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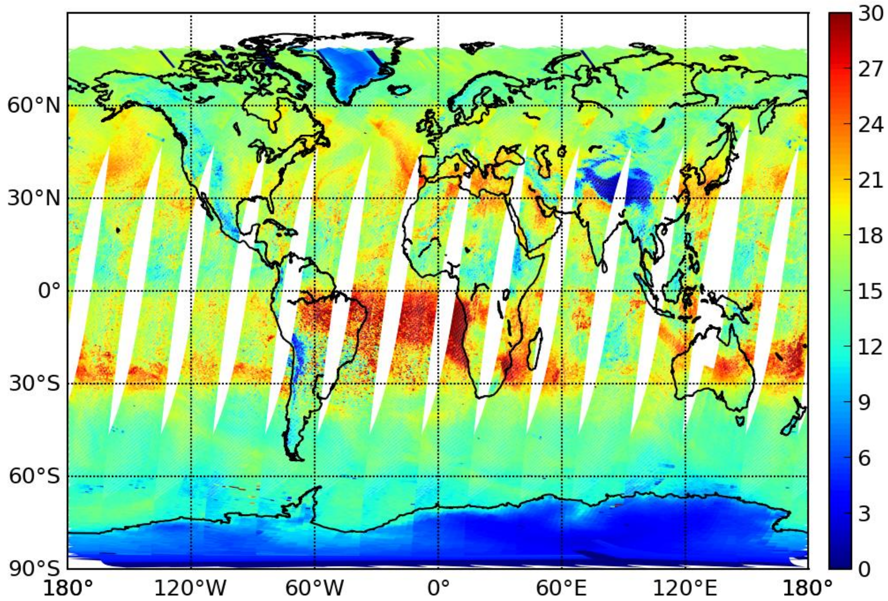
O3M SAF VALIDATION REPORT

Validated products:

Identifier	Name	Acronym
O3M-172	NRT Tropospheric Ozone, Ozone profiles, METOP-A	OTO/O3Tropo
O3M-173	Offline Tropospheric Ozone, Ozone profiles, METOP-A	OTO/O3Tropo
O3M-174	NRT Tropospheric Ozone, Ozone profiles, METOP-B	OTO/O3Tropo
O3M-175	Offline Tropospheric Ozone, Ozone profiles, METOP-B	OTO/O3Tropo



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Reporting period: January 2007 - December 2014

Validation methods: Balloon soundings

Input data versions: Base Algorithm Version: 5.3 – 6.0

Data processor Versions: Product Algorithm Version: 1.12

Product Software Version: 1.32

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1. Applicable O3MSAF Documents

[ATBD] Algorithm Theoretical Basis Document for Near Real Time and Offline Ozone profiles, KNMI/GOME/ATBD/01/17, Olaf Tuinder, 20150209.

[PUM] Product User Manual for Near Real Time and Offline Ozone profiles, KNMI/GOME/PUM/01/20, Olaf Tuinder, 20150520.

Both documents are available at http://o3msaf.fmi.fi in the *Documents* section.

2. General Introduction

This report contains validation results of the GOME-2A and GOME-2B coarse resolution (CR) and high resolution (HR) tropospheric ozone column products, retrieved by the Ozone Profile Retrieval Algorithm (OPERA) at KNMI. It covers the time period January 2007 until December 2014 for GOME-2A and January 2013 – December 2014 for GOME-2B.

Also a degradation corrected (DC) GOME-2A HR dataset will be validated. Since the current operational ozone profile products are influenced by the degradation of its sensors (Delcloo and Kreher, 2013), it is necessary to apply a degradation correction to improve these ozone profile products and therefore also the tropospheric ozone column (TOC) product.

We will validate two TOC products, i.e. the tropopause related product and a fixed altitude TOC product. The TOC products are derived from the daily operational ozone profile product.

Since these TOC products are derived from the OPERA ozone profile product, it is possible to take into account the averaging kernels in the analysis. The outcome is summarized at the end of this report and contains an advice if these products fulfill the user requirements.

3. Validation of tropospheric ozone columns using ozonesondes

3.1 Introduction

The O3M SAF GOME-2 tropospheric ozone column product validation was carried out using ozone profile measurements with balloon sounding data. 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

It is shown from Table 1 that the profiles from ozonesondes are most reliable around the 40 hPa level, which is around the ozone maximum. The error bar of profiles from ozonesondes increases rapidly at levels above the 10 hPa level, which is around 31 km altitude. For this validation report, only the station of Hohenpeissenberg is using B-M sondes, all the other stations under consideration (Table 2) use ECC sondes, while KC-79 sondes are not launched anymore.

3.2 Dataset description

GOME-2 ozone data used in this validation report is from the beginning of January 2007 up to the end of December 2014. GOME-2 tropospheric ozone column data was made available by KNMI at pre-selected sites. These sites correspond to sites where ozone soundings are performed on a regular basis. Data was made available by the World Ozone and Ultraviolet Data Center (WOUDC - http://www.woudc.org) and NILU's Atmospheric Database for Interactive Retrieval at Norsk Institutt for Luftforskning (NADIR - http://www.nilu.no/nadir/). However, since this report takes into account recently retrieved TOC data (until December 2014), it is not always possible for all the stations to have as much as ozonesonde data available to validate.

The statistics are shown in function of latitude belts. These are the belts taken into account:

Latitude belts from North to South:

1. Polar stations North: green (67N – 90 N)
2. Mid-Latitude stations North: black (30 N – 67 N)
3. Tropical stations: Red (30 N – 30 S)
4. Mid-Latitude stations South: grey (30 S – 70 S)

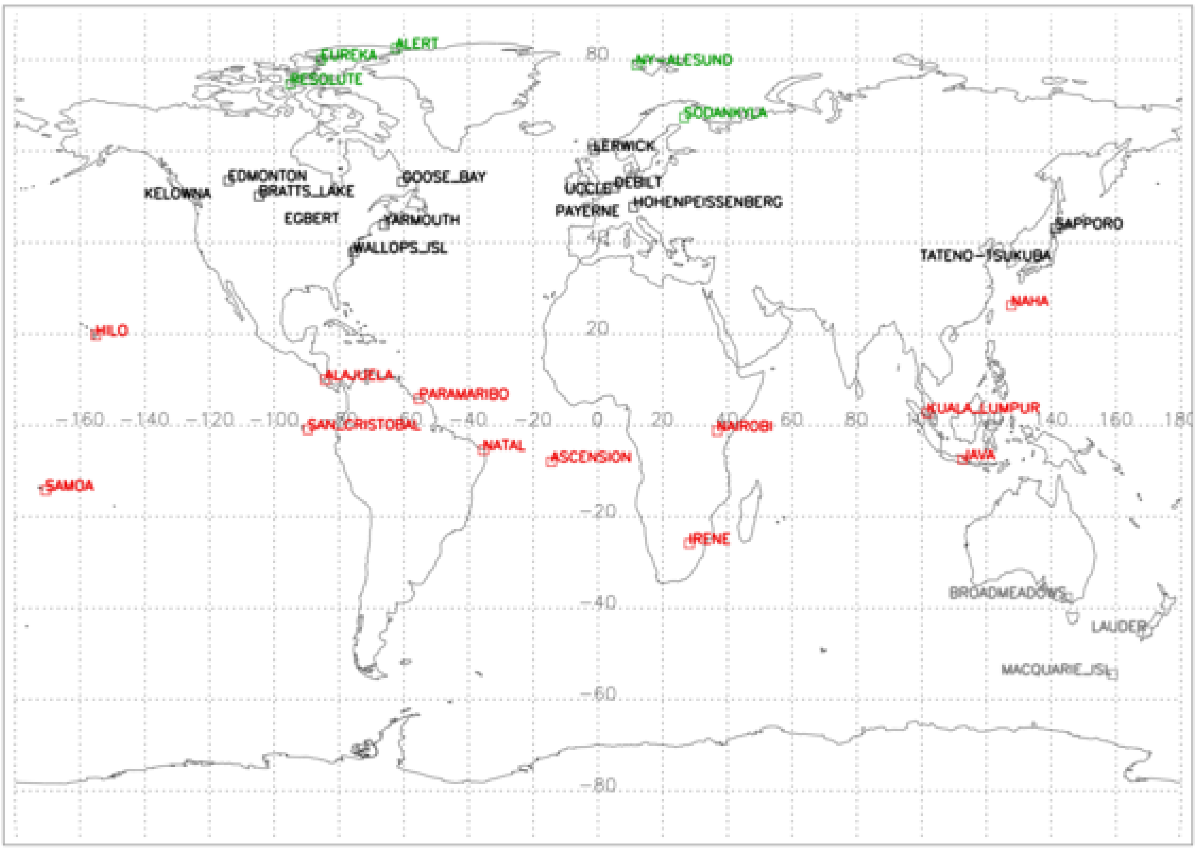


Figure 1: Stations used in the validation report

The level 1b algorithm versions used for the GOME-2A/GOME-2B tropospheric ozone products are **5.3** and **6.0**.

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.

The time period we consider for validation is:

- GOME-2A: January 2007 - December 2014
- GOME-2B: January 2013 - December 2014

The validation is performed in function of latitude belts. The number of coincidences is summarized in Table 2. The GOME-2 tropospheric ozone column data taken into consideration are the ones which have received the quality processing status of “Overall convergence, successful retrieval”. More details about the quality flags can be found in the PUM document (Product User Manual for the Near Real Time and Offline Ozone Profile), pages 22-23. Figure 1 and Table 3 show an overview of the stations used in this validation report.

Table 2: Overview of number of coincidences at different latitude belts for the different tropospheric ozone column products

	GOME-2A CR	GOME-2A HR	GOME-2A HR DC
January 2007 – December 2014			
Northern Polar Regions	68986	59442	59608
Northern Mid-Latitudes	66684	61648	61861
Tropical regions	17004	16155	16196
Southern Mid-Latitudes	14247	13237	13188
	GOME-2B CR	**GOME-2B HR**	
January 2013 – December 2014			
Northern Polar Regions	10320	9074	
Northern Mid-Latitudes	11588	10999	
Tropical regions	3027	2879	
Southern Mid-Latitudes	2316	2221	

Table 3: 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
BRATTS_LAKE	50.2	-104.7	218	28/09/2011
BROADMEADOWS	-37.69	144.95	333	18/12/2013
CHURCHIL	58.74	-94.07	203	12/03/2014
DEBILT	52.1	5.18	418	25/12/2014
EDMONTON	53.55	-114.1	264	9/04/2014
EGBERT	44.23	-79.78	211	31/08/2011
EUREKA	80	-85.56	452	1/10/2014
FIJI	-18.1	178.4	94	30/10/2013
GOOSE_BAY	53.3	-60.36	271	17/01/2013
HILO	19.717	-155.083	320	31/12/2014
HOHENPEISSENBERG	47.8	11.02	937	31/12/2014
IRENE	-25.9	28.22	64	29/10/2014
JAVA	-7.5	112.6	90	30/10/2013
KELOWNA	49.67	-119.4	291	9/04/2014
KUALA_LUMPUR	2.73	101.7	145	17/12/2013
LAUDER	-45.045	169.684	359	15/09/2014
LERWICK	60.14	-1.19	375	24/12/2014
MACQUARIE_ISL	-54.5	158.94	337	24/07/2014
NAHA	26.2	127.683	312	29/10/2014
NAIROBI	-1.27	36.8	314	31/12/2014
NATAL	-5.42	-35.38	162	10/12/2014
NY-ALESUND	78.93	11.95	618	29/12/2014
PARAMARIBO	5.81	-55.21	258	29/12/2014

Station	Lat (°)	Long (°)	Nr of sondes	Last day available
PAYERNE	46.817	6.95	1198	29/12/2014
RESOLUTE	74.71	-94.97	226	2/04/2014
SAMOA	-14.23	-170.56	211	23/12/2014
SAN_CRISTOBAL	-0.92	-89.6	89	30/01/2014
SAPPORO	43.06	141.3315	315	22/10/2014
SODANKYLA	67.3666	26.6297	499	31/12/2014
TATENO-TSUKUBA	36.1	140.1	348	29/10/2014
UCCLE	50.8	4.35	1126	24/12/2014
WALLOPS_ISL	37.84	-75.48	350	23/12/2013
YARMOUTH	43.87	-66.11	286	2/04/2014

3.3 Co-location criteria

The selection criteria, taken into account are twofold:

- The geographic distance between the GOME-2 pixel center and the sounding station location for the coarse resolution (CR) pixels is 300 km, for the high resolution (HR) pixels, this distance is reduced towards 100 km.
- The time difference between the pixel sensing time and the sounding launch time is the second criterion and is fixed at ten hours of time difference. Each sounding that is correlated with a GOME-2 overpass is generally correlated with several GOME-2 pixels if the orbit falls within the 300 km (resp 100 km for the HR pixels) circle around the sounding station. This means that a single ozone profile is compared to more than one GOME-2 measurement.

These selection criteria give a comparable number of collocations (Table 2).

Figure 2 summarizes in one plot the observations used for the time period 2007 – 2014 for the GOME-2A HR collocations.

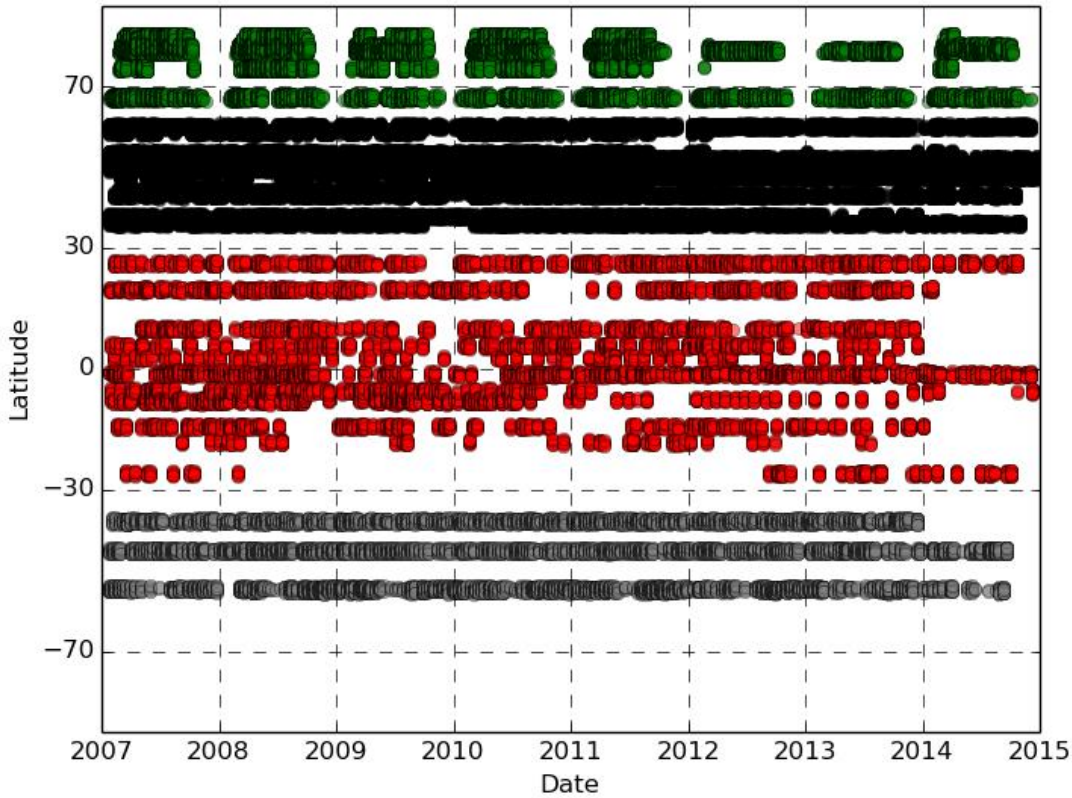


Figure 2: Latitude-time sampling of co-locations.

3.4 Ozone sounding pre-processing

GOME-2 ozone profiles are given as partial ozone columns on 40 varying pressure levels, calculated by the Ozone Profile Retrieval Algorithm (OPERA) developed by KNMI. Ozone partial columns are expressed in Dobson Units.

Ozonesondes measure the ozone concentration along the ascent with a much higher vertical resolution than GOME-2. Ozonesondes have a typical vertical resolution of 100m while GOME-2 profiles consist of 40 layers between the ground and 0.001hPa. Ozonesondes give the ozone concentration in partial pressure. The integration requires some interpolation, as GOME-2 levels never match exactly ozonesonde layers. (Delcloo and Kins, (2009, 2012))

For the comparison, ozonesonde profiles are integrated between the GOME-2 pressure levels of the GOME-2 profile being compared. This means when a single ozonesonde profile is compared to different GOME-2 profiles, the actual reference ozone values are not the same given that the GOME-2 level boundaries vary from one measurement to another. The derived tropospheric ozone column product (X_{GOME-2}) is the sum of the layers until the defined level. More information on how this level is defined for both TOC products, is discussed in the next section.

In this report we also take into account the averaging kernels (AVK) of the GOME-2 ozone profile (Delcloo and Kins, (2009, 2012); Rodgers, 1990). The motivation to apply the AVK is to "smooth" the ozone soundings towards the resolution of the satellite, to look at the GOME-2 profiles with "the eyes" from the satellite. Equation (1) shows how the kernels have been applied.

$$X_{avk\_sonde} = X_{apriori} + A\,(X_{raw\ sonde} - X_{apriori}) \qquad (1)$$

Where A represents the averaging kernel, X_{avk_sonde} is the retrieved ozonesonde profile, X_{raw_sonde} is the ozonesonde profile and $X_{apriori}$ is the a-priori profile.

4. Results

This report will communicate the results for two methods in order to retrieve the tropospheric ozone columns (TOC).

The first method derives the TOC by deriving the tropopause height from the ECMWF temperature profile. This method aims to extract the 'true' tropospheric ozone column; the atmosphere is separated vertically into two regimes by the presence of a temperature inversion that prevents the mixing of air between troposphere and stratosphere. This inversion layer is called the tropopause. The height of the tropopause varies, depending on the latitude, season and regional effects of large scale meteorological systems. The tropopause height definition used by the World Meteorological Organization is: "The lowest level at which the lapse rate decreases to 2 °C/km or less, provided that the average lapse rate between this level and all higher levels within 2 km does not exceed 2 °C/km" [WMO Manual on Codes, Vol. I. 1-A,WMO–No. 306]. When the tropopause level is defined, the TOC is then defined as the sum from the layers below the defined level. More information can be found in the ATBD. Although this extraction method for TOC is straightforward, it also introduces easily errors, related to stratosphere-troposphere exchange processes.

Therefore, a second derived product is proposed which takes into account the integrated tropospheric ozone until an altitude of about 500 hPa in order to avoid influences of stratospheric ozone in the TOC product. This product could also be useful as a boundary condition product for chemical transport models (CTM) in an operational context, since it only takes into account the lower troposphere (until 500 hPa).

In the next two subsections, the results for both listed products will be shown. In section 5 the outcome of both methods will be briefly discussed. Section 6 illustrates some examples and in section 7 we conclude.

4.1 Statistics for the tropopause product

To calculate the relative differences of the tropospheric ozone column product, we apply:

$$(X_{GOME\text{-}2} - X_{AVK\text{-}SONDE})/X_{AVK\text{-}SONDE} \qquad (2)$$

Where $X_{GOME\text{-}2}$ represents the integrated tropospheric ozone until the level below the tropopause height and $X_{AVK\text{-}SONDE}$ is the associated integrated smoothed ozonesonde profile.

The tropospheric ozone column (TOC) product has the following user requirements:

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

Table 4 describes some general statistics for the GOME-2A and GOME-2B datasets.

Table 4: Relative Differences (RD) and standard deviation (STDEV) are shown (in percent) on the accuracy of the GOME-2 tropospheric ozone column products for different latitude belts and for different products, validated against $X_{AVK\text{-}sonde}$.

	GOME-2A CR		GOME-2A HR		GOME-2A HR DC	
January 2007 – December 2014	**RD (%)**	**STDEV (%)**	**RD (%)**	**STDEV (%)**	**RD (%)**	**STDEV (%)**
Northern Polar Regions	22.97	30.93	5.11	21.36	0.52	17.55
Northern Mid-Latitudes	2.75	33	-2.68	23.7	8.85	19.7
Tropical regions	12.45	44.09	7.37	36.17	29.03	36.08
Southern Mid-Latitudes	0.55	29.8	-1.89	21.06	5.19	21.81
	GOME-2B CR		**GOME-2B HR**			
January 2013 – December 2014	**RD (%)**	**STDEV (%)**	**RD (%)**	**STDEV (%)**		
Northern Polar Regions	13.73	20.9	9.62	22.54		
Northern Mid-Latitudes	16.65	22.81	13.28	29.83		
Tropical regions	45.01	38.59	30.95	54.74		
Southern Mid-Latitudes	19.47	16.28	15.24	20.26		

The statistics, shown in Table 4, reveal that the GOME-2A and GOME-2B Tropospheric Ozone Column products are after comparison with balloon sounding ozonesonde data for most of the regions within the target accuracy (20 %), except for the tropical stations, which are within threshold values for the GOME-2B product.

In general, the GOME-2B product shows for all the belts a typical overestimation of about 10 - 20 %. For the degradation corrected GOME-2A HR dataset the overestimation is smaller (between 1 and 9 %), not taking into account the tropical stations.

The statistics shown for the HR and CR GOME-2A products should be interpreted with care, since there is a clear degradation present in the time series. We obtain statistics which are within target accuracy for most of the regions with a more elevated standard deviation when compared with the DC GOME-2A products. The time series show a strong decrease in retrieved tropospheric ozone concentrations related to the degradation of the GOME-2A sensor. When we compare the GOME-2A HR DC results with the current GOME-2B CR and

HR products, we observe the same tendencies, i.e. a general overestimation of tropospheric ozone. In the next subsections it is shown that there is a clear seasonal cycle dependency present in these products, which should be taken into account when interpreting the results.

4.1.1 Seasonal dependency

Figures 3a and 3b show the relative differences (%) on a monthly basis between the GOME-2A tropospheric ozone columns compared with the ozonesondes for 4 different latitude belts for the time period January 2007 – December 2014. On the left side the results for the high resolution product (HR) are shown while on the right side the results for the high resolution degradation corrected (HRDC) product are shown. Figure 4 shows the relative differences (%) on a monthly basis between the GOME-2B tropospheric ozone columns compared with the ozonesondes for 4 different latitude belts for the time period January 2013 – December 2014. On the left side the results for the coarse resolution product (CR) are shown while on the right side the results for the high resolution (HR) product are shown.

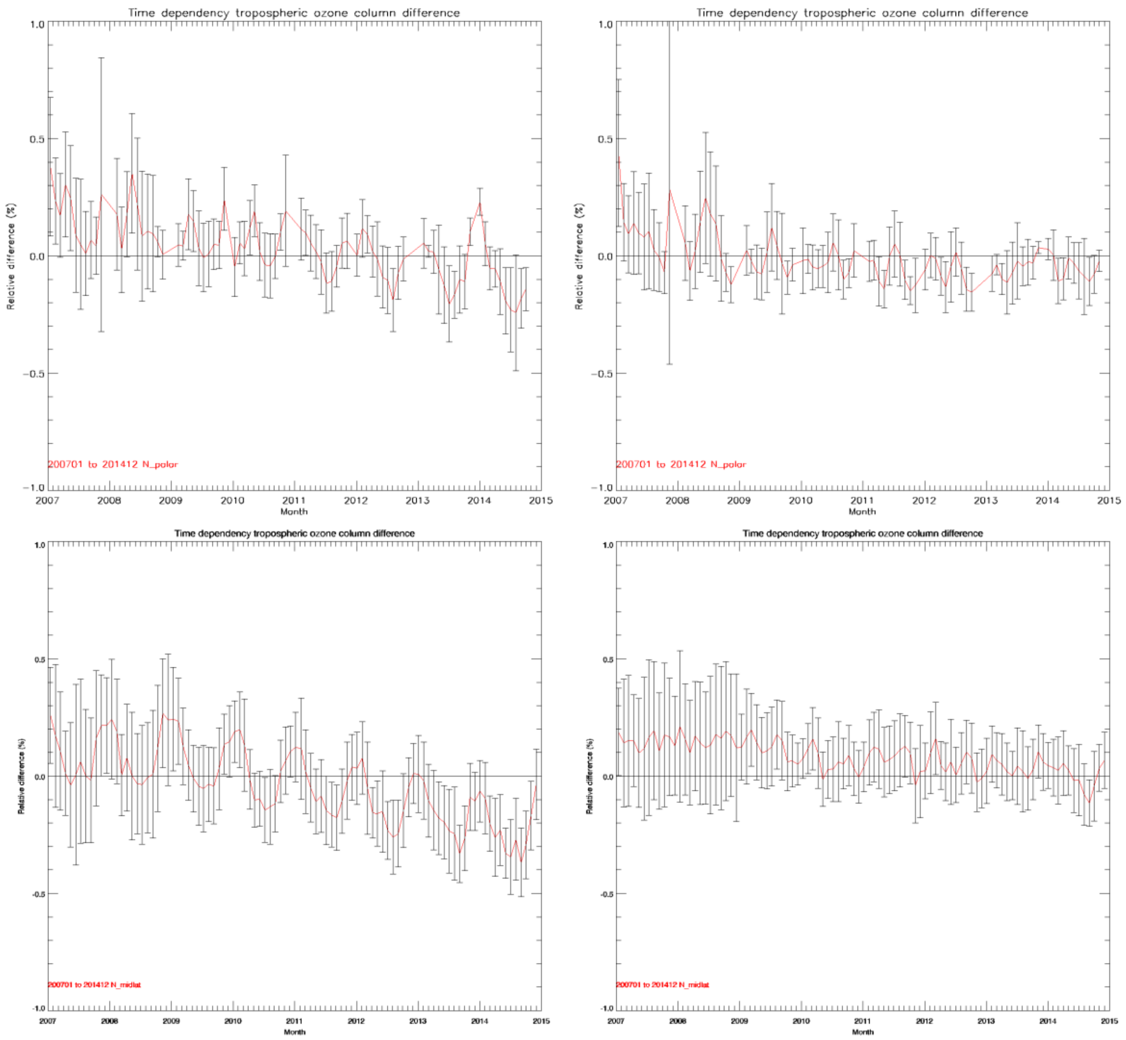


Figure 3a: Relative differences (%) between GOME-2A tropospheric ozone column compared with the ozonesondes for2 different latitude belts for the time period January 2007 – December 2014, HR (left) and HR DC (right)

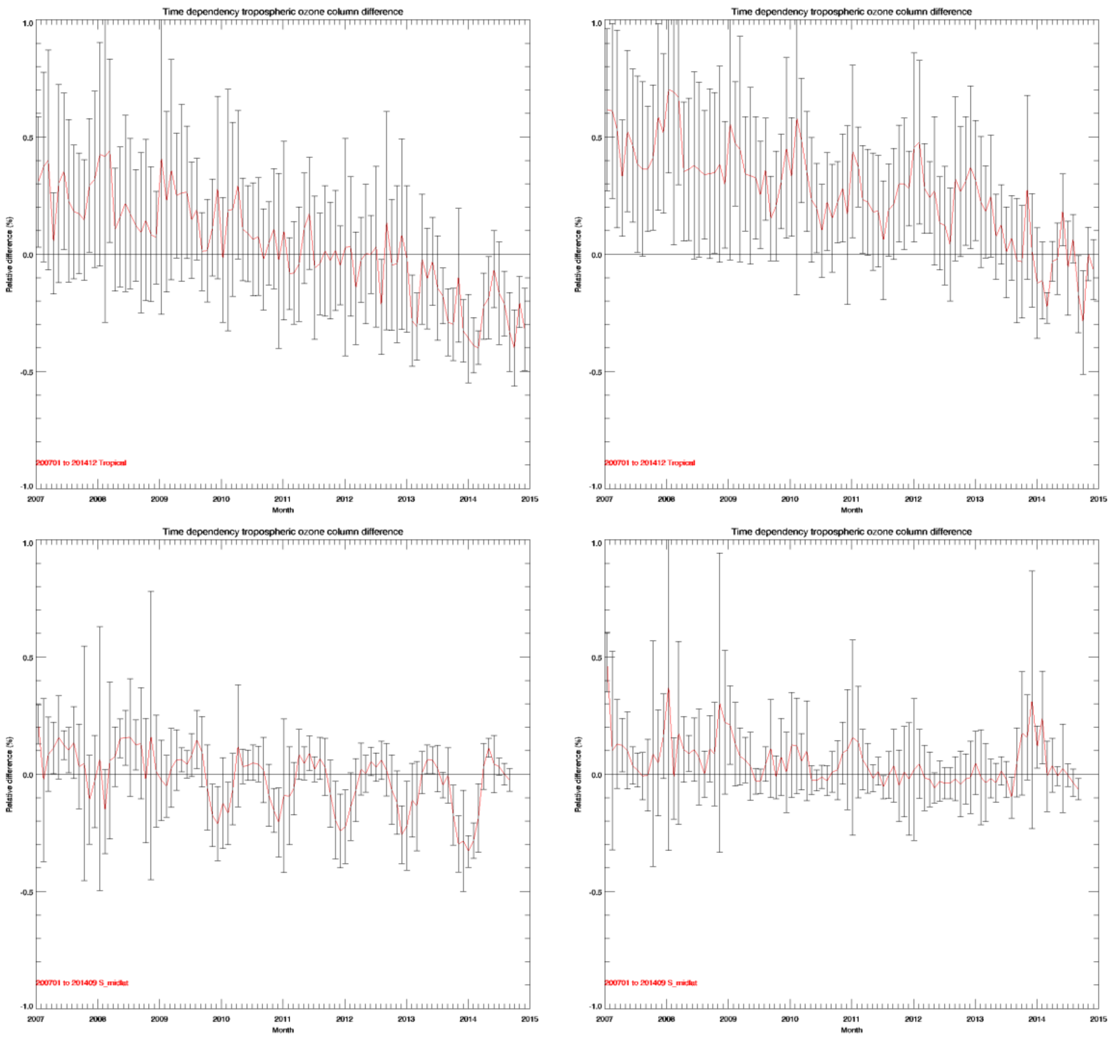


Figure 3b: Relative differences (%) between GOME-2A tropospheric ozone column compared with the ozonesondes for 2 different latitude belts for the time period January 2007 – December 2014, HR (left) and HR DC (right)

From previous studies on the quality of the ozone profile product, it is known that the ozone profile product shows a seasonal behavior (Delcloo and Kins, (2009,2012); Delcloo and Kreher, 2013). This is also the case for the current tropospheric ozone column products (Figures 3a, 3b, 4a and 4b). However, the degradation corrected high resolution (DCHR) dataset for GOME-2A shows a significant improvement on the reduction of this seasonal cycle behavior. For the polar and Mid-Latitude stations, the seasonal cycle is not present anymore, while this is still not solved for the tropical belt. The reason for this behavior is not fully understood and is under investigation.
For the current GOME-2B CR and HR products (Fig. 4a and Fig. 4b), a clear seasonal behavior can be identified for the Mid-Latitude and polar stations. The differences obtained for the tropical belt could be related to an overestimation of cloudy pixels in the HR product when compared with the GOME-2B CR product.

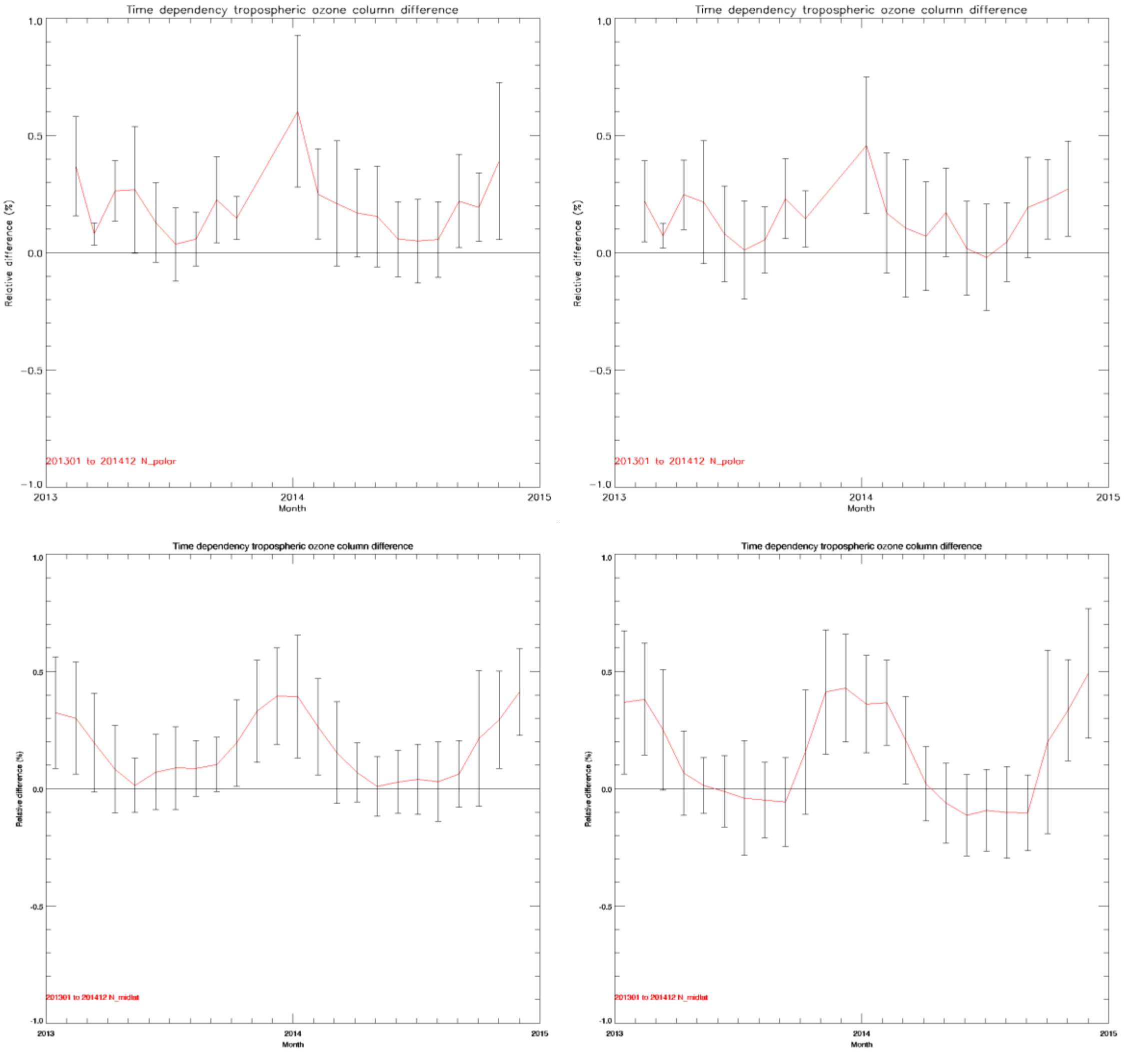


Figure 4a: Relative differences (%) between GOME-2B tropospheric ozone column compared with the ozonesondes for 2 different latitude belts for the time period January 2013 – December 2014, CR (left) and HR (right)

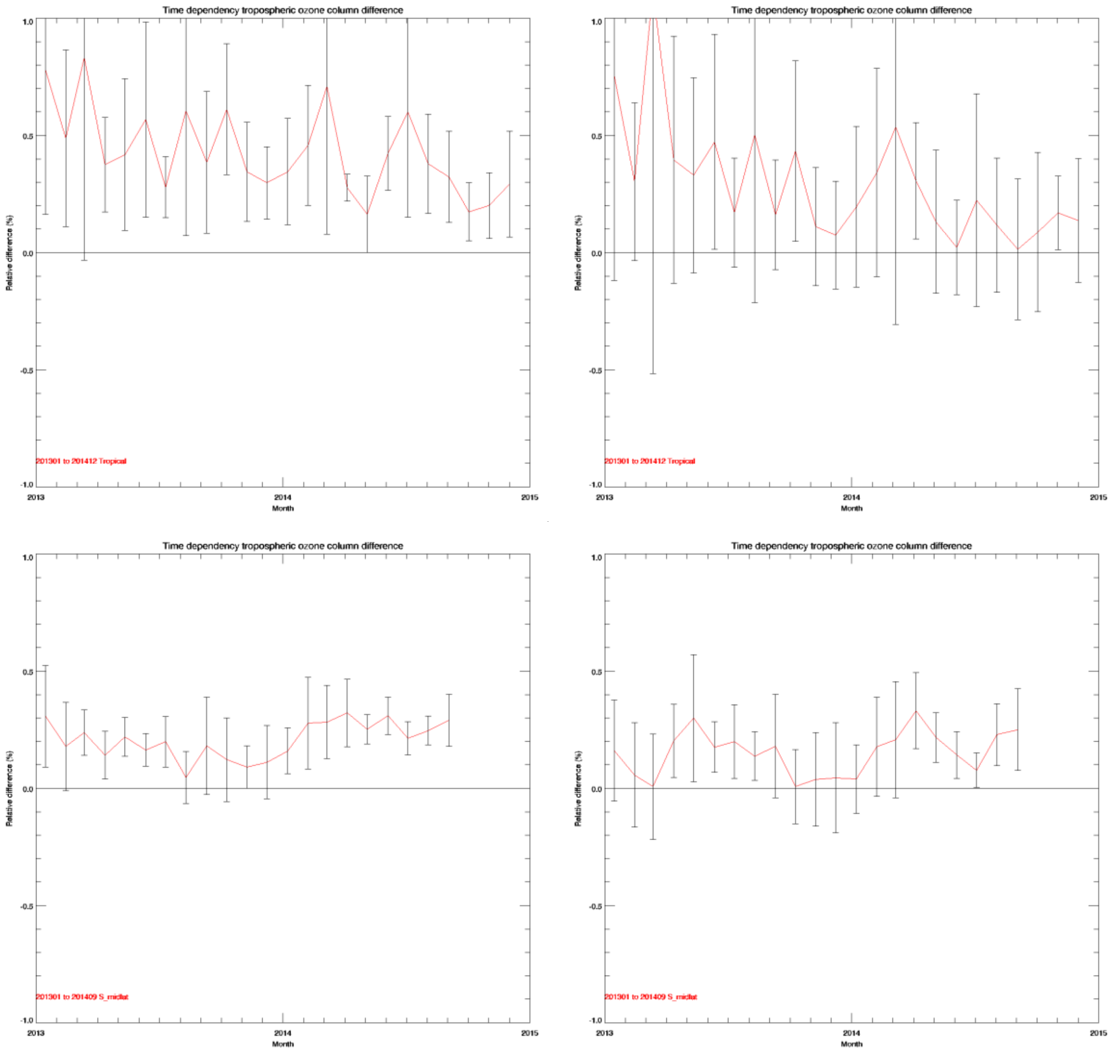
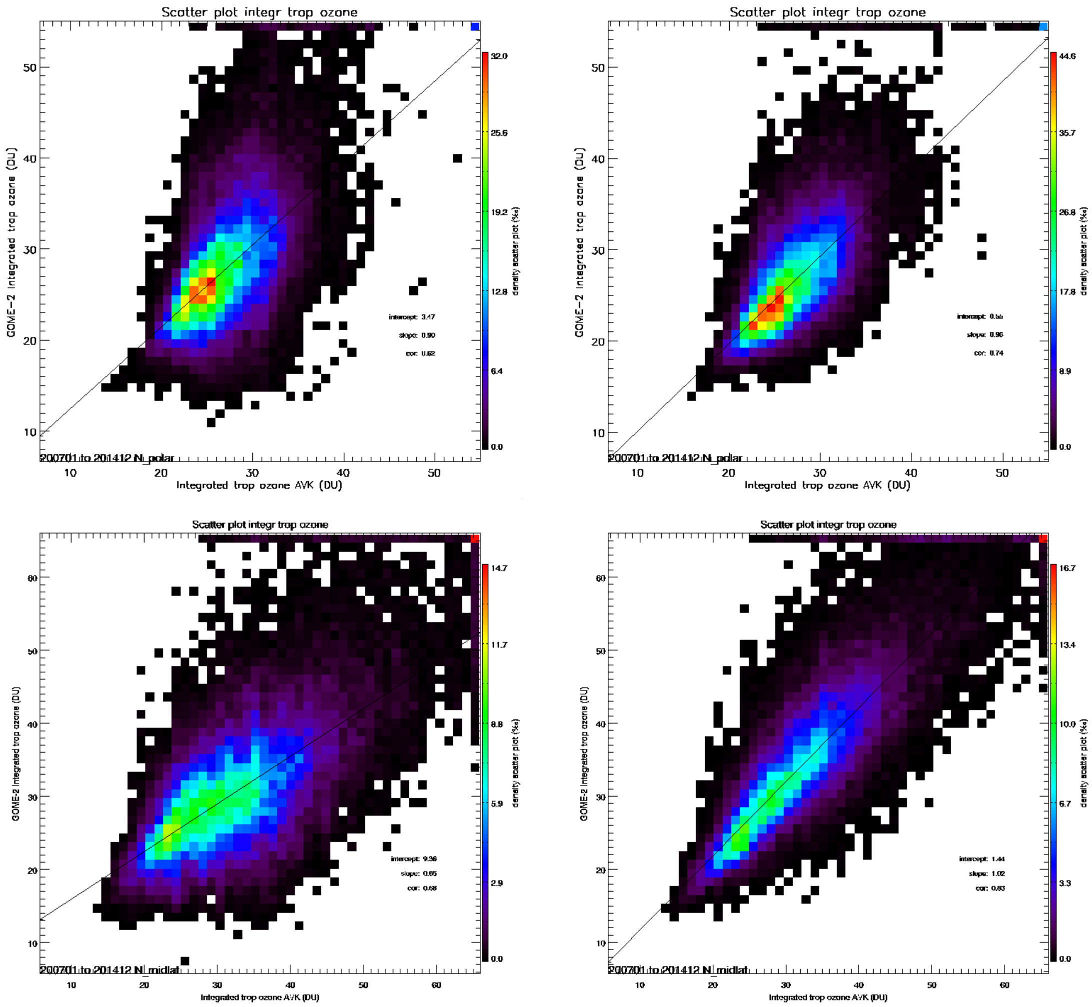


Figure 4b: Relative differences (%) between GOME-2B tropospheric ozone column compared with the ozonesondes for 2 different latitude belts for the time period January 2013 – December 2014, CR (left) and HR (right)

4.1.2 Scatter plots

To verify the skill of the tropospheric ozone column product more thoroughly, some scatter plots of the different versions are shown in Figure 5 and Figure 6. They illustrate the integrated tropospheric GOME-2 ozone concentrations against the smoothed ozonesonde data.

Figure 5 shows the intercomparison between the GOME-2A high resolution product at the left side and at the right side we show the degradation corrected product.
For the polar and Mid-Latitude stations the degradation corrected product improves significantly the quality of the tropospheric ozone column product. This results in a more dense cloud with less scatter and a slope, closer to 1. This reduction in scatter is a result from the absence of a seasonal cycle behavior, persistently present in previous versions of the ozone profile product. However, this is not true for the tropical tropospheric ozone column product. For this specific latitude belt the degradation correction applied did not improve significantly the product as earlier mentioned in this report.



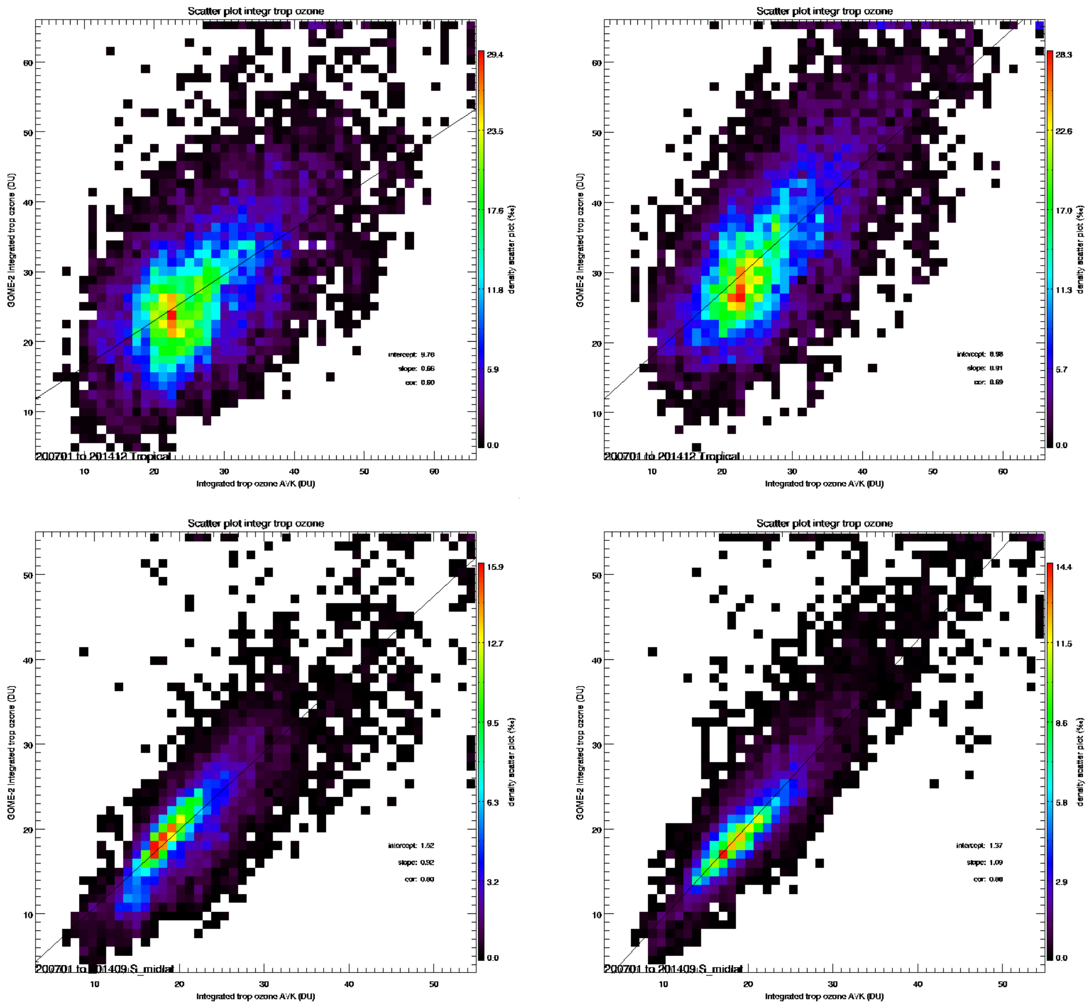
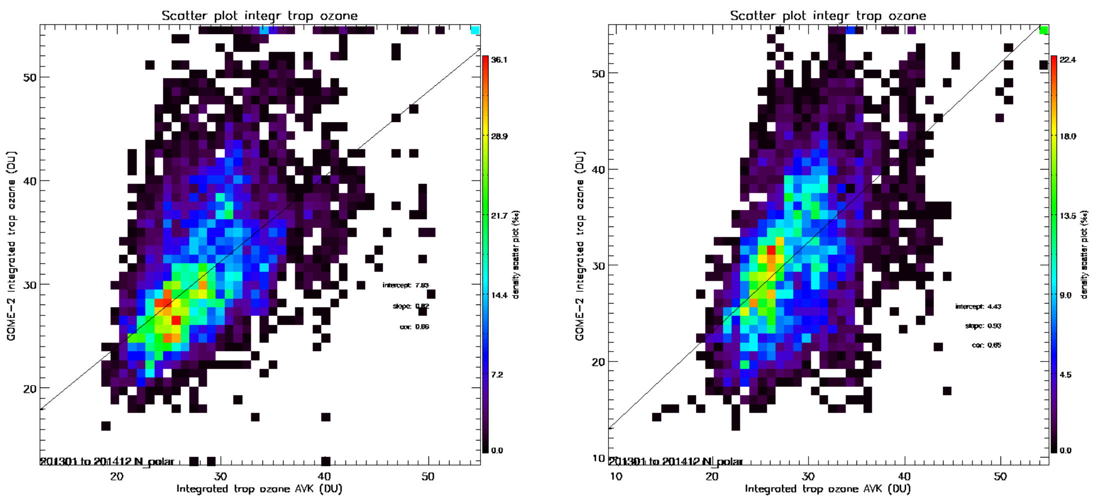


Figure 5: Scatter plots for the GOME-2A high resolution (left) and GOME-2A high resolution degradation corrected (right) tropospheric ozone column products for 4 different latitude belts (N-polar- , N-Mid-Lat- , Tropical- and S-polar belt) for the time period January 2007 – December 2014 (tropopause product).

For the GOME-2B CR and HR products, the scatter plots are comparable (Fig. 6).



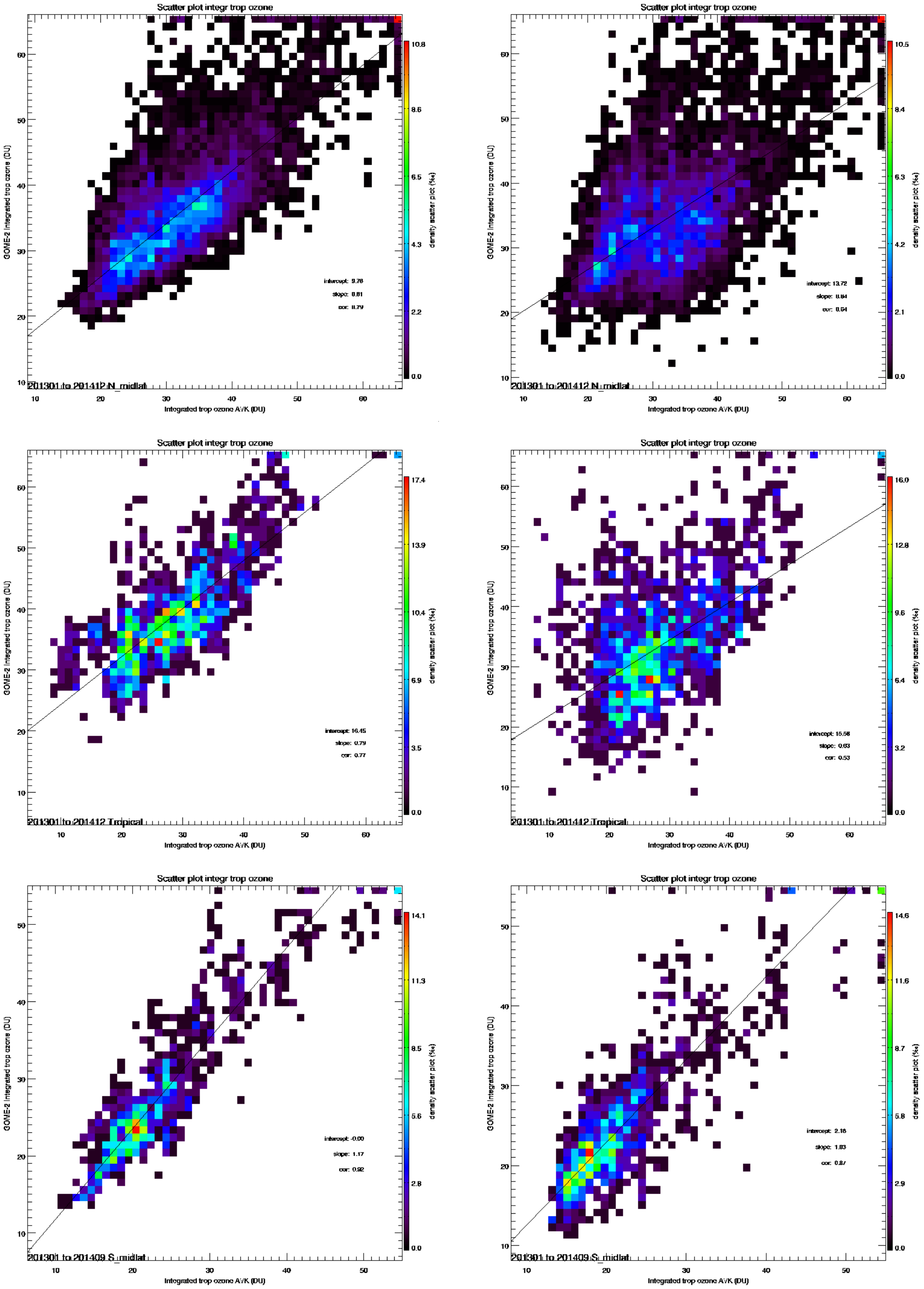


Figure 6: Scatter plots for the GOME-2B coarse resolution (left) and GOME-2B high resolution (right) tropospheric ozone column products for 4 different latitude belts (N-polar- , N-Mid-Lat- , Tropical- and S-polar belt) for the time period January 2013 – December 2014 (tropopause product).

4.2 Statistics for the fixed altitude product

To calculate the relative differences of the tropospheric ozone column product, we apply:

$$(X_{GOME\text{-}2} - X_{AVK\text{-}SONDE})/X_{AVK\text{-}SONDE} \quad (3)$$

Where $X_{GOME\text{-}2}$ represents the integrated tropospheric ozone until 500 hPa and $X_{AVK\text{-}SONDE}$ is the integrated smoothed ozonesonde profile **until 500 hPa**.

The tropospheric ozone column (TOC) product has the following user requirements:

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

Table 5 describes some general statistics for the GOME-2A and GOME-2B datasets.

Table 5: Relative Differences (RD) and standard deviation (STDEV) are shown (in percent) on the accuracy of the GOME-2 tropospheric ozone column products for different latitude belts and for different products, validated against $X_{AVK\text{-}sonde}$.

	GOME-2A CR		**GOME-2A HR**		**GOME-2A HR DC**	
January 2007 – December 2014	**RD (%)**	**STDEV (%)**	**RD (%)**	**STDEV (%)**	**RD (%)**	**STDEV (%)**
Northern Polar Regions	18.12	19.93	4.76	15.13	1.23	11.49
Northern Mid-Latitudes	-1.06	23.11	-3.8	17.28	5.64	12.87
Tropical regions	2.23	44.73	-0.64	36.59	27.16	36.58
Southern Mid-Latitudes	-3.13	20.60	-3.2	14.05	2.34	13.29
	GOME-2B CR		**GOME-2B HR**			
January 2013 – December 2014	**RD (%)**	**STDEV (%)**	**RD (%)**	**STDEV (%)**		
Northern Polar Regions	8.61	11.05	9.46	13.49		
Northern Mid-Latitudes	8.76	11.23	8.35	17.07		
Tropical regions	45.3	41.35	32.21	57.14		
Southern Mid-Latitudes	8.99	8.26	7.46	10.63		

The statistics, shown in Table 5, illustrate that the GOME-2A and GOME-2B Tropospheric Ozone Column products are after comparison with balloon sounding ozonesonde data for most of the regions within the optimal accuracy (20 %), except for the tropical stations, which are within threshold values for the GOME-2A and GOME-2B products.

In general, the GOME-2B product shows for all the belts a typical overestimation of about 7 - 10 %. For the degradation corrected GOME-2A HR dataset the overestimation is smaller (between 1 and 6 %), not taking into account the tropical stations.

The statistics shown for the high resolution GOME-2A product should also for this product be interpreted with care, since there is a clear degradation present in the time series. We obtain statistics which are within target accuracy for most of the regions with a more elevated standard deviation. The time series show a strong decrease in retrieved tropospheric ozone concentrations related to the degradation of the GOME-2A sensor.

4.2.1 Seasonal dependency

Figures 7a and 7b show the relative differences (%) on a monthly basis between the GOME-2A tropospheric ozone columns compared with the ozonesondes for 4 different latitude belts for the time period January 2007 – December 2014. On the left side the results for the high resolution product (HR) are shown while on the right side the results for the high resolution degradation corrected (HRDC) product are shown.

Figures 8a and 8b show the relative differences (%) on a monthly basis between the GOME-2B tropospheric ozone column products compared with the ozonesondes for 4 different latitude belts for the time period January 2013 – December 2014. On the left side the results for the coarse resolution product (CR) are shown while on the right side the results for the high resolution (HR) product are shown.

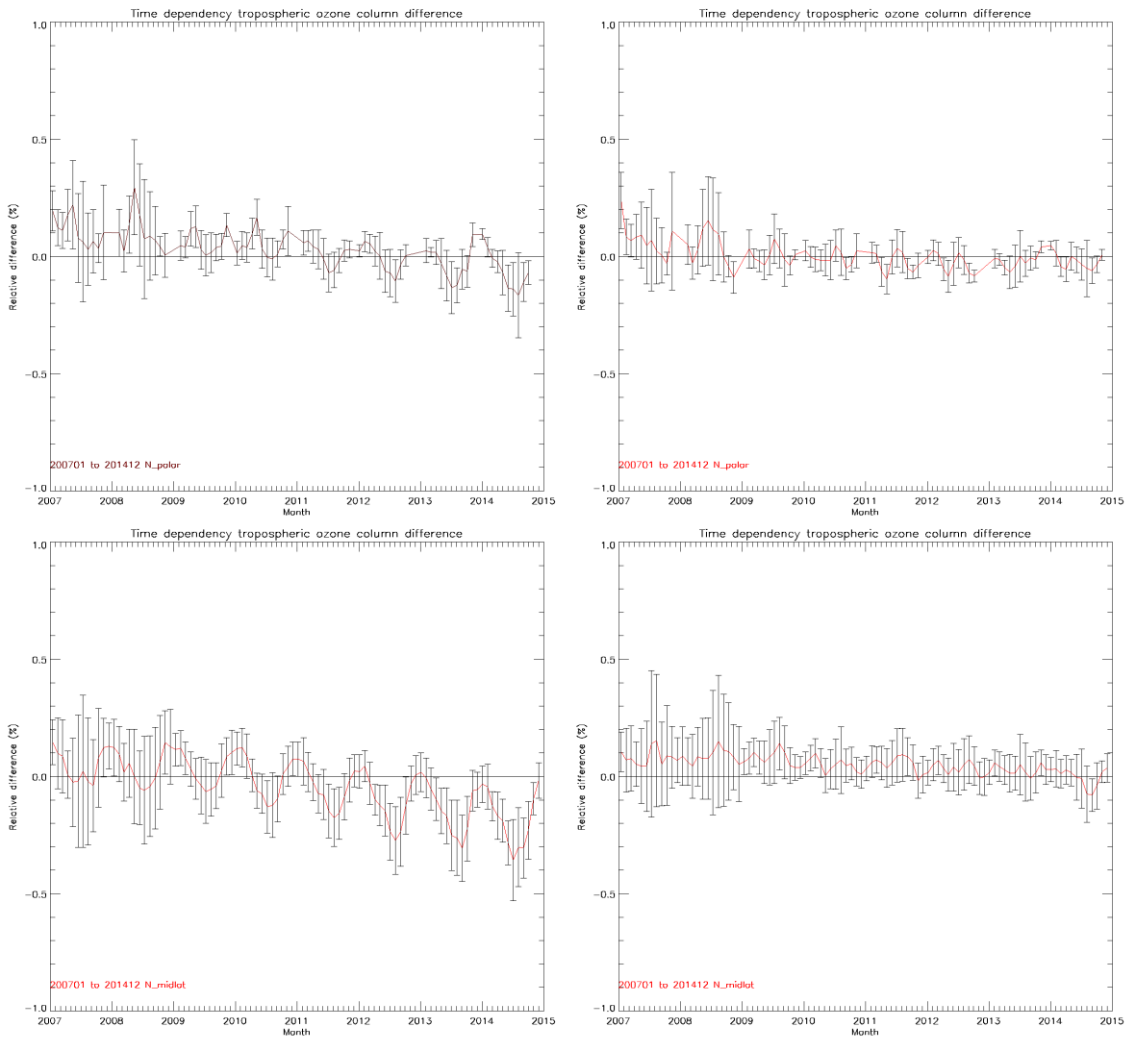


Figure 7a: Relative differences (%) between GOME-2A tropospheric ozone column compared with the ozonesondes for2 different latitude belts for the time period January 2007 – December 2014, HR (left) and HR DC (right)

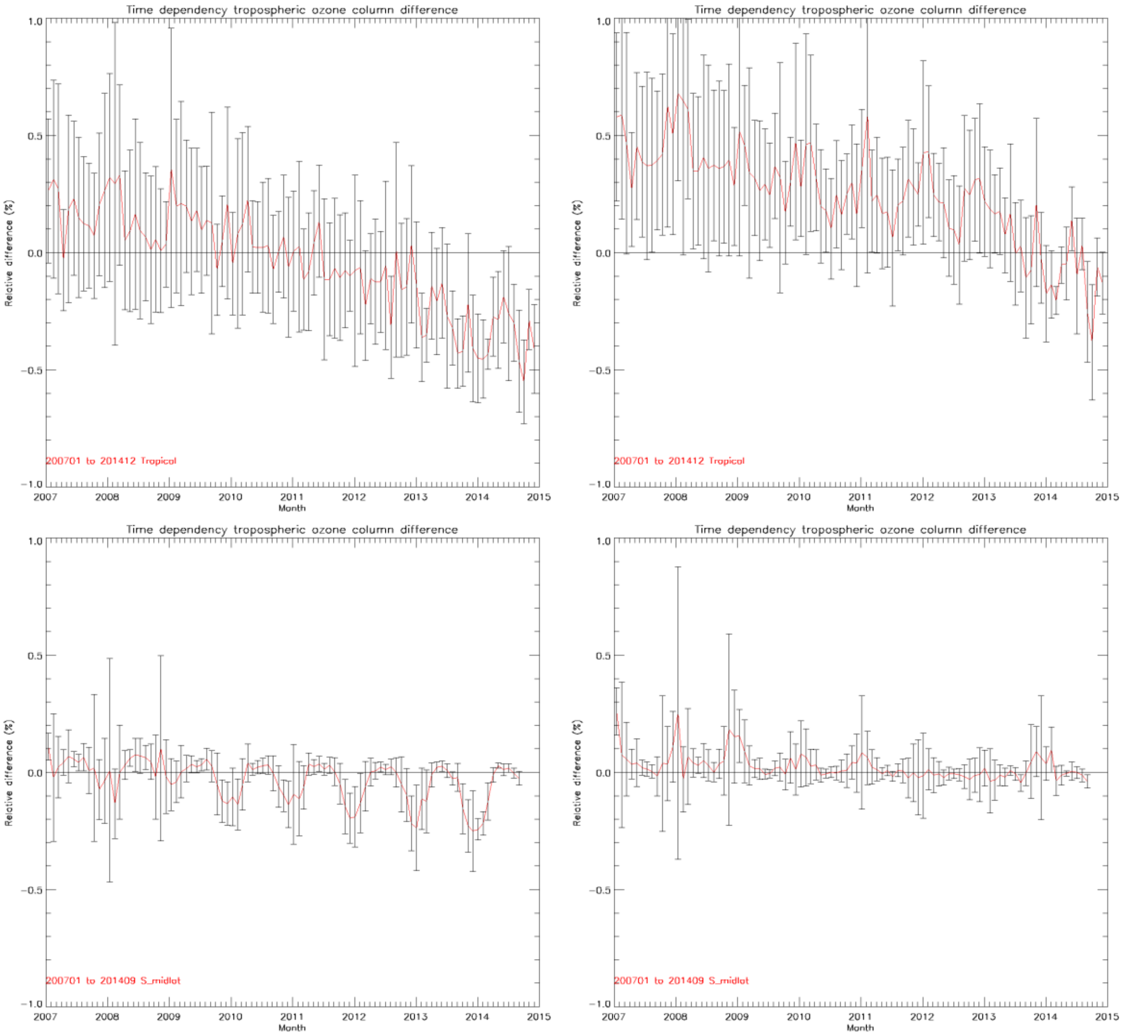


__Figure 7b: Relative differences (%) between GOME-2A tropospheric ozone column compared with the ozonesondes for 2 different latitude belts for the time period January 2007 – December 2014, HR (left) and HR DC (right)__

Also for this fixed altitude product we observe a clear seasonal cycle, present in the datasets as described in the previous section. For the degradation corrected high resolution (DCHR) GOME-2A dataset, there is also here a significant improvement on the reduction of this seasonal cycle behavior; for the polar and Mid-Latitude stations, the seasonal cycle is not present anymore, while this is not solved yet for the tropical belt.

For the current GOME-2B CR and HR products (Fig. 8a and Fig. 8b), a clear seasonal behavior is likewise present for the Mid-Latitude and polar stations. The differences obtained for the tropical belt could also be related to an overestimation of cloudy pixels in the HR product when compared with the GOME-2B CR product.

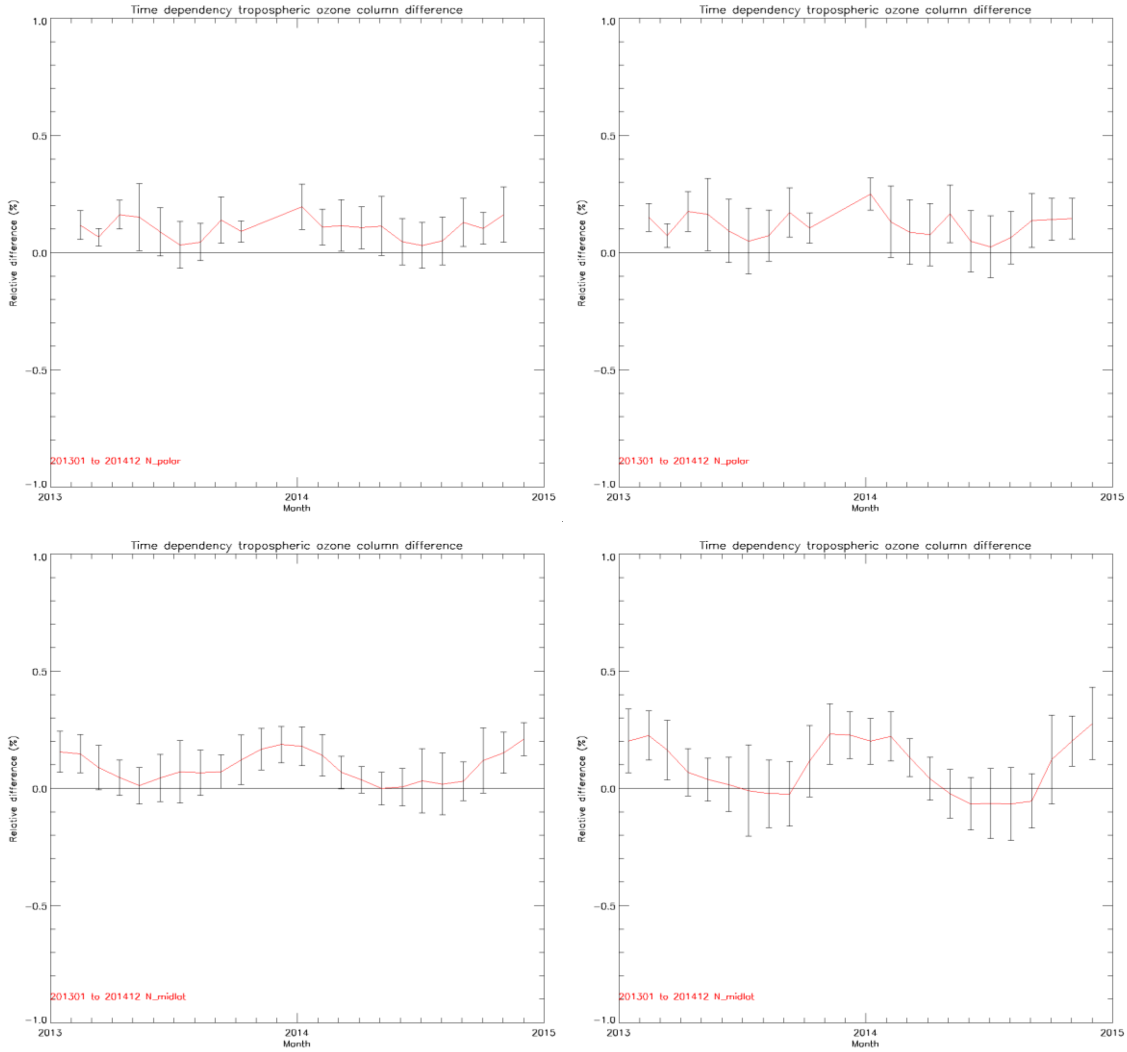


Figure 8a: Relative differences (%) between GOME-2B tropospheric ozone column compared with the ozonesondes for 2 different latitude belts for the time period January 2013 – December 2014, CR (left) and HR (right)

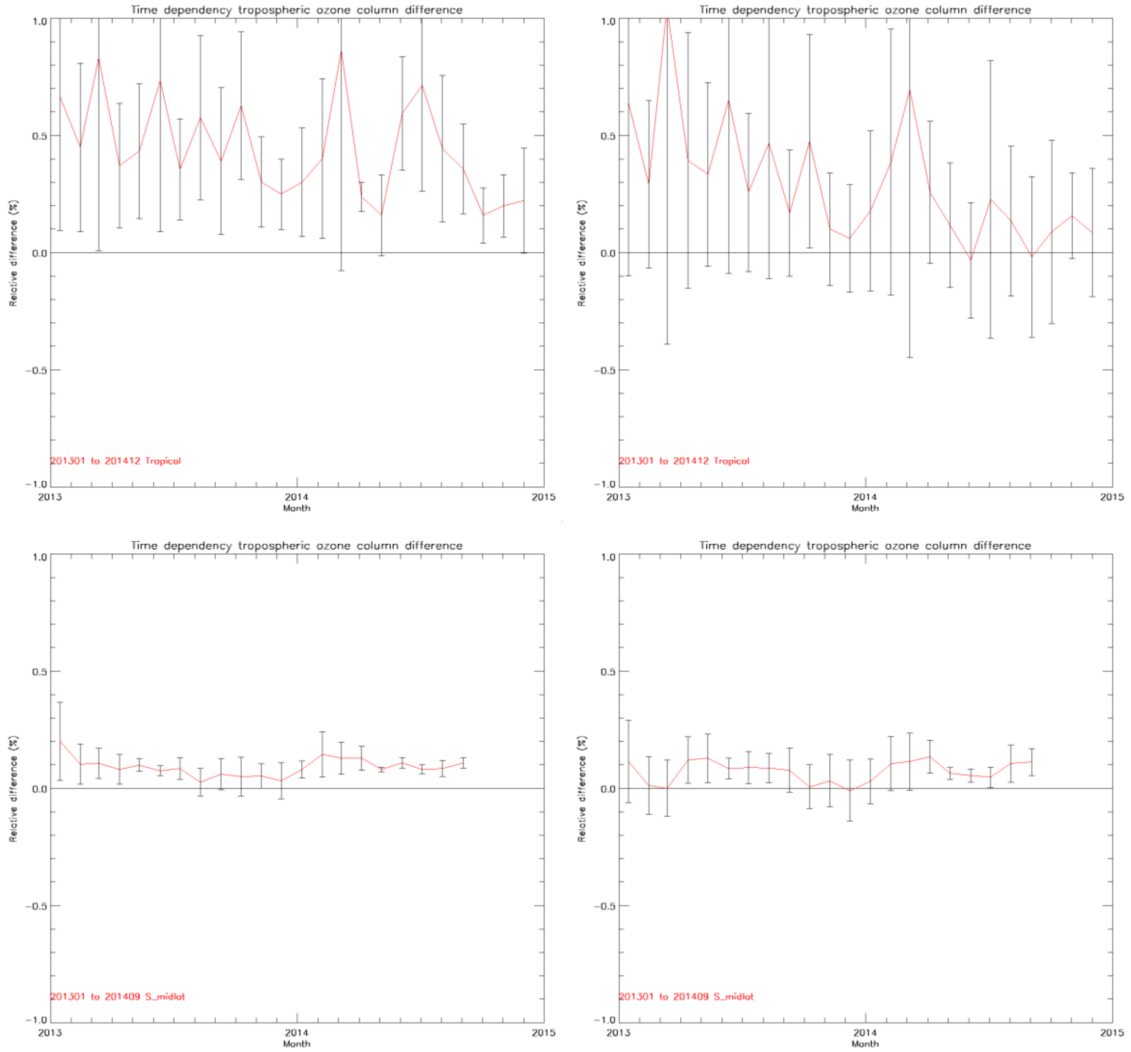
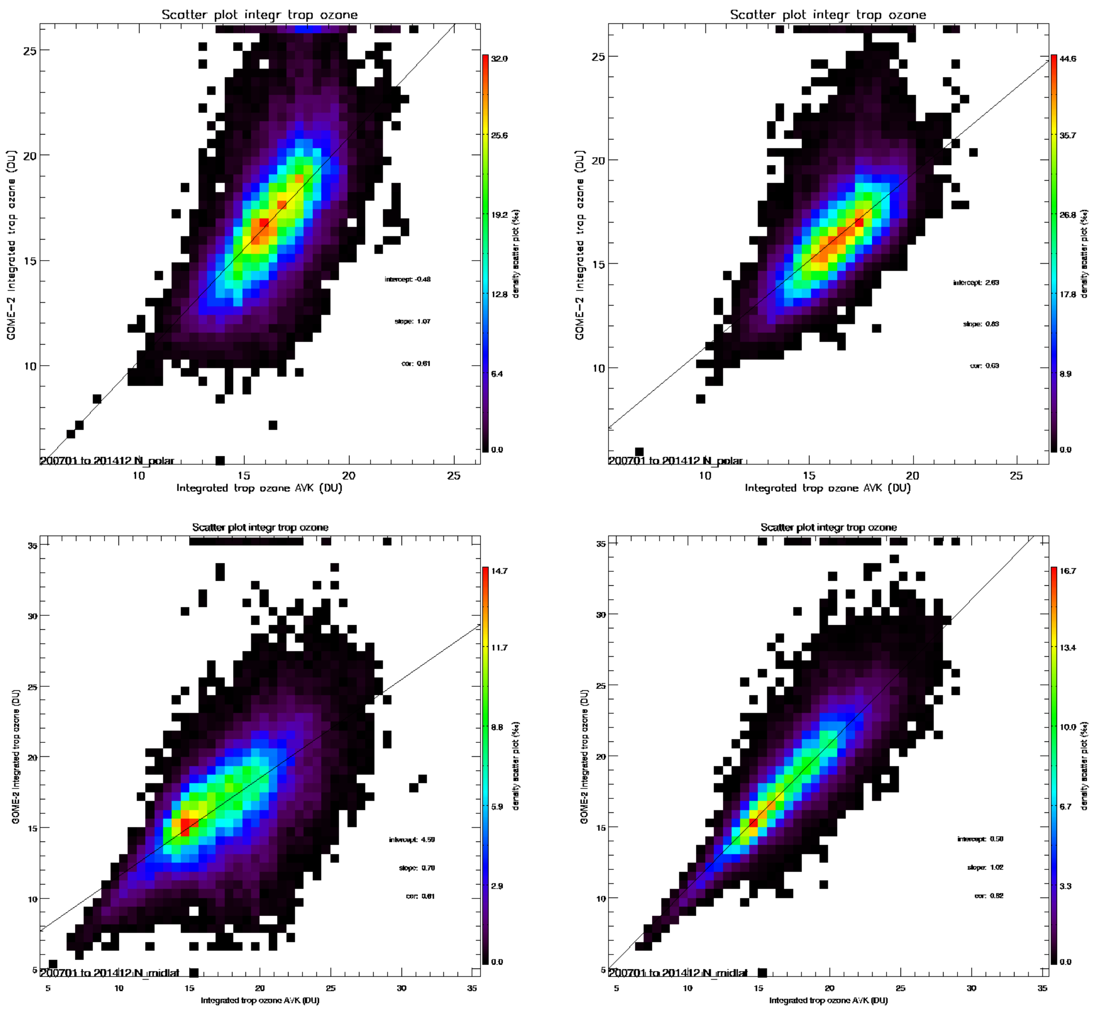


Figure 8b: Relative differences (%) between GOME-2B tropospheric ozone column compared with the ozonesondes for 2 different latitude belts for the time period January 2013 – December 2014, CR (left) and HR (right)

4.2.2 Scatter plots

To verify the skill of the tropospheric ozone column product more thoroughly, some scatter plots of the different versions are shown in Figure 9 and Figure 10. They illustrate the integrated tropospheric GOME-2 ozone concentrations against the smoothed ozonesonde data for the fixed altitude products.

Figure 9 shows the intercomparison between the GOME-2A high resolution product at the left side and at the right side we show the degradation corrected product.
For the polar and Mid-Latitude stations the degradation corrected product improves significantly the quality of the tropospheric ozone column product. This results in a more dense cloud with less scatter and also a slope, closer to 1. This reduction in scatter is a result from the absence of a seasonal cycle behavior, persistently present in previous versions of the ozone profile product. However, this is not true for the tropical tropospheric ozone column product. For this specific latitude belt the degradation correction applied did likewise not improve significantly the product as earlier mentioned in this report.



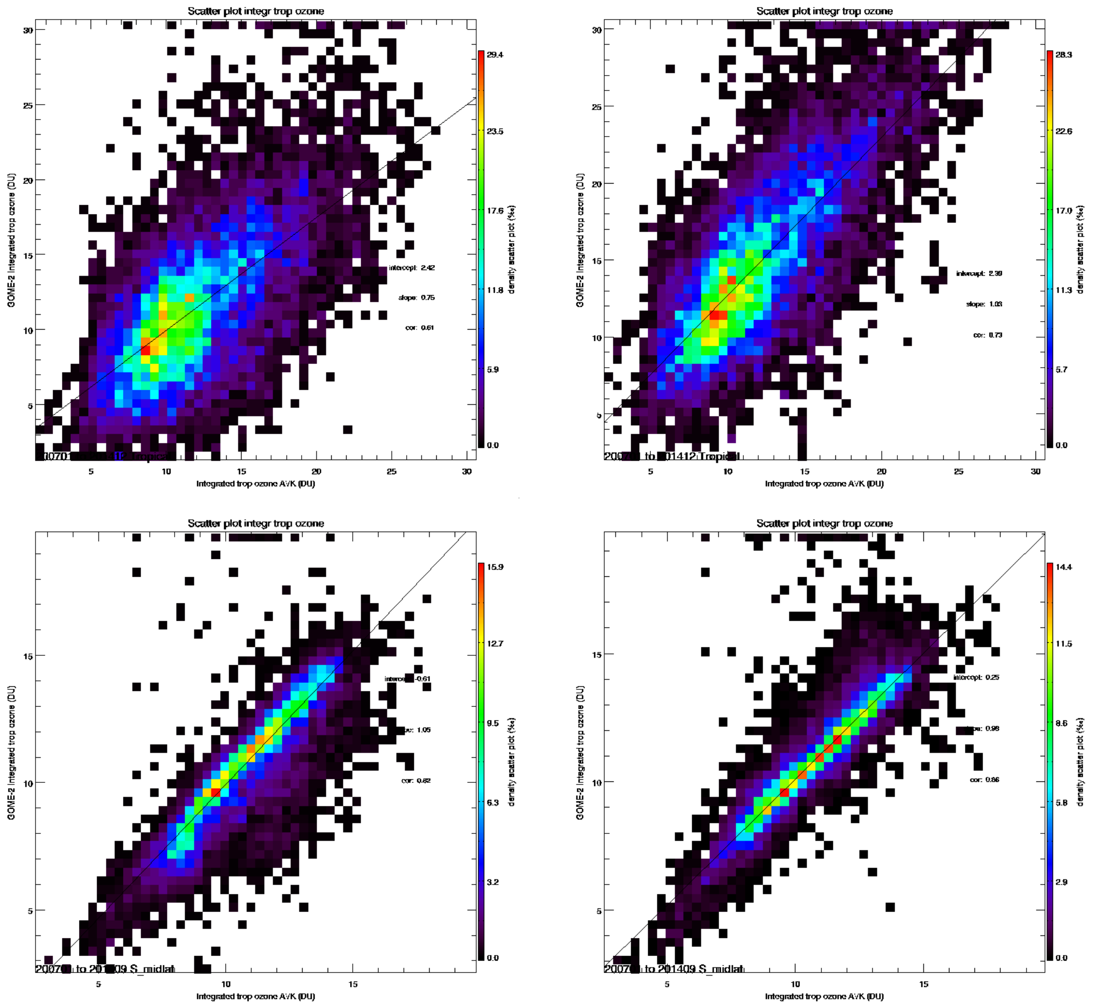
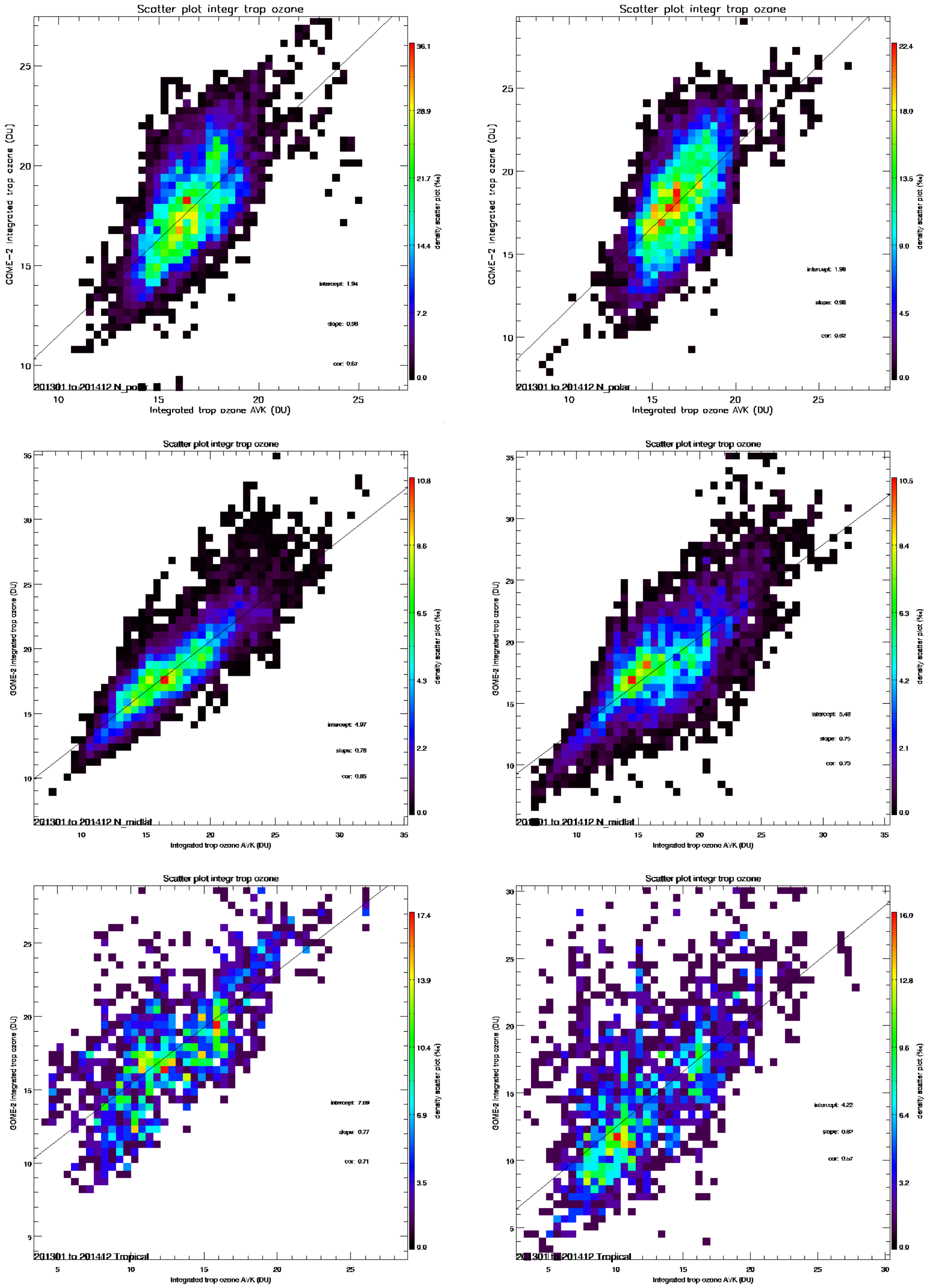


Figure 9: Scatter plots for the GOME-2A high resolution (left) and GOME-2A high resolution degradation corrected (right) tropospheric ozone column products for 4 different latitude belts (N-polar- , N-Mid-Lat- , Tropical- and S-polar belt) for the time period January 2007 – December 2014 (fixed altitude product).

For the GOME-2B CR and HR products, the scatter plots are comparable (Fig. 10).


Scatter plot integr trop ozone
GOME–2 integrated trop ozone (DU)
Integrated trop ozone AVK (DU)
density scatter plot (‰)
201301 to 201412 N_polar
201301 to 201412 N_midlat
201301 to 201412 Tropical

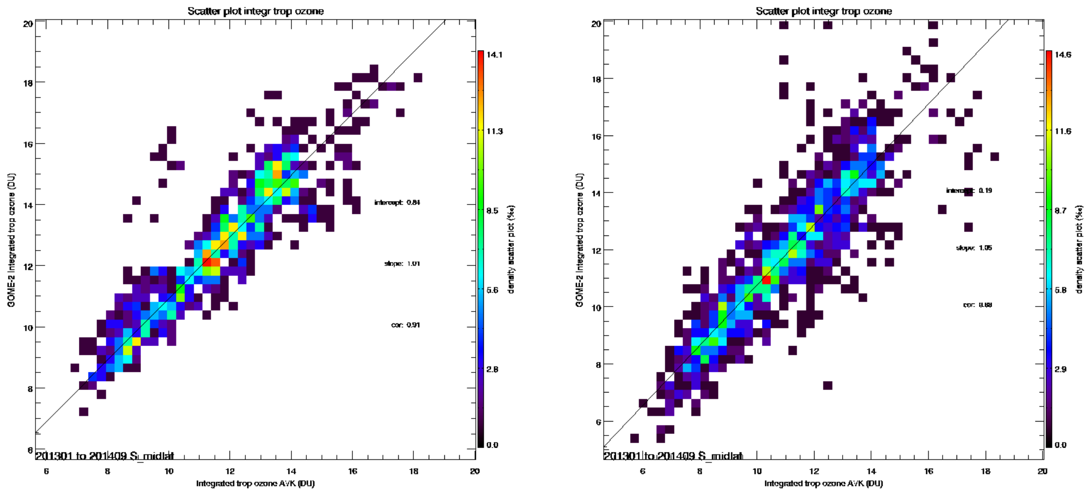


Figure 10: Scatter plots for the GOME-2B coarse resolution (left) and GOME-2B high resolution (right) tropospheric ozone column products for 4 different latitude belts (N-polar- , N-Mid-Lat- , Tropical- and S-polar belt) for the time period January 2013 – December 2014 (fixed altitude product).

5. Discussion

When we compare the results for both methods, it is illustrated that the “fixed altitude method” shows *better* statistics. This can be easily explained by the exclusion of the influence of stratospheric ozone in the TOC product, since we only take into account the ozone concentrations in the lower troposphere.

The comparison between the relative difference plots for both products shows that the amplitude in the seasonal cycle signal is also more pronounced in the tropopause related TOC product, which results in the presence of more scatter in these plots (Figs. 5 and 6).

Also the standard deviation is therefore more elevated in the tropopause related TOC product.

6. Examples of global output

To show that the tropospheric ozone column product has skill to identify elevated tropospheric ozone concentrations within the defined tropospheric ozone layers (tropopause related TOC product and fixed altitude TOC product) some examples are shown in the Figures 11, 12, 13, 14, 15, 16, 17 and 18 which are representative for different seasons for both products.

We compare the degradation corrected tropospheric ozone column products against the operational high resolution GOME-2A HR tropospheric ozone column products for days during the year 2010. The Figures 11, 12, 13 and 14 show results for the tropopause related TOC product while the Figures 15, 16, 17 and 18 show results for the fixed altitude TOC product.

Since the operational GOME-2A HR products are already influenced by the degradation effect, the plots show in general an enhancement in the detection of tropospheric ozone when the degradation correction is applied.

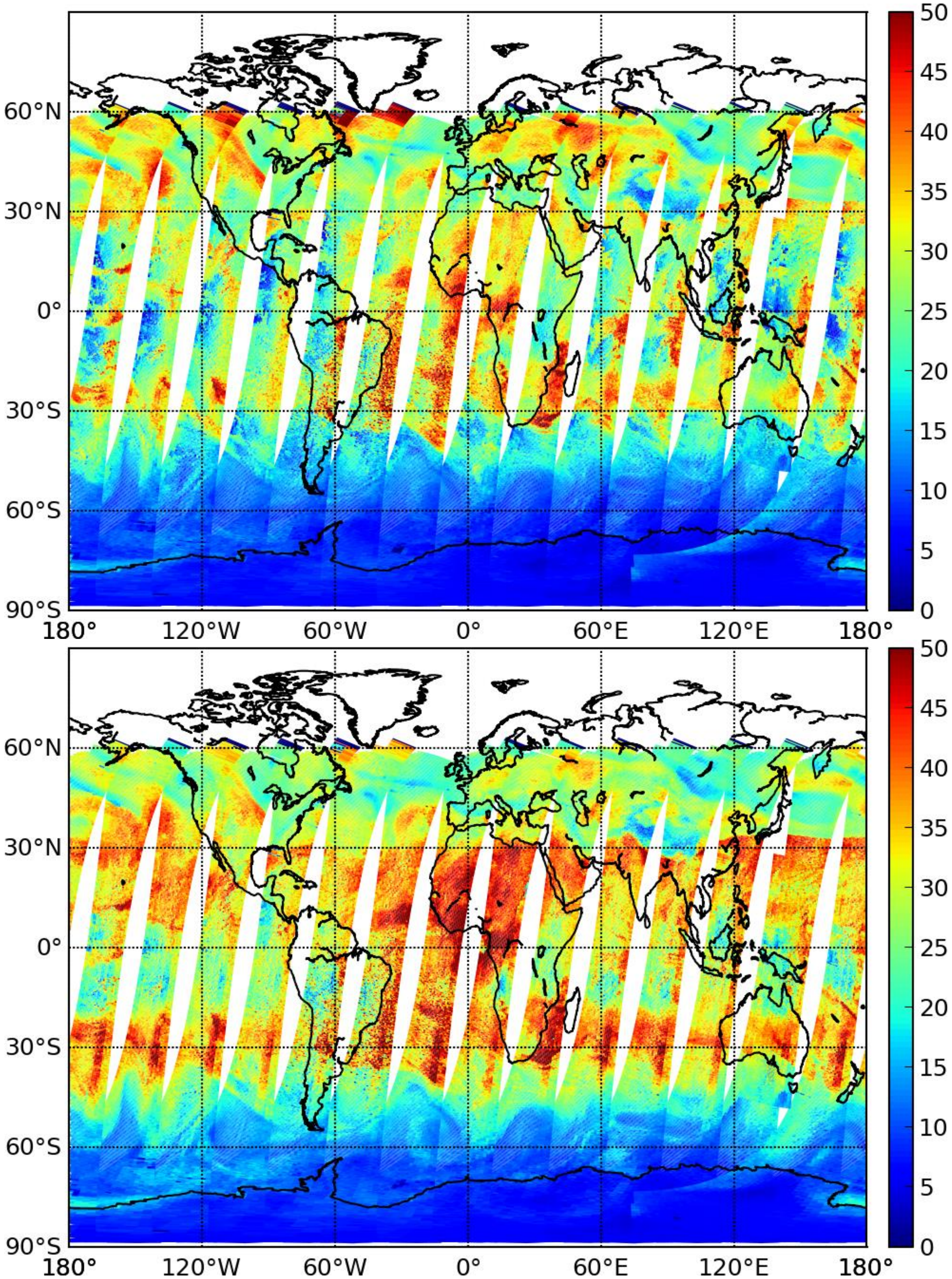


Figure 11: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 1st of January 2010 (tropopause TOC product).

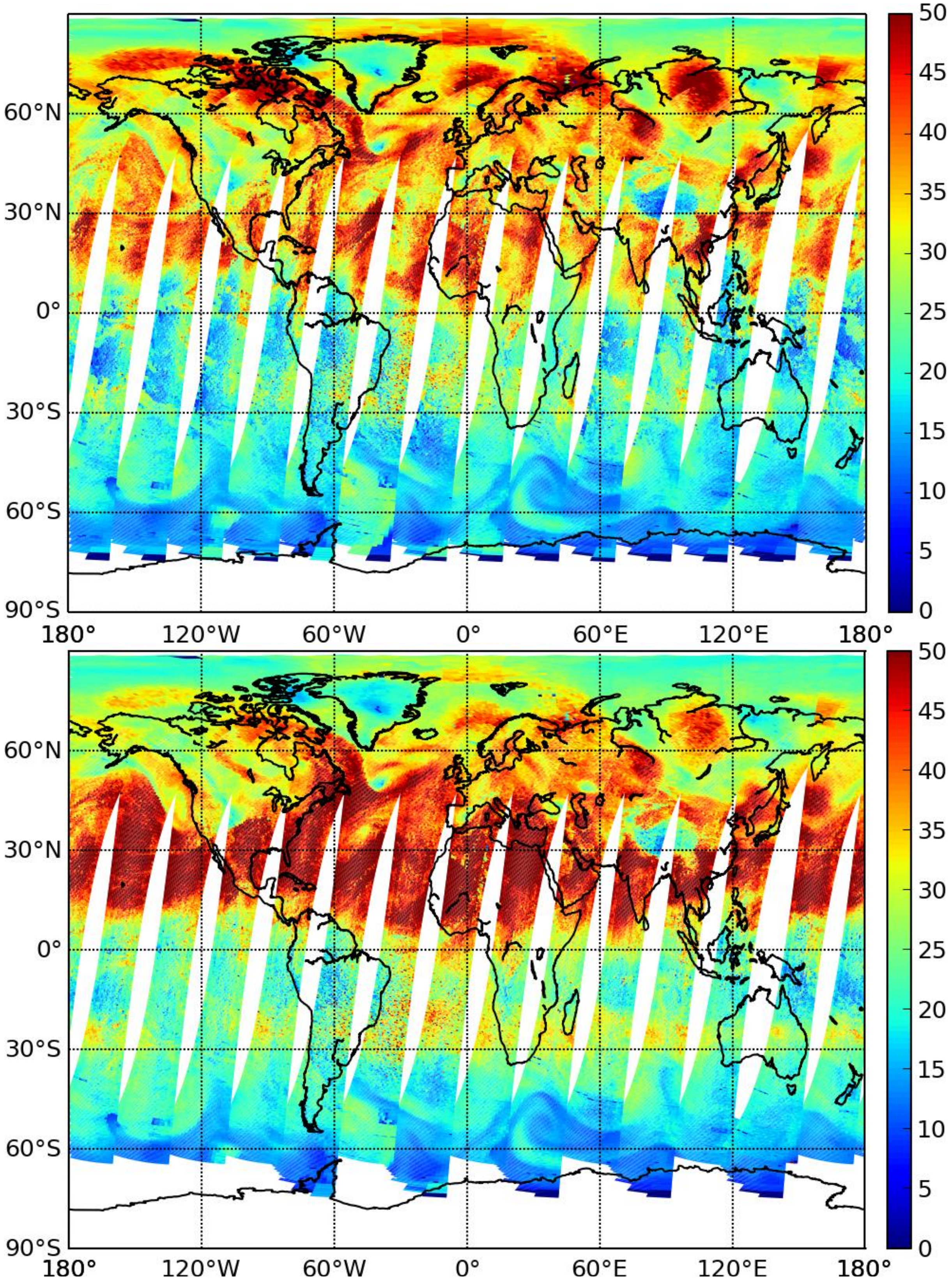


Figure 12: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 4th of April 2010 (tropopause TOC product).

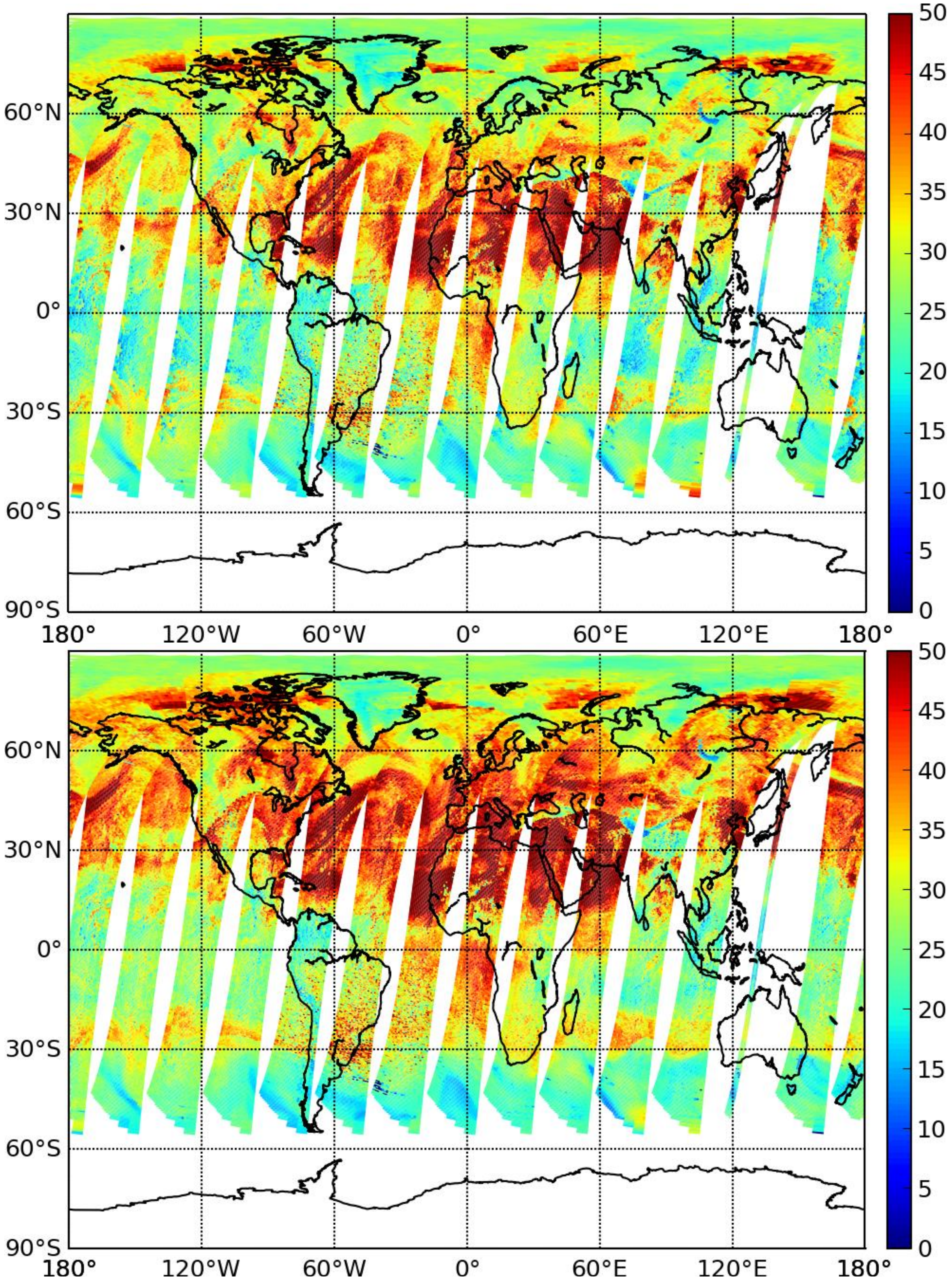


Figure 13: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 2nd of July 2010 (tropopause TOC product).

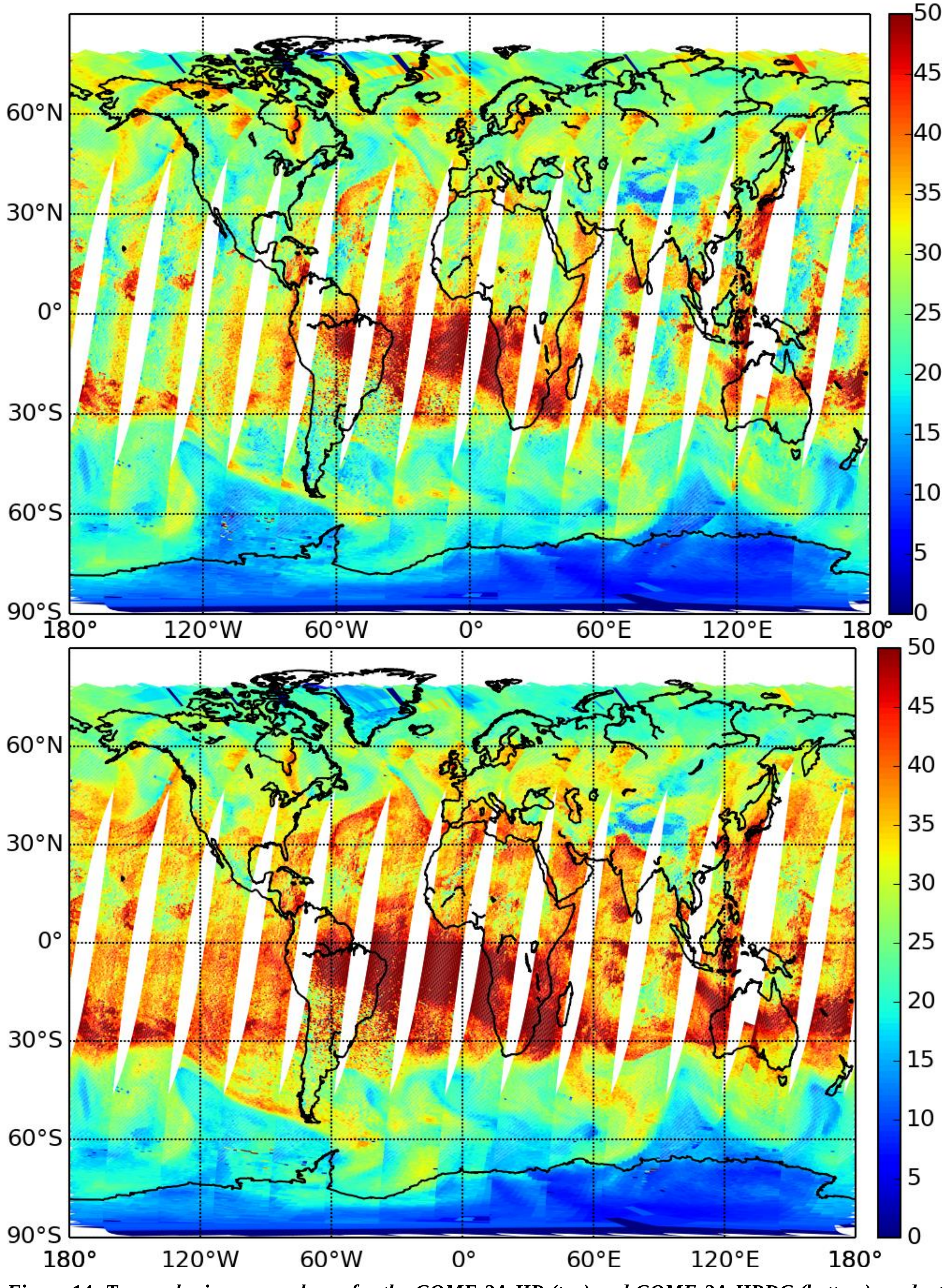


Figure 14: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 9th of October 2010 (tropopause TOC product).

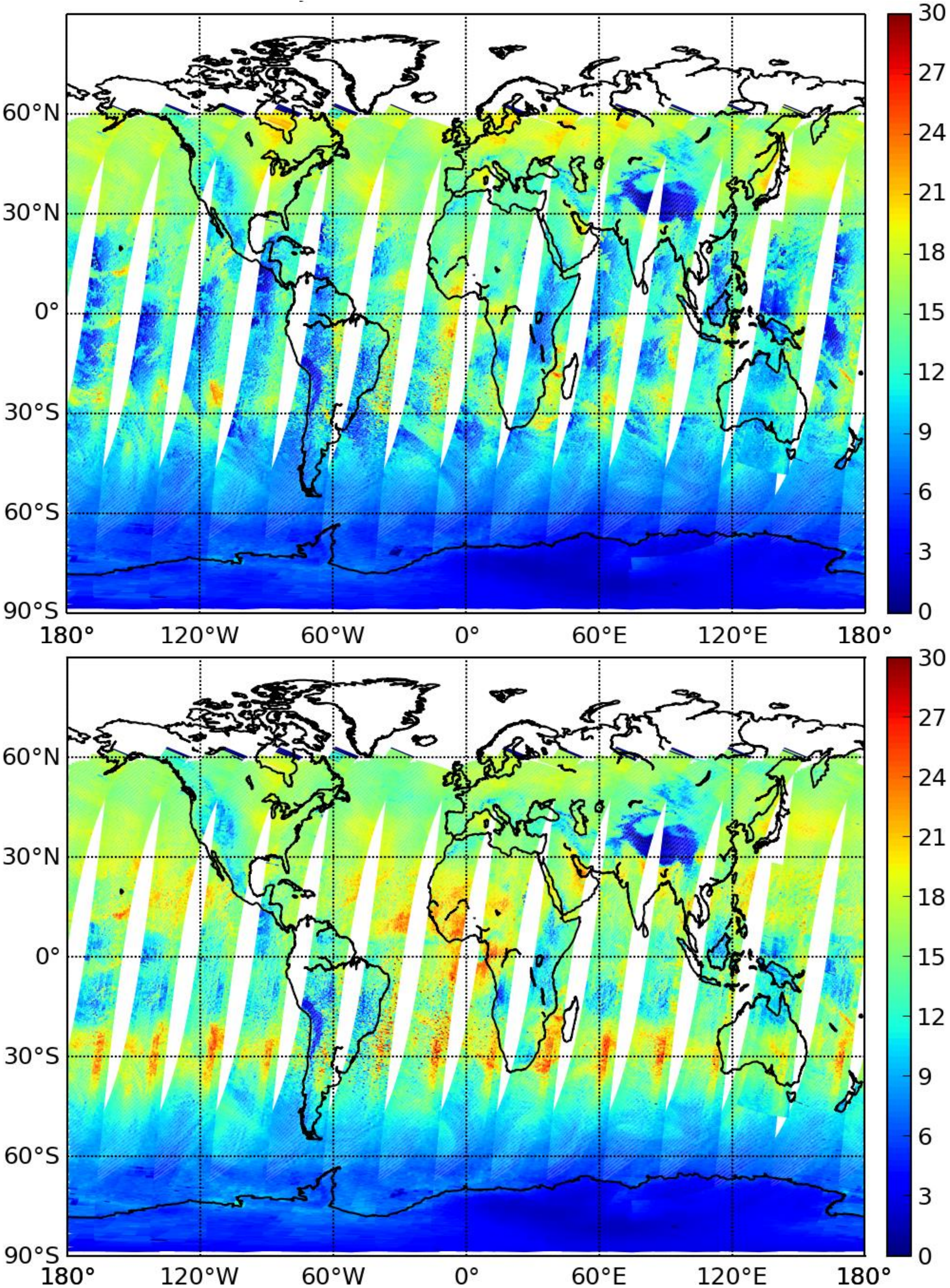
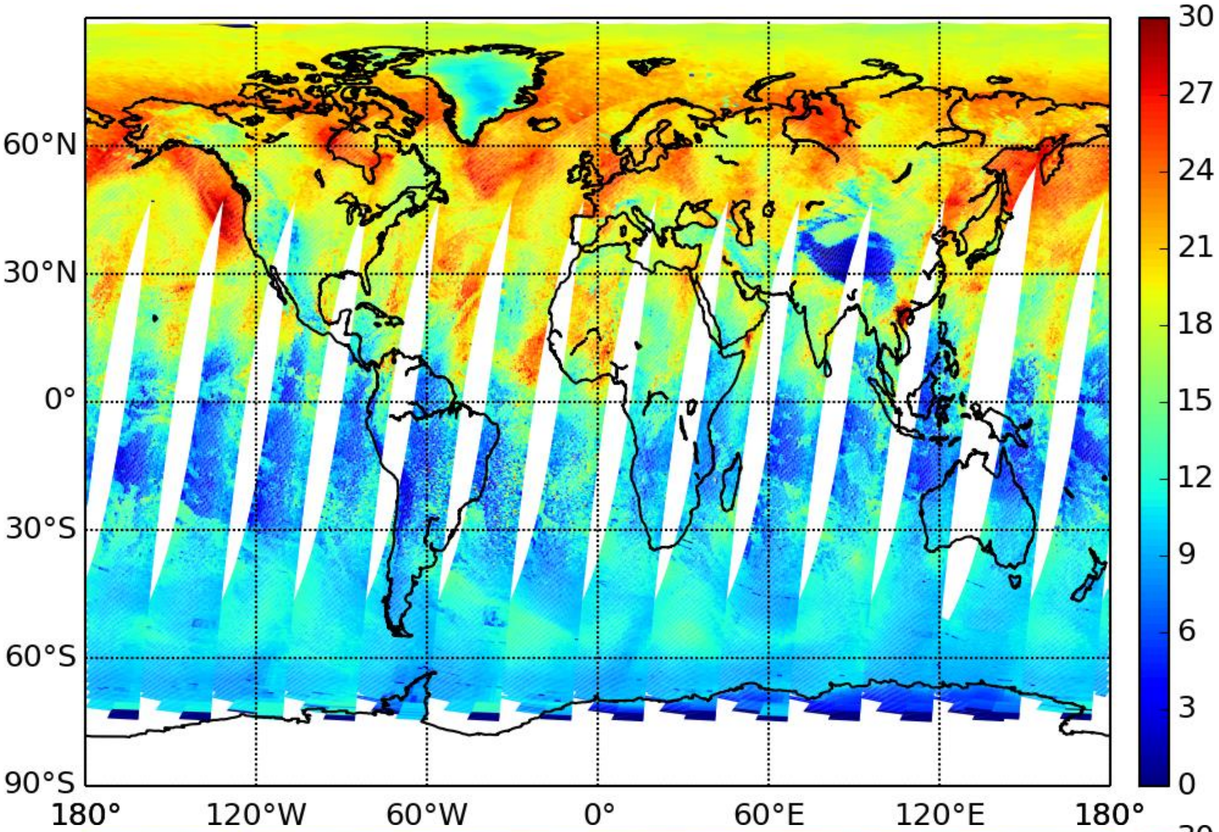


Figure 11: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 1st of January 2010 (fixed altitude TOC product).



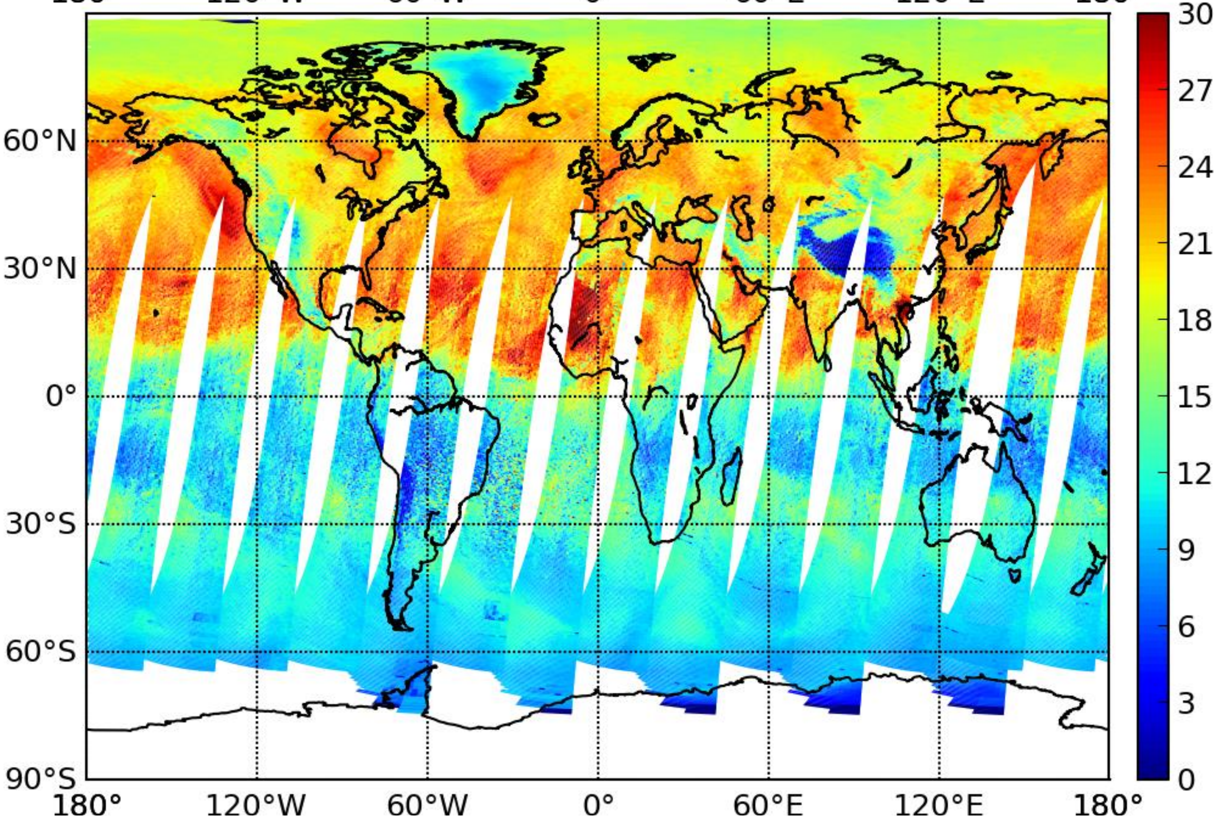
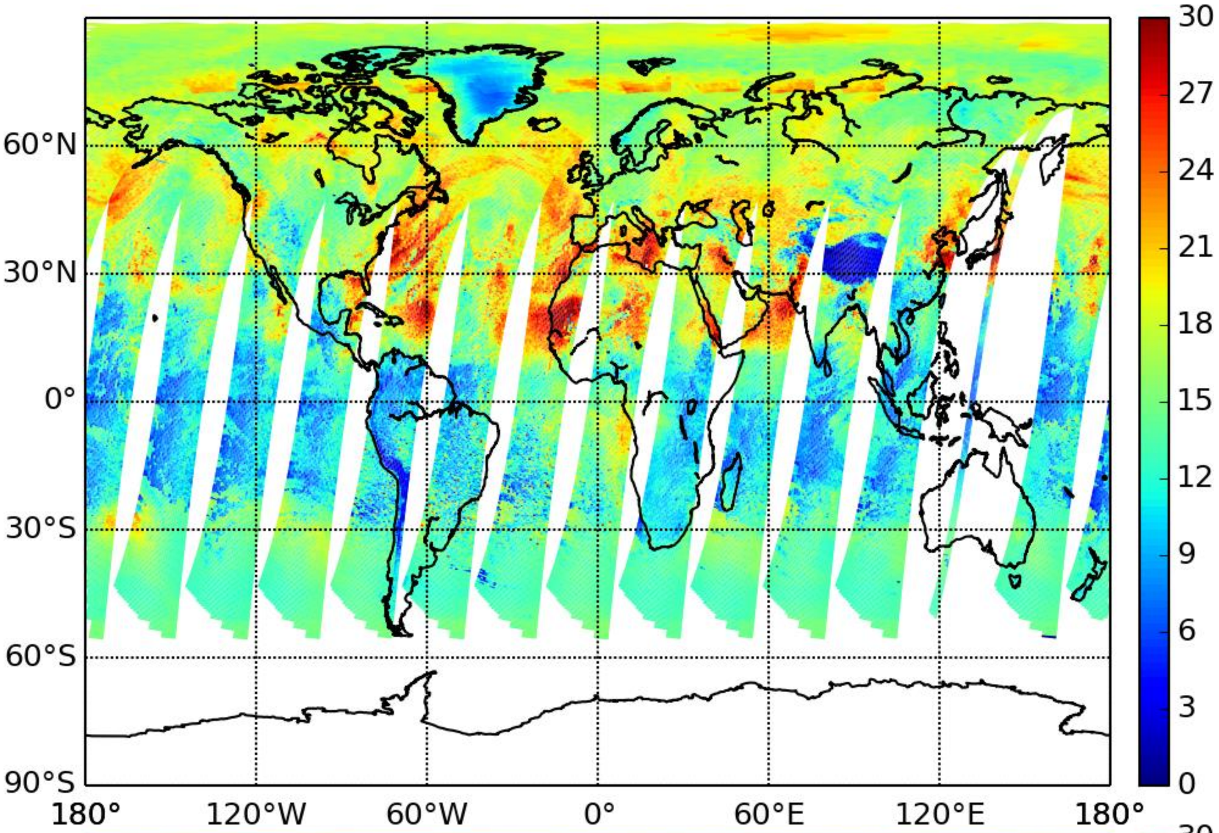


Figure 12: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 4th of April 2010 (fixed altitude TOC product).



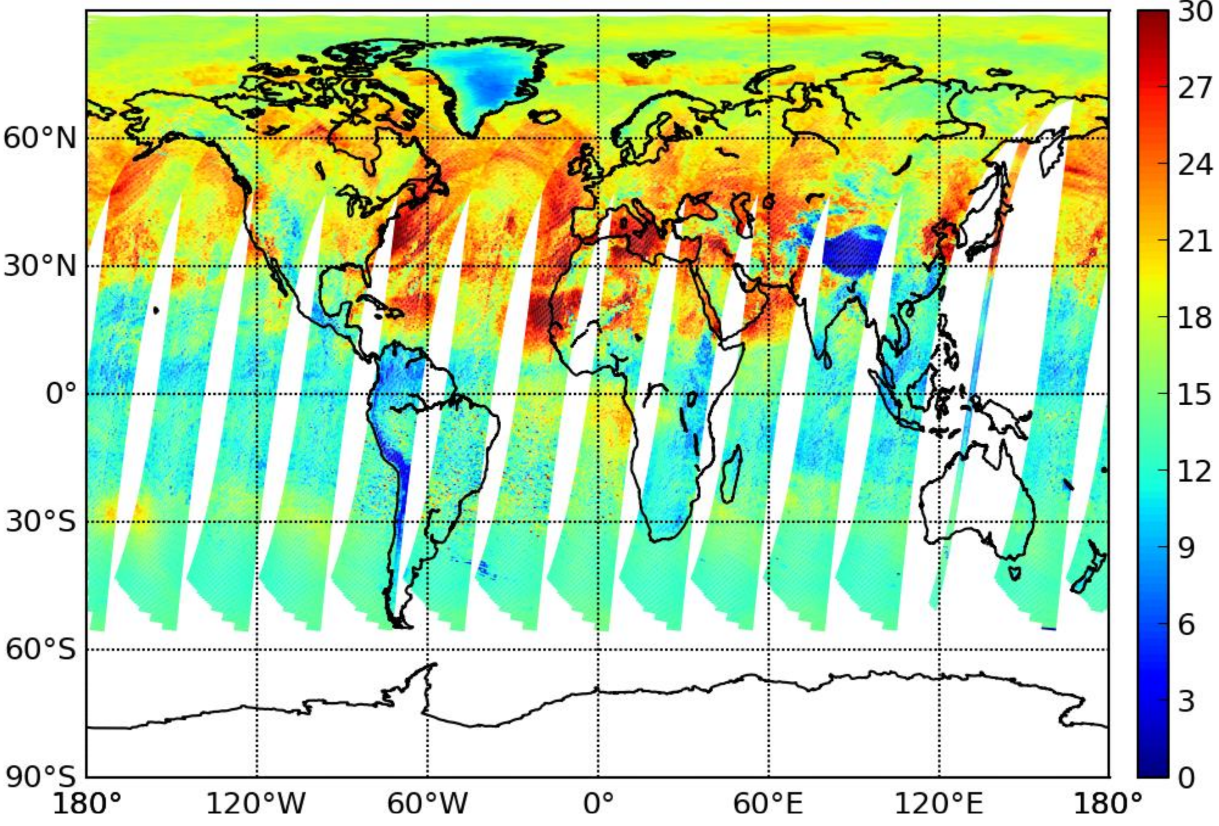


Figure 13: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 2nd of July 2010 (fixed altitude TOC product).

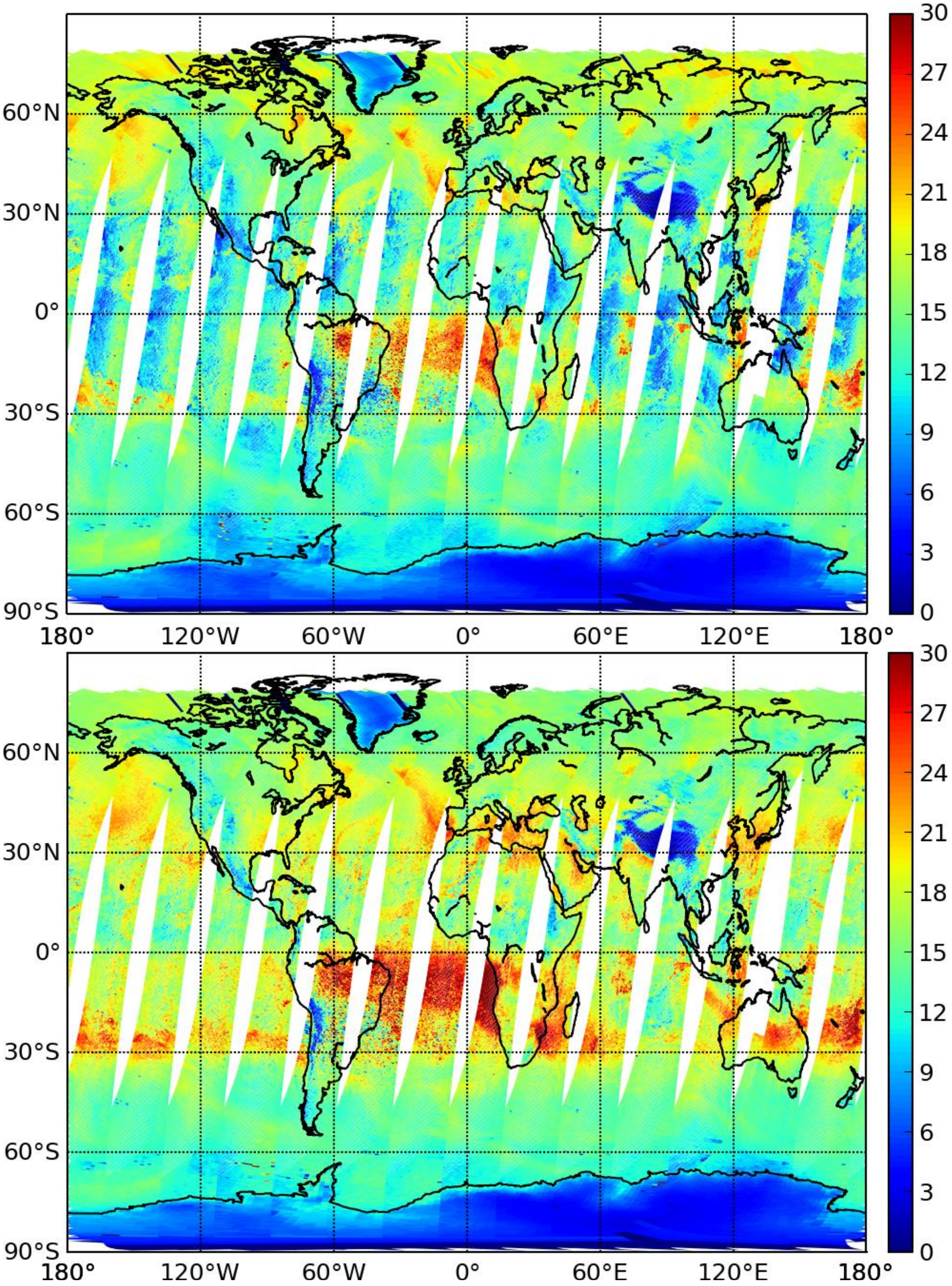


Figure 18: Tropospheric ozone column for the GOME-2A HR (top) and GOME-2A HRDC (bottom) product for the 9th of October 2010 (fixed altitude TOC product).

7. Conclusions

This validation report has examined the statistics of two different tropospheric ozone column products, i.e. the tropopause related and the fixed altitude TOC products.

It is shown that for the tropopause related TOC products, the GOME-2A and GOME-2B Tropospheric Ozone Column products are after comparison with balloon sounding ozonesonde data for most of the regions within the target accuracy (20 %), except for the tropical stations, which are within threshold values (Table 4). Therefore it can be concluded that the GOME-2A and GOME-2B tropospheric ozone column products fulfill the user requirements.

For the fixed altitude TOC products, the GOME-2A and GOME-2B Tropospheric Ozone Column products are after comparison with balloon sounding ozonesonde data for most of the regions within the optimal accuracy (15 %), except for the tropical stations, which are within threshold values for the GOME-2A product (Table 5). Therefore it can be concluded that the GOME-2A and GOME-2B tropospheric ozone column products fulfill the user requirements.

In general, both products show for all the belts a typical overestimation for the GOME-2B and GOME-2A degradation corrected datasets. The statistics shown for the GOME-2A CR and HR products are valid for the time period 2007 – 2014 and should therefore be interpreted with care. Since there is a clear degradation present in these time series, we obtain statistics which are within optimal accuracy for both TOC products for most of the regions with the presence of a more elevated standard deviation when compared with the associated degradation corrected datasets. The relative difference time series (Figs 3a, 3b, 7a, 7b) illustrate this negative trend in retrieved tropospheric ozone concentrations which is caused by the degradation of the GOME-2A sensor.

It is also shown when comparing the results of both methods that the “fixed altitude method” shows *better* statistics. This could be easily explained by the exclusion of the influence of stratospheric ozone in the TOC product, since we only take into account the ozone concentrations in the lower troposphere.

The degradation correction has proven to significantly improve the product. The seasonal behavior which is present in the operational GOME-2A and GOME-2B products is not present anymore in the degradation corrected GOME-2A HR product. For the tropical belt the degradation correction did not fully succeed to improve the statistics. This issue is currently under investigation.

Taking into consideration the significant improvement of the GOME-2A degradation corrected high resolution product, it is strongly recommended to initiate the full reprocessing of the GOME-2A HR dataset.

8. Acknowledgement

The ozonesonde data was made available by WOUDC (http://www.woudc.org), the SHADOZ network (http://croc.gsfc.nasa.gov/shadoz/) and the NILU's Atmospheric Database for Interactive Retrieval (NADIR) at Norsk Institutt for Luftforskning (NILU) (http://www.nilu.no/nadir/).

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