OMI TOMS Total Ozone Column

Validation Status

April 2006

		Date	Signature
Author:	M. Kroon E.J. Brinksma G. Labow D. Balis	31 May 06 31 May 06 31 May 06 31 May 06	
Checked:	J.P. Veefkind J.F. de Haan		
Approved:	P.F. Levelt		
Archive:	R. Noordhoek		

Distribution list:

OMI Science Team	
Johanna Tamminen	FMI
Aapo Tanskanen	FMI
Remco Braak	KNMI
Ellen Brinksma	KNMI
Johan de Haan	KNMI
Mark Kroon	KNMI
Pieternel Levelt	KNMI
René Noordhoek	KNMI
Piet Stammes	KNMI
Pepijn Veefkind	KNMI
Robert Voors	KNMI
Hennie Kelder	KNMI
Pawan K Bhartia	NASA/GSFC
James Gleason	NASA/GSFC
Ernie Hilsenrath	NASA/GSFC
Joanna Joiner	NASA/GSFC
Gordon Labow	NASA/GSFC
Richard McPeters	NASA/GSFC
Alexander Vassilkov	NASA/GSFC
Stanley Sander	NASA/JPL
Agencies	
Joost Carpay	NIVR
Anssi Mälkki	FMI
EOS-Aura Project	
Ann Douglass	NASA/GSFC
Ernie Hilsenrath	NASA/GSFC
Mark Schoeberl	NASA/GSFC
Lucien Froidevaux	NASA/JPL

Change status:

Issue	Release date	Comments	Affected pages
Version 1.0	19 April 2006	First version	All
Version 1.1	31 May 2006	Edited first version, added abstract, added E.J. Brinksma as co-author	All

Table of Contents

Abstract

OMI total ozone column data retrieved with the TOMS algorithm and labeled OMTO3, was compared to total ozone column recordings by ground based Dobson and Brewer networks, and to SBUV total ozone column data. Based on 15 months of data we conclude that OMTO3 compares very well to the measurement by these correlative instruments. With respect to the worldwide Dobson network, a global average bias of 1% is found for OMTO3 if the tropics are excluded. When considering individual station averages, biases are within the 3% range, now with respect to both Brewer and Dobson instruments. Above 35 N, comparisons are considerably better, with differences within the 1% range. There is no significant dependence on solar zenith angle, or on total ozone column. With respect to Brewer instruments, which are almost all located in the Northern Hemisphere, a "global" average difference of -0.1% is found. Time series of globally averaged differences between OMTO3 and ground instruments show an annual variation with amplitude of 1.5% with respect to Dobson instruments, and no annual variation with respect to Brewer instruments. It should be noted that annual cycles in the recording by ground based instruments are expected and may contribute to the differences observed. Comparisons with SBUV reveal a positive bias of OMI data. When comparing the validation of OMI with that of EP-TOMS, validated against the same ground based instrument set, OMI clearly shows better results.

1 Introduction

This document contains an overview of the validation results known at the time of writing (April 2006) of the OMI TOMS total ozone column data product, abbreviated OMTO3. This document accompanies the public release of this OMI data product and is intended for the general public who wish to use this satellite data product for their scientific studies and assessment, and to ensure awareness of the quality and the shortcomings of this satellite data product. The work reported in section 4.1 and chapter 5 was performed by Gordon Labow, NASA Goddard Space Flight Center, Greenbelt, Maryland, United States of America (labow@qhearts.gsfc.nasa.gov). The work reported in section 4.2 was performed by Dimitris Balis, Aristotle University of Thessaloniki, Greece (balis@auth.gr, http://lap.physics.auth.gr).

2 OMI TOMS total ozone column data product

The OMI TOMS total ozone column data product, abbreviated OMTO3, contains total ozone column, aerosol index, and ancillary information produced from the TOMS Version 8 (V8) algorithm applied to OMI global mode measurements [1,2]. In the global mode each file contains a single orbit of data covering the 20000 km pole-to-pole sunlit portion of the orbit, resolving a swath of ~ 2600 km wide with high spatial resolution. The accuracy and precision of OMTO3 total ozone data is roughly similar to the TOMS data of the preceding 25 years, however, the suitability of OMTO3 data for the analysis of long-term trends has not yet been established. It is expected that there will be at least one update to OMTO3 within 1-2 years after public release of the data product, when the long-term performance of the instrument is better understood.

3 Ground based stations measuring total ozone

In this document we report on the comparisons of satellite OMTO3 total ozone column data with collocated ground and satellite based observations. The ground based observations are performed by a world wide network of Dobson and Brewer instruments. Information on the Dobson and Brewer stations can be found, among others, on the WOUDC website by following the web link http://www.woudc.org.

In Figure 1 we show as an example a world map of Dobson stations currently contributing to the WOUDC total ozone column data base. The photograph of Figure 2 shows the Dobson instrument no. 40 at Uccle, Belgium. The Dobson spectrophotometer measures the ozone column amount with an accuracy of 2-3% for Sun elevation higher than 15°. It is a large and manually controlled two-beam instrument based on the differential absorption method in the ultraviolet Huggins band where ozone exhibits strong absorption features. The measurement principle relies on the ratio of the direct sunlight intensities at two standard wavelengths. The most widely used

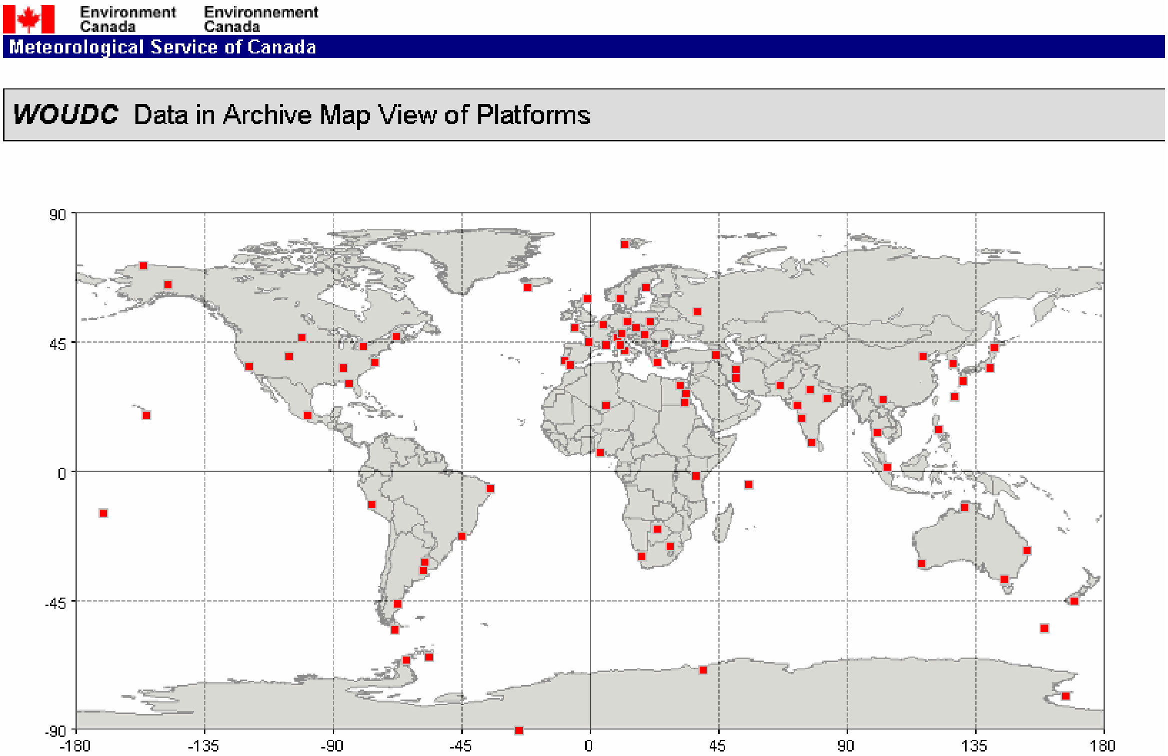


Figure 1: World wide map of Dobson stations measuring ozone in the timeframe 1994- 2006 and contributing their measurements to the WOUDC archives.

Figure 2: The Dobson instrument nr 40 at Uccle, Belgium.

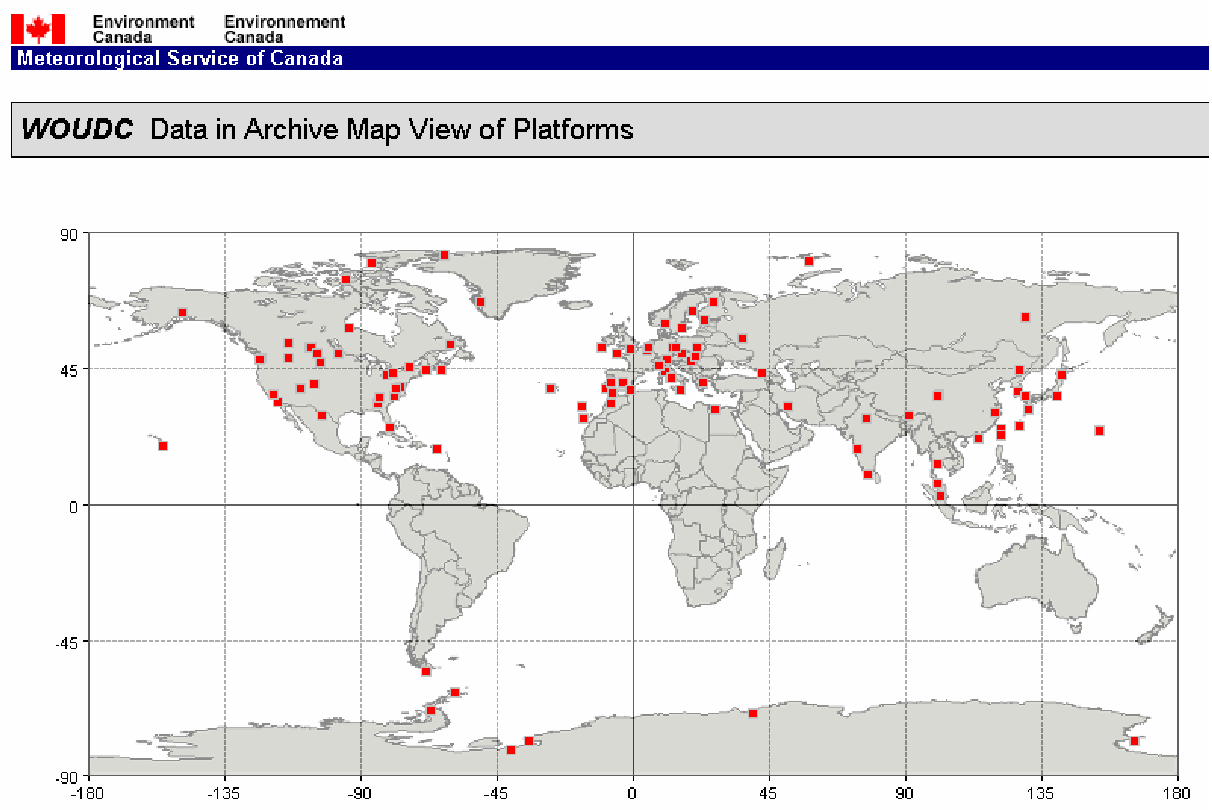


Figure 3: World wide map of Brewer stations measuring ozone in the timeframe 1994- 2006 and contributing their measurements to the WOUDC archives.

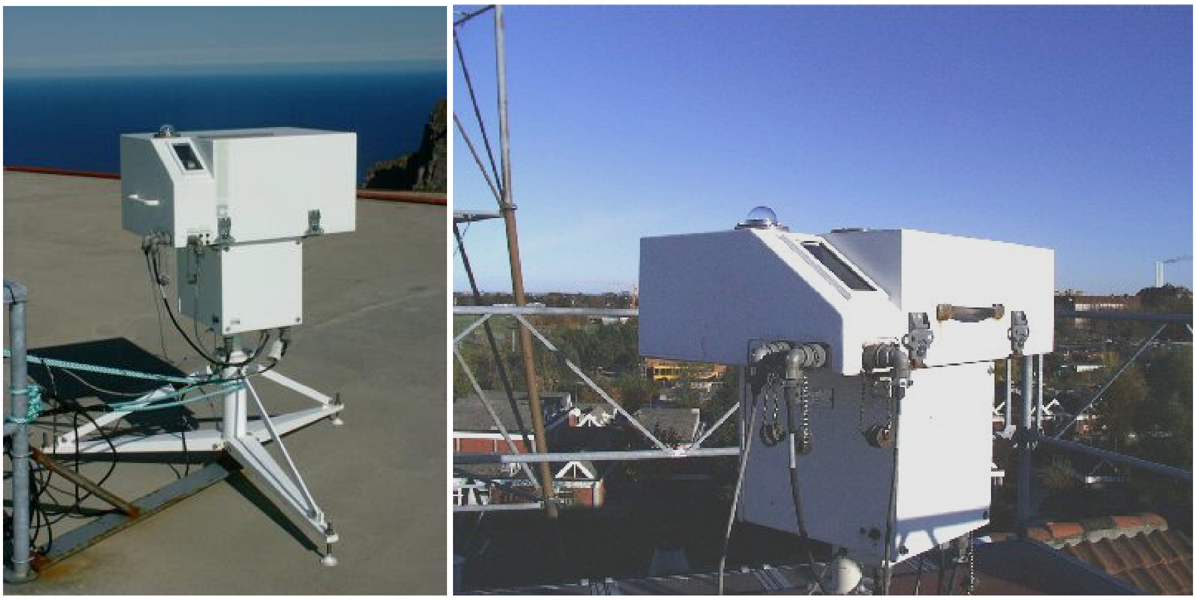


Figure 4: SCI-TEC Brewer ozone spectrophotometer (MK-III type) on the roof of ALOMAR, Norway (left) and Brewer ozone spectrophotometer (MK-II type) in Copenhagen, Denmark (right).

combination is the AD double pair (305.5-325.4; 317.6-339.8 nm), recommended as international standard for mid-latitudes. Since 1958 Dobson spectrophotometers have been deployed in a worldwide network.

In Figure 3 we show as an example a world map of Brewer stations currently contributing to the WOUDC total ozone column data base. The photographs of Figure 4 show the Brewer instrument at Alomar, Norway and Copenhagen, Denmark. The Brewer grating spectrophotometer is in principle similar to the Dobson, however, it has an improved optical design and is fully automated. The ozone column abundance is determined from a combination of five wavelengths between 306 and 320 nm. Since the 1980's, Brewer instruments are operated in ground based networks as well. Most Brewers are single monochromators, but a small number of systems are double monochromators with improved stray light performance.

More information on the principles of Dobson instruments can be obtained by following the web link http://www.cmdl.noaa.gov/ozwv/dobson/papers/report6/report6.html. More information on the principles of Brewer instruments can be obtained by following the web link http://www.kippzonen.com/product/brewer.html.

4 Validation against ground based total ozone observations

4.1 Brewer and Dobson stations collected

Satellite OMTO3 data are collocated with ground based data within the following criteria: (1) measurements are performed on the same day, (2) the OMI Field of View (FOV) must be over the ground station, (3) the OMI solar zenith angle must be less than 84 degrees, (4) and if multiple overpasses occur on the same day, the nearest spatial collocation is chosen

In Figure 5 we show an overview of the validation of OMTO3 against ground based observations as a function of latitude. Ground-stations within a given 10 degree latitude band are averaged together and plotted versus the satellite overpass values. EP-TOMS data include the time period 1996-2001 and are shown as a “reference” while OMI data covers the period August 2004 through January 2006. Error bars (one sigma) are shown for OMI data only to avoid making the figure too messy. Error bars for EP-TOMS data are similar in magnitude. OMTO3 agrees well with the ground based observations, deviations are mostly in the ±3% range. OMTO3 appears to show more variability than EP-TOMS most likely due to the fact that there is less OMI data (~ 1/5), due to the shorter time span considered. A strong outlier appears at 15 N which is not fully understood at this time but may be attributed to lack of ground-based data from these regions.

In Figure 6 we show an overview of the validation of OMTO3 against ground based observations as a function of the measured Earth reflectivity at 331 nm wavelength. This reflectivity is strongly correlated with clouds and/or surface albedo. From Figure 6, we conclude that OMTO3 is biased within 1.5% up to 80% reflectivity. It is performing better than EP-TOMS, shown in the same graph. However, over bright surfaces the comparison shows a stronger deviation from the zero line. There are various plausible explanations; first the amount of clouds may be very high, which may introduce errors, and, where the high reflectivity is due to snow or ice, OMI is looking mostly at latitudes where the ozone fields and meteorological conditions are most likely very variable, and may differ between the time and place that OMI observes with respect to the ground instrument. Also, for large cloud fractions, the ground instrument may not get a direct view of the sun at the time of OMI overpass, and thus either use zenith sky, which has worse accuracy, or use direct sun observations possibly hours before or after OMI overpass. The return of good agreement at extremely high reflectivity values is not fully understood, it may indicate that the satellite ozone profile climatology (ozone below the cloud) is relatively accurate.

In Figure 7 we show an overview of the validation of OMTO3 against ground based observations as a function of the solar zenith angle. From this graph we conclude that OMTO3 is performing well, with slight deviations above 75 degrees, which are comparable to error bars and thus not significant. In contrast, EP-TOMS results depend on solar zenith angle. The EP-TOMS instrument has degraded in a form that can not be fully characterized by internal satellite diagnostics alone. Comparisons to other satellite retrievals indicate that

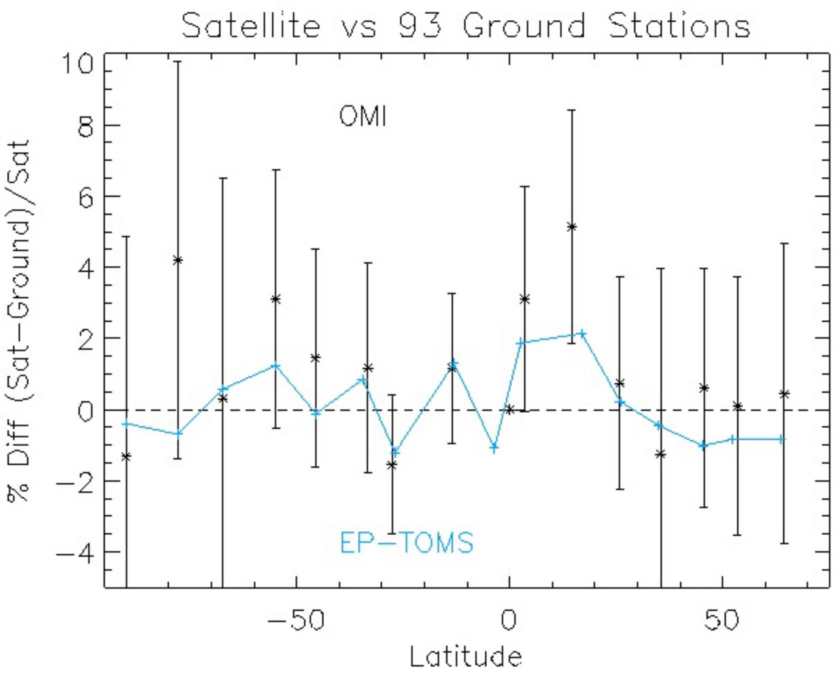


Figure 5: Publicly released OMI TOMS total ozone column versus ground station data for the time frame Aug 2004 - Jan 2006 plotted against latitude. OMI agrees well with the ground based Dobson observations and with earlier observations by EP-TOMS (1996-2001). Both show no significant or structural dependence on latitude.

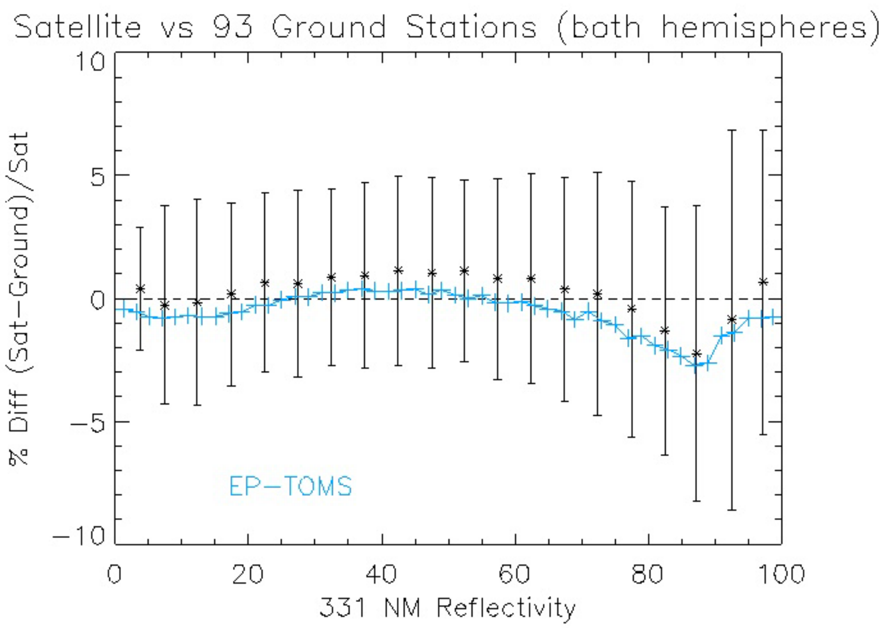


Figure 6: Publicly released OMI TOMS total ozone column versus ground station data for the time frame Aug 2004 - Jan 2006 plotted against the 331 nm UV channel Earth reflectivity. Both OMI and EP-TOMS (time span 1996-2001) show a reflectivity independent regime followed by a sharp downward trend recovering to zero.

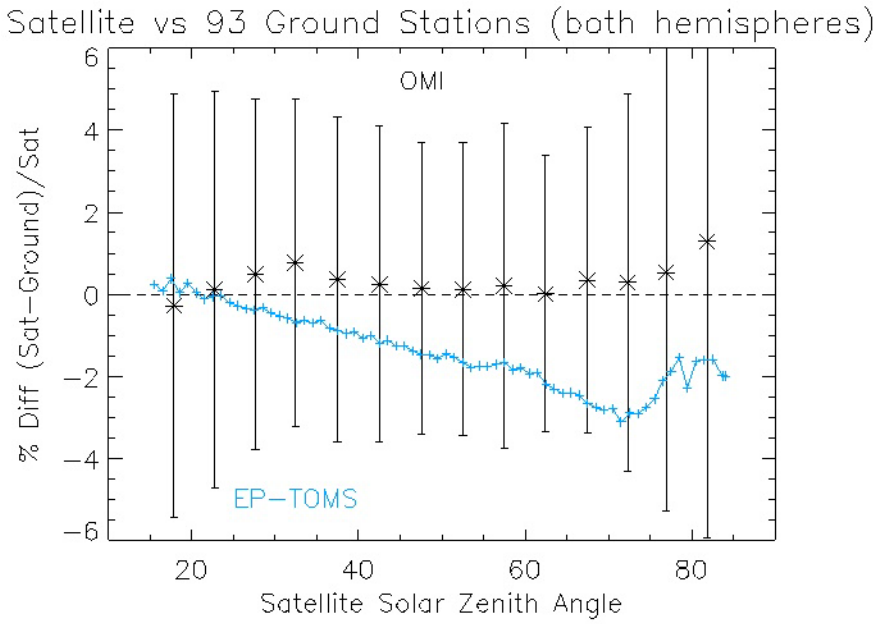


Figure 7: Publicly released OMI TOMS total ozone column versus ground station data for the time frame Aug 2004 - Jan 2006 plotted against the satellite solar zenith angle. High SZA indicate challenging measurement geometries. Where OMI appears SZA independent, EP-TOMS (time span 1996-2001) show a structural drift away from ground based observations.

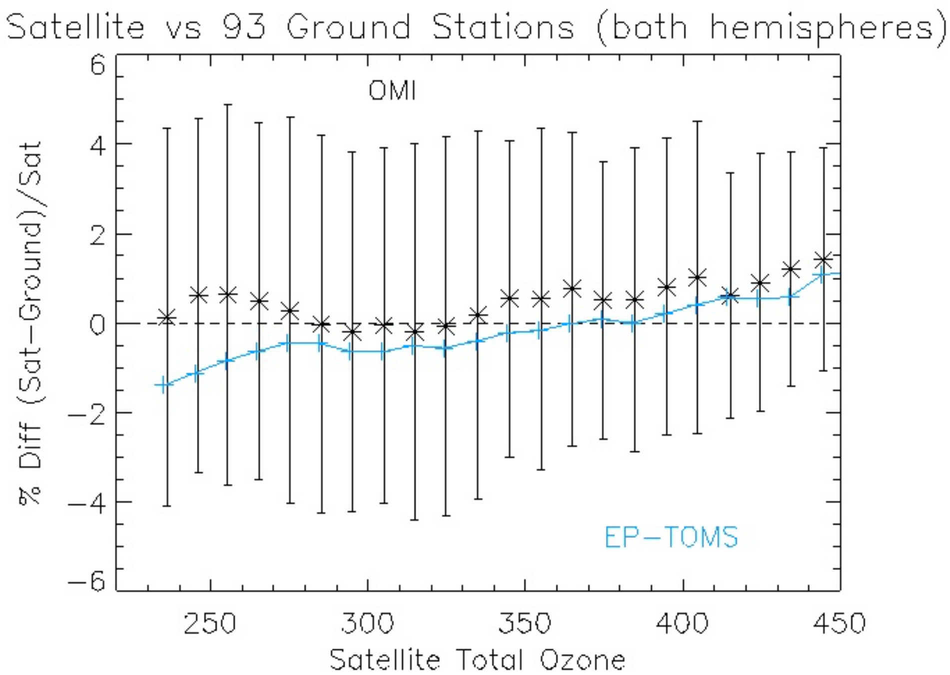


Figure 8: Publicly released OMI TOMS total ozone column versus ground station data for the time frame Aug 2004 - Jan 2006 plotted against the OMI TOMS total ozone values. Here OMI shows a strong improvement over EP-TOMS (time span 1996-2001), revealing absolute agreement with Dobson observations over the entire dynamic range.

EP-TOMS has a signal level dependent drift which is consistent with the plot above. Work is being done to fully understand the cause and severity of the instrument degradation and to better correct the EP-TOMS data record.

In Figure 8 we show an overview of the validation of OMTO3 against ground based observations as a function of the satellite total ozone column. From this graph we conclude that OMTO3 is performing very well, results do not significantly depend on total ozone. In contrast, EP-TOMS changes linearly from underestimating to overestimating total ozone with increasing total ozone column values. A possible explanation for the slight upward slope of the OMTO3 validation result at high total ozone can be that at higher air masses most of the ground-based instrumentation - single-pass Brewer instruments and Dobson instruments - underestimate column ozone values due to issues with stray light within the instrument. For OMI, factors such as instrument temperature, airmass calculation, errors in ozone cross sections, and/or instrument wavelength characterization may contribute to total column dependent errors [3].

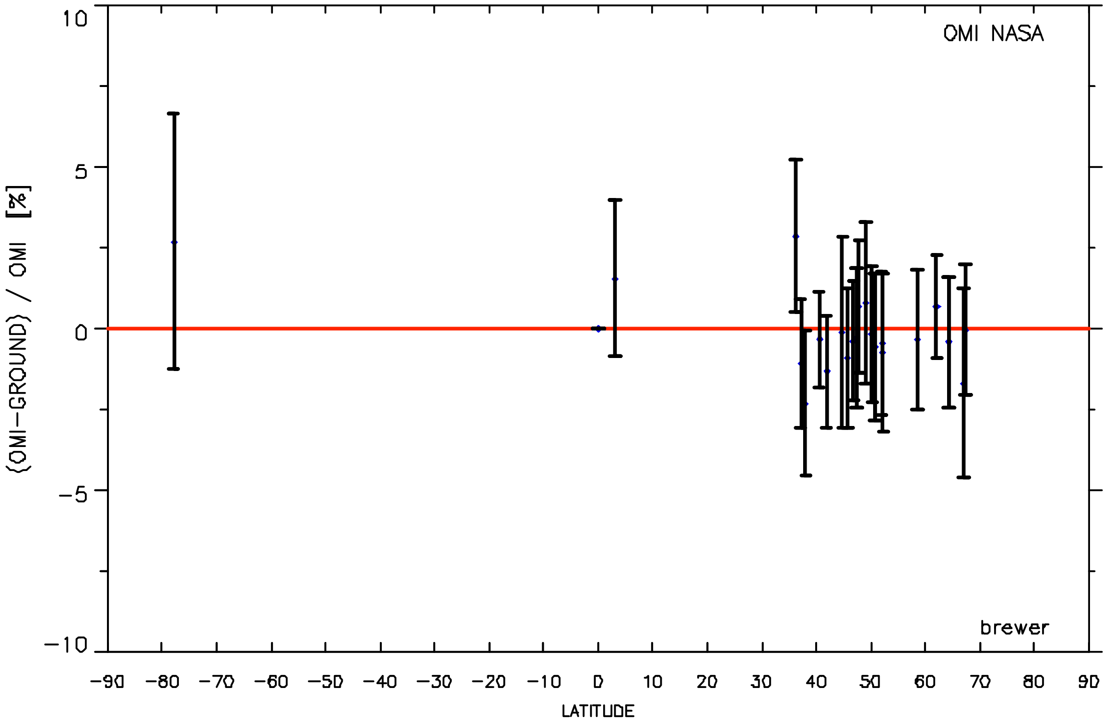
4.2 Brewer and Dobson stations individually

In this section we present comparison results for OMI using ground-based Brewer and Dobson total ozone measurements. Here comparison results are presented for these instrument types separately.

During the commissioning phase of OMI, the near-to-real time Brewer ground-based data, which are submitted to the WMO Northern Hemisphere Ozone Mapping Centre within few hours after observation, have been employed to check the behavior of the OMI instrument as a function of measuring geometry. In addition the near-to-real time ground based data are also used as an early warning tool for the detection of possible problems during the operation of OMI. Brewer total ozone observations are limited to the Northern Hemisphere. We used near-to-real time as well as “archive quality” data. Archived ground-based data have been used to validate more than one year of OMI-TOMS total ozone measurements. Validation results using either preliminary Brewer data, or archived Brewer data, are consistent. For the off-line validation of the OMI total ozone, we used in addition also archived Dobson data, available at WOUDC database. All data used correspond to stations that have been compared in the past with other satellite data (GOME, TOMS) [4, 5] and for which the quality has been assessed. Data from 22 Brewer and 47 Dobson instruments have been used (see appendix). For each of these stations time series of the differences have been generated and features like offsets, scatter, seasonal dependence, and SZA dependence have been examined.

The error of individual total ozone measurements for a well maintained Brewer instrument is about 1% for optimal observation conditions and the standard deviation of the difference between Brewer and satellite data can be as low as 2% for these conditions. The errors are higher (about 5%) at lower sun elevation and in polar winter with mostly zenith sky measurements. Despite the similar performance between the Brewer and Dobson stations, small differences within ±0.6% are introduced due to the use of different wavelengths and different temperature dependence for the ozone absorption coefficients [6]. The temperature sensitivity of the ozone absorption cross sections in the Huggins bands, and to a lesser extent the ozone profile, affects the performance of the Brewer and Dobson instruments. In particular, the atmospheric seasonal changes result in seasonal variations of the Brewer and Dobson ozone data. The effect is estimated to be up to 4% in Dobson instruments [6a] and less than 1% in Brewer instruments [7]. In addition, stray light problems in single pass Brewer instruments and in Dobson instruments cause seasonal changes, as was discussed using Figure 8.

Figure 9 shows the mean percent differences between the satellite OMTO3 data and the ground based total ozone observations separately for the Brewer and Dobson instruments. Global average differences can only be estimated from the Dobson comparisons, since there are almost no Brewer instruments in the southern hemisphere. The average difference between OMI-TOMS and Brewer observations is -0.12%. The average difference between OMI-TOMS and Dobson observations, which have a better latitudinal coverage, is about 1%, with higher values for the tropics. Comparison results from high latitude stations cannot be considered significant at present since they are based on only a few observations, which is demonstrated in the large standard deviations of the mean values. However, they do provide a first estimate for the performance of the instrument and the algorithm.



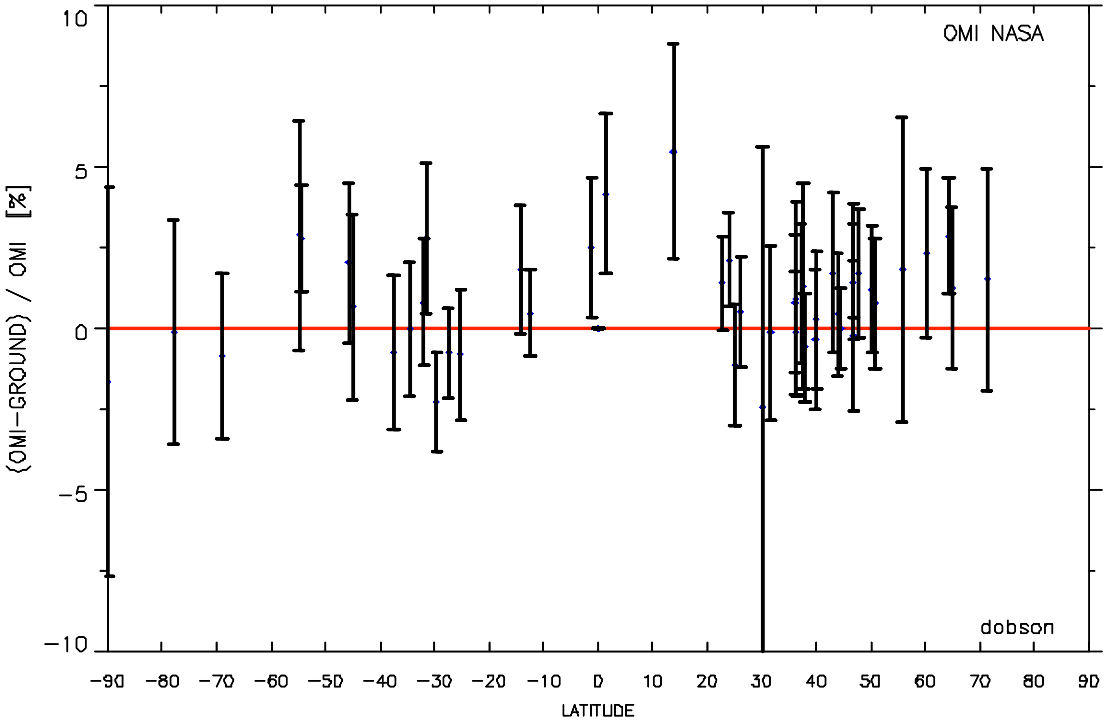
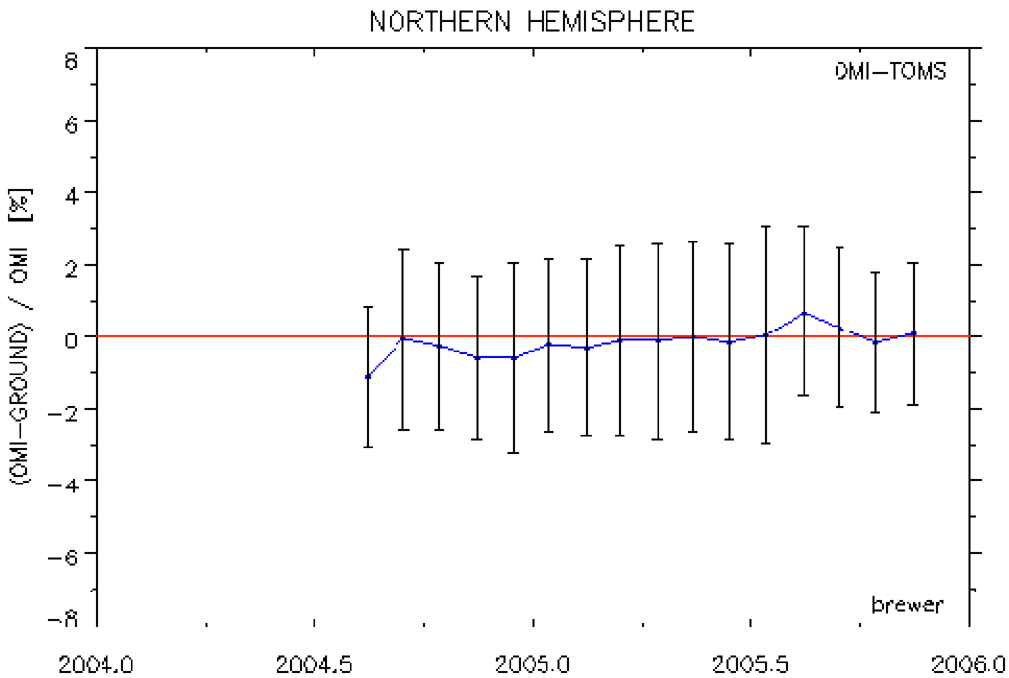


Figure 9: Mean differences between OMI TOMS total ozone and ground based total ozone data, separately for Brewer (9a upper) and Dobson (9b lower) instruments.



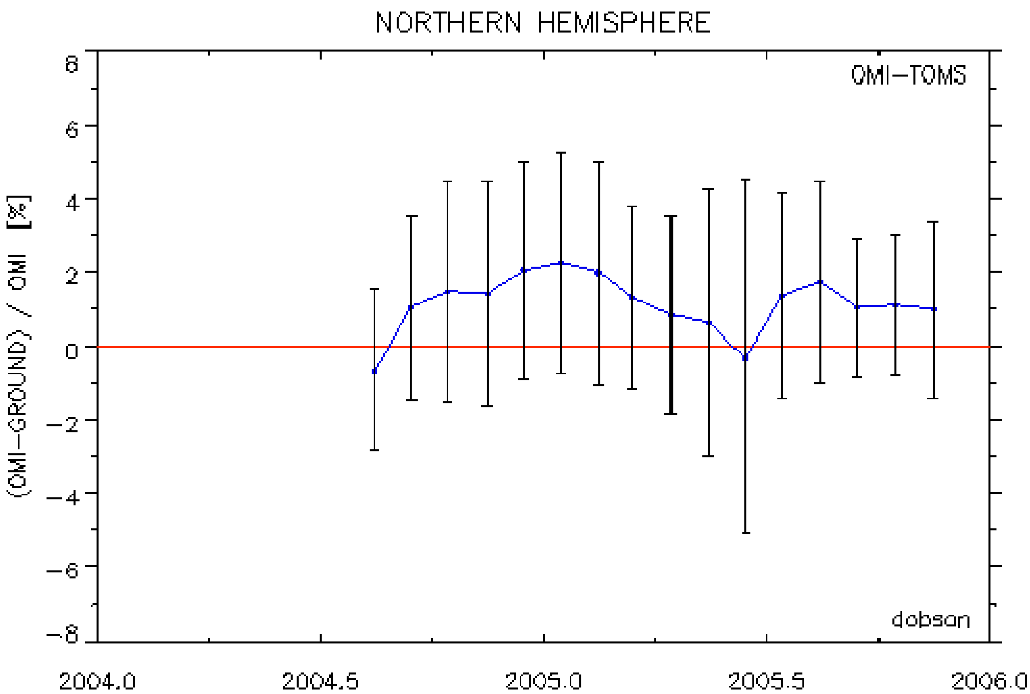


Figure 10: Monthly mean differences between OMI TOMS total ozone and ground-based total ozone measurements, separately for Brewer (10a upper) and Dobson (10b lower) instruments, averaged over the northern hemisphere.

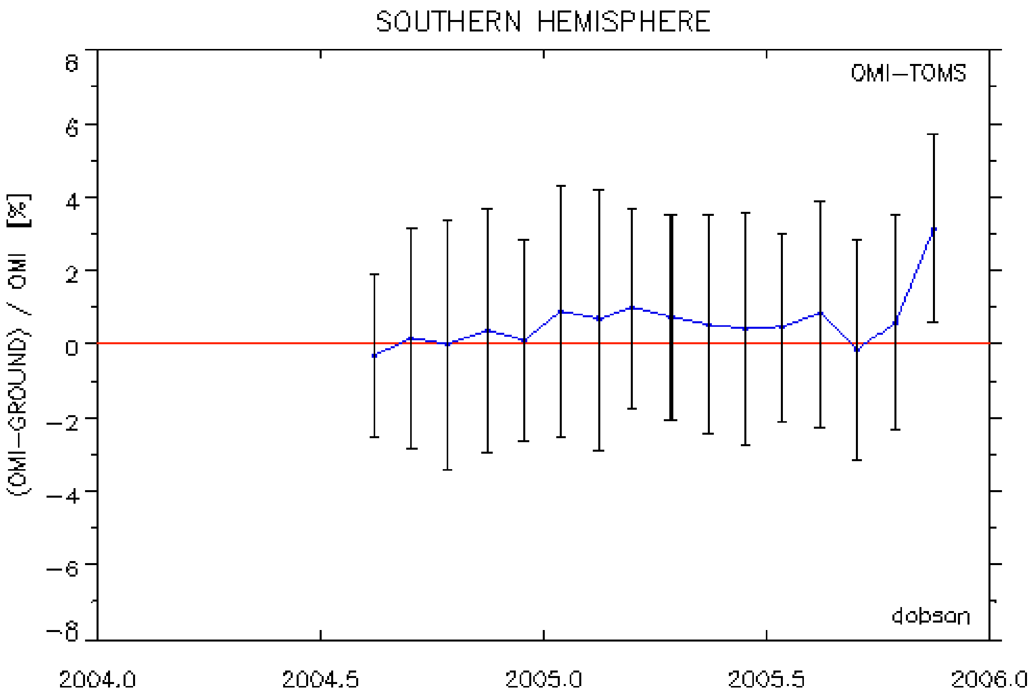


Figure 11: Monthly mean differences between OMI TOMS total ozone data and Dobson ground-based total ozone measurements averaged over the southern hemisphere.

In Figure 10 we present time series of the monthly mean differences between satellite data and ground-based total ozone observations for the northern hemisphere. OMI TOMS to Dobson comparisons show indications for a seasonal dependence with an amplitude of 1.5%. OMI TOMS to Brewer comparisons presented in Figure 10 do not show any seasonality and are remarkably stable around zero. Note here that although OMI-TOMS uses the same algorithm as EP-TOMS, this results is not consistent with TOMS v8 data, where comparisons with Dobson data showed almost no seasonality and comparisons with Brewer data showed a weak seasonality.

There are only few Brewer instruments situated in the southern hemisphere and for this region we therefore only calculated time series of the monthly mean differences between satellite data and Dobson total ozone observations. The OMI TOMS to Dobson comparisons as presented in Figure 11 shows no offset. At the end of the time series the high difference observed is mostly due to the limited number of coincidences, since at the time of writing there were only a limited number of ground-based observations available for the last months of 2005. It is remarkable to note that the seasonal variability in the southern hemisphere for OMI-TOMS is much weaker than in the northern hemisphere comparisons. Similar differences but less pronounced were also found when considering EP-TOMS and GOME-GDP4.0 data [5], indicating that the temperature variability in the northern hemisphere exhibits larger annual variability than in the southern hemisphere.

In order to study in more detail this seasonal behavior, we estimated the monthly mean differences between the satellite data and the ground-based observations as function of latitude. The results are shown in Figure 12. When examining the OMI TOMS to Dobson comparisons, we can see a small amplitude seasonality of the differences over the middle latitudes of both hemispheres. An overestimation of 3% is found over the tropics during the September-December period. Over Antarctica OMI-TOMS seems to underestimate total ozone by 2% on average, a result based on only a few observations. Over northern hemisphere high latitudes the amplitude of the seasonal dependence of the differences is larger than over middle latitudes. The corresponding estimates for the Brewer comparisons are presented in Figure 12, where we can observe that the amplitude of seasonal

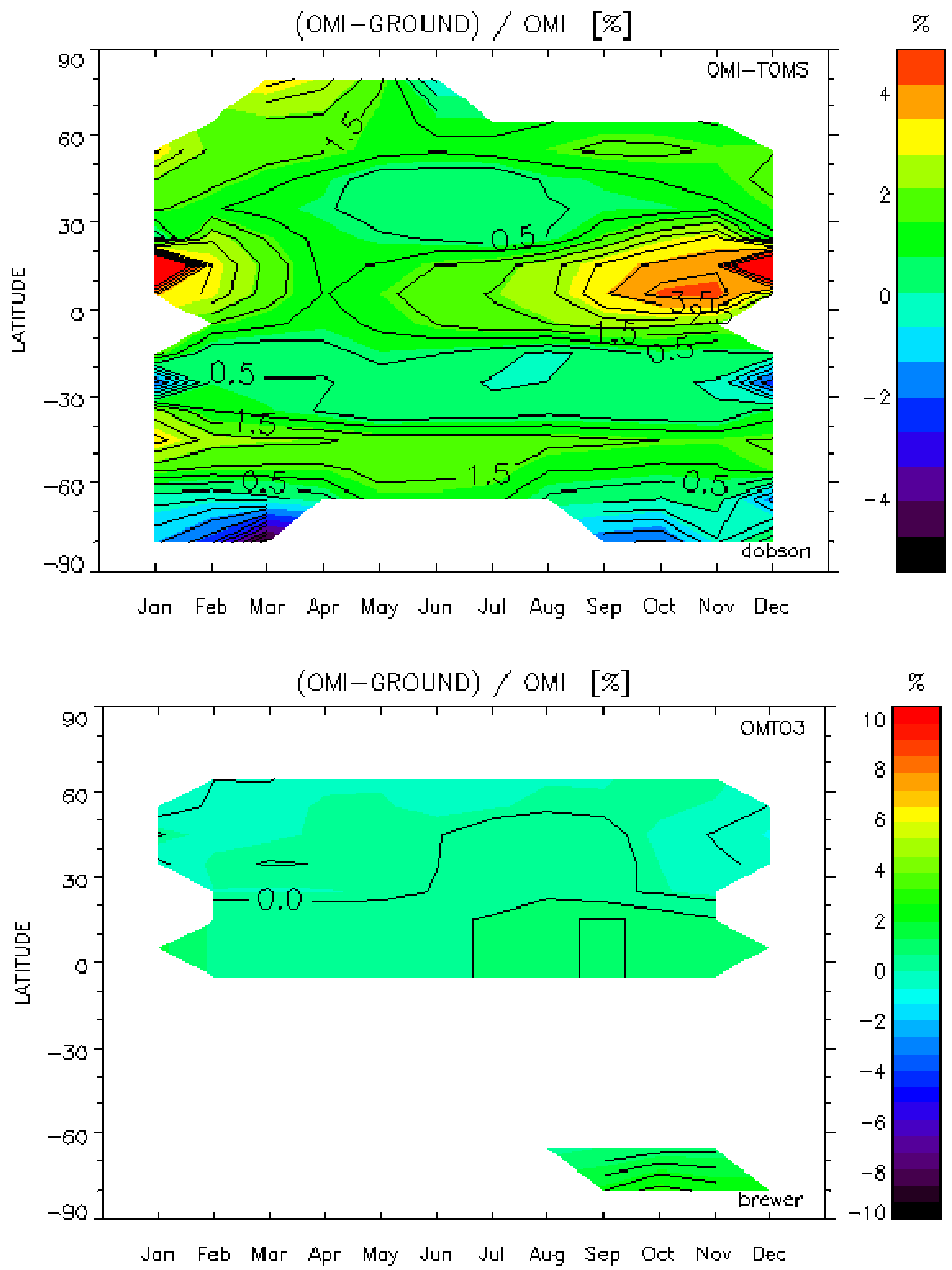


Figure 12: Month-latitude cross-section of the relative difference between OMI-TOMS and ground-based total ozone. The results obtained by comparison with Dobson and Brewer instruments are presented separately.

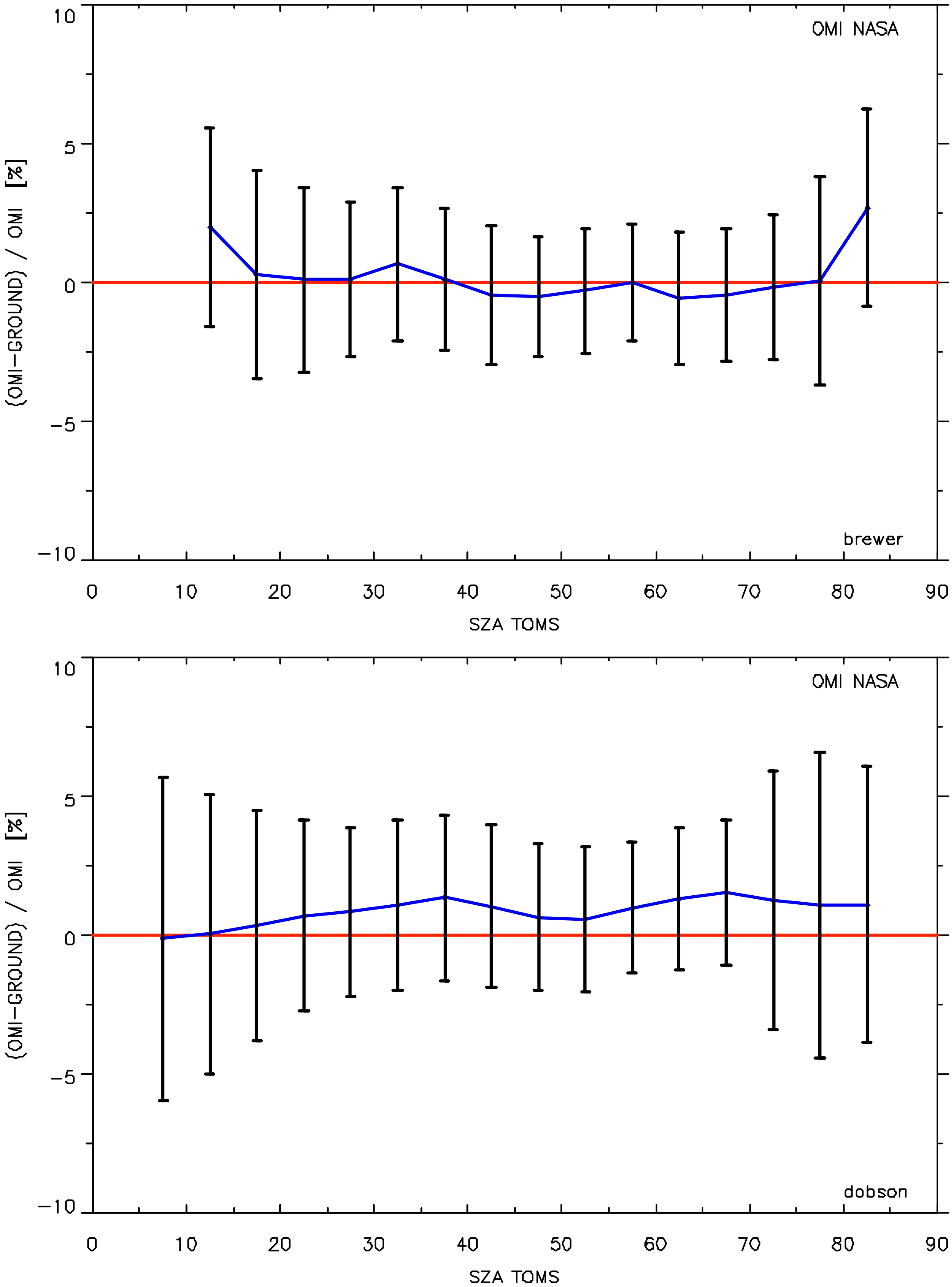


Figure 13: Solar zenith angle (SZA) dependence of the differences between satellite and ground-based total ozone observations.

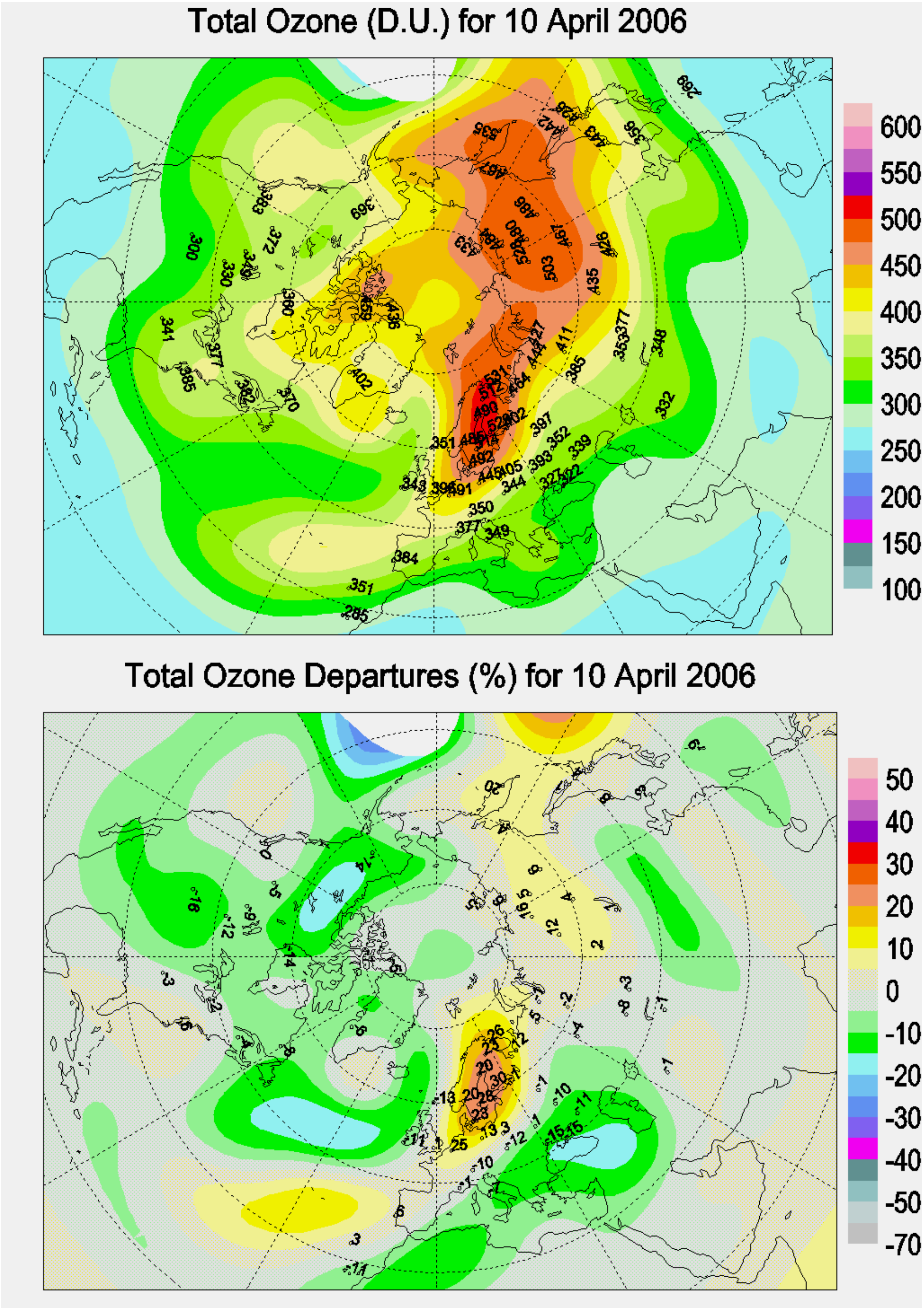


Figure 14: Sample of combined ground-based and OMI maps of the Northern Hemisphere available at http://lap.physics.auth.gr/ozonemaps

behavior of the differences is smaller both over the middle latitudes and the tropics. Over the southern hemisphere there is only one Brewer instrument located in Antarctica with few spring observations available, which however shows a good agreement.

In Figure 13 we present the solar zenith angle (SZA) dependence of the differences between satellite and ground-based total ozone observations. OMI-TOMS comparisons with Brewer and Dobson observations indicates the absence of any significant solar zenith angle dependence.

Operational provision of EP-TOMS level-3 total ozone stopped on the 31st of December 2005. Necessary changes have been adopted at the WMO Northern Hemisphere Ozone Mapping Centre to use level 3 OMI-TOMS data, which has become publicly available recently, and since 1st of January 2006 EP-TOMS data have been replaced with OMI data. A sample of maps that are now operationally available at the Mapping Centre (http://lap.phyics.auth.gr/ozonemaps) are shown in Figure 14. The Centre's web-site has been recently upgraded and now includes the option to choose different satellite sensors to combine with ground-based data, for the time being limited to SCIAMACHY assimilated total ozone data [8]. In this way it will be possible to have a first quick comparison between different instruments, concerning mainly their consistency.

This work has been performed in the frame of the OMI Calibration/Validation Announcement of Opportunity, proposal nr. 2925. Dimitris Balis acknowledges the support of GSRT-Greece.

5 Validation results against satellite based observations

In this section we present the results of comparing OMTO3 total ozone column observations with the observations of SBUV/2 aboard the NOAA-16 satellite. The SBUV/2 instrument measures only in the nadir position along its orbital track and has a FOV of 180 km square. The orbit of SBUV/2 aboard NOAA-16 is very similar to the orbit of OMI aboard Aura; an 8 degree inclination, sun synchronous, 14:00 hrs local equator crossing time. In Figure 15 below we show an example of the orbits of OMI and SBUV/2 for a single day.

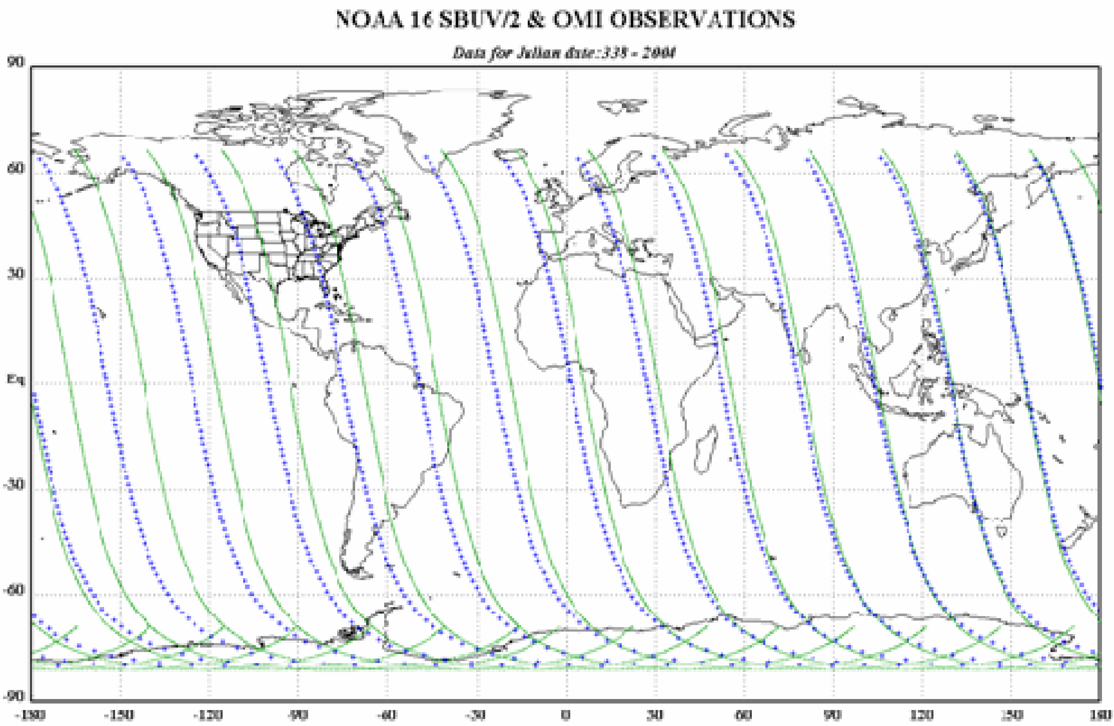


Figure 15: Example of the orbits of OMI aboard Aura (green) and SBUV/2 aboard NOAA-16 (blue) for a single day.

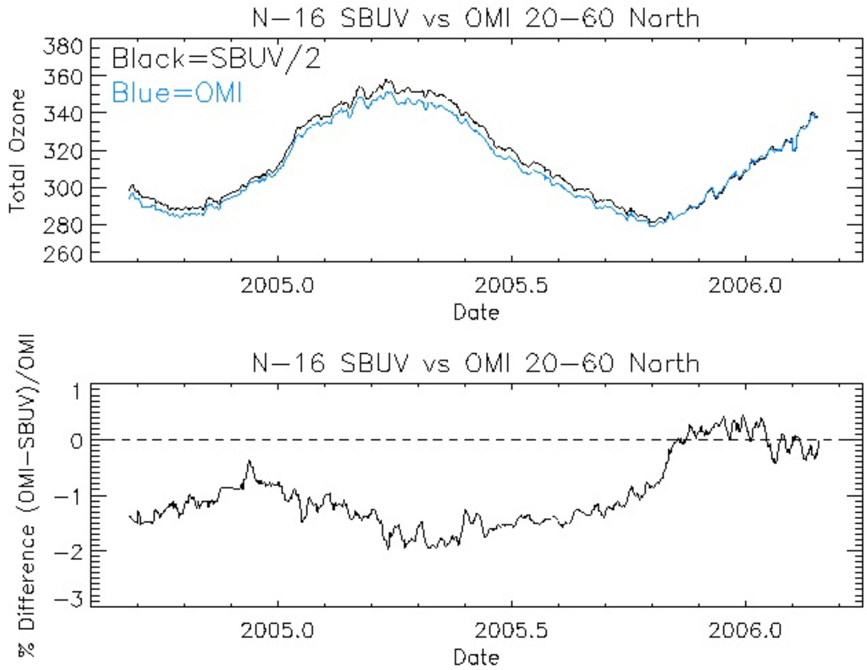


Figure 16: Publicly released OMI TOMS total ozone column and NOAA 16 SBUV/2 total ozone column for the Northern hemisphere for the time frame Aug 2004 - Jan 2006 plotted versus time. OMI shows agreement to the 1-2% level with SBUV/2 with a significant seasonal signature.

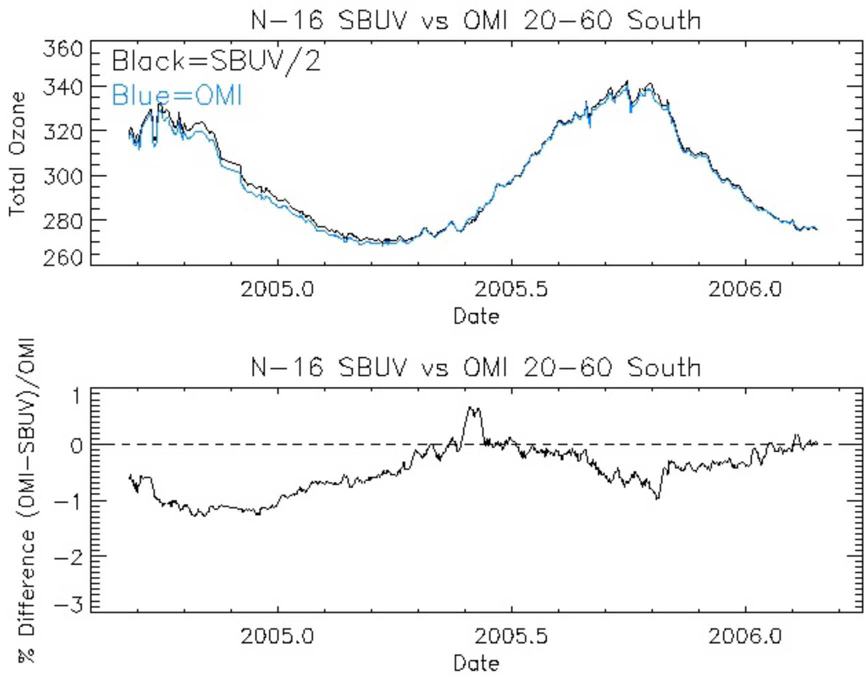


Figure 17: Publicly released OMI TOMS total ozone column and NOAA 16 SBUV/2 total ozone column for the Southern hemisphere for the time frame Aug 2004 - Jan 2006 plotted versus time. OMI shows agreement to the 1-2% level with SBUV/2 with a significant seasonal signature.

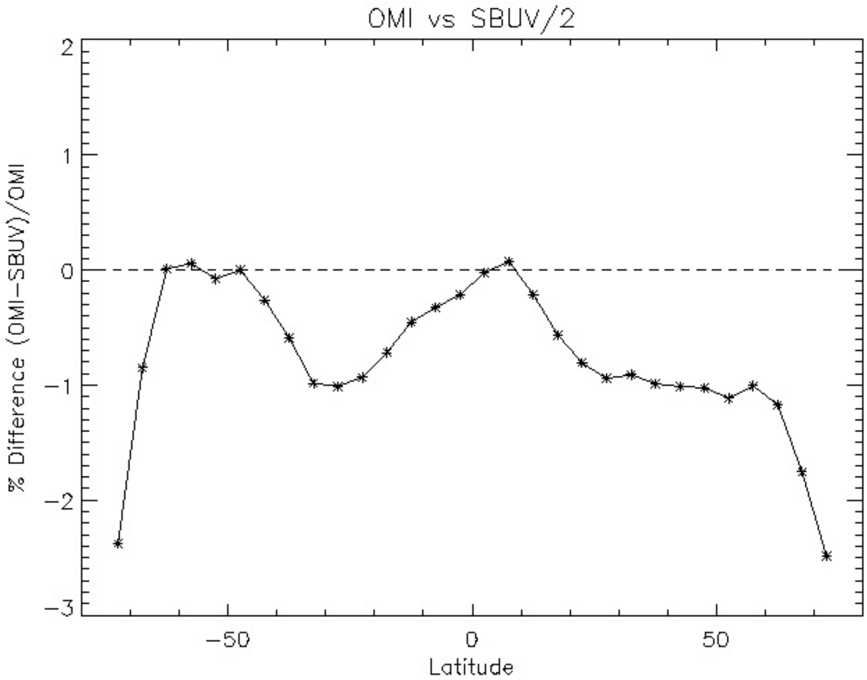


Figure 18: Publicly released OMI TOMS total ozone column minus NOAA 16 SBUV/2 total ozone column for the time frame Aug 2004 - Jan 2006 plotted versus latitude. In general OMI shows agreement to the 1-2% level. However, differences tend to increase near the poles hence at the higher solar zenith angle, i.e., the more extreme viewing geometries.

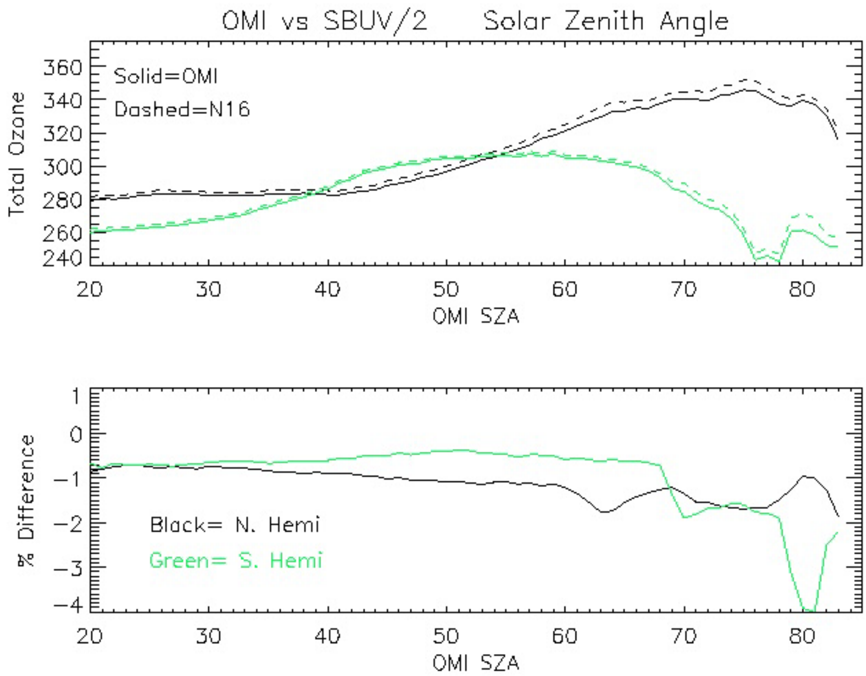


Figure 19: Publicly released OMI TOMS total ozone column and NOAA 16 SBUV/2 total ozone column and their difference for the time frame Aug 2004 - Jan 2006 plotted versus solar zenith angle for the two hemispheres. Note the different and almost opposite behavior at the extremes.

There are approximately 1100 coincident match-ups per day. Match-ups are obtained within 1 hour temporally and precisely the same FOV where OMI pixels are averaged under the larger SBUV footprint. The total number of coincident measurements as of January 2006 is over 550,000. Ozone retrievals from both instruments are processed with the version 8 algorithm, the only difference being that the SBUV/2 column is the summation of the profile layer amounts. Both retrievals use the same initial (*a-priori*) information such as climatologies and absorption cross sections. The ozone profile climatology that was used for the version 8 retrievals can be found by anonymous FTP at: http://jwocky.gsfc.nasa.gov (goto /pub/tmp/LLM_climatology).

In Figure 16 we show the results of comparing OMTO3 to SBUV/2 collocated observations over the northern hemisphere. Observations within the range of 20-60 North are included. Figure 17 shows the results for the southern hemisphere, where observations within the range of 20-60 South are included. On both hemispheres OMTO3 and SBUV/2 total ozone column follow each other closely over a large dynamic range with a clear seasonal cycle. The northern hemisphere cycle is 180° - or half a year - out of phase to the southern hemisphere cycle. On both hemispheres the difference between OMI and SBUV/2 total ozone columns amounts to less than 2%. The difference also shows a clear seasonal signature where the behavior on both hemispheres is again anti-correlated. At the time of writing the cause for the seasonal behavior of the total ozone column difference is unknown but one speculates on the solar zenith angle to be the root cause.

In Figure 18 we show an overview of the OMI and SBUV/2 total ozone column difference against latitude. OMTO3 agrees well with the SBUV/2 observations, deviations are mostly in the zero to -2% range. However, differences tend to increase near the poles hence at the higher solar zenith angles, i.e., the more extreme viewing geometries. Again, one speculates on the solar zenith angle to be the root cause.

In Figure 19 we show an overview of the OMI and SBUV/2 total ozone column observations and their difference as a function of the solar zenith angle for both hemispheres. OMTO3 shows agreement to the 1% level with SBUV/2 on the southern hemisphere up to 70 degrees from where the comparison rapidly deteriorates, most probably due to the presence of the ozone hole. On the northern hemisphere the difference shows a dependence on solar zenith angle with a rather smooth behavior between 1-2 % up to the highest solar zenith angles.

6 Conclusions

OMI TOMS total ozone column observations agree very well with data from an ensemble of Dobson and Brewer instrument ground-stations and with data recorded by the SBUV/2 instrument aboard the NOAA-16 satellite.

Comparisons of OMI TOMS total ozone column data against ground based total ozone column observations by Brewer and Dobson instruments reveal the absence of a clear dependence on the latitude of the ground stations, on the Earth's surface reflectivity at 331 nm wavelength, on the solar zenith angle and on the satellite total ozone column. Furthermore, observed total ozone column differences are small and mostly fall within the range of ±2%. Here OMTO3 is doing a much better job as compared to EP-TOMS total column observations where pronounced dependencies on the before mentioned quantities are observed. No major OMTO3 retrieval errors can be extracted from these comparisons. However, the results at higher solar zenith angles, where ground based instruments also tend to have their problems, needs to be further investigated.

Validation of OMI TOMS total ozone column observations against satellite based SBUV/2 observations reveal good agreement within the range of ±2%. There is a clear seasonal signature observed from the difference in recorded total ozone columns that is anti correlated over both hemispheres. Most probably this feature is to be attributed to an opposing solar zenith angle dependence of both retrieval algorithms, the signature of which is further enhanced by taking the difference.

7 References

[1] OMI Ozone Products Algorithm Theoretical Baseline Document
http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/atbd/docs/OMI/ATBD-OMI-02.pdf

[2] OMI TOMS Total Ozone README files at AVDC
http://avdc.gsfc.nasa.gov/Data/Aura/OMI/OMTO3/OMTO3_OVP_readme.html

[3] Bernhard, Evans, Labow & Oltmans, *Bias in Dobson Total Ozone Measurements at High Latitudes due to approximations in calculations of ozone absorption coefficients and air mass*, J. Geophys. Res. 110, D10305.

[4] Fioletov V., et al., *An assessment of the world ground-based total ozone network performance from the comparison with satellite data*, J. Geophys. Res., 104, 1,737-1,747, 1999.

[5] Balis D., et al., *Reprocessing the 10-year GOME/ERS-2 total ozone record for trend analysis: the new GOME Data Processor Version 4.0, Validation,* J. Geophys. Res., in press, 2006

[6] Staehelin J., et al., *Comparison of total ozone measurements of Dobson and Brewer spectrophotometers and recommended transfer functions*, WMO TD N. 1147, No 149, 2003.

[7] Van Roozendael, et al., *Validation of Ground-based UV-visible Measurements of Total Ozone by Comparison with Dobson and Brewer Spectrophotometers*, J. Atm. Chem., 29, 55-83, 1998.

[8] Eskes, H. J., et al., *Retrieval and validation of ozone columns derived from measurements of SCIAMACHY on Envisat*, Atmos. Chem. Phys. Discuss., 5, 4429–4475, 2005

Appendix

ID	NAME	LATITUDE	LONGITUDE	ELEVATION	COUNTRY
100	BUDAPEST	47.43	19.18	140	Hungary
123	YAKUTSK	62.08	129.75	98	Russia
174	LINDENBERG	52.22	14.12	98	Germany
213	EL ARENOSILLO	37.10	-6.73	41	Spain
261	THESSALONIKI	40.52	22.97	4	Greece
262	SODANKYLA	67.37	26.65	179	Finland
267	SONDRESTROM	67.00	-50.98	150	Greenland
279	NORKOPING	58.58	16.12	0	Sweden
284	VINDELN	64.25	19.77	0	Sweden
295	MT.WALIGUAN	36.17	100.53	3816	China
301	ISPRA	45.80	8.63	0	Italy
305	ROME UNIVERSITY	41.90	12.52	0	Italy
308	MADRID	40.45	-3.55	0	Spain
314	BELGRANO	-77.87	-34.63	255	Antarctica
316	DEBILT	52.00	5.18	0	Netherlands
322	PETALING JAYA	3.10	101.65	46	Malaysia
326	LONGFENSHAN	44.75	127.6	0	China
346	MURCIA	38.00	-1.17	69	Spain
35	AROSA	46.77	9.67	1860	Switzerland
53	UCCLE	50.8	4.35	100	Belgium
96	HRADEC KRALOVE	50.18	15.83	285	Czech Rep.
99	HOHENPEISSENBERG	47.80	11.02	975	Germany

Table 1: List of Brewer stations selected for validation of OMI total ozone in section 4.2.

ID	NAME	LATITUDE	LONGITUDE	ELEVATION	COUNTRY
101	SYOWA	-69.00	39.58	21	Antarctica
105	FAIRBANKS	64.8	-147.89	138	USA
106	NASHVILLE	36.25	-86.57	182	USA
107	WALLOPS ISLAND	37.87	-75.52	4	USA
11	QUETTA	30.18	66.95	1799	Pakistan
111	AMUNDSEN-SCOTT	-89.98	-24.80	2835	Antarctica
116	MOSCOW	55.75	37.57	187	Russia
12	SAPPORO	43.05	141.33	19	Japan
14	TATENO	36.05	140.13	31	Japan
152	CAIRO	30.08	31.28	35	Egypt
159	PERTH	-31.95	115.85	2	Australia
175	NAIROBI	-1.27	36.80	1710	Kenya
19	BISMARCK	46.77	-100.75	511	USA
190	NAHA	26.20	127.67	29	Japan
191	SAMOA	-14.25	-170.57	82	USA
199	BARROW	71.32	-156.60	11	USA
2	TAMANRASSET	22.80	5.52	1395	Algeria
20	CARIBOU	46.87	-68.02	192	USA
208	SHIANGHER	39.77	117.00	13	China
209	KUNMING	25.02	102.68	1917	China
213	EL ARENOSILLO	37.10	-6.73	41	Spain
214	SINGAPORE	1.33	103.88	14	Singapore
216	BANGKOK	13.73	100.57	2	Thailand
219	NATAL	-5.83	-35.20	32	Brazil

226	BUCHAREST	44.48	26.13	92	Romania
245	ASWAN	23.97	32.45	193	Egypt
252	SEOUL	37.57	126.95	84	Korea
253	MELBOURNE	-37.48	144.58	125	Australia
256	LAUDER	-45.03	169.68	3701	N. Zealand
265	IRENE	-25.25	28.22	1524	S. Africa
268	ARRIVAL HEIGHTS	-77.83	166.40	250	Antarctica
27	BRISBANE	-27.47	153.03	5	Australia
284	*VINDELN*	*64.25*	*19.77*	*0*	*Sweden*
29	MACQUARIE ISLAND	-54.48	158.97	6	Australia
339	USHUAIA	-54.85	-68.31	7	Argentina
340	SPRINGBOK	-29.67	17.90	1	S. Africa
341	HANFORD	36.32	-119.63	73	USA
342	COMODORO RIVAD.	-45.78	-67.50	43	Argentina
343	SALTO	-31.58	-57.95	31	Uruguay
35	AROSA	46.77	9.67	1860	Switzerland
40	HAUTE PROVENCE	43.92	5.75	580	France
43	LERWICK	60.15	-1.15	90	UK
53	UCCLE	50.80	4.35	100	Belgium
67	BOULDER	40.02	-105.25	1634	USA
68	BELSK	51.83	20.78	180	Poland
7	KAGOSHIMA	31.63	130.60	283	Japan
84	DARWIN	-12.47	130.83	0	Australia
91	BUENOS-AIRES	-34.58	-58.48	25	Argentina
96	HRADEC KRALOVE	50.18	15.83	285	Czech R.
99	HOHENPEISSENBERG	47.80	11.02	975	Germany

Table 2: List of Dobson stations selected for validation of OMI total ozone in section 4.2.