O3M SAF ORR VALIDATION REPORT

Validated products:

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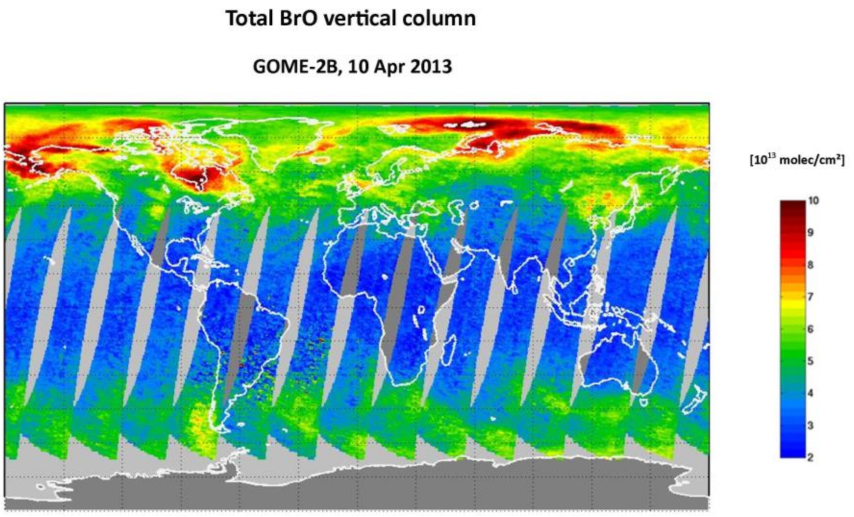
O3M-82	Offline Total BrO, GOME-2/Metop-B	OTO/BrO



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Interim verification report of GOME-2 GDP 4.7 BrO column data for MetOp-B Operational Readiness Review

CONTENTS

ACRONYMS AND ABBREVIATIONS

AMF	Air Mass Factor, or optical enhancement factor
BIRA	Belgisch Instituut voor Ruimte-Aëronomie
BrO	Bromine monoxide
CAO	Central Aerological Observatory
CNRS/LATMOS	Laboratoire Atmosphère, Milieux, Observations Spatiales du CNRS
DLR	German Aerospace Centre
DMI	Danish Meteorological Institute
DOAS	Differential Optical Absorption Spectroscopy
D-PAF	German Processing and Archiving Facility
Envisat	Environmental Satellite
ERS-2	European Remote Sensing Satellite -2
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FMI-ARC	Finnish Meteorological Institute – Arctic Research Centre
GAW	WMO’s Global Atmospheric Watch programme
GDOAS/SDOAS	GOME/SCIAMACHY WinDOAS prototype processor
GDP	GOME Data Processor
GOME	Global Ozone Monitoring Experiment
GOME-2A	Second Global Ozone Monitoring Experiment (MetOp-A)
GOME-2B	Second Global Ozone Monitoring Experiment (MetOp-B)
GVC	Ghost Vertical Column
H_2O	water vapour
IASB	Institut d’Aéronomie Spatiale de Belgique
IFE/IUP	Institut für Fernerkundung/Institut für Umweltphysik
IMF	Remote Sensing Technology Institute
INTA	Instituto Nacional de Técnica Aeroespacial
KSNU	Kyrgyzstan State National University
LOS	Line Of Sight
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
NDACC	Network for the Detection of Atmospheric Composition Change
NDSC	Network for the Detection of Stratospheric Change
NIWA	National Institute for Water and Atmospheric research
BRO	nitrogen dioxide
O_3	ozone
O3M-SAF	Ozone and Atmospheric Chemistry Monitoring Satellite Application Facility
OCRA	Optical Cloud Recognition Algorithm
OMI	Ozone Monitoring Instrument
ROCINN	Retrieval of Cloud Information using Neural Networks
RRS	Rotational Raman Scattering
RTS	RT Solutions Inc.
SAOZ	Système d’Analyse par Observation Zénithale
SCD	Slant Column Density
SCIAMACHY	Scanning Imaging Absorption spectroMeter for Atmospheric CHartography
SNR	Signal to Noise Ratio
SZA	Solar Zenith Angle
TEMIS	Tropospheric Emission Monitoring Internet Service
UNESP	Universidade Estadual Paulista
UPAS	Universal Processor for UV/VIS Atmospheric Spectrometers
UVVIS	ground-based DOAS ultraviolet-visible spectrometer

VCD	Vertical Column Density

DATA DISCLAIMER FOR THE METOP-B GOME-2 TOTAL BRO (NTO/OTO) DATA PRODUCTS

In the framework of EUMETSAT's Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF), GOME-2 bromine oxide (BrO) total column data products, as well as associated cloud parameters, are delivered operationally off-line (OTO). Those data products are generated at DLR from MetOp-B GOME-2 measurements using the UPAS environment version 1.3.9, the level-0-to-1 v5. processor and the level-1-to-2 GDP v4.7 DOAS retrieval processor (see ATBD, Valks et al., 2013 and PUM, Valks et al., 2013). BIRA-IASB ensures detailed quality assessment of algorithm upgrades and continuous monitoring of GOME-2 BrO data quality with a recurring geophysical validation using correlative measurements from the NDACC ground-based network and from other satellites, modelling support, and independent retrievals.

This present the initial validation of MetOp-B GOME-2 BrO column data (OTO) recorded over December 2012 through April 2013. Total BrO column data are compared to similar Envisat SCIAMACHY and MetOp-A GOME-2 results, and to ground-based columns retrieved from Zenith-Sky measurements at the Harestua station.

The main results are summarized hereafter:

- The current quality of the MetOp-B GOME-2 radiance and irradiance spectra (level-1b data version 5.3) in the 332-359 nm spectral window enables stable DOAS retrievals. Resulting BrO slant columns and DOAS fit residuals are comparable to those obtained from Metop-A spectra at the beginning of operations.
- GOME-2 GDP 4.7 total BrO column retrievals are found consistent with independent retrievals from SCIAMACHY, GOME-2A and ground-based observations at Harestua, Norway. In most cases the optimal accuracy of 15% agreement is reached.

A. INTRODUCTION

A.1. Scope of this document

The present document reports on the verification and validation of MetOp-B GOME-2 BrO total column data over the Dec. 2012 – Apr. 2013 time period, produced by the GOME Data Processor (GDP) version 4.7 operated at DLR on behalf of EUMETSAT. This report includes verification work performed using the BIRA-IASB scientific retrieval tool (Theys et al., 2011) synchronized on the GDP settings, as well as comparisons with SCIAMACHY, GOME-2A and ground-based measurements. The aim is to investigate the consistency of the GOME-2B BrO total columns and whether the GOME-2B BrO product fulfill the user requirements in terms of accuracy (Threshold accuracy: 50%; Target accuracy: 30%; Optimal: 15%), as stated in the O3MSAF Service Specification Document (http://o3msaf.fmi.fi/docs/O3M_SAF_Service_Specification.pdf).

A.2. Preliminary remarks

BrO total columns as generated from GDP version 4.7 represent a new GOME-2 product, generated within the GDP operational environment system at DLR.

The aim of the present document is first to report on the status of the verification of the MetOp-B GOME-2 BrO column against a synchronized scientific algorithm available at BIRA (Theys et al., 2011). For this exercise, BrO retrieval settings selected by DLR scientists for GDP version 4.7 are being used. The consistency of this BrO product is then explored by performing various comparisons with existing correlative data sets, including scientific data sets from SCIAMACHY and GOME-2A. Ground-based BrO column measurements available for the stations at Harestua in Norway are also used in an attempt to further document the geophysical consistency of the GOME-2 BrO product.

It should be noted here that improvements have been made in the BrO column retrieval for both the satellite instruments GOME-2 and SCIAMACHY and for the ground-based DOAS instruments, to resolve the apparent inconsistencies in the GOME-2 retrievals reported in the previous validation report (Van Roozendael et al., 2008a). The algorithm improvements for the satellite and ground-based DOAS instruments are described in this document.

Reported validation studies were carried out at the Belgian Institute for Space Aeronomy (IASB-BIRA, Brussels, Belgium) and at DLR Remote Sensing Technology Institute (DLR-IMF, Oberpfaffenhofen, Germany) in the framework of EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF)

A.3. Plan of this document

This document is divided in four main parts, addressing respectively the description of the retrieval settings applied for the BrO product, the verification of this product, comparisons against satellite data and comparisons against ground-based measurements at Harestua. This is followed by concluding remarks and perspectives for future work.

B. DATA DESCRIPTION

B.1. Total BrO columns retrieval

In a previous validation report for GOME-2A (O3-SAF Validation Report, 2009), we evaluated an initial data set generated for the years 2007 and 2008. The outcome of this validation study was that, although the product fulfilled some of the user requirements in terms of accuracy, the quality of the GOME-2 product was deceiving. Indeed, the general seasonal variations of the BrO column amount were not physical. In addition, though the mean vertical column levels were generally acceptable for 2007-2008, the effect of the instrumental degradation on the results for the years 2009 and 2010 was very high, leading to a strong overestimation of the total column for this period. For these reasons, improved retrieval settings have been implemented (see below) for GOME-2 A and GOME-2B, which we now consider for evaluation. The new BrO DOAS settings have been developed (see details in Theys et al., 2011) with the objective to stabilize the fit as much as possible. An important difference with respect to past settings relies in the choice of the fitting window which has been extended towards shorter wavelengths (332-359 nm instead of 336-351 nm) in order to cover five BrO absorption bands. While the BrO values retrieved using both fitting windows are consistent above regions of enhanced tropospheric BrO precursors emissions, the use of this extended wavelength interval leads to an overall reduction of the noise of the slant columns and allows minimizing the impact of several well-known artefacts: a spurious slant column viewing angle dependence, the presence in the measurement maps of cloud structures due to imperfect correction of the Ring effect and a strong interference with formaldehyde absorption over regions heavily polluted or affected by biomass burning or biogenic emission. The impact of changing from one window to another can be of $1\text{-}2 \times 10^{13}$ molec/cm² on the columns outside of the hotspots regions. Moreover, the results show reasonable seasonal variations at all latitudes and are also much less affected by the degradation of the instrument than past results. In addition to the settings presented in Theys et al. (2011), an equatorial offset correction is applied to the data (Richter et al., 2002). The latter correction enables to correct – to some extent –the effect of the instrumental degradation (see next sections) on the total BrO column data time series. It consists of a daily correction: the averaged BrO slant column in the tropical latitudinal band of ±5° is calculated and subtracted to all slant columns and an equatorial slant column offset of 7.5×10^{13} molec/cm² is added. The algorithm has been implemented in the operational GDP 4.7 for both GOME-2A and GOME-2B (ATBD, 2012).

As a side note, we have also consistently applied this equatorial correction to SCIAMACHY data (used as correlative data set in this report). Applying this equatorial correction to SCIAMACHY BrO data, no sign of zonal vertical column trend is visible anywhere.

The detailed DOAS settings used for GOME-2 BrO slant columns retrieval are given in Table1.

Table 1. DOAS settings used for GOME-2 BrO slant column verification

Fitting interval	332 – 359 nm
Sun reference	Sun irradiance from file
Wavelength calibration	Wavelength calibration of sun reference optimized by NLLS adjustment on convolved Chance and Spurr solar lines atlas
Absorption cross-sections	
- BrO	Fleischmann et al., 223°K
- NO_2	GOME FM3, 243°K
- Ozone	Brion et al. 1998, convolved at GOME-2 resolution, 218°K + 243°K

	Two pseudo-cross-sections accounting for non-linearity of O3absorption (Pukite et al., 2010)
- H_2CO	Meller et al. 2000 at 297K
- OClO	Bogumil et al., 2003 at 293K
- Ring effect	2 Ring eigenvectors generated using SCIATRAN
- Polarization	GOME-2 FM-203 Calibration Key Data, Eta and Zeta
Polynomial	5^{rd} order (6 parameters)
Intensity offset correction	Constant +slope

In order to convert the retrieved BrO slant columns into vertical columns, Air Mass Factors (AMF) are calculated for each pixel. The AMFs are generated with the LIDORT 3.3 radiative transfer model in the GDP 4.7 environment, using pure stratospheric BrO profiles.

Figure 1 presents an example of GOME-2B BrO results for one day in April 2013.

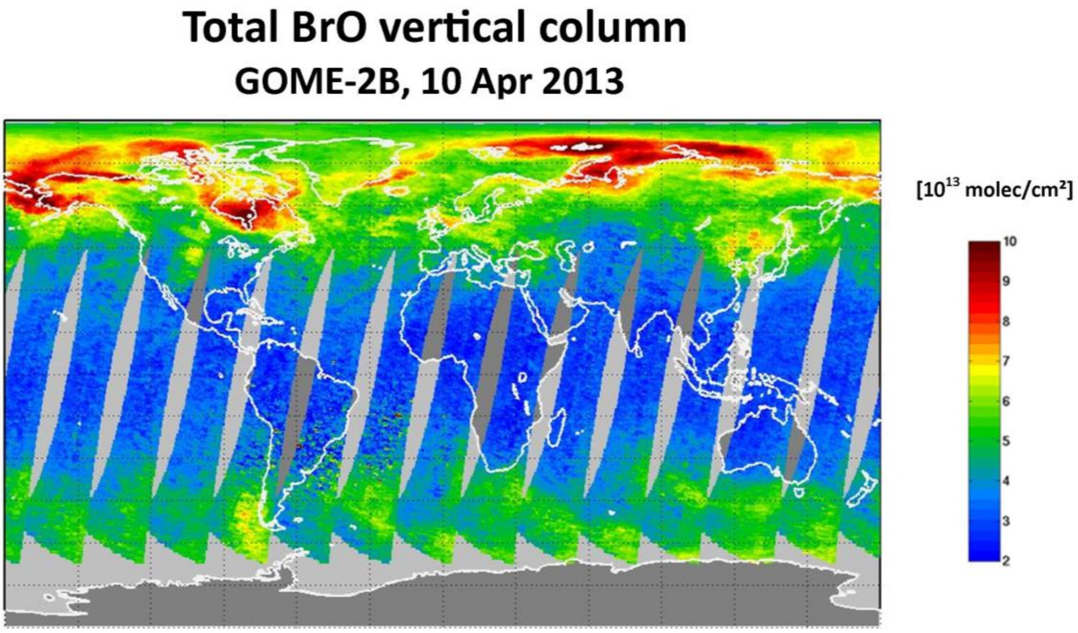


Figure 1. BrO vertical columns derived from GOME-2B nadir radiances for 10^{th} April 2013 (using the baseline settings given in Table 1). Only data corresponding to solar zenith angles lower than 80° are shown.

B.2. Validation data sets

Before presenting any results, it is important to note that the validation of the GOME-2B total BrO column product is difficult because of 1) the scarcity of correlative ground-based measurements and 2) limited quality satellite data sets. The following datasets can be used:

- SCIAMACHY/ENVISAT total BrO columns (De Smedt et al., 2004; Afe et al., 2004; Theys et al., 2011) proved to be of very good quality even a decade long after launch but unfortunately the data record ends on the 8^{th} of April 2012 (after the loss of contact with ENVISAT). Hence SCIAMACHY cannot be used properly to validate GOME-2B total BrO columns. Nevertheless, for the purpose of this study, we have averaged 5 years of SCIAMACHY data (2007-2011) to investigate whether the observed latitudinal-time variations of GOME-2 BrO total columns were geophysically coherent or not.

- GOME-2A is operating in parallel to GOME-2B and can (in principle) be used to validate /verify the total BrO columns. However, GOME-2A suffers for many years of a strong instrumental degradation affecting the quality of the total BrO column product. This is illustrated in Figure 2 showing the increase in fitting residuals and slant column errors (averaged over the equatorial pacific) as a function of time.

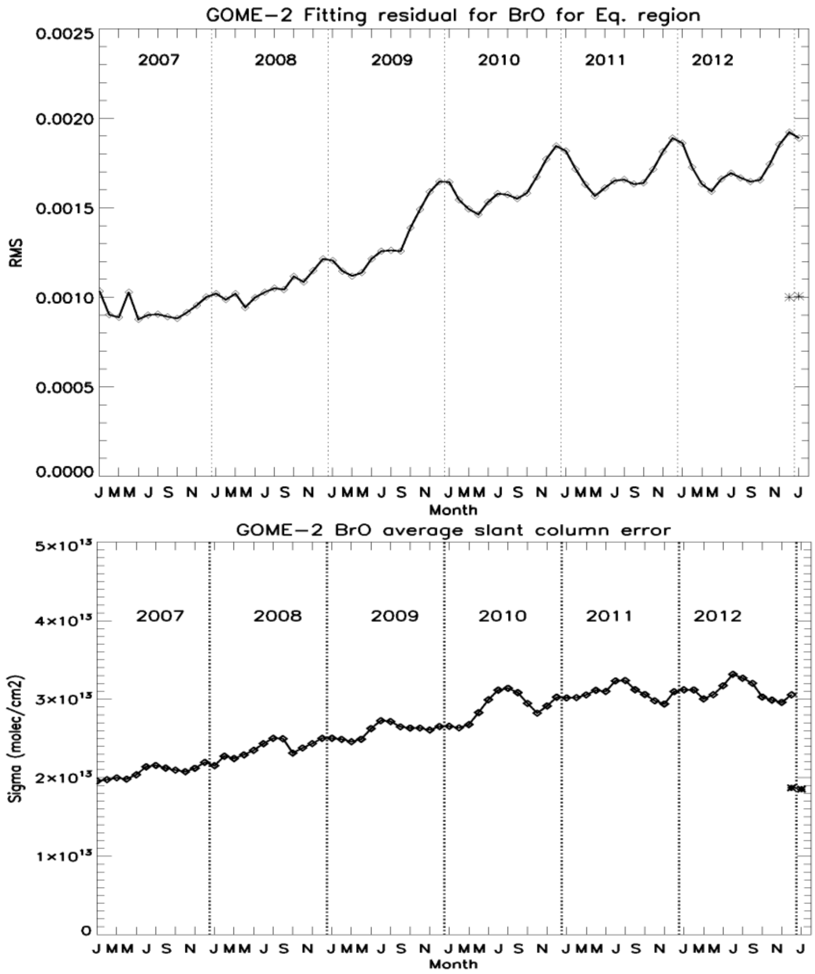


Figure 2. Average DOAS fitting residuals (top) and slant column error (bottom) in the equatorial Pacific as a function of time for GOME-2A(dots) and GOME-2B (stars)

The instrumental degradation affects not only the residuals and data scatter but also the average slant column values (not shown). Therefore we have applied an equatorial slant column offset correction to the GOME-2A data. Although this correction somehow compensate for the effect of the instrumental degradation, it does so only to some extend and one needs to be cautious in the use of the data in 2012-2013 (when GOME-2B data becomes available). Please note also in Figure 2 that GOME-2B data in Dec. 2012-Jan. 2013 seems to be of similar quality than GOME-2A in early 2007 (beginning of operations).

- OMI/Aura total BrO columns (e.g., Salawitch et al., 2010) will not be used in this report. BIRA-IASB is currently developing a scientific algorithm but it has not been documented yet. The official

OMI total BrO column product could eventually be used but it has not been evaluated yet by BIRA-IASB.

- Ground–based total BrO columns at Harestua, Norway are available for more than a decade long (Hendrick et al., 2007, 2008, 2009) and will be used. BIRA-IASB is operating ground-based DOAS systems (Beijing, Jungfraujoch, Observatoire de Haute-Provence) but no consolidated BrO column data sets are available, at the time of writing.

C. VERIFICATION OF SLANT COLUMNS

For verification purposes, the retrieval software of BIRA-IASB was synchronised with the GDP 4.7 processor, using a common set of slant column retrieval settings, as documented in Table 1. Comparisons between the two processing systems were performed on a limited set of GOME-2 orbits. Results of these comparisons are illustrated in Figure 3 for GOME-2B orbit 2835. As can be seen, a good level of agreement was obtained, demonstrating the consistency between the two slant column fitting algorithms. The differences in BrO SCDs retrieved from GDP 4.7 processor and BIRA-IASB software show a small bias of 1-2 x 10^{13} molec/cm² at high latitudes of unknown origin but it translates to an acceptable percentage difference of less than 5%.

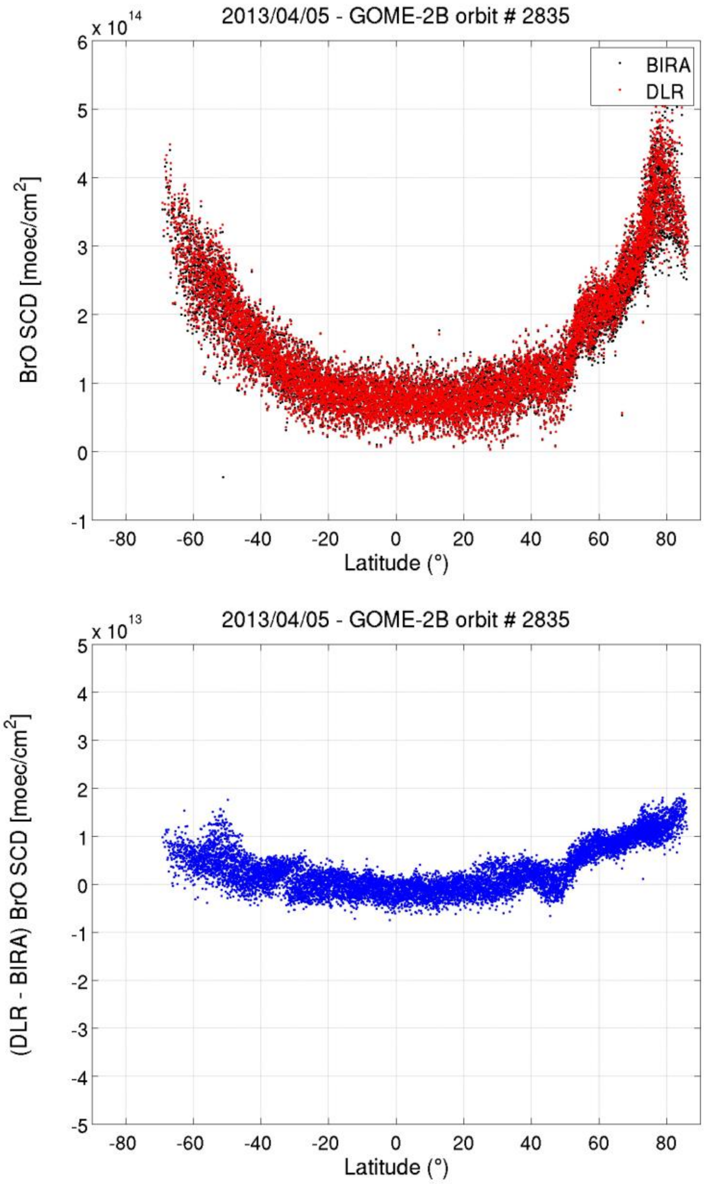


Figure 3: Comparison of BrO slant columns retrieved from GDP 4.7 and from the BIRA-IASB scientific algorithm. The lower plot corresponds to the difference between GDP 4.7 and BIRA-IASB BrO SCDs. DOAS settings were synchronized according to Table 1.

D. EVALUATION OF THE BRO COLUMN DATA PRODUCT

D.1 Comparison against satellite data

As a first step, the GOME-2B BrO data from the operational product are analysed for their internal consistency. The objective is to evaluate if the overall total column patterns are as expected. In Figure 1 and 4, daily averages of the BrO vertical columns are shown for selected days in Arctic spring 2013. GOME-2 BrO columns nicely pick up enhanced BrO in the polar regions associated with the well know tropospheric BrO explosions phenomenon. Moreover, large scale patterns extending to the mid-latitudes and associated to stratospheric BrO (Theys et al., 2009, 2011) are also visible. In Figure 4, one can also see that the transition from GOME-2 full swath mode (footprint size: 40x80km²) to the narrow swath mode (footprint size: 40x40km²) reduces the daily coverage of GOME-2B but without any negative impact on the quality of the measurements for the BrO total column product.

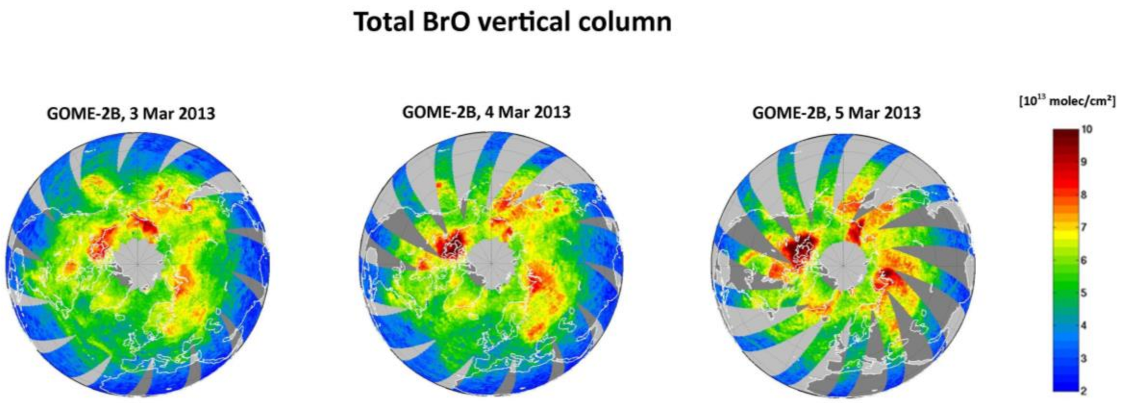


Figure 4. BrO vertical columns derived from GOME-2B in the Northern hemisphere for three consecutive days in March 2013. The transition from the full swath to the narrow swath mode is clearly visible on the 4th of March. Only data corresponding to solar zenith angles lower than 80° are shown.

The next step of the analysis is to compare qualitatively the BrO column results obtained from GOME-2A and GOME-2B for one particular day. This is displayed in Figure 5.

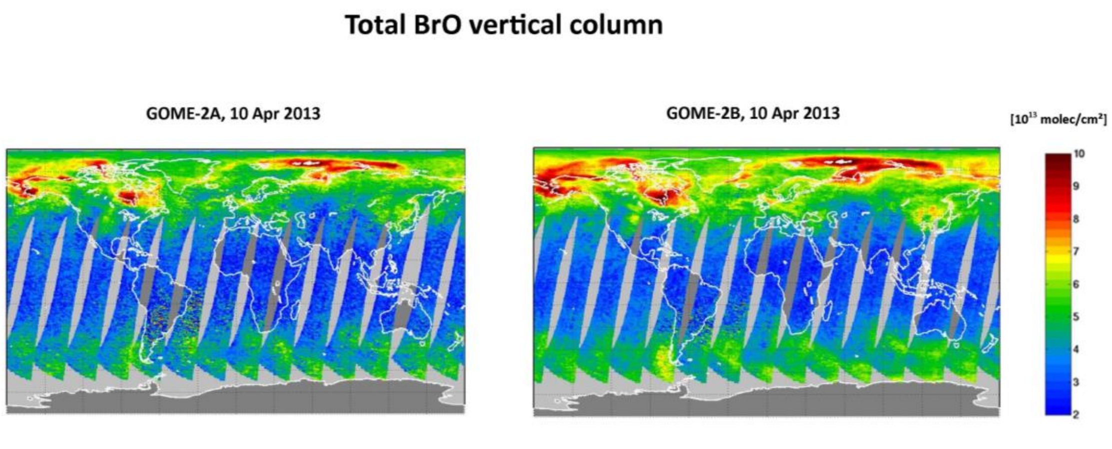


Figure 5. Daily averages of total BrO vertical columns from GOME-2A and GOME-2B for April 10, 2013. Only data corresponding to solar zenith angles lower than 80° are used.

Overall, a remarkable agreement between GOME-2A and GOME-2B BrO columns is observed as for the spatial patterns. However, GOME-2B tends to produce slightly larger values than GOME-2A, but not more than 10% higher. One can also see that the noise on the column data is larger for GOME-2A than for GOME-2B, as expected from the degradation of GOME-2A after six years of operation (see also Figure 2).

We now extend the comparison using SCIAMACHY data. BrO vertical column amounts derived from the SCIAMACHY instrument have been produced at BIRA-IASB as part of the DUP/DUE TEMIS service (www.temis.nl) and SCIAMACHY Quality Working Group (SQWG) project. This data set has been used here for comparison with GOME-2 retrievals and has been processed in the 336-351nm fitting window with the BrO cross-section of Fleischmann et al. (2004), the same as used in the GOME-2 retrieval (but convolved at the spectral resolution of SCIAMACHY).

Figure 6 provides a first illustration of the good geophysical consistency of the total BrO column products from the different instruments. Similar BrO column spatial patterns are observed for each instrument for each spring months. A striking feature in Figure 6 is the good agreement overall between SCIAMACHY and GOME-2B, although the color maps are for different years. It suggests that the GOME-2 BrO total column product can be used for scientific purposes and to extend the BrO time series. Conversely, Figure 6 also shows that the GOME-2A column values are generally lower than SCIAMACHY and GOME-2B. We attribute this feature to an effect of the degradation of the instrument.

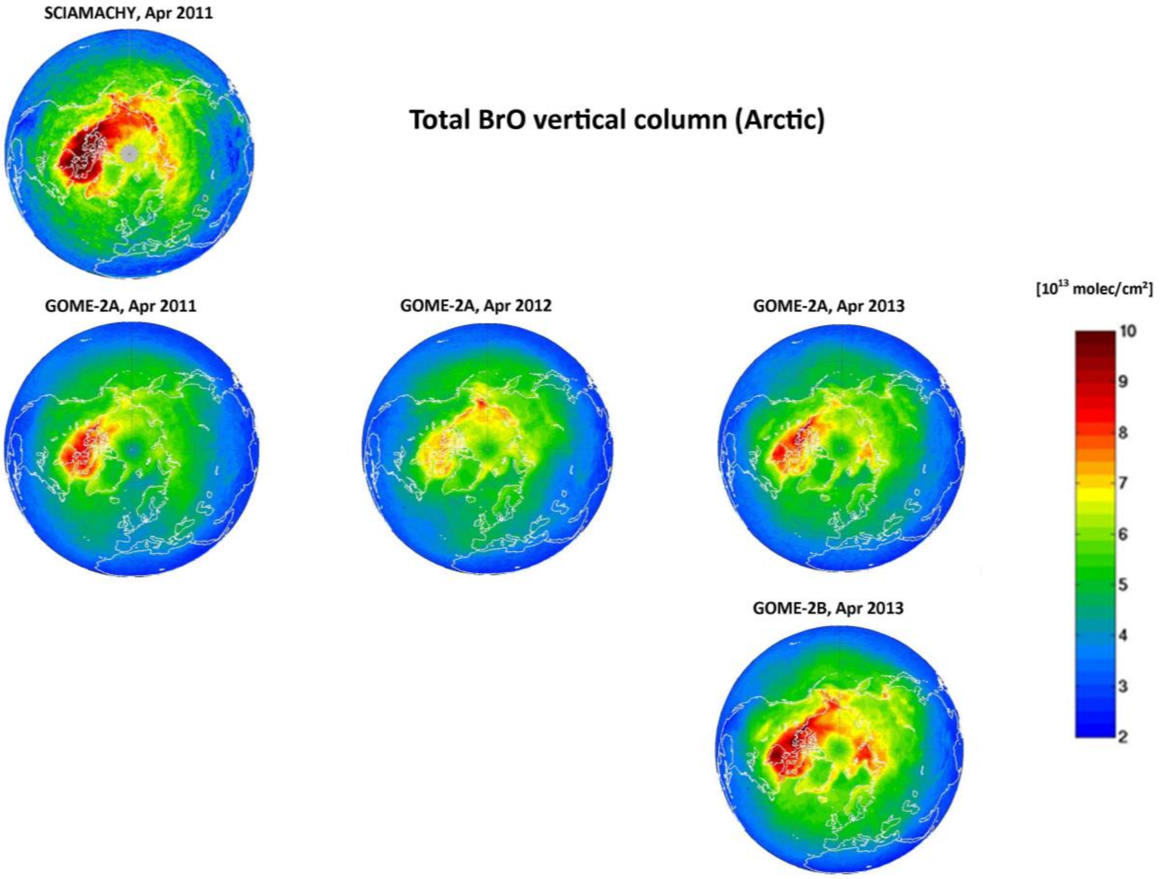


Figure 6. Monthly averages of total BrO vertical columns in Arctic spring (April, 2011-2013) from SCIAMACHY (2011), GOME-2A (2011-2013) and GOME-2B (2013). Only data corresponding to solar zenith angles lower than 80° are used.

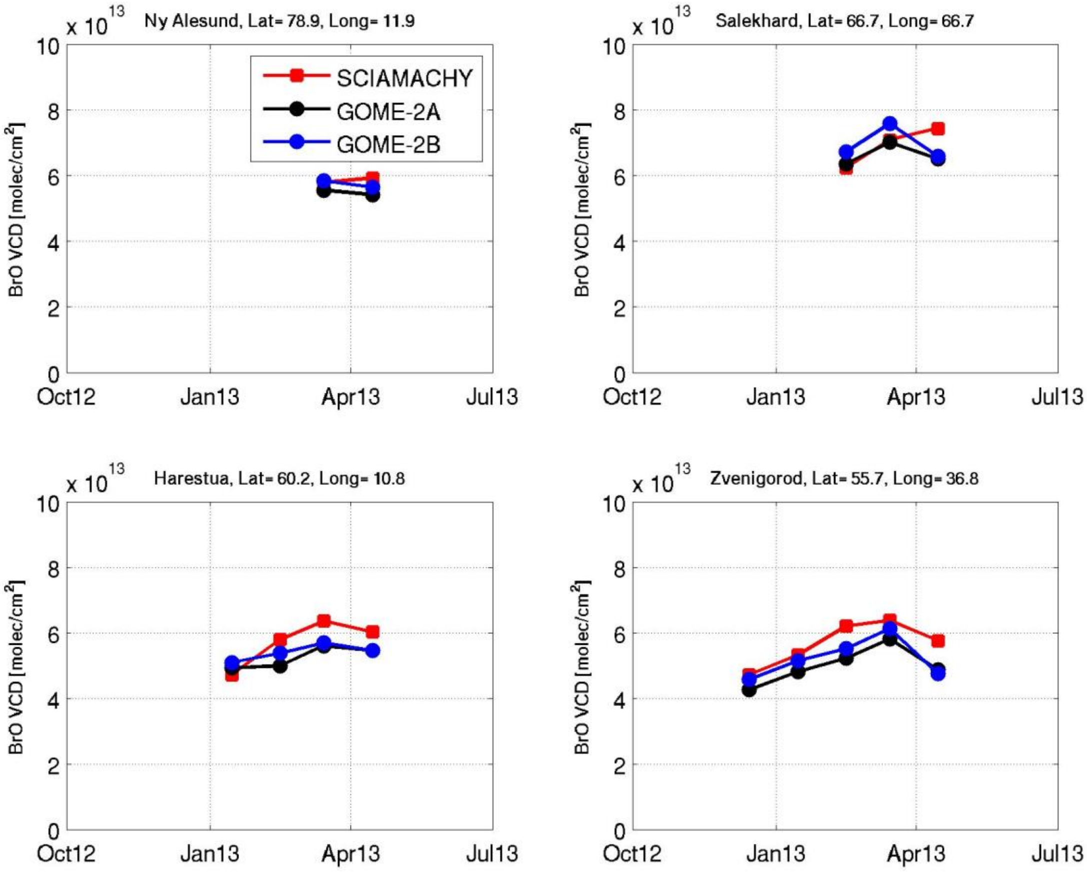
We now compare the different satellite datasets quantitatively. In order to simplify the comparison process within the limited timeframe available for this study, we based our analysis on overpass files extracted by the DLR team for a number of ground-based correlative sites, as detailed in Table 2.

Table 2. List of overpass sites used for the comparison

Station	**Latitude [°]**	**Longitude [°]**	**Altitude [m]**
Ny_Alesund	78.92	11.92	8
Scoresbysund	70.48	-21.97	17
Sodankyla	67.37	26.65	179
Salekhard	66.67	66.67	0
Jokioinen	60.82	23.48	103
Helsinki	60.32	24.97	56
Harestua	60.20	10.80	580
St_Petersburg	59.97	30.30	60
Zvenigorod	55.68	36.77	200
Hamburg	53.57	9.97	105
Leicester	52.62	-1.12	90
De_Bilt	52.10	5.18	15
Cabauw	51.97	4.93	10
Paris	48.85	2.35	50
Verrieres_Le_Buisson	48.76	2.24	0
Jungfraujoch	46.55	7.98	3450
Haute.Provence	43.91	5.75	580
Issyk Kul	42.62	76.97	1640
Thessaloniki	40.63	22.96	60
XiangHe	39.75	116.96	36
GSFC	38.99	-76.84	102
Table_Mountain	34.38	-117.68	2200
Sevilleta	34.35	-106.88	1477
Kanpur	26.45	80.35	142
Mussafa	24.37	54.47	10
Mukdahan	16.61	104.68	166
Djougou	9.71	1.68	430
Ilorin	8.32	4.34	350
Merida	8.24	-71.08	4765
Nairobi	-1.32	36.92	1624

La Reunion	-21.06	55.48	24
Sao_Paulo	-23.56	-46.73	865
Kerguelen	-49.35	70.25	2
Dumont_D'Urville	-66.67	140.02	40

GOME-2A and GOME-2B BrO columns have been extracted above each site for the period December 2012-April 2013. In order to provide a meaningful temporal perspective, time-series of monthly averaged BrO columns have been plotted. SCIAMACHY BrO columns from 2007-2011 have been extracted using the same criteria and monthly averaged (multi-years). Results from the SCIAMACHY, GOME-2A and GOME-2B comparisons are represented in Figure 7 for a representative selection of sites.



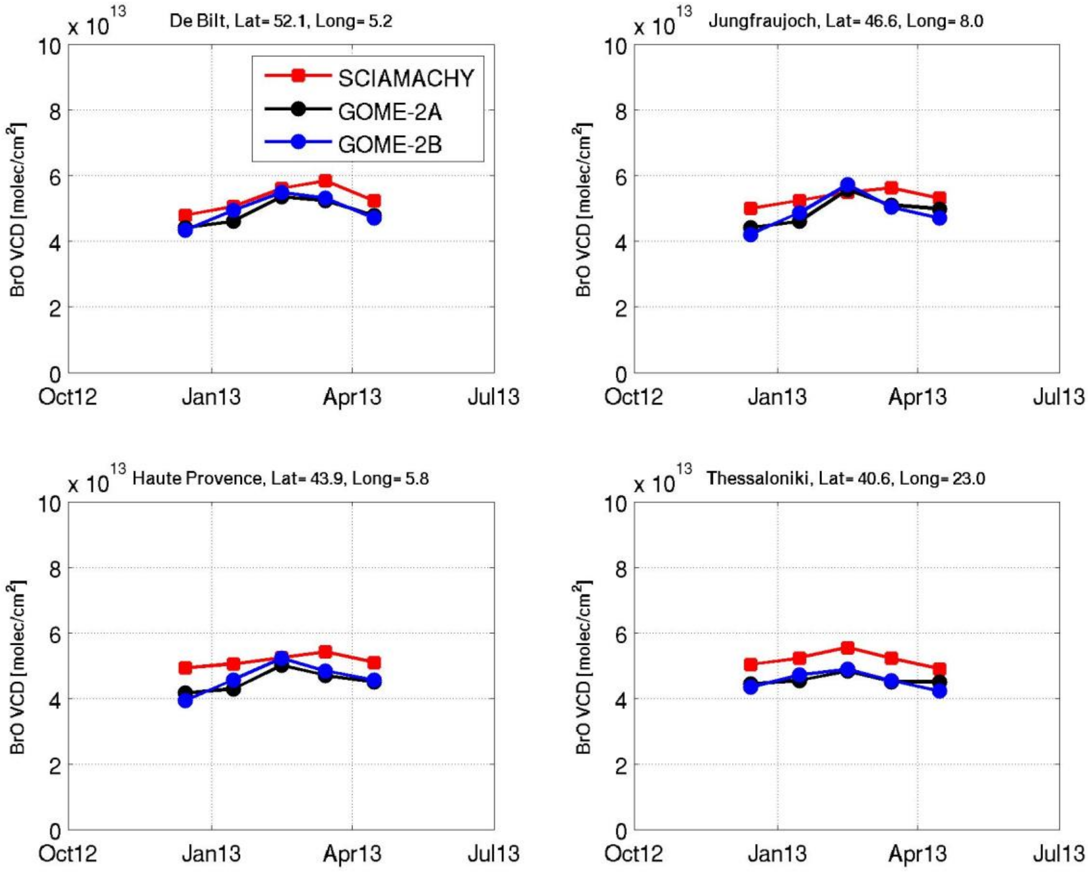


Figure 7. Comparison of time-series of monthly averaged BrO vertical columns retrieved from SCIAMACHY, GOME-2A and GOME-2B over the December 2012- April 2013 period, at a number of ground-based sites (using a 200 km radius overpass).

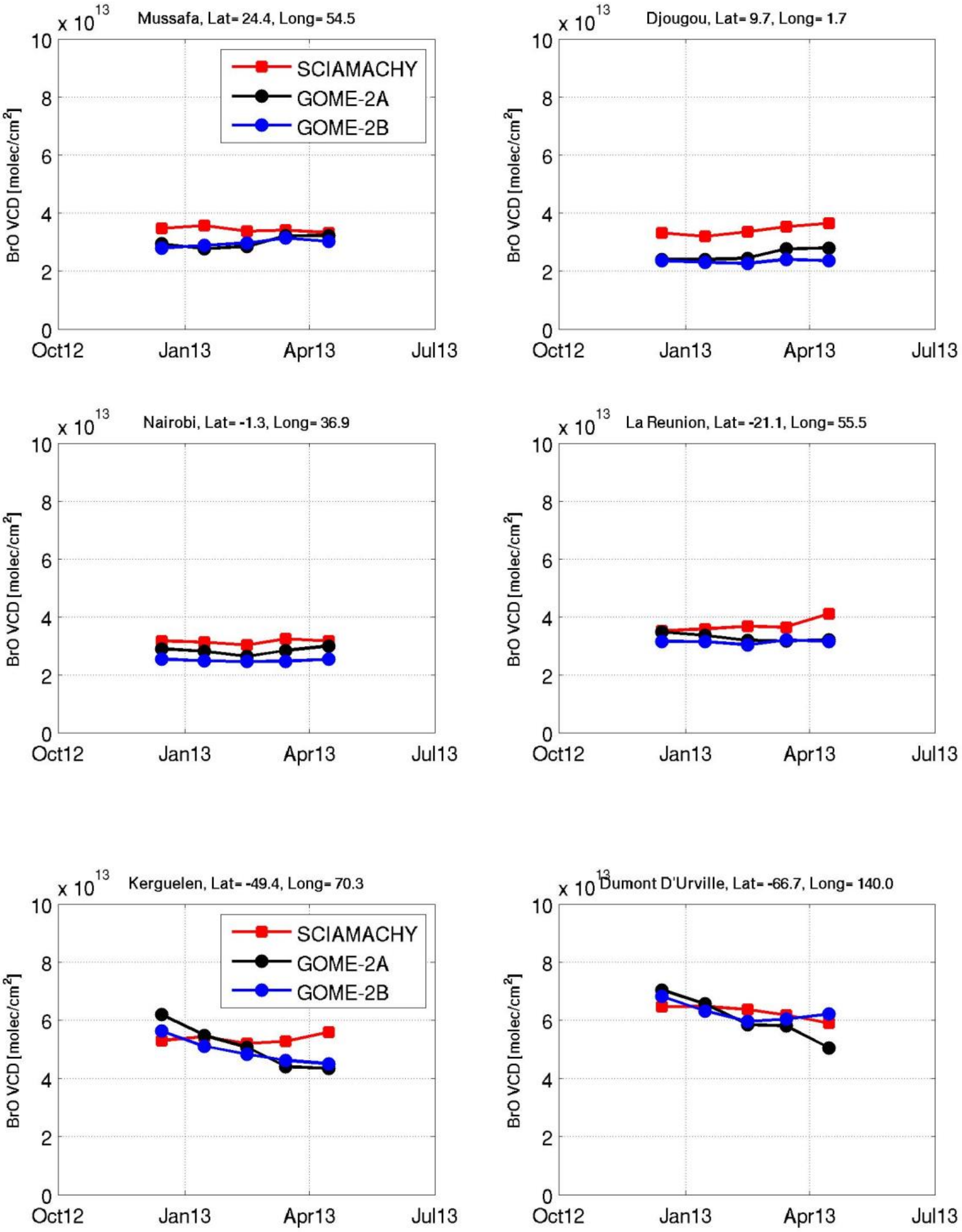


Figure 7. Continued.

In general, the GOME-2A, GOME-2B and SCIAMACHY BrO columns show a fairly good agreement. At all latitudes, the seasonal patterns are remarkably well reproduced by GOME-2A, GOME-2B and SCIAMACHY, although the amount of data is quite limited (only five months). However, as can be seen in Figure 7, the GOME-2A and GOME-2B retrievals generally give lower BrO columns than the SCIAMACHY data. This tendency is also observed for tropical sites (e.g., Djougou) and this might look in contradiction with the equatorial offset correction of 7.5 x 10^{13} molec/cm² that is consistently applied to the three satellite data sets. There are two possible reasons for the lower values of GOME-2 BrO VCDs compared to SCIAMACHY: 1) the equatorial correction is applied to the slant columns but not to the vertical columns. Since GOME-2 has a larger swath than SCIAMACHY, the air mass factors applied to GOME-2 are larger (due to larger viewing angles) and thus the vertical columns are expected to be smaller. We have done the same comparison as in Fig. 6 but limiting the GOME-2 viewing angles to maximum ±31° (similar as SCIAMACHY) and the agreement between GOME-2 and SCIAMACHY was found better (not shown) confirming the impact of the equatorial correction. In the next validation exercises, one should probably find another ad-hoc post-processing normalization procedure than the equatorial correction used here (e.g. based on vertical columns rather than slant columns). Although the accuracy of the GOME-2 total BrO column product depends on the equatorial offset used, this is less the case as the solar zenith angles increases. 2) SCIAMACHY BrO retrievals are known to suffer from a strong positive correlation with formaldehyde absorption (De Smedt et al., 2004) over regions heavily polluted or affected by biomass burning or biogenic emission (e.g Djougou).

In Figure 8, the differences in % ((GOME-2B-GOME-2A)/GOME-2A and (GOME-2B-SCIAMACHY)/SCIAMACHY) of all monthly averaged BrO VCD values are displayed as a function of the BrO column for the Dec. 2012-Apr. 2013 period. One can see that the relative differences between GOME-2B and GOME-2A BrO VCDs are within the optimal/target/threshold accuracies, 95%, 100%, 100% of the time, respectively. These values are respectively of 72%, 95% and 100% between GOME-2B and SCIAMACHY BrO VCDs.

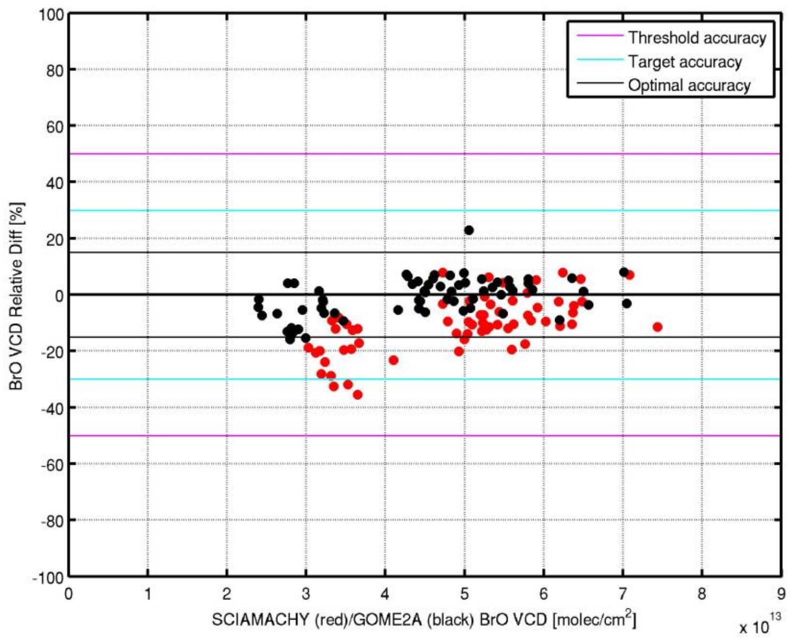


Figure 8. Relative difference in the monthly averaged BrO VCD (see Figure 6) between GOME-2B and SCIAMACHY (red points) and GOME-2A (black points) plotted as a function of SCIAMACHY/GOME-2A BrO VCD.

Figures 9 and 10 provide additional illustration of the good geophysical consistency of the SCIAMACHY and GOME-2A and -B total BrO column products for monthly zonal columns averages. Figure 9 also shows the clear impact of the instrumental degradation on the GOME-2A vertical column (decrease over time: blue curves time series) and the effect of the offset correction on the vertical columns (black curves time series). As can be seen, the offset correction has only a slight effect at the beginning (2007-mid 2009) but then becomes essential for a good stability of the data with time and reasonable agreement with SCIAMACHY. Figure 10 shows the results for both GOME-2A and GOME-2B data for the most recent observations (Dec 2012-Apr 2013), one can see that the quality of the GOME-2A data is significantly affected by the instrumental degradation while applying the offset correction scheme has almost no effect on the GOME-2B data.

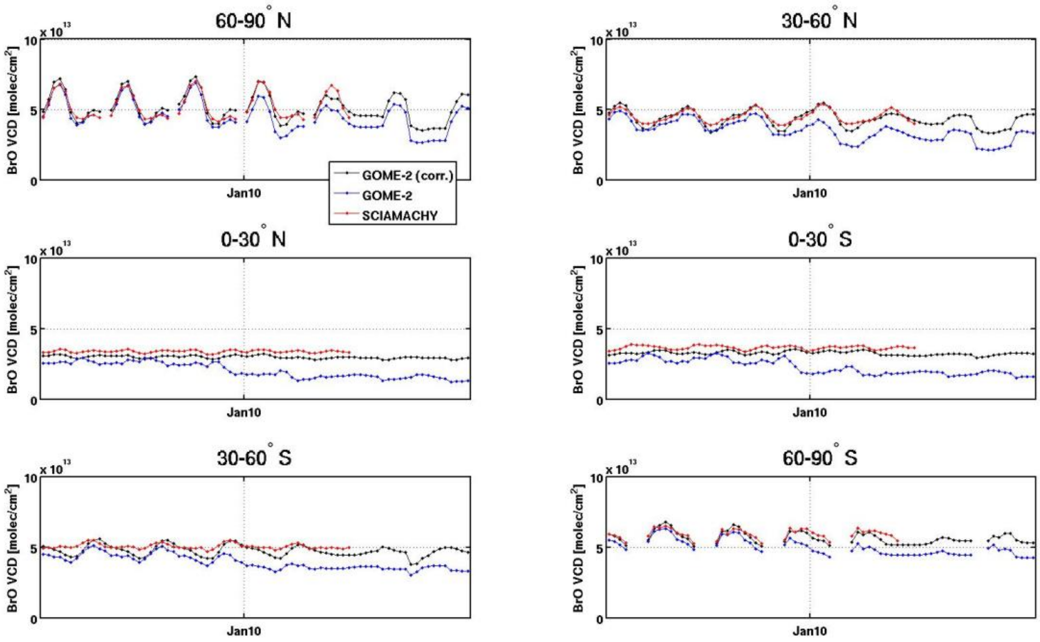


Figure 9. Time-series of total BrO vertical columns from GOME-2A (with or without offset correction) and SCIAMACHY observations (2007-2011) for different latitudinal bands (monthly zonal averages). Only data corresponding to solar zenith angles lower than 80° are shown.

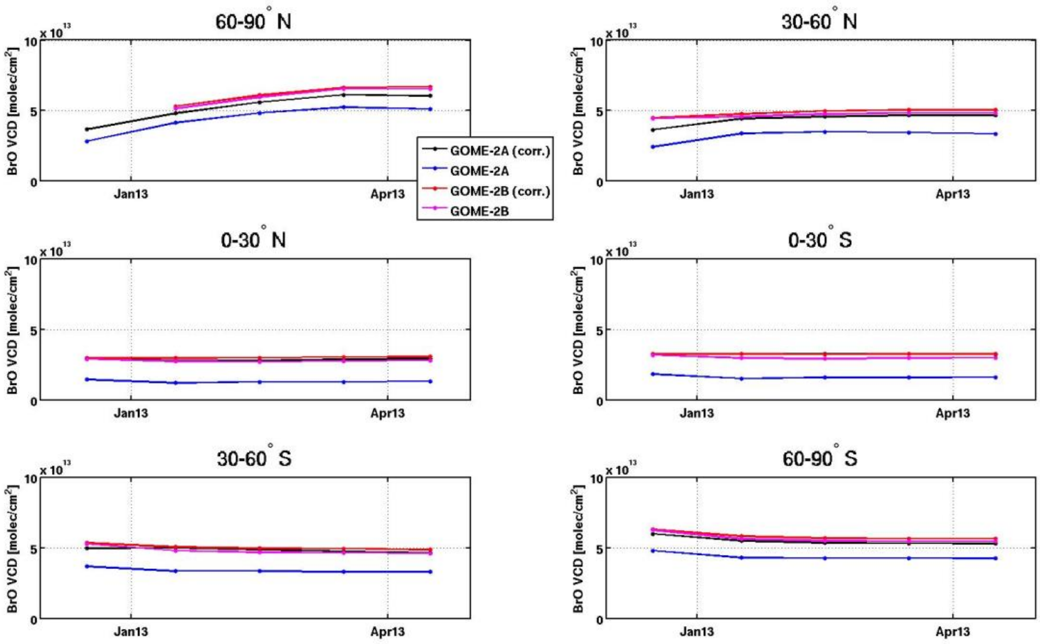


Figure 10. Time-series of total BrO vertical columns from GOME-2A and GOME-2B with or without offset correction for the period December 2012-April 2013 and for different latitudinal bands (monthly zonal averages). Only data corresponding to solar zenith angles lower than 80° are shown.

D.2 Comparison against ground-based data

The direct comparison of GOME-2 BrO columns with ground-based correlative sources is under progress. In this report, we focus on a first comparisons zenith-sky measurements at the Harestua station in Southern Norway.

D.2.1 Comparison with Zenith-sky observations at Harestua

GOME-2A and -2B total columns of BrO have been compared to ground-based UV-visible zenith-sky measurements at Harestua, Norway (60°N, 11°E). Ground-based (GB) columns are derived from vertical profiles retrieved by applying an OEM (Optimal Estimation Method)-based profiling technique to zenith-sky measurements at sunrise (Hendrick et al., 2007). The sensitivity of these measurements to the troposphere is increased by using a fixed reference spectrum corresponding to clear-sky noon summer conditions for the spectral analysis. In order to ensure the photochemical matching between satellite and ground-based observations, sunrise ground-based columns have been photochemically converted to the satellite overpass SZAs using a stacked box photochemical model (Hendrick et al., 2007 and 2008). The uncertainty on the ground-based BrO total columns is about 20% (Hendrick et al., 2007). Comparison results (200 km overpasses) are shown in Figure 11 and mean biases and standard deviations are summarized in Table 3. For both GOME-2 instruments (A and B), two different products are involved in the verification exercise: the standard product provided in the DLR data files and obtained using a stratospheric AMF and a second product derived by dividing the SCDs by total AMFs calculated from retrieved GB profiles. As shown in Figure 12, the tropospheric contribution to the total BrO columns is not negligible and it can impact significantly the AMFs especially at low solar elevation. For the February-April 2013 period, the agreement between GOME-2B and ground-based observations is good with mean biases of -7 ± 8 % (stratospheric AMF) and +11 ± 10 % (total AMF). The corresponding bias values for GOME-2A are -15 ± 8 % and -1 ± 8 %, respectively. Hence, the GOME-2 B and GOME-2A BrO total columns products clearly reach the optimal accuracy requirement of 15%.

Table 3. Mean biases between GOME-2 (A and B) and ground-based BrO observations at Harestua (60°N, 11°E) for the February-April 2013 period. The number of coincidences is 55 for GOME-2A and 49 for GOME-2B.

	GOME-2A (stratospheric AMF)	GOME-2A (total AMF)	GOME-2B (stratospheric AMF)	GOME-2B (total AMF)
Mean bias with ground-based observations (%)	-15 ± 8	-1 ± 8	-7 ± 8	+11 ± 10

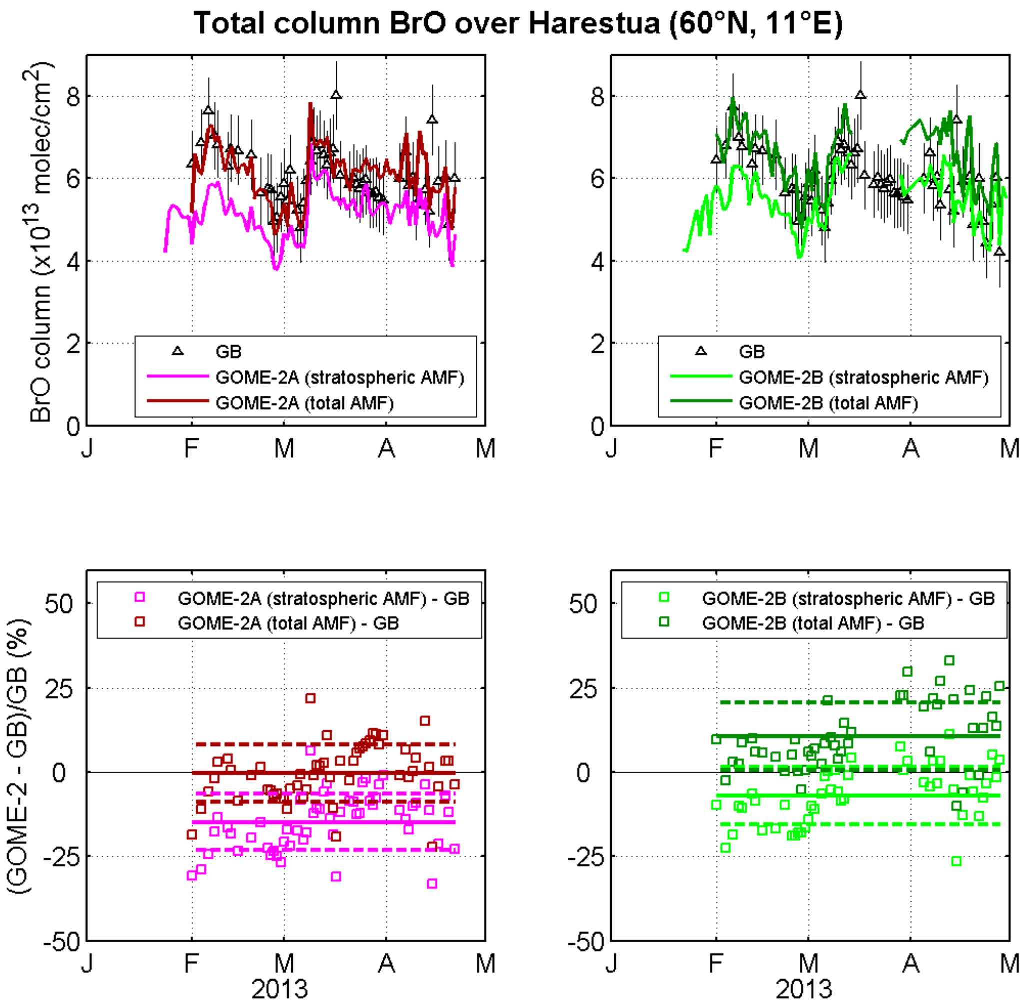


Figure 11. Comparison between GOME-2 (A and B) and ground-based total BrO columns at Harestua (60°N, 11°E) over the February-April 2013 period. The relative differences (squares) and mean biases (solid lines) appear in the lower plots. The number of coincidences is 55 for GOME-2A and 49 for GOME-2B.

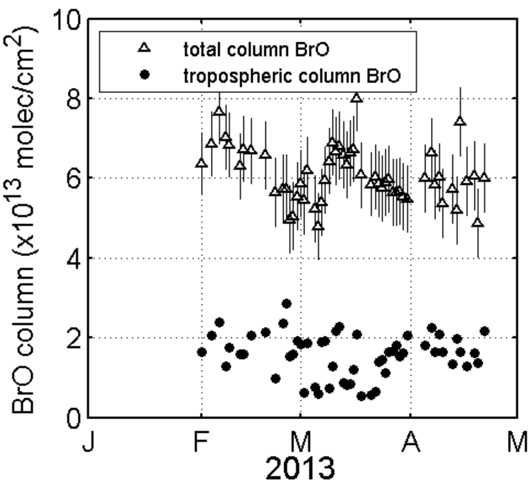


Figure 12. Total and tropospheric BrO columns as retrieved from ground-based observations at Harestua (February-April 2013 period). The mean tropopause height, estimated from NCEP temperature profiles, is 10.7 km in February, 8.3 km in March, and 9.6 km in April.

E. CONCLUSION AND PERSPECTIVES

This document reports on the validation of O3M-SAF GOME-2 BrO column data products retrieved at DLR with versions 4.7 of the GOME Data Processor (GDP), using level-1B data based on the level-0-1B processor version 5.3.

As part of this report, the verification and validation of the GOME-2B total BrO product has been addressed, based on tools available at BIRA-IASB.

GOME-2B BrO vertical columns have been evaluated using (1) scientific retrievals based on the BIRA-IASB tool and (2) comparisons with correlative data sets from SCIAMACHY, GOME-2A and from ground-based zenith-sky measurements.

For verification purpose, the GDOAS and GDP 4.7 retrieval tools were compared and a reasonably good agreement was found confirming the reliability of the GDP for BrO slant column fitting.

The difference between GOME-2B and SCIAMACHY/GOME-2A data show a moderate column-dependent pattern for the Dec. 2012-Apr. 2013 period. In a majority of cases (>70% of the time), the GOME-2B GDP 4.7 total BrO column product agrees within 15% with the other satellite datasets. Additional comparisons using the latest version of available ground-based DOAS measurements at the NDACC station of Harestua (Norway) further consolidate the findings of the SCIAMACHY- GOME-2 comparison with mean bias within the optimal accuracy (15%) as stated in the O3MSAF Service Specification Document.

Based on the validation with ground-based measurements and the comparisons with correlative satellite data, we conclude that the current GOME-2B GDP 4.7 BrO column product (based on the limited period Dec. 2012-Apr. 2013) fulfill the user requirements in terms of accuracy (threshold and target accuracy, virtually all the time ; optimal accuracy, in a majority of cases).

In the future, more work is needed to further reduce the impact of the degradation of the GOME-2 instrument on the quality of the total BrO column product and on the development of an improved BrO post-processing normalization procedure.

More effort is needed to validate the column product. This should include OMI total BrO columns and ground-based columns observations at other sites than Harestua. A validation of the complete, reprocessed GOME-2A BrO column data-set (2007-2013) is planned for end 2013.

In a later stage of the CDOP-2 project, retrievals of tropospheric BrO columns based on the total BrO slant columns will be undertaken.

F. REFERENCES

F.1. Applicable documents

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F.2. Reference documents

F.2.1 Peer-reviewed articles

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F.2.2 Technical notes

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