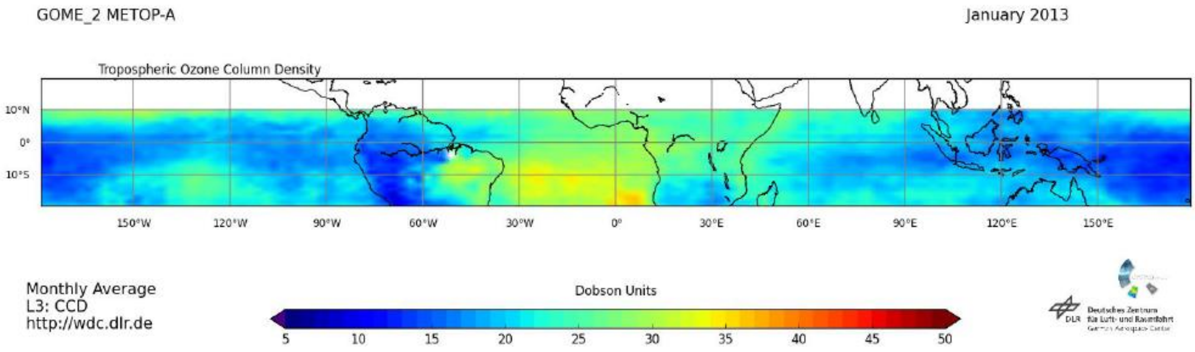
O3M SAF VALIDATION REPORT

Validated products:

Identifier	Name	Acronym
O3M-35	Offline Tropospheric Ozone column Product GOME-2A	OTO/O3Tropo
O3M-43	Offline Tropospheric Ozone column Product GOME-2B	OTO/O3Tropo



Author:

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Reporting period: January 2007 - December 2014

Validation methods: Balloon soundings

Input data versions: Base Algorithme Version: GDP 4.8

Table of Contents

1. Applicable O3MSAF 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.

2. General Introduction

This report contains validation results of the GOME-2A and GOME-2B 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 4.8) 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 January 2007 until December 2014 for GOME-2A and January 2013 – December 2014 for GOME-2B. 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 fulfills the user requirements.

3. Tropospheric ozone retrieval

The Convective Cloud Differential (CCD) algorithm is described in detail in [R1] and [R7]. 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 [R7].

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.

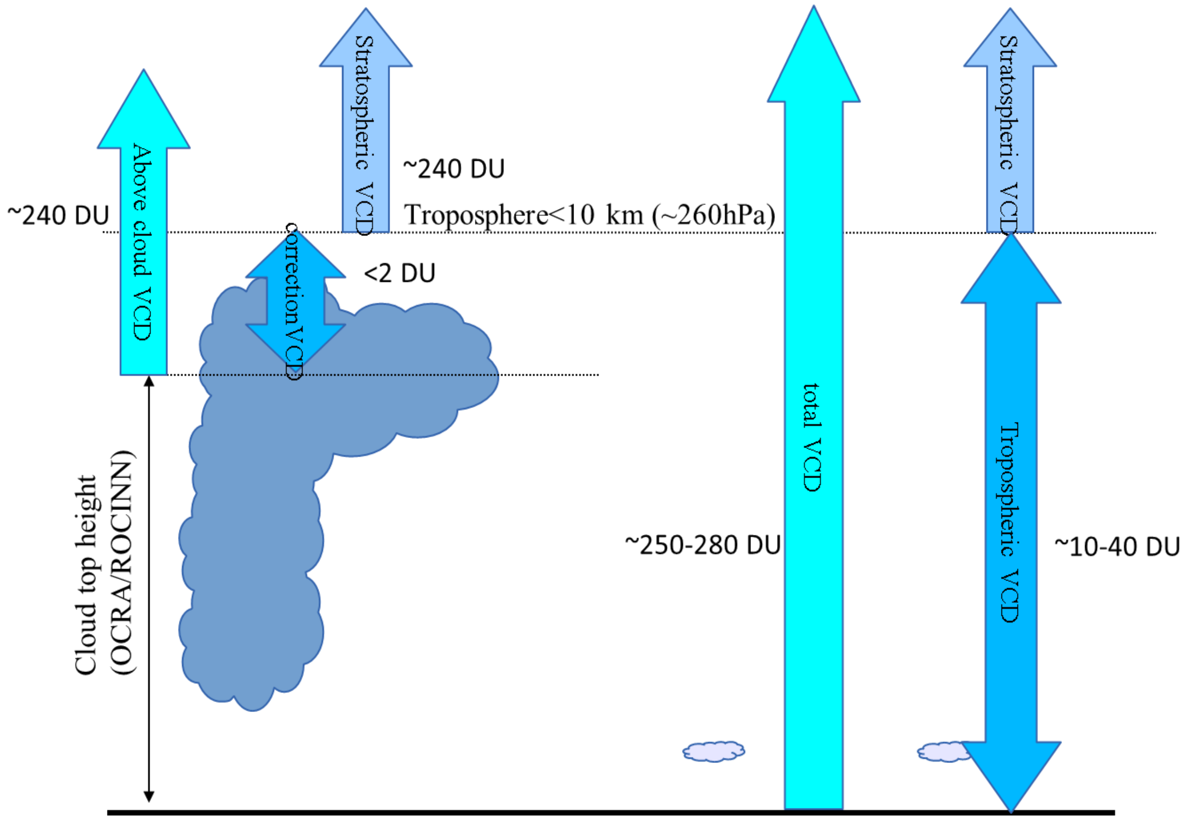


Figure 1: The total columns in the cloud free GOME pixels contain the complete tropospheric signal in addition to the stratospheric one. Therefore the difference between the total ozone columns for cloud free observations and the stratospheric column for the respective latitude band equals the tropospheric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

4. Validation of tropical tropospheric ozone columns using ozonesondes

4.1 Introduction

This report contains validation results of the GOME-2A and GOME-2B offline tropical tropospheric ozone column (TTOC) products 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 O3MSAF 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]).

4.2 Dataset description

The offline Tropical tropospheric ozone dataset used in this validation report for the GOME-2A product contains the time period January 2007 till December 2014 and for the GOME-2B product, the time period under consideration is January 2013 till December 2014.

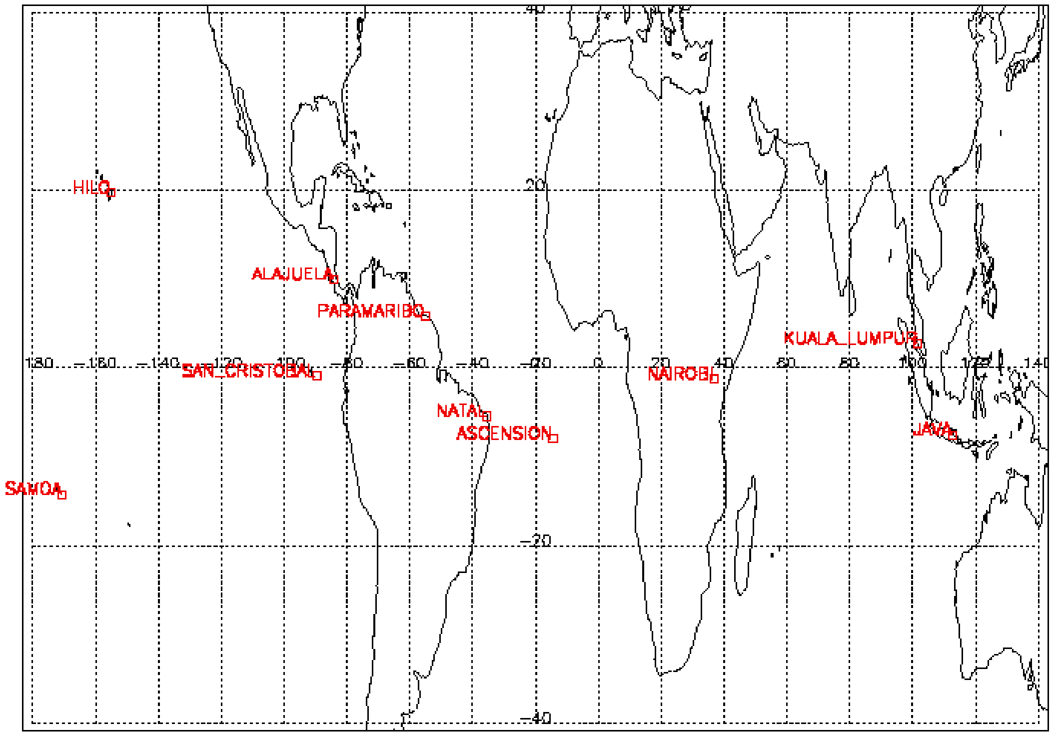


Figure 2: Stations used in the validation report

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 with the numbers of sondes used in the analysis and the last day, a sonde was available for the intercomparison

STATION	Lat(°)	Long(°)	Nr of sondes	Last day available
ASCENSION	-7.98	-14.42	131	24/08/2010
HILO	19.717	155.083	321	7/01/2015
ALAJUELA	9.98	-84.21	270	20/12/2013
JAVA	-7.5	112.6	90	30/10/2013
KUALA_LUMPUR	2.73	101.7	145	17/12/2013
NAIROBI	-1.27	36.8	314	31/12/2014
NATAL	-5.42	-35.38	162	10/12/2014
PARAMARIBO	5.81	-55.21	258	29/12/2014
SAMOA	-14.23	-170.56	213	28/01/2015
SAN_CRISTOBAL	-0.92	-89.6	89	30/01/2014

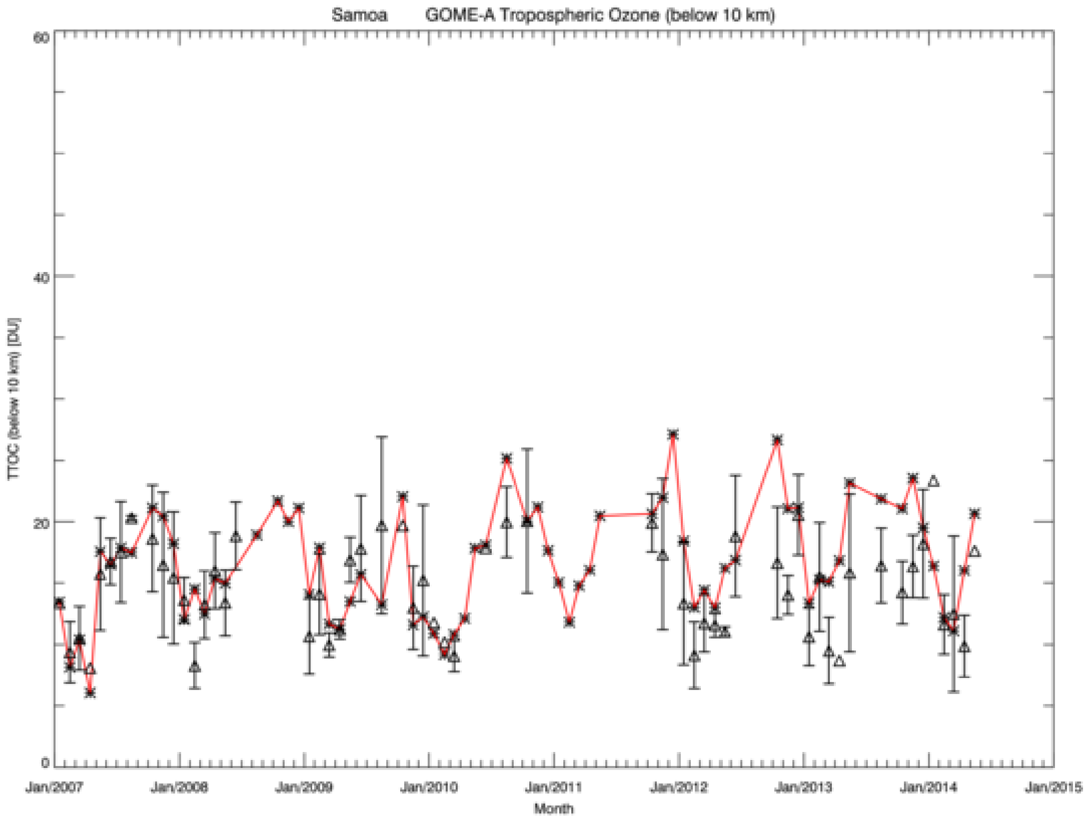
5. Results

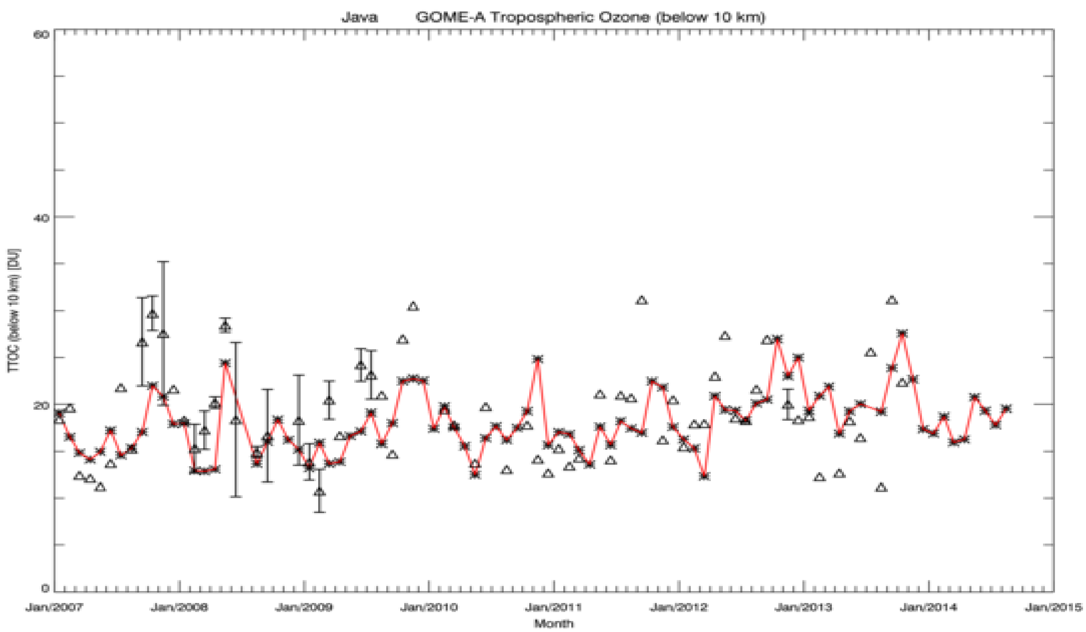
5.1 Comparisons with ozonesonde data from the SHADOZ network

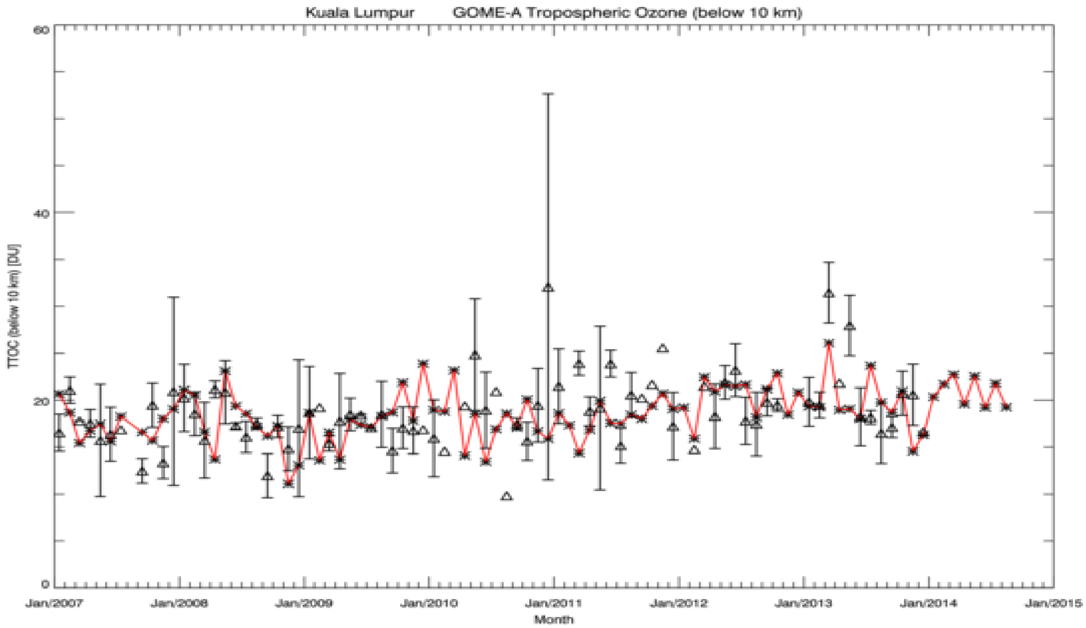
5.1.1 METOP-A

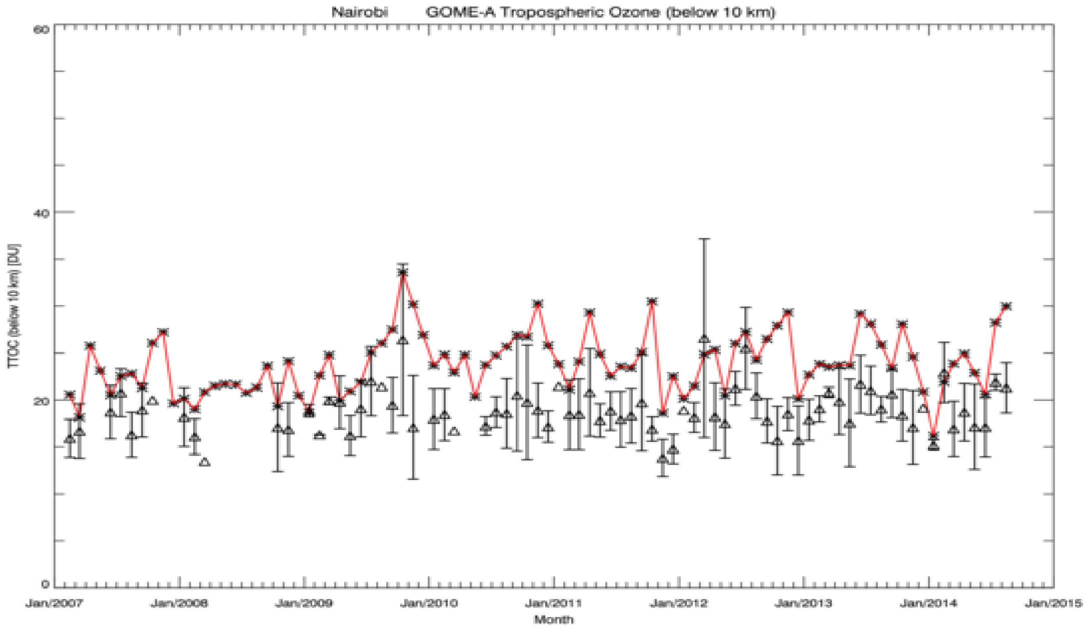
The accuracy of the GOME-2/CCD method has been assessed by comparing the tropospheric ozone columns with tropical ozonesonde measurements from the SHADOZ network as earlier described. Measurements have been used from ten sites (Table 2).

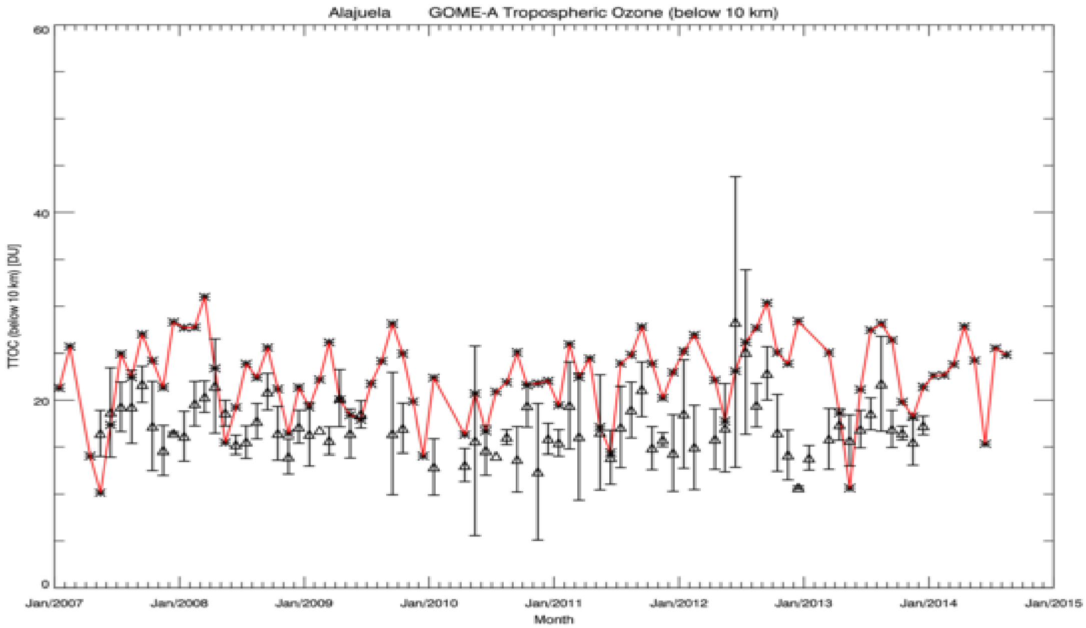
The monthly mean 0 - 10 km ozone column based on ozonesonde measurements is plotted against the monthly mean 0 - 10 km ozone column derived with the CCD method. The agreement is generally good, although the variability in the ozonesonde measurements is larger than the variability which is obtained from the zonally averaged CCD values.
The TTOC values at Ascension Island, Java and Kuala Lumpur show an underestimation when compared with the ozonesonde data for the GOME-2A TTOC product, but are most of the time within the one sigma error bounds (Fig. 3).
The TTOC values at Nairobi and Alajuela show an overestimation when compared with the observations (Table 3).
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 (Fig. 4). Most of the other tropical stations however only reveal a very weak seasonal cycle.

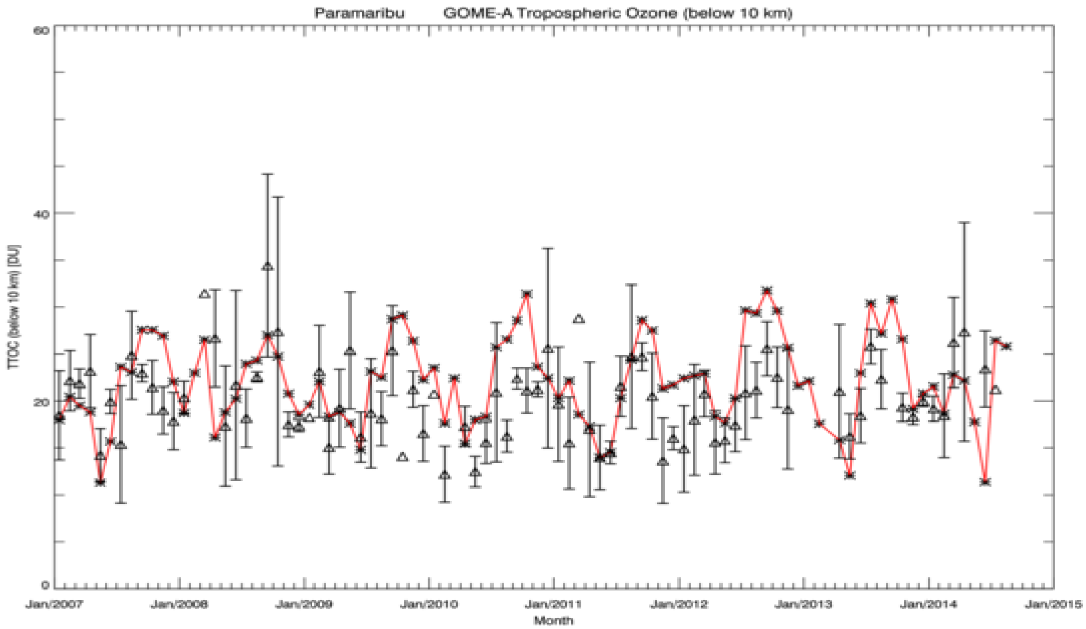

Samoa GOME-A Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
Jan/2007
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Jan/2014
Jan/2015

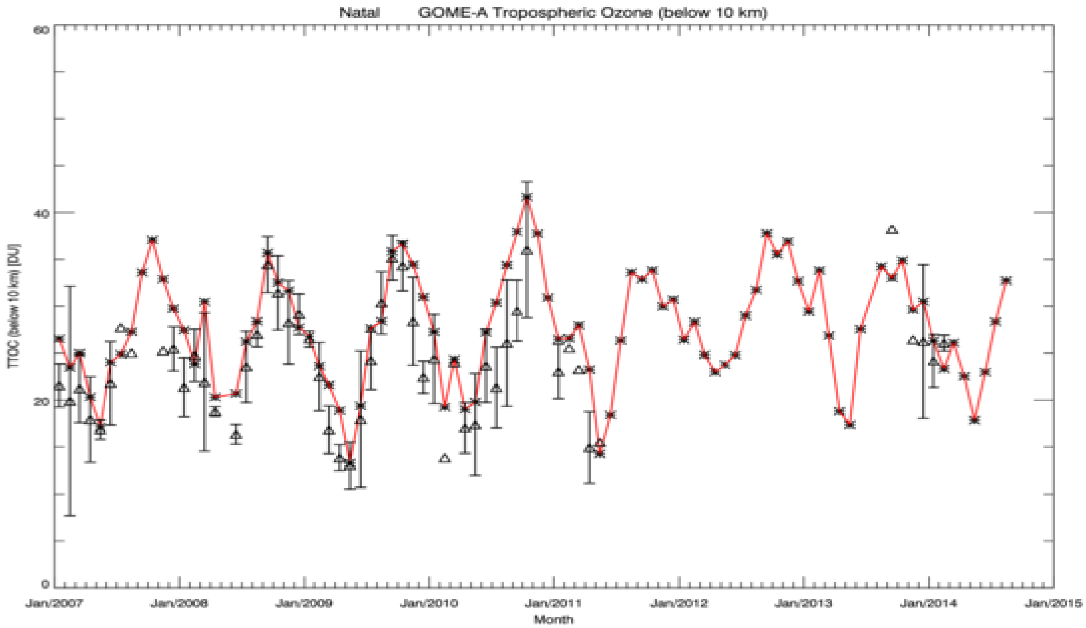

Java GOME-A Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
Jan/2007
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Jan/2014
Jan/2015


Kuala Lumpur GOME-A Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
Jan/2007
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Jan/2014
Jan/2015


Nairobi GOME-A Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
Month
Jan/2007
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Jan/2014
Jan/2015


Alajuela GOME-A Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
0
20
40
60
Jan/2007
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Jan/2014
Jan/2015
Month


Paramaribu GOME-A Tropospheric Ozone (below 10 km)
TTOC (below 10 km) [DU]
0
20
40
60
Jan/2007
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Jan/2014
Jan/2015
Month



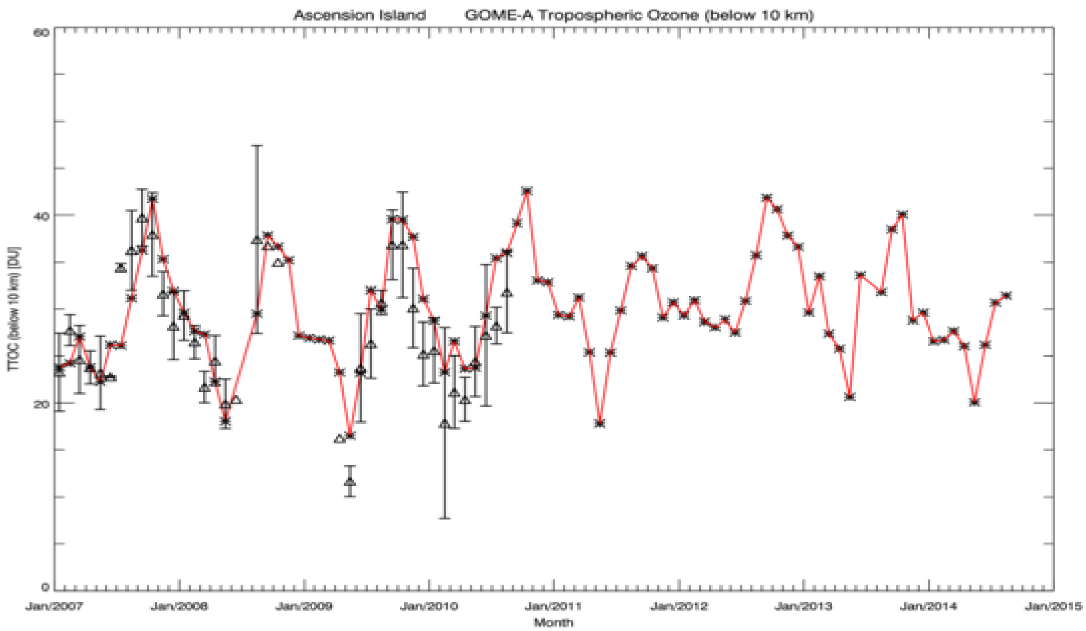


Figure 3: Tropospheric ozone columns (below 10 km) for American Samoa, Java, Kuala Lumpur, Nairobi, Alajuela, Paramaribo, Natal and Ascension for the period January 2007 – December 2014. The triangles denote the integrated ozonesonde measurements with 1σ error bars. The asterisks denote the tropospheric ozone columns derived with the GOME-2/CCD method.

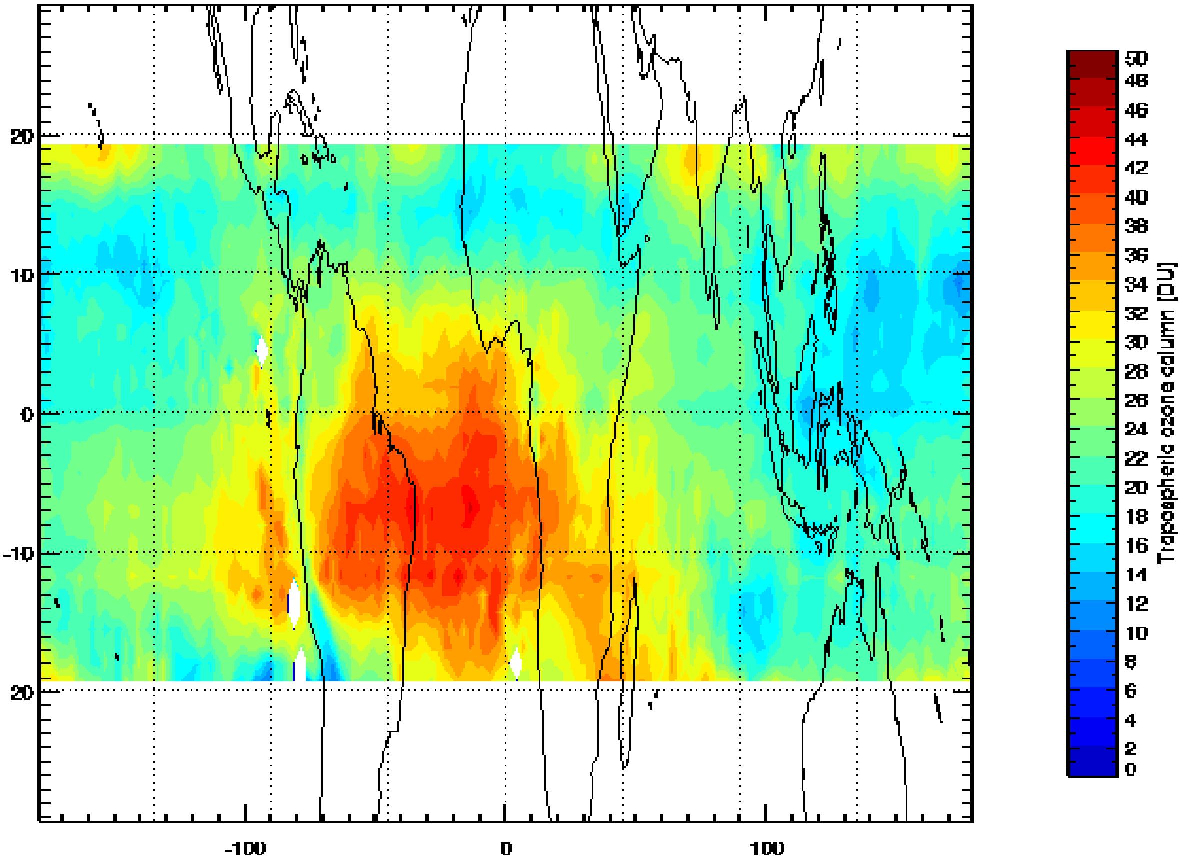
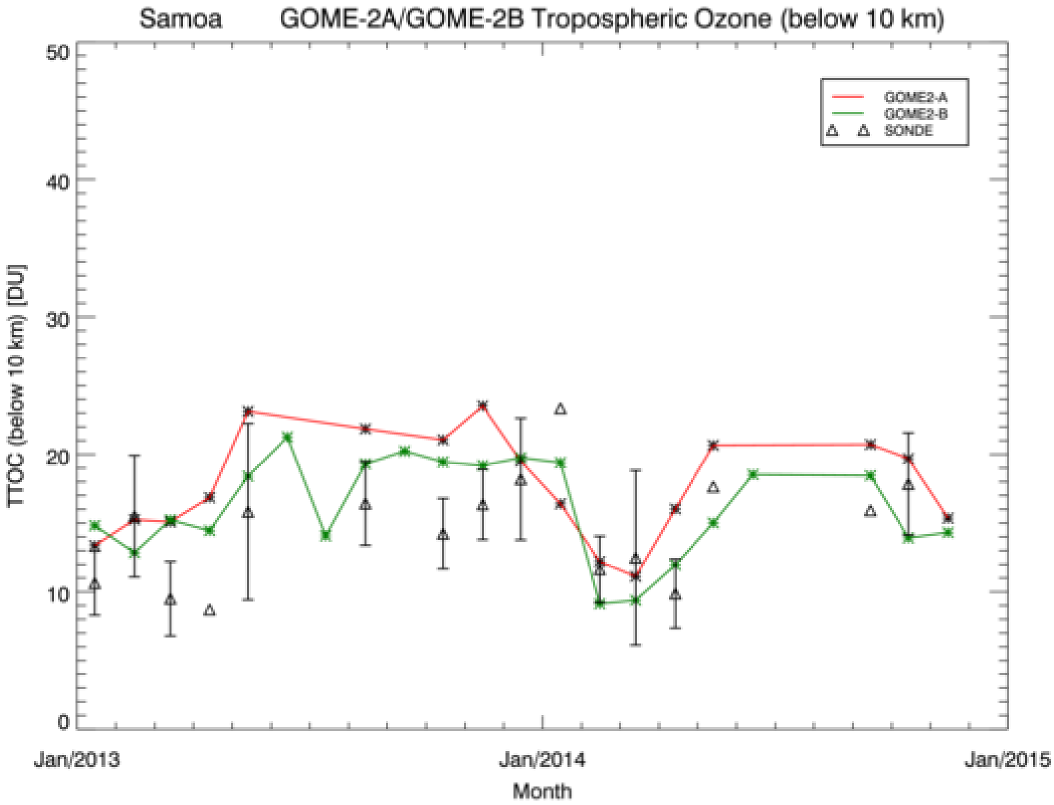
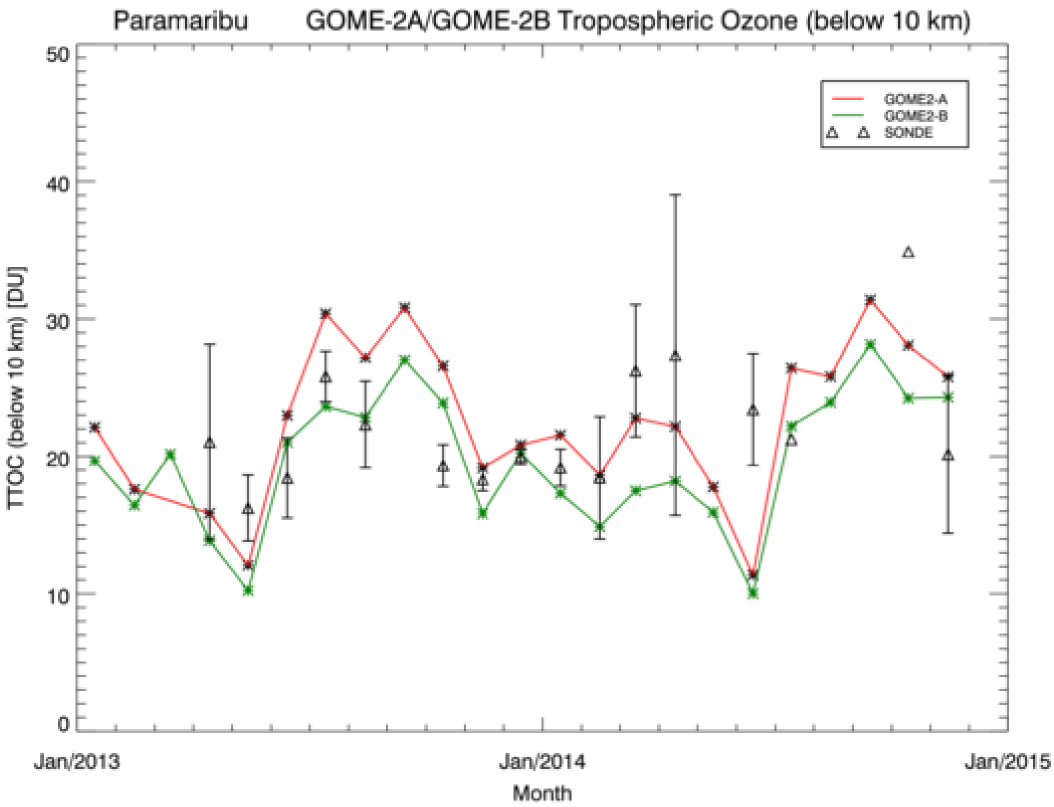


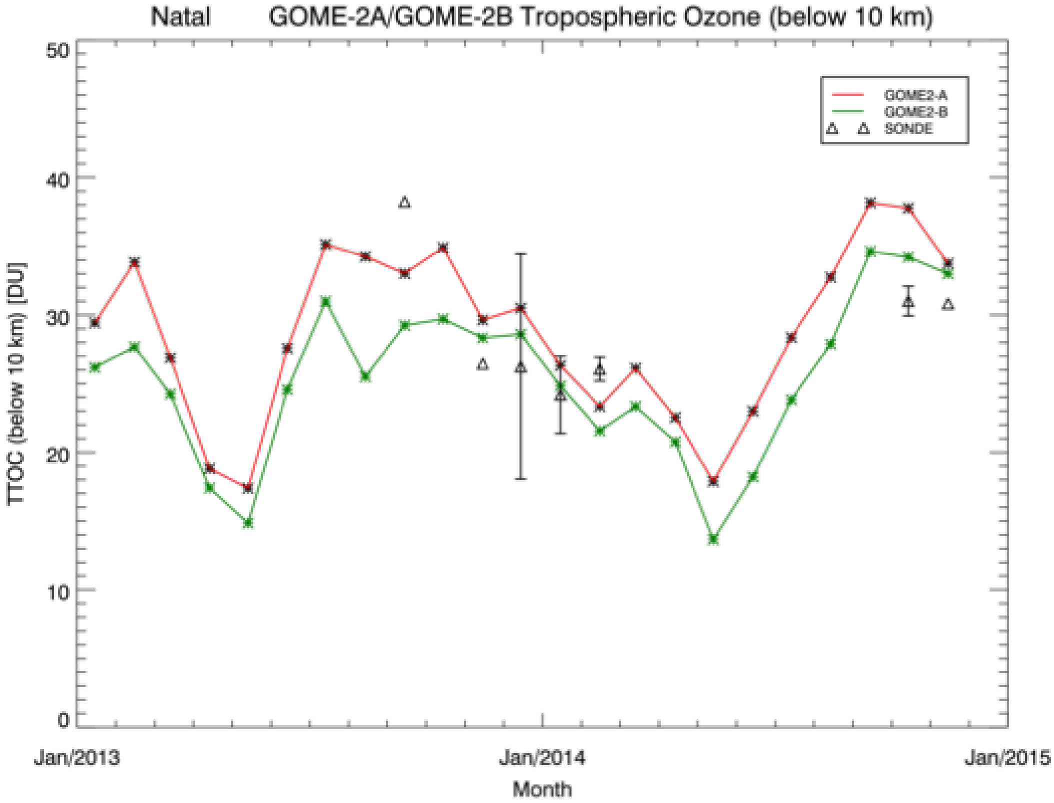
Figure 4: Southern hemisphere biomass burning hot spots measured by GOME-2 in October 2010

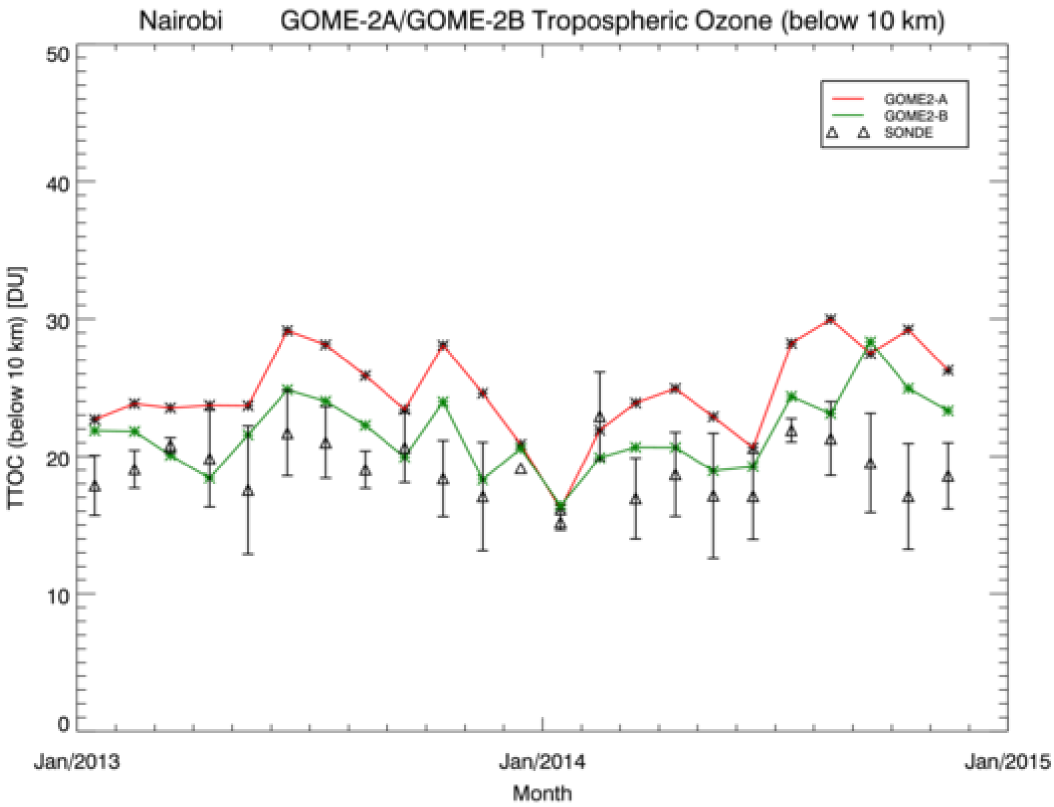
5.1.2 METOP-B

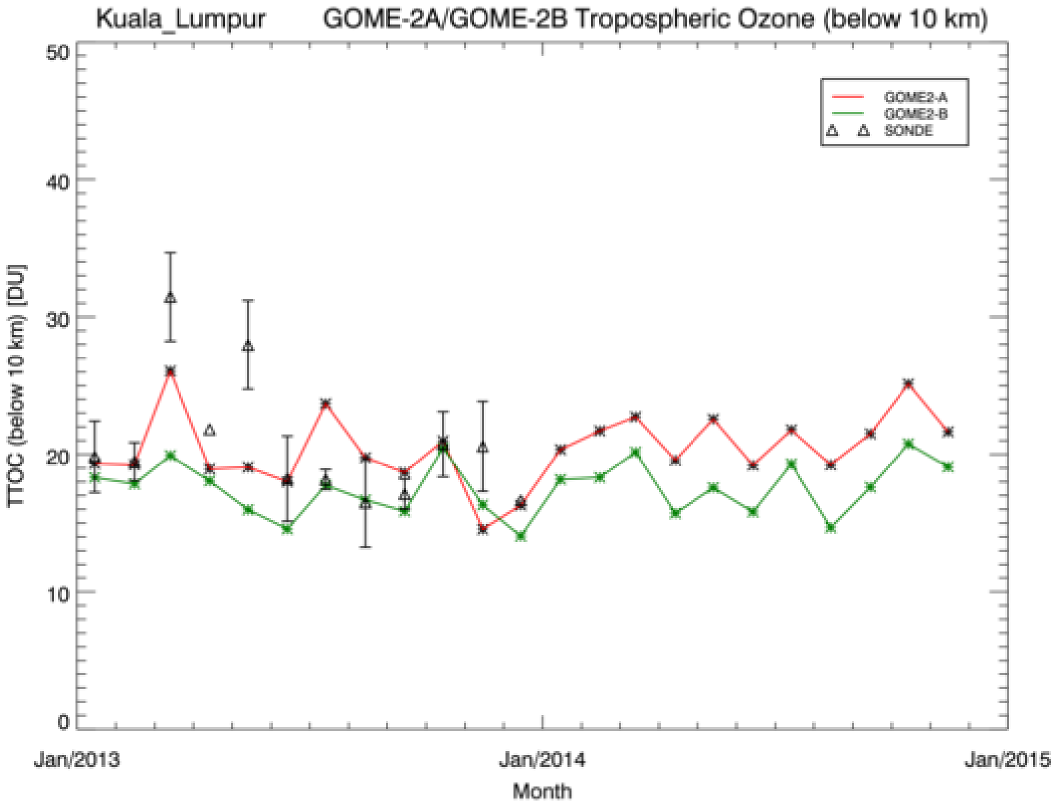
Also for the GOME-2B instrument intercomparisons with ozonesonde data have been performed for some stations. It has to be stressed that data becomes for most of the stations available after a few months after sensing. For this reason, for most of the stations, we didn't have 2 years of sonde data available yet to be used in this validation study. Figure 5 shows some time series for the GOME-2A and GOME-2B TTOC product together with the integrated ozonesonde measurements with 1σ error bars.

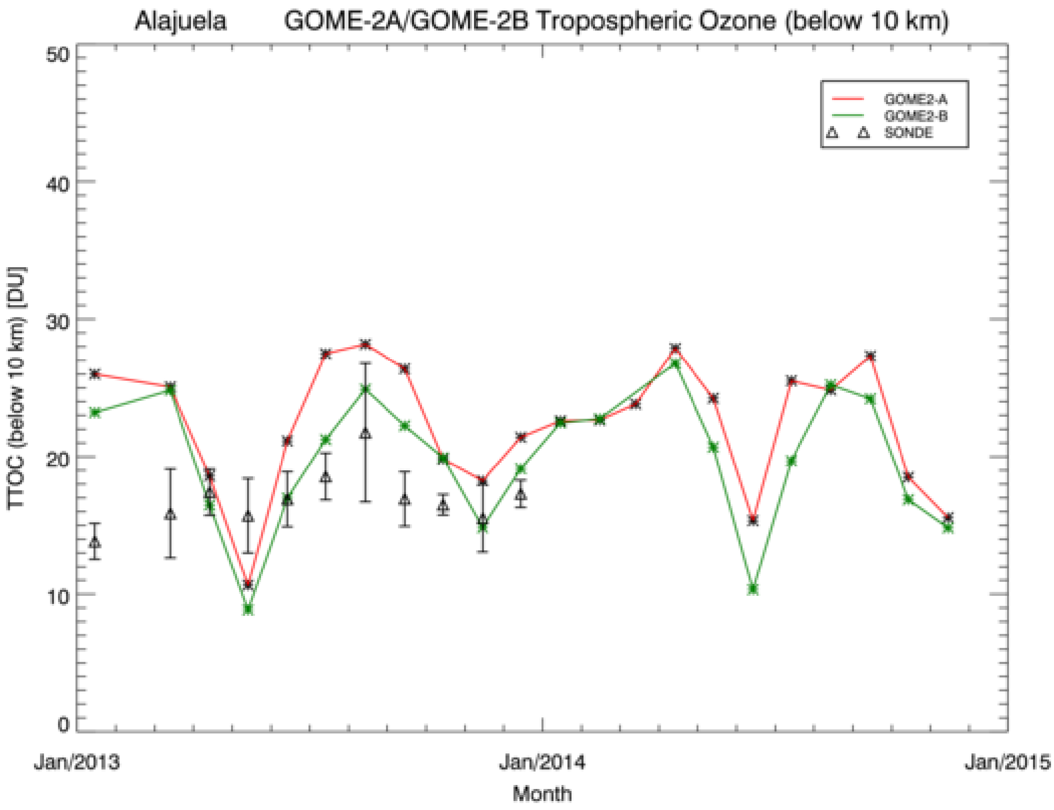

Samoa GOME-2A/GOME-2B Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
SONDE
TTOC (below 10 km) [DU]
0
10
20
30
40
50
Jan/2013
Jan/2014
Jan/2015
Month


Paramaribu GOME-2A/GOME-2B Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
SONDE
TTOC (below 10 km) [DU]
0
10
20
30
40
50
Jan/2013
Jan/2014
Jan/2015
Month


Natal GOME-2A/GOME-2B Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
SONDE
TTOC (below 10 km) [DU]
0
10
20
30
40
50
Jan/2013
Jan/2014
Jan/2015
Month


Nairobi GOME-2A/GOME-2B Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
SONDE
TTOC (below 10 km) [DU]
0
10
20
30
40
50
Jan/2013
Jan/2014
Jan/2015
Month


Kuala_Lumpur GOME-2A/GOME-2B Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
SONDE
TTOC (below 10 km) [DU]
Jan/2013
Jan/2014
Jan/2015
Month


Alajuela GOME-2A/GOME-2B Tropospheric Ozone (below 10 km)
GOME2-A
GOME2-B
SONDE
TTOC (below 10 km) [DU]
Jan/2013
Jan/2014
Jan/2015
Month

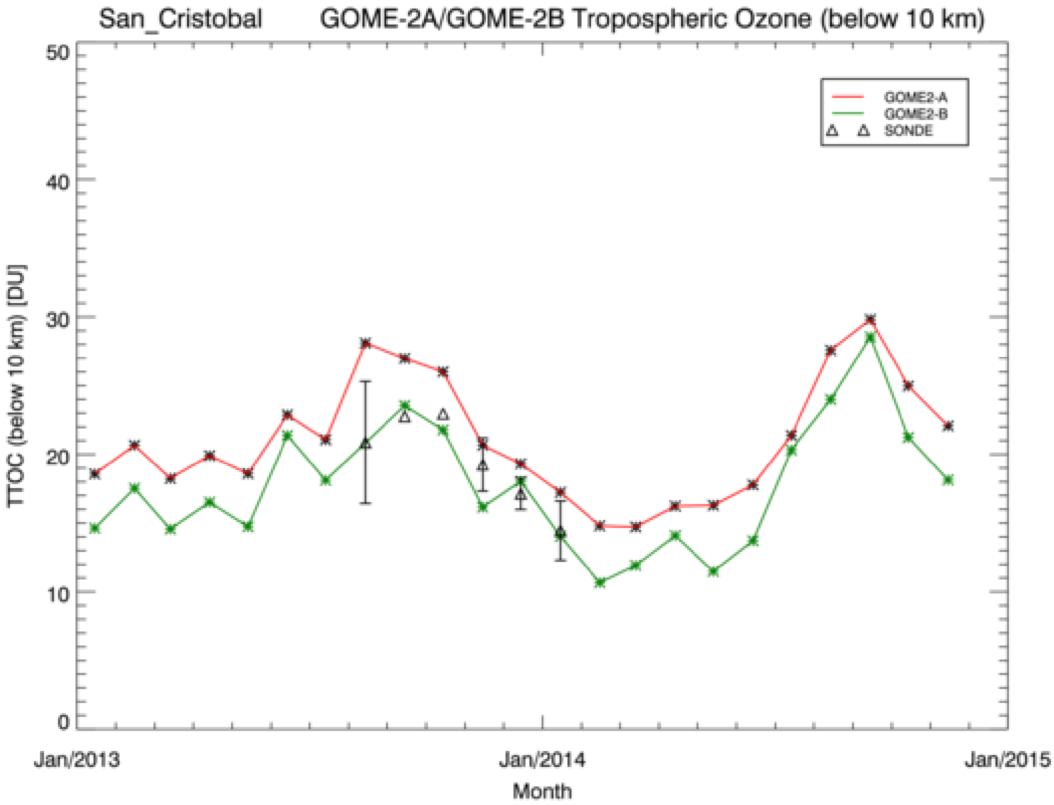


Figure 5. Tropospheric ozone columns (below 10 km) for Alajuela, Paramaribo, Nairobi, Natal, San Cristobal, Kuala Lumpur and Samoa for the time period January 2013 – December 2014. The triangles denote the integrated ozonesonde measurements with 1σ error bars. The asterisks denote the tropospheric ozone columns derived with the GOME-2/CCD method for GOME-2A (in red) and for GOME-2B (in green).

6. Statistics

The TTOC product has the following requirements:

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

6.1 METOP-A

Table 3 describes some general statistics for the GOME-2A dataset. It shows that most of the stations are within the optimal accuracy. The correlation varies between 0.20 and 0.89 with a rmse between 3 and 7 DU.

Comparisons of the GOME-2 tropospheric ozone data with simulations of the ECHAM/MESSy Atmospheric Chemistry (EMAC) model are shown in [R7]. 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.

Table 3. Relative Differences (RD), standard deviation (STDEV), bias, correlation and rmse are shown on the accuracy of the GOME-2 TTOC product for the time period January 2007 – December 2014

Station	RD (%)	STDEV (%)	COR	bias (DU)	rmse (DU)
Paramaribo	14.0	22.6	0.53	2.34	4.89
Alajuela	33.7	29.8	0.34	5.39	6.87
Samoa	14.9	24.1	0.65	1.92	3.85
Ascension_Island	-1.6	15.4	0.75	-0.34	3.12
Kuala_Lumpur	-1.3	19.5	0.20	-0.75	4.09
Nairobi	31.1	18.1	0.45	5.61	6.39
Natal	16.6	14.8	0.89	3.53	4.54
San_Cristobal	16.4	31.3	0.47	2.51	6.35
Java	-13.2	21.0	0.68	-3.34	5.14
Hilo	25.3	18.4	0.61	5.43	7.35

6.2 METOP-B

Table 4 summarizes the statistics obtained for the GOME-2B TTOC dataset. It shows that all the stations are within the optimal accuracy.

Table 4. Relative Differences (RD), standard deviation (STDEV), bias, correlation and rmse are shown on the accuracy of the GOME-2 TTOC product for the time period January 2013 – December 2014

Station	RD (%)	STDEV (%)	COR	bias (DU)	rmse (DU)
Paramaribo	-13.2	23.3	0.34	-3.27	6.20
Alajuela	14.6	30.4	0.30	2.37	5.01
Samoa	13.9	30.1	0.47	1.43	3.95
Kuala_Lumpur	-14.9	13.7	0.45	-3.56	5.30
Nairobi	14.0	14.5	0.36	2.57	3.70
Natal	-0.7	13.8	0.51	-0.46	4.24
San_Cristobal	-3.1	8.5	0.91	-0.60	1.59

The GOME-2B TTOC data generally shows a small negative offset compared to GOME-2A, which is most likely related to a small negative bias in the GOME-2B total ozone columns for cloud-free conditions (currently under investigation).

7. Conclusions

The validation report reveals that the GOME-2A offline Tropical Tropospheric Ozone Column product is after comparison with balloon sounding ozonesonde data for most of the stations within the optimal accuracy (15 %). For the GOME-2B product this is true for all the stations used in the validation.

The offset issue between the GOME-2A and GOME-2B is currently under investigation and is related to the cloud cover as earlier described in this report.

Therefore it can be concluded that these offline Tropical Tropospheric Ozone Column products fulfill the user requirements.

8. Acknowledgement

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

9. 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.
[R4] Thompson, A.M., J.C. Witte, 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, J.P.F. Fortuin, and H.M. Kelder, Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 Tropical ozone climatology 2. Tropospheric variability and the zonal wave-one, *J. Geophys. Res.*, Vol. 108 No. D2,8241, doi: 10.1029/2002JD002241, 31 January 2003.
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[R7] Valks, P., Hao, N., Gimeno Garcia, S., Loyola, D., Dameris, M., Jöckel, P., and Delcloo, A.: Tropical tropospheric ozone column retrieval for GOME-2, Atmos. Meas. Tech., 7, 2513-2530, doi: 10.5194/amt-7-2513-2014, 2014.