMACHY SGP 6.01 Level-2 Data Products O3, NO2, CO, CH4, BrO and H2O, TN-BIRA-IASB-MultiTASTE-Phase-F-SCIA-SGP6-Iss1-RevB, Issue 1 / Rev. B, 53pp., https://earth.esa.int/documents/700255/2683862/TN-BIRA-IASB-MultiTASTE-Phase-F-SCIA-SGP6-Iss1-RevB.pdf/582bd039-5bf6-45a0-9199-dab307a0cbf2, 21 December 2016.

Lambert, J.-C., M. Van Roozendael, M. De Mazière, P.C. Simon, J.-P. Pommereau, F. Goutail, A. Sarkissian, and J.F. Gleason, *Investigation of pole-to-pole performances of spaceborne atmospheric chemistry sensors with the NDSC*, Journal of the Atmospheric Sciences, Vol. 56, pp. 176-193, 1999.

Lambert, J.-C., C. De Clercq, and T. von Clarmann, *Comparing and merging water vapour observations: A multi-dimensional perspective on smoothing and sampling issues*, Chapter 9 (p. 177-199) of book "Monitoring Atmospheric Water Vapour: Ground-Based Remote Sensing and In-situ Methods", N. Kämpfer (Ed.), ISSI Scientific Report Series, Vol. 10, Edition 1, 326 p., ISBN: 978-1-4614-3908-0, DOI 10.1007/978-1-4614-3909-7_2, © Springer New York 2012.

Loew, A., W. Bell, L. Brocca, C. E. Bulgin, J. Burdanowitz, X. Calbet, R. V. Donner, D. Ghent, A. Gruber, T. Kaminski,J. Kinzel, C. Klepp, J.-C. Lambert, G. Schaepman-Strub, M. Schröder, and T. Verhoelst, *Validation practices for satellite based earth observation data across communities*, Rev. Geophys., DOI: 10.1002/2017RG000562, 2017.

Sarkissian, A., H. K. Roscoe, D. Fish, M. Van Roozendael, M. Gil, H. B. Chen, P. Wang, J.-P. Pommereau, J. Lenoble, Ozone and NO2 air-mass factors for zenith-sky spectrometers: Intercomparison of calculations with different radiative transfer models, Geophysical Research Letters, v22, issue 9, 1995.

SCIAMACHY Quality Working Group: *Product Quality README file for SCIAMACHY Level 2 version 6.01 dataset*, ENVI-GSOP-EOGD-QD-16-0132, issue 1.0, available at https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/sciamachy/products-and-algorithms/products-information, 2016.

Verhoelst, T., F. Hendrick, U. Köhler, C. Lerot, J.-P. Pommereau, A. Redondas, M. Van Roozendael, and J.-C. Lambert, *Metrology of ground-based satellite validation: co-location mismatch and smoothing issues of total ozone comparisons*, Atmos. Meas. Tech., 8, 5039-5062, doi:10.5194/amt-8-5039-2015, 2015.

VII Acronyms and abbreviations

BIRA-IASB	Belgisch Instituut voor Ruimte-Aëronomie / Institut d'aéronomie spatiale de Belgique (Belgian Institute for Space Aeronomy)
CF	Cloud Fraction
DDS	Diagnostic Data Set
DHF	NDACC Data Host Facility
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DOAS	Differential Optical Absorption Spectroscopy
Envisat	ESA's Environmental Satellite
ESA	European Space Agency / Agence spatiale européenne
GAW	WMO's Global Atmospheric Watch
KNMI	Koninklijk Nederlands Meteorologisch Instituut
Multi-TASTE	Technical Assistance to Multi-mission Validation by Sounders, Spectrometers and Radiometers
NDACC	Network for the Detection of Atmospheric Composition Change (formerly NDSC)
QWG	Quality Working Group
SAOZ	Système d'Analyse par Observation Zénithale
SCIAMACHY	Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY
SGP	SCIAMACHY Ground Processor
SZA	Solar Zenith Angle
TASTE	Technical Assistance to Envisat validation by Soundings, Spectrometers and Radiometers
UV	Ultra Violet
UV-VIS	Ultra Violet - Visible
VCD	Vertical Column Density
WMO	World Meteorological Organization