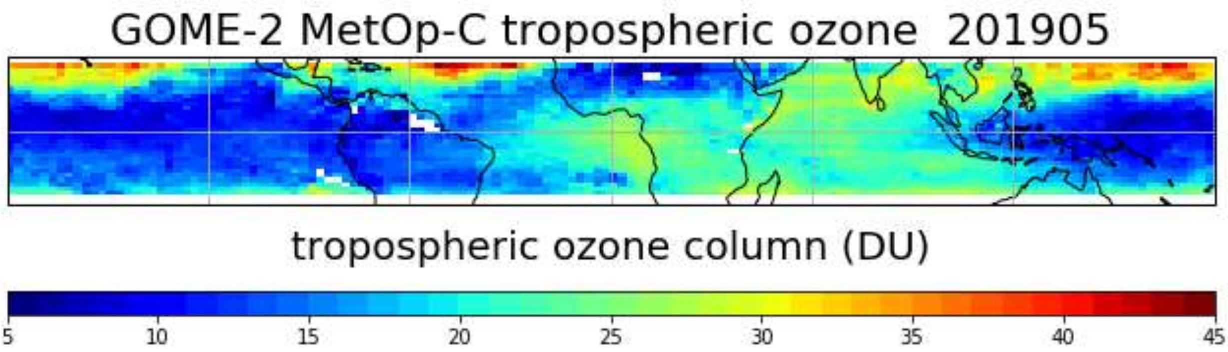
SAF/AC VALIDATION REPORT

Validated products:

Identifier	Name	Acronym
O3M-302	Offline Tropical Tropospheric Ozone column Product GOME-2C	OTO/O3Tropo



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Reporting period: February 2019 - December 2019

Validation methods: Balloon soundings

Input data versions: Base Algorithme Version: GDP 4.9

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Acronyms and abbreviations

ATBD	Algorithm Theoretical Basis Document
GDP	GOME Data Processor
GOME	Global Ozone Monitoring Experiment
MetOp	Meteorological Operational satellite
NDACC	Network for the Detection of Atmospheric Composition Change
NH	Northern Hemisphere
PUM	Product User Manual
SH	Southern Hemisphere
SZA	Solar Zenith Angle
TTOC	Total Tropical Ozone Column
WOUDC	World Ozone and UV Data Center

1. Applicable AC SAF Documents

[ATBD] Algorithm Theoretical Basis Document for GOME-2 Offline Tropospheric Ozone, Cloud slicing, SAF/DLR/GOME/ATBD_toc/01/A, Valks, P., 2015.

[PUM] Product User Manual for GOME-2 Offline Tropospheric Ozone, Cloud slicing, SAF/DLR/GOME/PUM/01/A, Heue K.-P., 2015.

1. General Introduction

This report contains validation results of the GOME-2A, GOME-2B and GOME-2C offline tropical tropospheric ozone column (TTOC) products. The tropospheric ozone retrieval is based on the GOME-2 ozone columns as derived by the GOME Data Processor (GDP, version 4.9) and covers the tropical latitude belt (20° S – 20° N). This product is available on a monthly basis and has a resolution of 1.25° latitude x 2.5° longitude.

This validation report covers the time period February 2019 until December 2019 for GOME-2C. It also includes results from the previous TTOC products from the GOME-2A and GOME-2B sensors. In the next sections we will briefly describe the algorithm applied to obtain the TTOC product, the validation approach, the results obtained and finally we conclude.

The major outcome of this report is to verify if this TTOC product meets the user requirements.

2. Tropospheric ozone retrieval

The Convective Cloud Differential (CCD) algorithm is described in detail in [R1] and [R9]. The GDP uses an optimized DOAS fit to retrieve slant column densities (SCD) of several trace gases from the measured spectra. The ozone SCD fit is performed in a fitting window between 325 and 335 nm. The DOAS slant column retrieval is followed by the Air Mass Factor (AMF) conversions to generate vertical column densities. Cloud information used in the trace gas retrieval and in the calculation of the tropospheric ozone column is obtained with the OCRA and ROCINN algorithms. A detailed description of the GDP algorithms is given in [R1], [R5], [R6] and [R9].

The retrieval uses the level 2 data product as input. The stratospheric column is approximated by the ozone column above high reaching convective clouds. The level 2 ozone columns are filtered for high reaching convective clouds with high cloud fraction and cloud albedo. After dividing the data by the above cloud AMF the monthly averaged and gridded data define the local stratospheric column. The principle of the convective cloud differential method is shown in Figure 1. The data are gridded to a 1.25° x 2.5° latitude by longitude grid.

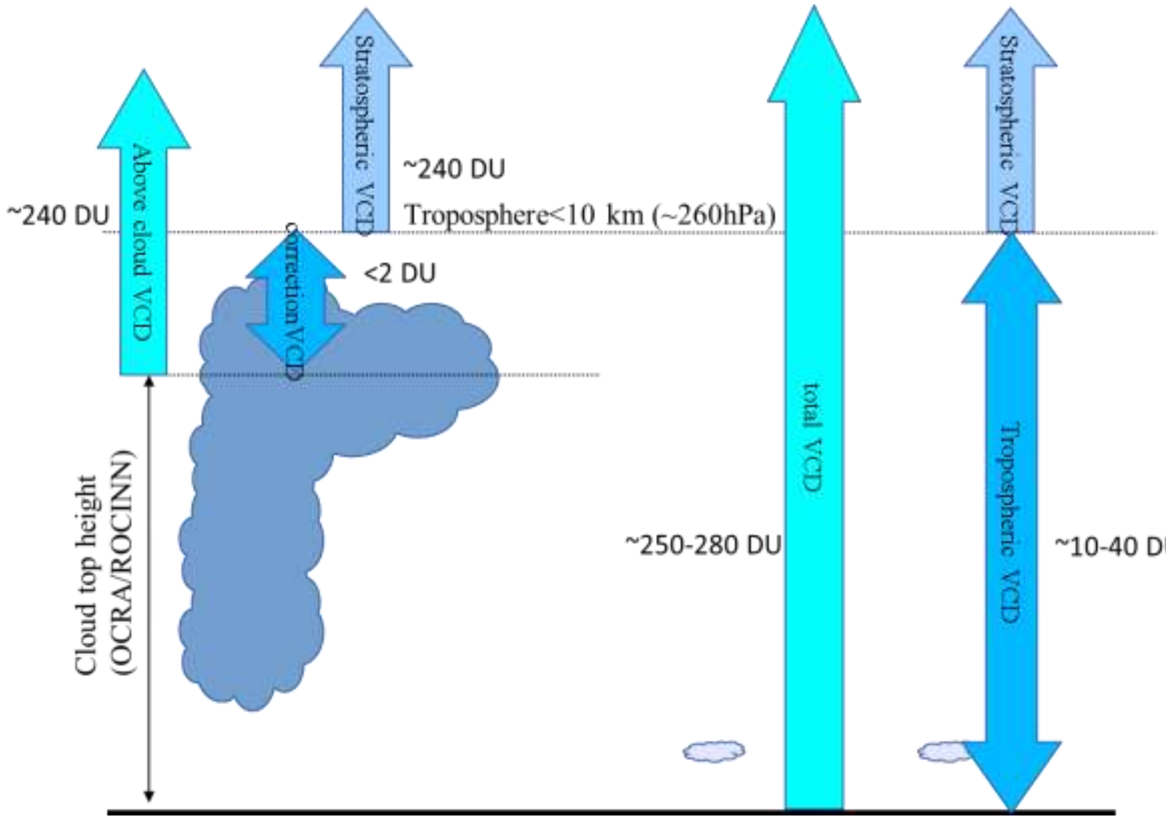


Figure 1: The total columns in the cloud free GOME pixels contain the complete tropospheric signal in addition to the stratospheric one. Therefore the difference between the total ozone columns for cloud free observations and the stratospheric column for the respective latitude band equals the tropospheric column product.

3. Validation of tropical tropospheric ozone columns using ozonesondes

3.1 Introduction

This report aims to verify the status of the new GOME-2C offline tropical tropospheric ozone column (TTOC) product as described in the general introduction. The validation is done using balloon sounding data from ozonesondes.

Ozonesondes are lightweight balloon-borne instruments which are able to make ozone measurements from the surface up to about 30 km, with much better vertical resolution than satellite data. In general also the precision and accuracy will be better, at least in the lower stratosphere and the troposphere. Another advantage is that ozone soundings can be performed at any time and at any meteorological condition.

The precision of ozonesondes varies with altitude and depends on the type of ozonesonde used. Table 1 below shows indicative precision (in percent) of the Electrochemical Concentration Cell (ECC), Brewer-Mast (B-M) and the Japanese KC79 ozonesondes, at different pressure levels of the sounding (taken from the AC SAF Science Plan).

Table 1: Precision of different types of ozonesondes at different pressure levels (%).

Pressure level (hPa)	ECC	B-M	KC79
10	2	10	4
40	2	4	3
100	4	6	10
400	6	16	6
900	7	14	12

For this validation report, only the ECC sondes from the SHADOZ network are used ([R3] and [R4]). Recently, [R7] and [R8] reported issues in the SHADOZ network. Specifically, there are instrumental problems with stratospheric (and total) ozone data after ~2015 at 8 or 9 of 12 currently reporting stations. This is due to the type of instrument used and changes in manufacturer, twice after 2011. The problem is manifested as a mean ‘sharp’ dropoff in total ozone at 2014-2016 depending on the station, at 3-5% for SHADOZ data. For this validation, since we are focusing on the troposphere, we could not detect an influence of these issues on our analysis, but it should be verified in the future when more data becomes available.

3.2 Dataset description

The offline Tropical tropospheric ozone dataset used in this validation report is the same as reported in the AC SAF Operations Report 2/2019, available at the AC SAF website. The time period under consideration for the validation of the GOME-2A and GOME-2B products contain the time period January 2017 till June 2019. Since there is no significant dataset from the SHADOZ network available as earlier mentioned, we will validate the TTOC product from GOME-2C by looking at difference plots between GOM-2C and GOME-2A/GOME-2B.

Figure 2: Stations used in the validation report.

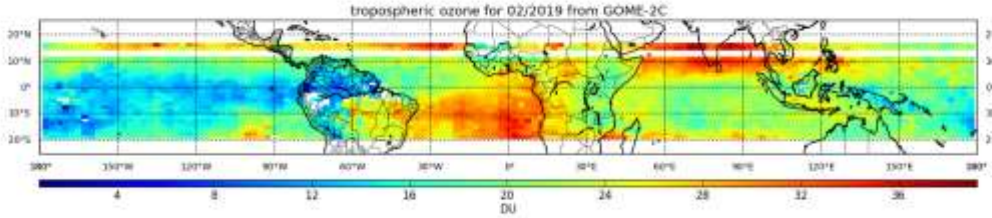
Ozonesonde data are generally made available by the organization carrying out observations after a delay in order to leave time for necessary verification and correction of the data quality. Nevertheless, some organizations make their ozone profile data readily available for validation purposes.

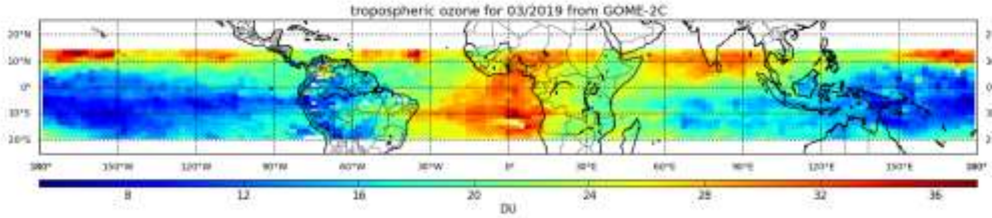
Table 2 Overview of the stations taken into account since January 2017 with the numbers of ozonesondes used in the analysis and the last day, an ozonesonde was available for the intercomparison.

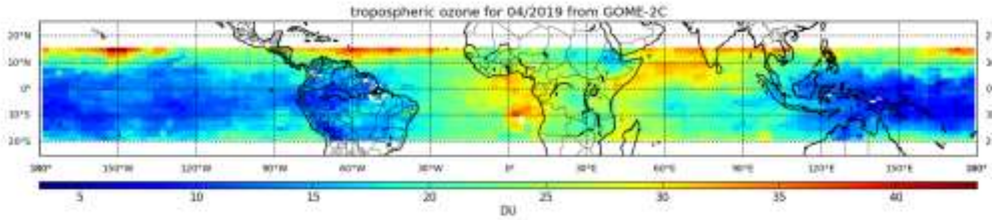
STATION	Lat(°)	Long(°)	Nr of sondes	Last day available
ALAJUELA	9.98	-84.21	92	20-Dec-19
ASCENSION	-7.98	-14.42	93	11-Dec-19
HILO	19.717	-155.083	107	28-Feb-19
KUALA_LUMPUR	2.73	101.7	40	29-Oct-18
NAIROBI	-1.27	36.8	90	28-Feb-19
NATAL	-5.42	-35.38	60	11-Dec-18
PARAMARIBO	5.81	-55.21	84	25-Jun-19
SAMOA	-14.23	-170.56	93	28-Feb-19

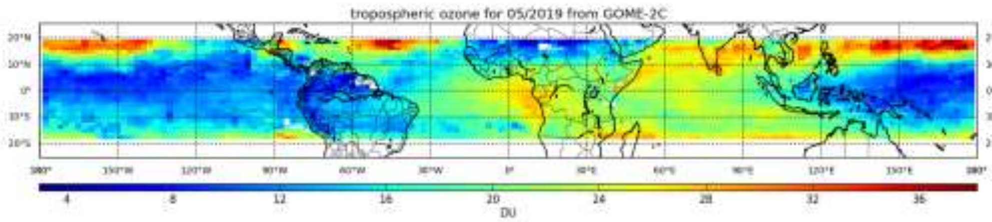
4. Offline TTOC product for the sensor GOME-2C

In the next Figure 3, some first results are shown for the offline TTOC GOME-2C product including the months February until July 2019.


tropospheric ozone for 02/2019 from GOME-2C
4 8 12 16 20 24 28 32 36
DU


tropospheric ozone for 03/2019 from GOME-2C
8 12 16 20 24 28 32 36
DU


tropospheric ozone for 04/2019 from GOME-2C
5 10 15 20 25 30 35 40
DU


tropospheric ozone for 05/2019 from GOME-2C
4 8 12 16 20 24 28 32 36
DU

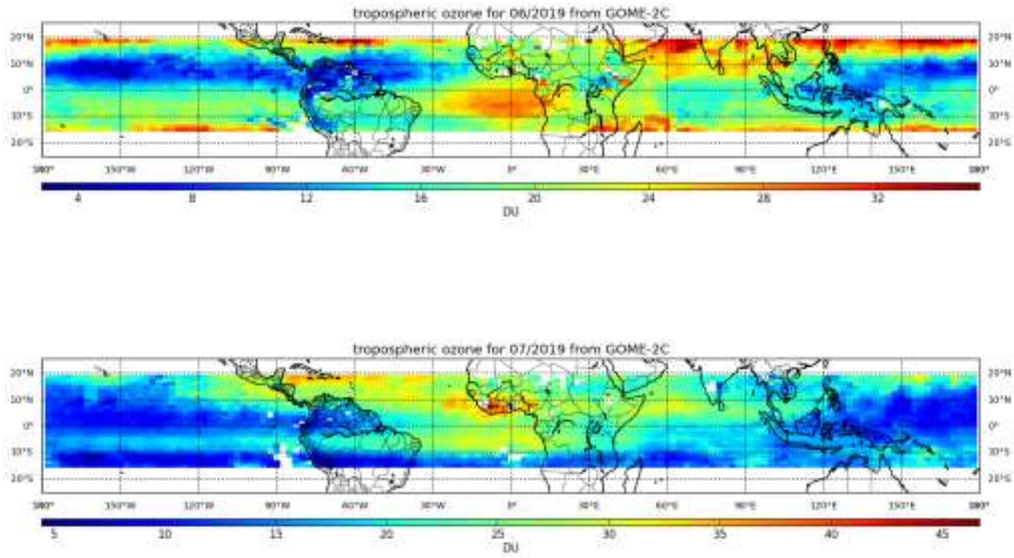


Figure 3: Total Tropical Ozone Column (DU) for the time period February – July 2019.

The effect of biomass burning is clearly visible in the product, especially during February and March. In the next section we will discuss the obtained results for GOME-2A and GOME-2B and verify the consistency of both TTOC products with the new TTOC product from GOME-2C. Figure 3 also shows that for e.g. in February there are issues with the data at the northern ends of the area. This is due to a reduced quality, caused by stratospheric influence in this latitude band and season. There is a *stratospheric_O3_reference_flag* available in the metadata of the file which give the user feedback on its quality. More details on the meaning of the flags can be found in the PUM. Flagged data are given as fillvalue in the data file. However, in some cases the flagging algorithm is not stringent enough to filter a few lines.

5. Results

5.1 Comparisons with ozonesonde data from the SHADOZ network

5.1.1 Statistics for GOME-2A/2B

Since there are not enough data to make a good validation with ground-truth data available, we will first include the operational validation results for the TTOC products retrieved from the sensors GOME-2A (Table 3) and GOME-2B (Table 4).

Table 3: Relative Differences (RD), standard deviation (STDEV), bias, correlation and rmse are shown on the accuracy of the GOME-2A TTOC product for the time period January 2017 – June 2019.

Station	RD (%)	STDEV (%)	COR	bias (DU)	rmse (DU)
Paramaribu	12.08	21.32	0.69	2.32	4.47
Alajuela	39.78	15.15	0.67	6.48	6.91
Samoa	15.73	26.03	0.61	2.15	4.27
Ascension Island	13.95	13.15	0.70	3.62	4.93
Kuala Lumpur	0.59	15.28	0.59	-0.29	2.91
Nairobi	28.05	19.18	0.54	5.04	6.12
Natal	15.10	11.72	0.80	3.47	4.26
Hilo	30.77	26.77	0.62	6.68	8.94

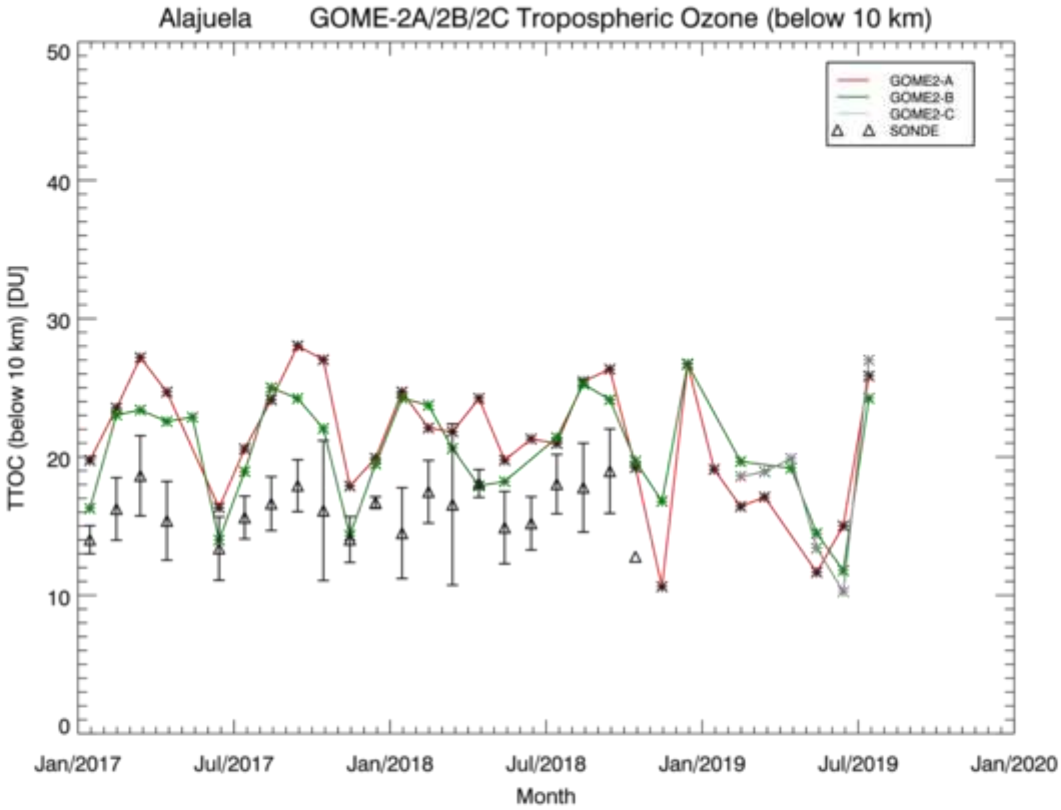
Table 4: Relative Differences (RD), standard deviation (STDEV), bias, correlation and rmse are shown on the accuracy of the GOME-2B TTOC product for the time period January 2017 – June 2019.

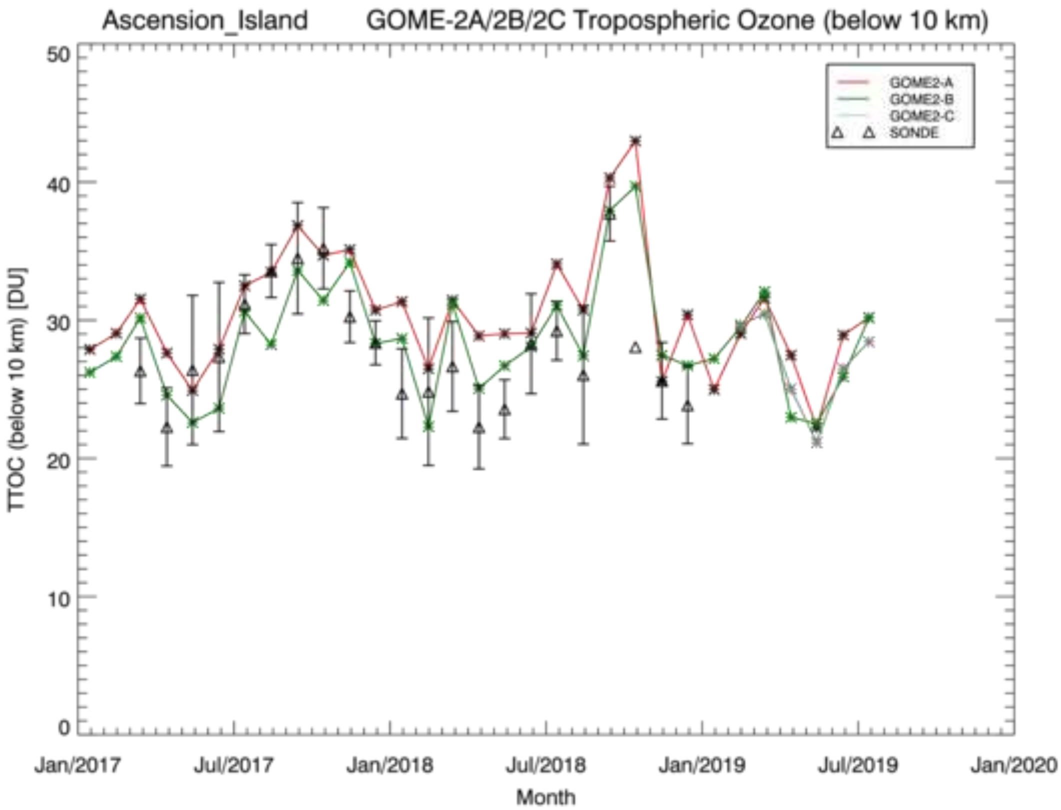
Station	RD (%)	STDEV (%)	COR	bias (DU)	rmse (DU)
Paramaribu	5.70	20.26	0.78	1.22	3.88
Alajuela	29.74	18.49	0.58	4.82	5.57
Samoa	-0.12	28.22	0.52	-0.02	3.97
Ascension Island	6.00	13.84	0.62	1.40	3.94
Kuala Lumpur	-9.29	14.16	0.65	-2.04	3.42
Nairobi	20.16	12.78	0.67	3.60	4.24
Natal	5.90	10.57	0.86	1.43	2.75
Hilo	27.42	23.03	0.78	6.30	8.30

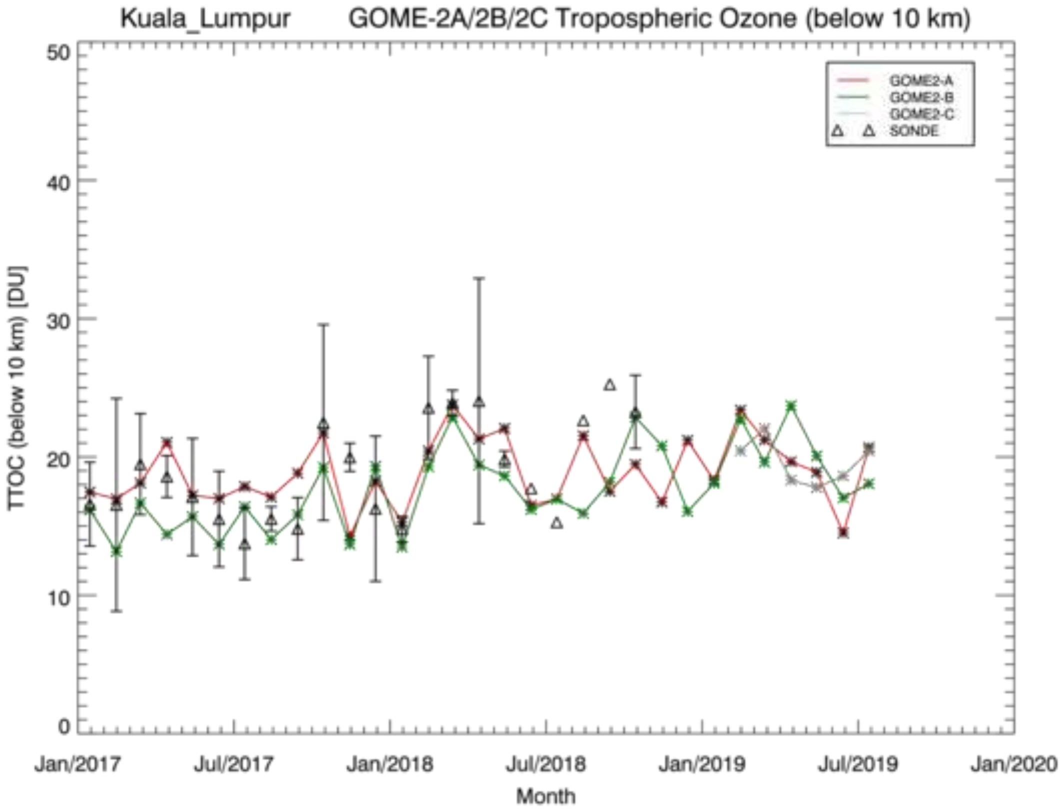
The accuracy of the GOME-2/CCD method has been assessed by comparing the tropospheric ozone columns with tropical ozonesonde measurements from the SHADOZ network as earlier described. Measurements have been used from eight sites (Table 2).

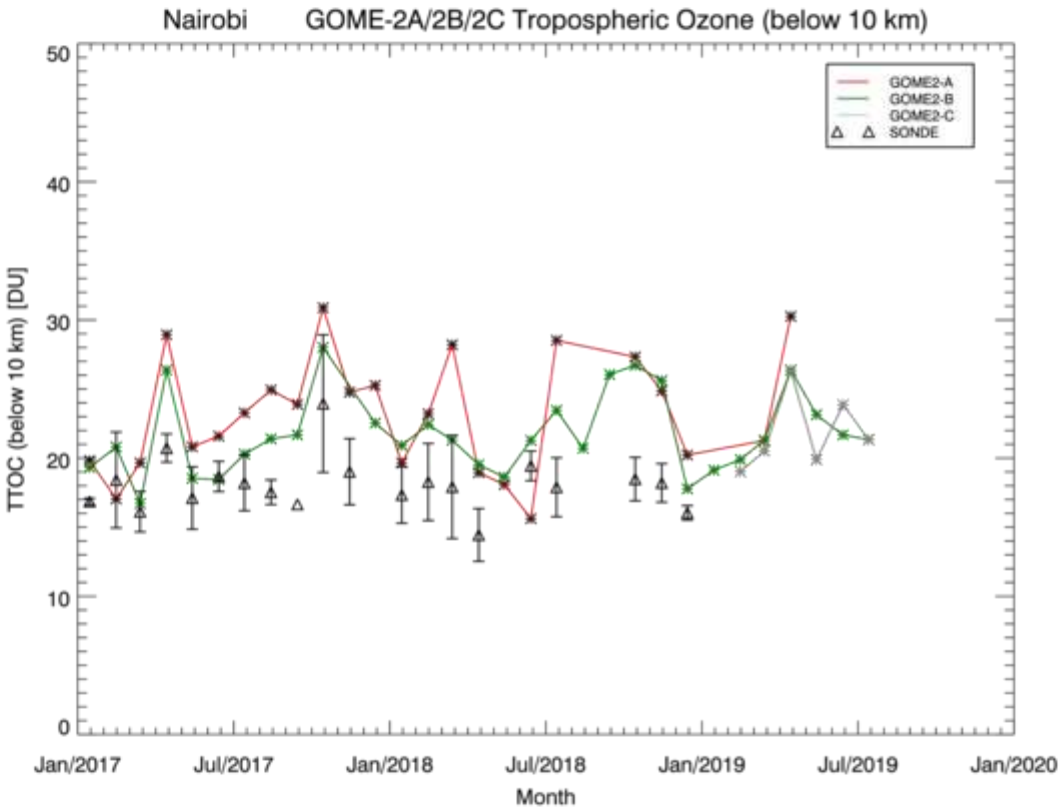
The monthly mean 0 - 10 km ozone column based on ozonesonde measurements is plotted against the monthly mean 0 - 10 km ozone column derived with the CCD method. The agreement is generally good, although the variability in the ozonesonde measurements is larger than the variability which is obtained from the zonally averaged CCD values.
The TTOC values at Kuala Lumpur show an underestimation when compared with the ozonesonde data for the GOME-2A/2B TTOC products, but are in general within the one sigma error bounds (Figure 4).
The TTOC values at Nairobi and Alajuela show a clear overestimation when compared with the observations.

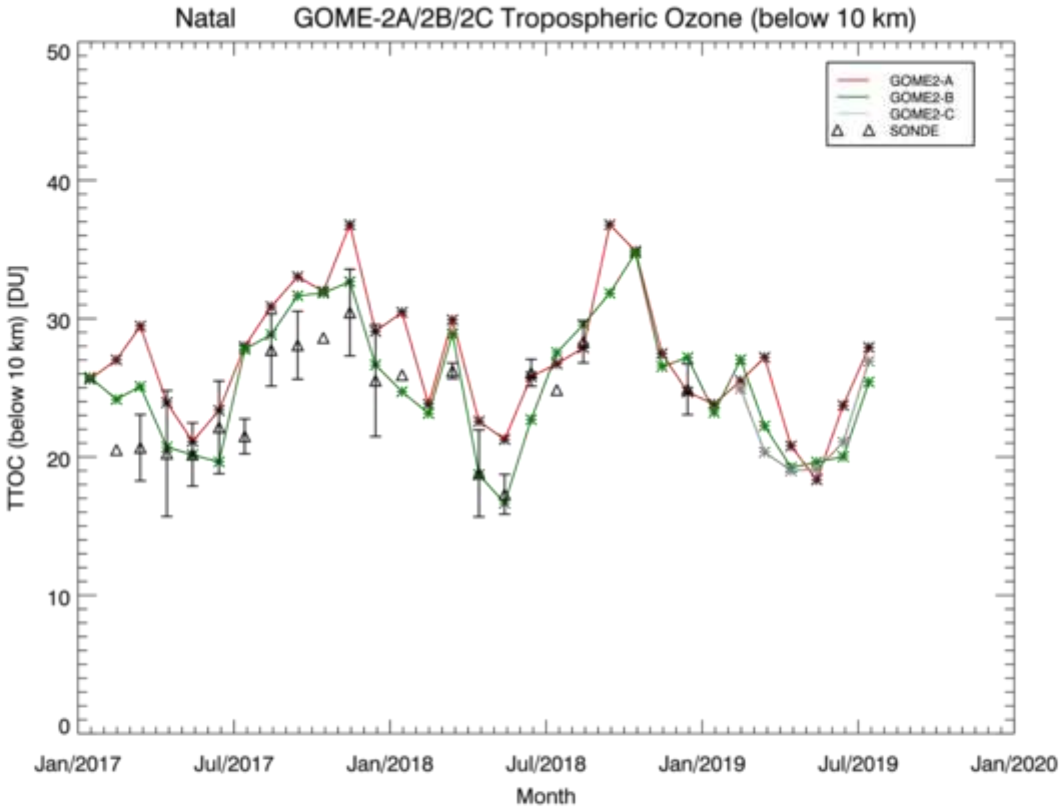
Stations like Natal, Ascension Island and to some extent Paramaribo show that the seasonal pattern observed by the ozonesondes is in good agreement with the obtained TTOC values. It is also shown that the variability in ozone concentrations from the ozonesonde data is lower, compared to the seasonal variation of the ozone concentrations, derived with the CCD method. Those stations are typically influenced by air pollution related to biomass burning and long-range transport, which enhances the production of tropospheric ozone concentrations in those regions. Most of the other tropical stations however only reveal a very weak seasonal cycle.
On top, the current available dataset, available for GOME-2C, has been plot in Figure 4.


Alajuela GOME-2A/2B/2C Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
Jan/2017
Jul/2017
Jan/2018
Jul/2018
Jan/2019
Jul/2019
Jan/2020
GOME2-A
GOME2-B
GOME2-C
SONDE

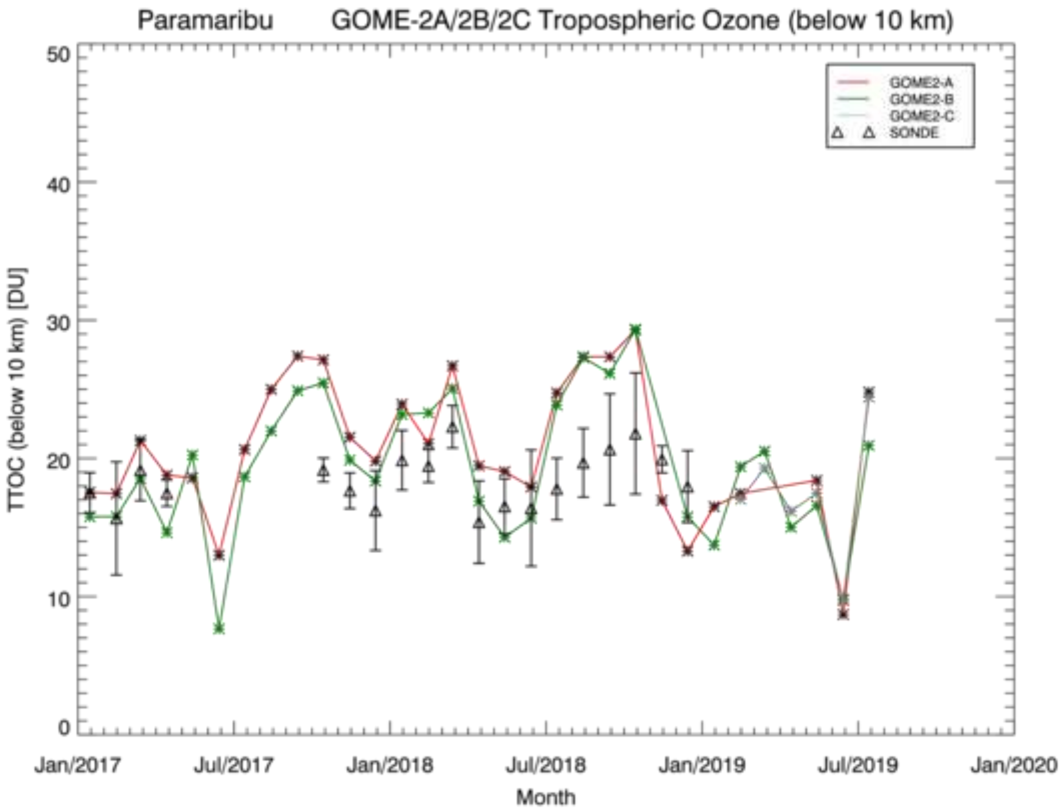

Ascension_Island GOME-2A/2B/2C Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
Jan/2017
Jul/2017
Jan/2018
Jul/2018
Jan/2019
Jul/2019
Jan/2020
GOME2-A
GOME2-B
GOME2-C
SONDE


Kuala_Lumpur GOME-2A/2B/2C Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
GOME2-A
GOME2-B
GOME2-C
SONDE
Jan/2017
Jul/2017
Jan/2018
Jul/2018
Jan/2019
Jul/2019
Jan/2020
0
10
20
30
40
50


Nairobi GOME-2A/2B/2C Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
GOME2-A
GOME2-B
GOME2-C
SONDE
Jan/2017
Jul/2017
Jan/2018
Jul/2018
Jan/2019
Jul/2019
Jan/2020
0
10
20
30
40
50



Natal GOME-2A/2B/2C Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
GOME2-C
SONDE
TTOC (below 10 km) [DU]
Jan/2017
Jul/2017
Jan/2018
Jul/2018
Jan/2019
Jul/2019
Jan/2020
Month



Paramaribu GOME-2A/2B/2C Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
GOME2-C
SONDE
TTOC (below 10 km) [DU]
Jan/2017
Jul/2017
Jan/2018
Jul/2018
Jan/2019
Jul/2019
Jan/2020
Month

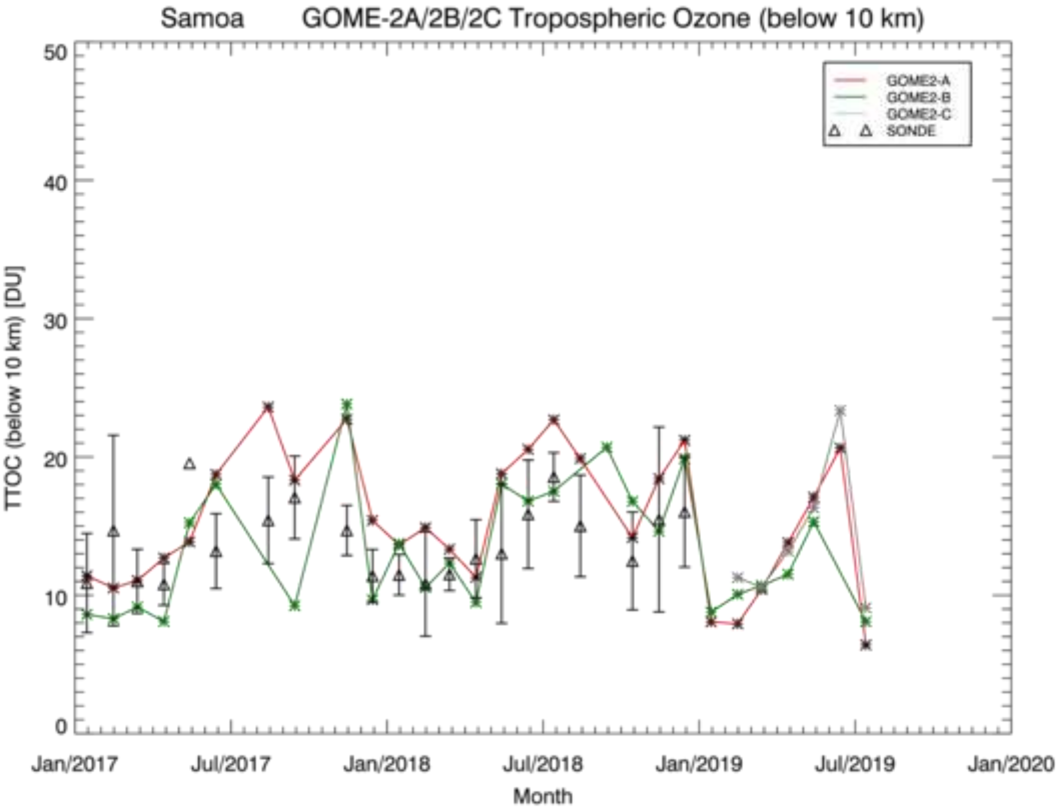


Figure 4: Tropospheric ozone columns (below 10 km) for Alajuela, Ascension, Kuala Lumpur, Nairobi, Natal, Paramaribo and Samoa for the time period January 2017 – July 2019. The triangles denote the integrated ozonesonde measurements with 1 σ error bar.

The TTOC product has the following user requirements:

- Threshold accuracy: within 50 %
- Target accuracy: within 20 %
- Optimal accuracy: within 15 %

Comparisons of the GOME-2 tropospheric ozone data with simulations of the ECHAM/MESSy Atmospheric Chemistry (EMAC) model are shown in [R9]. These comparisons for the 2009 El Niño conditions illustrate the usefulness of the GOME-2 TOC product in evaluating chemistry climate models (CCM's). Evaluation of CCM's with appropriate satellite observations helps to identify strengths and weaknesses of the model systems, providing a better understanding of driving mechanisms and adequate relations and feedbacks in the Earth atmosphere, and finally leading to improved models.

It is shown (Table 3 and Table 4) that most of the stations are within the target accuracy (20 %). The correlation varies between 0.5 and 0.9 with a rmse between 2.8 and 8.9 DU. There is also an offset present between GOME-2A and GOME-2B as described in [R10].

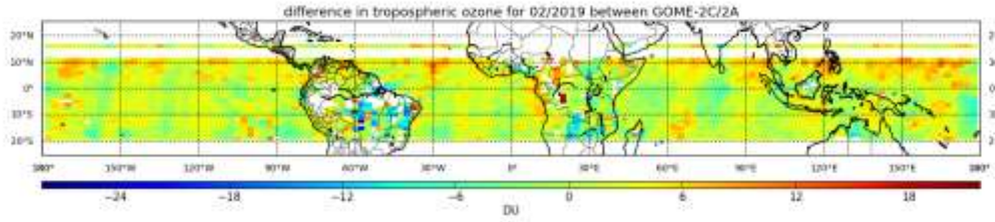
The TTOC products for GOME-2A/2B still meet the user requirements. The time period under consideration is January 2017 until June 2019. This is due to a lack of new ground truth data.

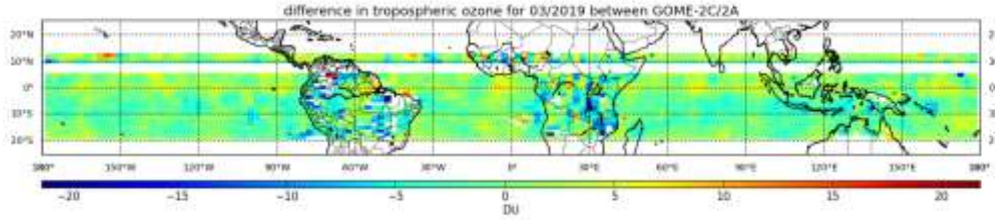
We will evaluate the GOME-2C product as earlier mentioned in this report by looking at difference plots between GOME-2C/2A and GOME-2C/2B in the next section.

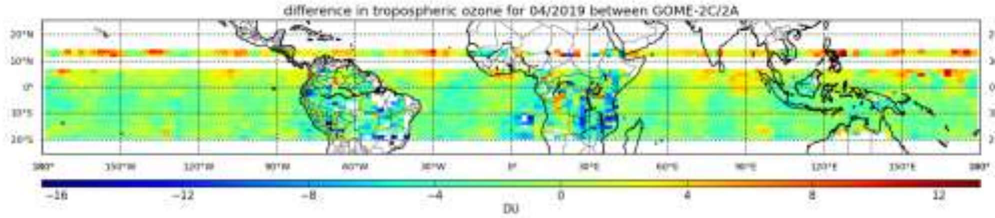
5.2 Difference plots

5.2.1 Difference plots between GOME-2C and GOME-2A

Figure 5 shows some examples of difference plots in tropospheric total ozone column for GOME-2C – GOME-2A, including the months February until July 2019. Table 5 shows the statistics on these differences.







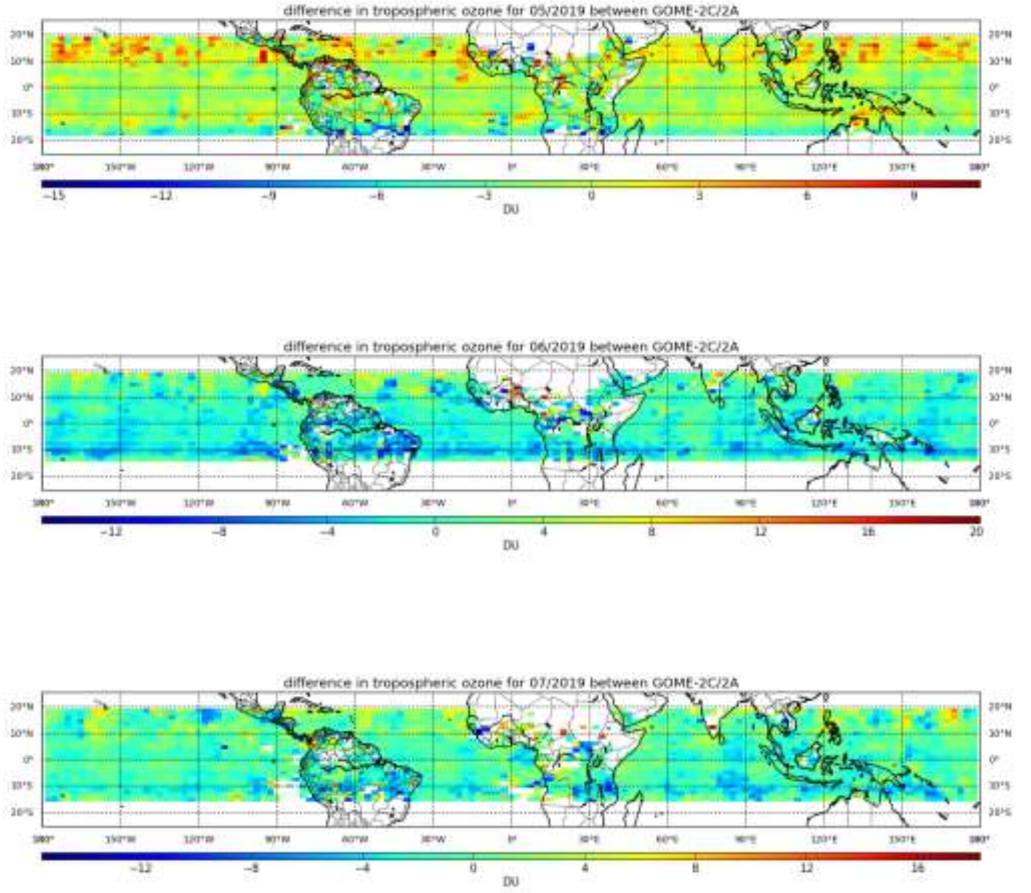
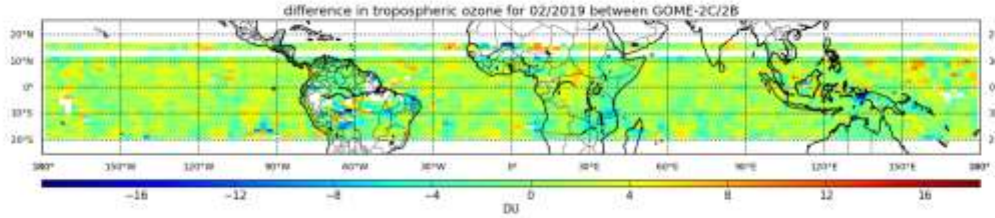
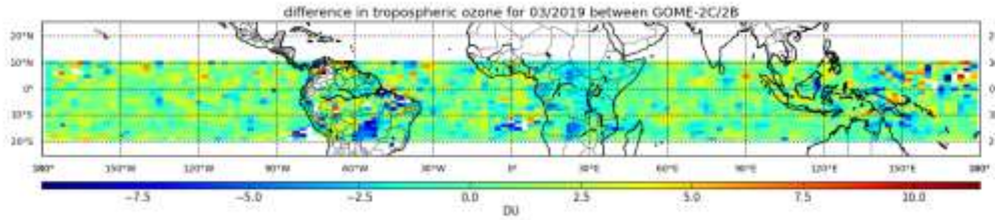


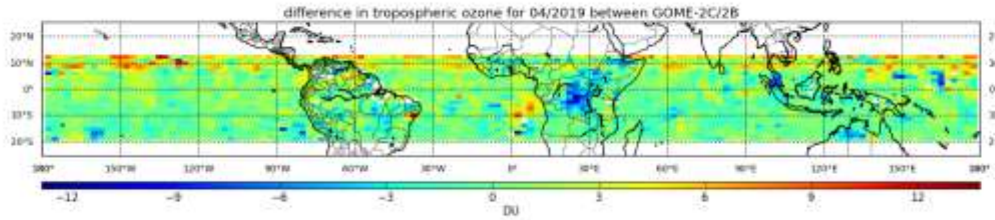
Figure 5: Difference plots in tropospheric total ozone column (DU) for the time period February until July 2019 between GOME-2C and GOME-2A.

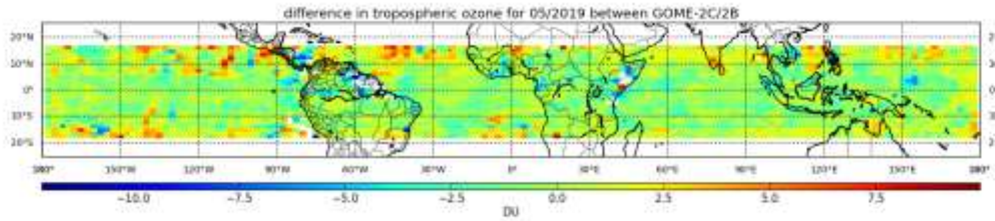
5.2.2 Difference plots between GOME-2C and GOME-2B

Figure 6 shows some difference plots in TTOC between GOME-2C and GOME-2B including the months February until July 2019. Table 6 shows the statistics on these differences.









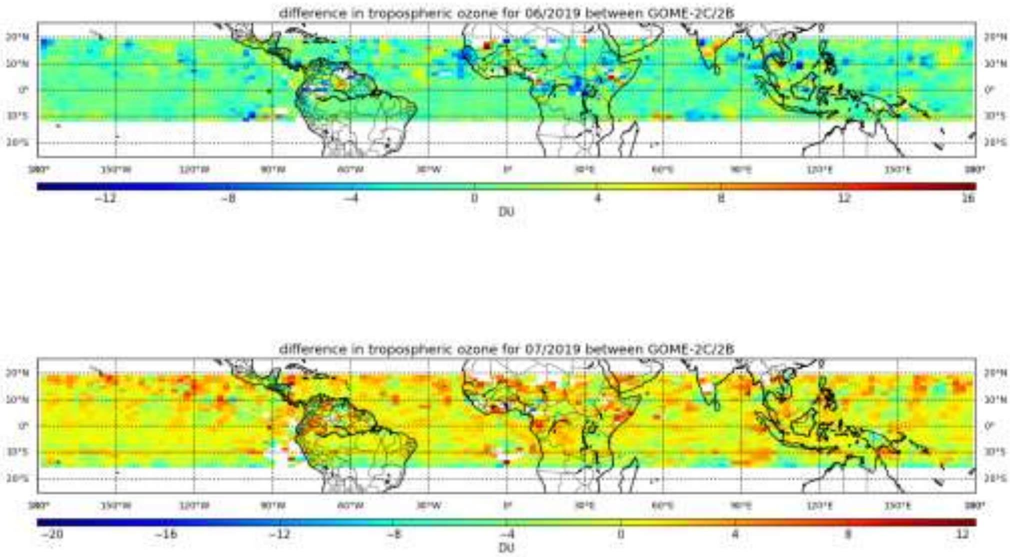


Figure 6: Difference plots in total tropospheric total ozone column (DU) for the time period February until July 2019 between GOME-2C and GOME-2B.

In Table 5 the averaged differences between the TTOC products for the GOME-2C and the GOME-2A sensors are shown, together with the standard deviation (DU) for 6 months. Table 6 shows averaged differences between the TTOC products for the GOME-2C and the GOME-2B sensors.

Table 5:Statistics on difference plots between the TTOC products for the GOME-2C and the GOME-2A sensors.

Month	Mean (DU)	std (DU)
February	1.71	3.82
March	-0.22	3.52
April	-0.92	2.85
May	-0.69	2.70
June	-0.46	2.88
July	-0.55	2.82
All	-0.19	3.10

Table 6:Statistics on difference plots between the TTOC products for the GOME-2C and the GOME-2B sensors.

Month	Mean (DU)	std (DU)
February	0.79	2.77
March	0.50	2.19
April	0.60	2.52
May	0.01	1.95
June	0.17	2.43
July	0.28	2.56
All	0.39	2.40

These differences are small and confirm the offset which is present between GOME-2A and GOME-2B TTOC product [R10]. The averaged differences between GOME-2C and respectively GOME-2A and GOME-2B are within on average -0.2 (3.1) DU and 0.4 (2.4) DU.

6. Conclusions

This validation report reveals that the GOME-2C offline Tropical Tropospheric Ozone Column product is after comparison with the operational TTOC products onboard GOME-2A and GOME-2B are within an acceptable averaged range of respectively -0.2 (3.1) DU and 0.4 (2.4) DU.

The comparisons of TTOC products from GOME-2A and GOME-2B, validated against balloon sounding data, are still for most of the stations within the target accuracy (20 %). Therefore, it can be concluded that the offline Tropical Tropospheric Ozone Column products also meets the user requirements.

7. Acknowledgement

The ozonesonde data was made available by the SHADOZ network (http://croc.gsfc.nasa.gov/shadoz/).

8. References

[R1] Algorithm Theoretical Basis Document for GOME-2 Offline Tropospheric Ozone, Cloud slicing, SAF/DLR/GOME/ATBD_toc/01/A, Valks, P., 2015.
[R2] Product User Manual for GOME-2 Offline Tropospheric Ozone, Cloud slicing, SAF/DLR/GOME/PUM/01/A, Klaus-Peter Heue, 2015.
[R3] Thompson, A.M., J.C. Witte, R.D. McPeters, S.J. Oltmans, F.J. Schmidlin, J.A. Logan, M.Fujiwara, V.W.J.H. Kirchhoff, F. Posny, G.J.R. Coetzee, B. Hoegger, S. Kawakami, T. Ogawa, B.J. Johnson, H. Vömel and G. Labow, Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 Tropical ozone climatology 1. Comparison with Total Ozone Mapping Spectrometer (TOMS) and ground-based measurements, *J. Geophys. Res.*, Vol. 108 No. D2, 8238, doi: 10.1029/2001JD000967, 30 January 2003.
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