Validation of the Suomi NPP Ozone Mapping and Profiler Suite total column ozone using Brewer and Dobson spectrophotometers

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Abstract

The objective of this study was to evaluate the accuracy of the nadir total column (TC) ozone products derived from the Ozone Mapping and Profiler Suite (OMPS) on board the NASA Suomi National Polar-orbiting Partnership satellite (NPP). OMPS is an advanced suite of three hyperspectral instruments that maps global ozone on a daily basis and extends the more than 30 years of recorded total ozone and ozone profile data. In this study, the nadir TC ozone data generated by the NASA OMPS science team was validated utilizing the version 8 algorithms applied to the Ozone Monitoring Instrument (OMI) with minor modifications. The analysis includes a comparison of OMPS with globally distributed and spatially co-located ground-based Brewer and Dobson spectrophotometer measurements. The linear regression shows fair agreement between OMPS and ground-based TC ozone measurements with a root mean square error (RMSE) of approximately 3% (10 DU). The comparison results indicate that the OMPS TC ozone estimates are 0.59% higher than the Brewer measurements with a standard deviation of 2.82%. When compared with the Dobson measurements, the OMPS TC ozone average is 1.09% higher than the station average with a standard deviation of 3.27%. Additionally, the relative differences between OMPS and ground TC ozone were analyzed as a function of latitude, time, and viewing geometry. The relative differences vary within 2% over most of the latitudes and viewing conditions; latitudinal- and viewing condition-dependent errors are not observed. The dependence of the relative differences between the satellite- and ground-based measurements on the TC ozone values is consistent for TC ozone values between 220 DU and 450 DU.

1 Introduction

Although the total amount of ozone comprises only 0.6 parts per million of the Earth's atmospheric composition, the trace gas plays an important role in protecting life by blocking much of the potentially harmful high frequency ultraviolet (UV) radiation from the sun (Varotsos et al., 1995; Antón et al., 2011). As a major greenhouse gas, ozone absorbs some of the infrared energy emitted by the Earth and has very strong radiative forcing effects on a regional scale. Ozone layer changes could be closely associated with regional and global climate changes and vice versa (World Meteorological Organization (WMO), 2006; Antón et al., 2010).

Since ozone depletion was observed in the early 1970s and the first sharp ozone decrease in the lower stratosphere was observed in the 1980s (Crutzen and Arnold, 1986; Stolarski et al., 1986), many scientific research programs have proposed to monitor the ozone layer thickness and investigate the causes of depletion. According to scientific research, this decrease is primarily attributed to photochemical losses related to anthropogenic activities and dynamical factors (e.g., Farman et al., 1985; Cariolle and Déqué, 1986; Varotsos, 2002; Antón et al., 2011). A relevant consequence of ozone depletion is the increase in harmful UV radiation at the Earth's surface; thus, monitoring the amount of ozone in the ozone layer and analyzing its variability with high accuracy have become major challenges that must be addressed to protect the ozone layer.

Traditional ground-based spectrophotometers that measure the total ozone, such as the Brewer and Dobson spectrophotometers, can provide daily total column (TC) ozone measurements with high accuracy; however, the spatial coverage is limited. In this context, satellite instruments that measure TC ozone with high spatial and temporal resolutions are becoming the main scientific research technique for ozone layer monitoring. To date, many instruments specifically designed for TC ozone and ozone profile monitoring have been launched into space, such as the Solar Backscatter Ultraviolet (SBUV and SBUV/2) (Flynn et al., 2009; Bhartia et al., 2012), Total Ozone Mapping Spectrometer (TOMS) (McPeters et al., 1996a, 1996b, 1998) and Ozone Monitoring Instrument (OMI) (Levelt et al., 2006). Additional European missions include the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) (Bovensmann et al., 1999) and the Globe Ozone Monitoring Experiment (GOME and GOME-2) (Van Roozendael et al., 2006; Van Roozendael et al., 2012). The Total Ozone Unit (TOU) on board the Chinese FY-3 series satellite is also designed to map global TC ozone on a daily basis (Wang et al., 2011; Bai et al., 2013).

For more than 30 years, these instruments have provided a very detailed and important long-term record of the global distribution of ozone. The Ozone Mapping and Profiler Suite (OMPS) on board the Suomi National Polar-orbiting Partnership satellite, launched on October 28, 2011, continues to measure ozone from space. These ozone records have been widely used by ozone-assessment researchers and policy makers to track the state of the ozone layer and the quality of TC ozone data derived from space-borne instruments; thus, the records should be examined for accuracy and relevancy.

The main objective of this study was to report the quality and accuracy of the TC ozone products derived from the OMPS observations since it was launched (i.e., 14 months of data). Validation was conducted by comparing the OMPS TC ozone data with the spatially co-located ground-based Brewer and Dobson spectrophotometer TC ozone measurements. Discrepancies between the OMPS TC ozone and spatially co-located ground-based measurements were analyzed as a function of latitude and viewing conditions, and the possible reasons for these discrepancies were examined.

The article is organized as follows: Section 2 describes the instrument and data records used for comparisons, Section 3 presents the detailed validation process using ground-based measurements, and the conclusions are summarized in Section 4.

2 Instruments and Measurements

The instruments to measure TC ozone used in this study are described in two sections. The OMPS instruments and the algorithm to derive TC ozone from OMPS observations are introduced in Section 2.1, and the spatially co-located ground-based Brewer and Dobson measurements are described in Section 2.2.

2.1 OMPS Observations

2.1.1 OMPS System

OMPS, an important component of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) on Suomi NPP, is the latest in a series of space-borne ozone-mapping instruments (Pan et al., 2012). OMPS is designed to describe the vertical, horizontal, and temporal distribution of ozone in the Earth's atmosphere on a daily basis and determine whether the ozone layer is recovering as expected after the sharp decrease of ozone in the 1980s (Suomi NPP, 2013).

OMPS is an advanced suite of three hyperspectral instruments that measure sunlight in the ultraviolet and visible ranges backscattered from the Earth's atmosphere. The system consists of a nadir mapper that maps global ozone with an approximate ground resolution of 50 km, a nadir profiler that measures the vertical distribution of ozone in the stratosphere, and a limb profiler that measures ozone in the lower stratosphere and troposphere with high resolution (Dittman et al., 2002; Jaross et al., 2012).

The OMPS radiation detectors are two-dimensional charge-coupled device (CCD) focal plane arrays (FPA), each arranged in one spectral and one spatial dimension. The nadir total column sensor uses a single grating and a CCD array detector to measure backscattered radiance every 0.4 nm from 300 to 380 nm with 1-nm full-width half maximum (FWHM) spectral resolution. It has a 110° cross-track field-of-view (FOV) and a 0.27° along-track slit width. The measurements from cross-track are combined into 35 bins as 3.35° (50 km) at nadir and 2.84° at ±55°. The along-track resolution is 50 km at nadir for mapping TC ozone across a 2800 km swath with a 7.6 second reporting period (Flynn et al., 2004, 2012).

The nadir profiler employs a double monochromator and a CCD array detector to take measurements every 0.4 nm from 250 to 310 nm with 1-nm FWHM resolution. The profiler has a 16° cross-track FOV and a 0.26° along-track slit width. The reporting period is 38 seconds, which forms a 250 × 250 km cell size synchronized with five nadir mapper cells (Flynn et al., 2004, 2012).

For the NPP mission, OMPS also contains a limb system with a focal plane operating from 290 to 1000 nm for high vertical resolution ozone profile observations. The system has three vertical slits separated by 4.25° (across track) and a 19 second reporting period; these features result in 125 km along-track motion. Each slit has a vertical FOV of 1.95° (112 km) equating to 0 to 60 km coverage at the limb and offsets for pointing uncertainty, orbital variation, and Earth oblateness (Flynn et al., 2004, 2012).

2.1.2 Nadir Total Ozone Measurements

In this study, the TC ozone collected from the daily granule nadir OMPS total ozone product, generated by the NASA OMPS science team for January 2012 to February 2013, was compared with ground-based Brewer and Dobson measurements. The TC ozone data were acquired from the ozone and air quality archive sets available from the NASA OMPS website (http://ozoneaq.gsfc.nasa.gov/beta/data/omps/); thus, only the algorithm to derive the OMPS TC ozone product used by the NASA OMPS science team will be discussed.

The nadir TC ozone product consists of the total ozone in a column of air from the surface to the top of the atmosphere (TOA) and is observed for all solar zenith angle (SZA) viewing conditions less than or equal to 80° (Baker and Kilcoyne, 2011). The algorithm used by the NASA OMPS science team to derive this OMPS TC ozone product is a version of the V8 algorithm (Bhartia and Wellemeyer, 2002) applied to OMI with some minor differences. The detail of this algorithm and its errors has been reported by Bhartia et al. (2012). This algorithm estimates the TC ozone based on the comparison of measured normalized radiance to calculated normalized radiance by using a standard UV radiative transfer model for different ozone amounts, specific measurement geometry, viewing conditions and surface conditions. A detailed description of the scientific basis of ozone retrieval from solar backscatter UV (SBUV) irradiance has been previously reported (e.g., Dave and Mateer, 1967; McPeters et al., 1996a; Mcpeters et al., 1998; Rodriguez et al., 2003).

According to Bhartia et al. (2012), compared with the OMI V8 algorithm, the OMPS algorithm incorporates several changes including the use of new ozone absorption cross-sections, new ozone (McPeters and Labow, 2012) and cloud height climatology. The forward model used by this algorithm to compute the TOA radiances is based on the vector radiative transfer model developed by Dave (1964); some modifications were made to account for molecular anisotropy and rotational Raman scattering correction. The Malicet et al. (1995) ozone absorption cross-sections were applied to this algorithm instead of those from Bass and Paur (1984) as used previously. A month/latitude climatology of temperatures developed using NOAA temperature datasets was applied to account for the temperature dependence of the cross-section (Bhartia et al., 2012).

The inverse model, as applied to this algorithm, is based on the optimum estimation formula of Rodgers (1976). The model is designed for retrievals for which the numbers of layers are larger than the number of wavelengths. According to Bhartia et al. (2012), the typical algorithmic errors are those in the ozone absorption cross-section or in various climatologies used in the forward model. Several sources of systematic errors can create time-independent (but month- and latitude-dependent) bias in the SBUV retrieved profiles, such as errors in a priori profiles for measured and calculated N-values.

2.2 Ground-based Measurements

To date, the worldwide, well-established ground-based network of Brewer and Dobson spectrophotometers has been generally considered the ground-truth of total ozone monitoring. Over past decades, TC ozone measured from these two spectrophotometers has been widely used to validate space-borne instruments due to its high accuracy (Fioletov, 2005; Fioletov, et al., 2008). The working principles and scientific basis of these two spectrophotometers have been described in many scientific papers; see Dobson (1968), Brewer (1973), Van Roozendael et al. (1998), Kerr (2002) and Bernhard (2005) for more detailed descriptions.

A well-maintained and calibrated Dobson instrument measures total ozone with an estimated accuracy of 1% for direct sun and 2–3% for zenith sky or for SZAs less than 75° (Basher, 1982). A well-calibrated Brewer instrument has an error level comparable to the Dobson instrument, with a precision of 1% over long time intervals (Antón et al., 2009b). Despite the similarity in performance between the Brewer and Dobson instruments, small differences (within ±0.6%) are still observed due to the use of different wavelengths and varying temperature dependencies for the ozone absorption coefficients (Van Roozendael et al., 1998).

In this study, TC ozone measurements recorded from well-maintained 34 Brewer and 39 Dobson spectrophotometers from January 2012 to February 2013, available from the World Ozone and Ultraviolet Data Centre (WOUDC) archive (http://www.woudc.org), were employed as the ground reference to compare with the TC ozone generated by the NASA OMPS science team. The ground stations of Brewer and Dobson are listed in Tables 1 and 2, respectively. A global study of latitudinal dependence can only be analyzed from the Dobson measurements because there are no quality-assured TC ozone data from Brewer instruments in the Southern Hemisphere (Antón et al., 2010). To obtain a meaningful evaluation, only the ground-based TC ozone measurements under direct sun (DS) were included to compare with the spatially co-located OMPS TC ozone observations.

3 Validation Using Ground-based Measurements

Discrepancies between spatially co-located nadir OMPS TC ozone records and ground-based measurements were analyzed separately using the Brewer and Dobson datasets. Bias errors generated by data dependence on latitude, SZA, radiative cloud fraction and other parameters were also analyzed. The relative differences (RDs) and mean bias error (MBE) between ground-based total ozone measurements and collocated OMPS TC ozone were calculated with the following equation:

$$RDs = 100\times\frac{OMPS-Ground}{OMPS} \quad (1)$$

$$MBE = \frac{1}{N}\sum RD_i \quad (2)$$

where *OMPS* denotes nadir OMPS TC ozone, *Ground* denotes ground-based TC ozone measurements, and *N* is the total number of data pairs. Uncertainties regarding *MBE* are characterized by the standard deviation of the *RDs*.

Linear regressions were performed to analyze the consistency of OMPS TC ozone and ground station measurements (Fig. 1); the statistical parameters are also presented (Table 3). The results indicate a good agreement between OMPS TC ozone and both types of ground-based TC ozone measurements with an R^2 value of 0.96 and *RMSE* values of 2.88% (9.5 DU) for Brewer and 3.44% (10.2 DU) for Dobson. These values reveal a high degree of proportionality with a small spread. The *MBE* values are +0.59% with a standard deviation of 2.82% (OMPS-Brewer) and +1.09% with a standard deviation of 3.27% (OMPS-Dobson), indicating the OMPS TC ozone tends to estimate Dobson measurements higher than Brewer measurements. These discrepancies can possibly be ascribed to the different measuring principles and station distributions of the two types of ground-based spectrophotometers (Kerr et al., 1988). Additionally, the frequency count of *RDs*, as shown in Fig. 2, demonstrates fair agreement (i.e., most of the *RDs* vary within ±2%).

Fig. 3 displays the distribution of the relative differences between OMPS TC ozone and ground-based TC ozone measurements as a function of latitude. The mean bias error for each station (Fig. 3a) has a value within 2% for most latitudes compared using both types of ground-based measurements. Compared with the Brewer measurements, OMPS displays a positive bias near the equator to mid-latitudes in the northern hemisphere, whereas negative bias is observed over high latitudes in both hemispheres. Compared with Dobson measurements, OMPS nearly overestimates the Dobson TC ozone measurements with a mean bias error within 2% over all latitudes. Comparison results from the high latitude stations in the southern hemisphere indicate a large spread; this effect can be partially attributed to the fewer observational points in this region. The mean bias error binned at 10° latitude intervals (Fig. 3b) indicates good OMPS TC ozone results. No significant latitude dependence error is observed for OMPS TC ozone compared with both Brewer and Dobson measurements.

The time series of the monthly mean relative differences were analyzed to evaluate the long-term stability of the OMPS TC ozone (Fig. 4). Again, the mean bias error is within 2% for the Brewer and Dobson measurements. The time series of both comparisons do not show significant mean bias error drift through these periods, which indicates a stable performance of the OMPS. Due to limited time series, seasonality behavior is not observed for the OMPS-Brewer and OMPS-Dobson comparisons. However, Antón et al. (2010) showed a distinct seasonality for TOMS-Brewer comparisons with an amplitude of ~1.5% but weak seasonality for TOMS-Dobson comparisons. This effect is partially attributed to the different temperature dependencies of the ozone absorption cross-sections in the wavelength ranges used in the retrievals (Balis et al. 2007a). The TOMS V8 and Dobson total ozone data have a similar dependence on the lower stratospheric temperature because the wavelengths used by the TOMS algorithm are closer to those for the Dobson spectrophotometer than for the

Brewer instruments. To a certain extent, the minor time series variation differences between OMPS-Brewer and OMPS-Dobson comparisons could be partly explained by these dependencies and distinct station distributions, as observed from the monthly TC ozone averages in Fig. 4b.

Fig. 5 presents the mean relative differences variation as a function of SZAs. The comparison reveals different variation behaviors between OMPS-Brewer and OMPS-Dobson measurements. The relative differences for the OMPS-Brewer comparisons exhibit some significant changes under large SZAs, whereas the *MBE* varies from 0.26% to 1.39% as SAZs increase from 65° to 85°. In contrast, the values for the OMPS-Dobson comparisons exhibit a smoother behavior with a *MBE* of 1% as the SZAs increase from 0° to 90°. This effect is consistent with former studies, which have shown little to no significant dependence on SZAs in comparisons between OMI-TOMS TC ozone and ground measurements under all sky conditions (Balis et al., 2007b; Antón et al., 2009a). The relative differences varying with the viewing zenith angles (VZAs) are also analyzed (Fig. 6). Both comparison results present smooth variation behaviors as the VZAs increase from 0° to 70°; no VZA-dependent error is observed for OMPS TC ozone.

The relative differences varying with radiative cloud fraction are shown in Fig. 7. The comparison indicates that no cloud-dependent error is observed (i.e., the bias is approximately 0.6% for Brewer and 1.2% for Dobson). Due to cloud contamination, the satellite sensor can only confidently derive the ozone amount above clouds. The ozone below the cloud top must be inferred from climatological tables (McPeters et al., 2008). Thus, the cloud height should be estimated with high accuracy for TC ozone derived under cloudy conditions. The new cloud height climatologies used in the algorithm are feasible and reliable based on the smooth variation behavior of the results. Fig. 8 displays the variability of the relative differences as a function of reflectivity. In this study, the reflectivity derived from 311 nm measurements of OMPS is employed. Reflectivity-dependent errors are not observed for any comparisons. The *MBE* is 0.6% for the OMPS-Brewer comparisons and 1.1% for the OMPS-Dobson comparisons.

The variation of the mean relative differences as a function of the OMPS TC ozone and ground-based TC ozone measurements is shown in Fig. 9. Comparative analysis suggests fair agreement for TC ozone values varying between 220 DU and 450 DU. Negative bias (about -2%) is observed for TC ozone values less than 220 DU, which is usually considered the level of the ozone hole. For values less than 220 DU, ozone is always measured with large SZAs, and many other errors will be introduced into the long viewing limb. In contrast, large positive bias error (~ 4%) is observed for TC ozone greater than 450 DU. This effect is related to the ground instruments' signal-to-noise limits, which will fail under very high ozone conditions due to less ground-measurable UV radiation penetrating the atmosphere (Antón et al., 2010). The dependency of TC ozone relative differences on TC ozone itself can change under different TC ozone values compared with satellite TC ozone and ground-based TC ozone (Fioletov et al., 2006; Kravchenko et al., 2009). Kravchenko et al. (2009) indicated that total ozone measurements in the polar regions, especially in Antarctica, remain influenced by the total ozone dependence; this effect is probably most significant below 220 DU and above 220 DU for Dobson and EP-TOMS. Similar methods will be applied to the OMPS ground-based comparisons to investigate individual contributions to the relative differences in the TC ozone dependence.

4 Conclusions and Discussion

Based on 14 months of TC ozone records, the performance of nadir OMPS TC ozone data generated by the NASA OMPS science team was evaluated. The evaluation utilizes an algorithm similar to that of OMI-TOMS V8 with some enhancements. OMPS TC ozone compares very well with collocated ground-based measurements from the network of worldwide well-maintained Brewer and Dobson spectrophotometers. No latitudinal- and viewing condition-dependent errors are observed. Comparisons between the relative differences and the TC ozone values display fair agreement for TC ozone values between 220

DU and 450 DU. However, individual contributions to the relative differences in the TC ozone dependencies require further investigation.

Overall, the OMPS TC ozone product generated by the NASA OMPS science team performs very well with a mean bias error of approximately 1%. The product can be used with confidence for global ozone monitoring and other atmospheric applications over most regions of the world.

Acknowledgements

This work was partly supported by the National Basic Research Program of China (No. 2010CB951603), the Shanghai Science and Technology Committee (No.10DZ0581600) and the National Natural Science Foundation of China (41101037). The authors thank the Goddard Earth Sciences Data and Information Services Center and the World Ozone and Ultraviolet Data Center for their data support.

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Table 1. List of 34 ground-based Brewer stations selected for comparison with OMPS total ozone datasets.

STN ID	NAME	LAT. (deg.)	LON. (deg.)	ELEV. (m)	COUNTRY
499	Princess	-71.95	23.35	1350	Antarctica
322	Petaling Jaya	3.102	101.645	86	Malaysia
002	Tamanrasset	22.8	5.5	1384	Algeria
349	Lhasa	29.67	91.13	3650	China
332	Pohang	36	129.4	5	Korea
295	Mt. Waliguan	36.287	100.9	3816	China
213	El Arenosillo	37.1	-6.73	41	Spain
346	Murcia	38	-1.16	69	Spain
348	Ankara	39.97	32.863	913	Turkey
308	Madrid	40.45	-3.717	680	Spain
411	Zaragoza	41.63	-0.89	258	Spain
405	La Coruna	43.33	-8.41	60	Spain
326	Longfengshan	44.73	127.59	334	China
479	Aosta	45.74	7.36	570	Italy
035	Arosa	46.78	9.68	1840	Switzerland
099	Hohenpeissenberg	47.81	11.01	975	Germany
290	Saturna	48.77	-123.13	178	Canada
331	Poprad-Ganovce	49.03	20.32	706	Slovakia
096	Hradec Kralove	50.18	15.83	285	Czech Republic
053	Uccle	50.8	4.35	100	Belgium
353	Reading	51.44	-0.94	66	Great Britain
318	Valentia Observatory	51.93	-10.25	14	Ireland
076	Goose Bay	53.31	-60.36	44	Canada
021	Edmonton	53.55	-114.1	766	Canada
352	Manchester	53.47	-2.23	76	Britain
307	Obninsk	55.12	36.3	100	Russia
279	Norrkoeping	58.58	16.15	43	Sweden
077	Churchill	58.74	-94.07	35	Canada
165	Oslo	59.938	10.717	90	Norway
284	Vindeln	64.24	19.77	225	Sweden
267	Sondrestrom	66.996	-50.621	300	Greenland
024	Resolute	74.72	-94.98	40	Canada
315	Eureka	79.99	-85.93	10	Canada
018	Alert	82.5	-62.4	62	Canada

Table 2. List of 39 ground-based Dobson stations selected for comparison with OMPS total ozone datasets.

STN ID	NAME	LAT. (deg.)	LON. (deg.)	ELEV. (m)	COUNTRY
057	Halley	-75.36	-26.13	33	Antarctica
101	Syowa	-69.01	39.58	22	Antarctica
232	Vernadsky	-65.15	-64.16	16	Antarctica
233	Marambio	-64.23	-56.62	198	Antarctica
339	Ushuaia	-54.85	-68.28	17	Argentina
029	Macquarie Island	-54.5	158.95	10	Australia
091	Buenos Aires	-34.58	-58.48	25	Argentina
159	Perth	-31.92	115.96	2	Australia
340	Springbok	-29.67	17.9	1006	South Africa
027	Brisbane	-27.39	153.13	4	Australia
265	Irene	-25.92	28.217	1523	South Africa
084	Darwin	-12.42	130.89	30	Australia
216	Bangkok	13.67	100.61	53	Thailand
002	Tamanrasset	22.8	5.5	1384	Algeria
311	Havana	23.143	-82.341	50	Cuba
245	Aswan	23.97	32.78	190	Egypt
190	Naha	26.21	127.69	28	Japan
409	Hurghada	27.28	33.75	7	Egypt
014	Tsukuba	36.06	140.13	31	Japan
106	Nashville	36.25	-86.57	182	USA
341	Hanford	36.32	-119.63	73	USA
213	El Arenosillo	37.1	-6.73	41	Spain
208	Xianghe	39.98	116.37	80	China
067	Boulder	40.03	-105.25	1689	USA
410	Amberd	40.38	44.25	2070	Armenia
012	Sapporo	43.06	141.33	26	Japan
065	Toronto	43.781	-79.468	198	Canada
040	Haute Provence	43.93	5.7	684	France
019	Bismarck	46.77	-100.75	511	USA
035	Arosa	46.78	9.68	1840	Switzerland
020	Caribou	46.87	-68.03	192	USA
099	Hohenpeissenberg	47.81	11.01	975	Germany
096	Hradec Kralove	50.18	15.83	285	Czech Republic
498	Kyiv-Goloseyev	50.364	30.497	206	Ukraine
068	Belsk	51.84	20.79	180	Poland
043	Lerwick	60.13	-1.18	82	Great Britain
051	Reykjavik	64.13	-21.9	64	Israel

105	Fairbanks	64.82	-147.87	138	USA
199	Barrow	71.32	-156.6	11	USA

Table 3. The number of correlative data points (*N*), the slope of the regression, the coefficient of regression (R^2), the root mean square error (*RMSE*) and the mean bias error (*MBE*) with standard deviation collected from the comparisons.

	N	***Slope***	R^2	***RMSE***		***MBE* (%)**
				%	DU	
Brewer	7437	1.01	0.96	2.88	9.54	+0.59±2.82
Dobson	6139	1.00	0.96	3.44	10.24	+1.09±3.27

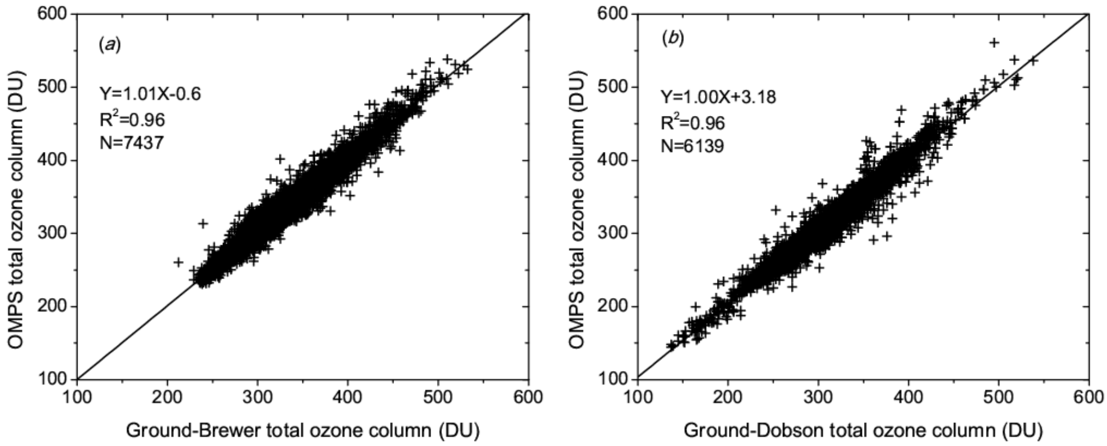

Figure 1. Scatterplots of OMPS TC ozone and ground-based observations for Brewer (*a*) and Dobson (*b*) measurements.

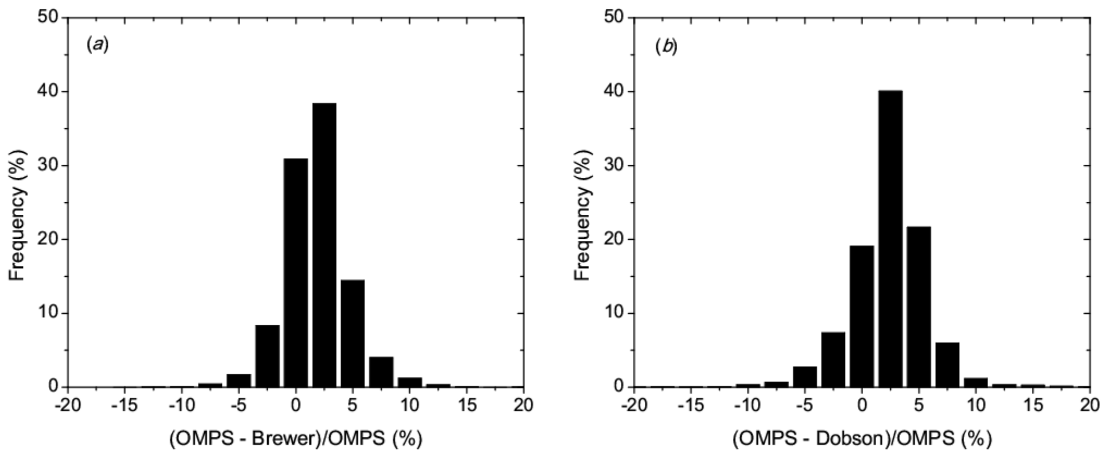

Figure 2. Frequency statistics of the relative differences between OMPS TC ozone and Brewer (a) and Dobson (b) measurements.

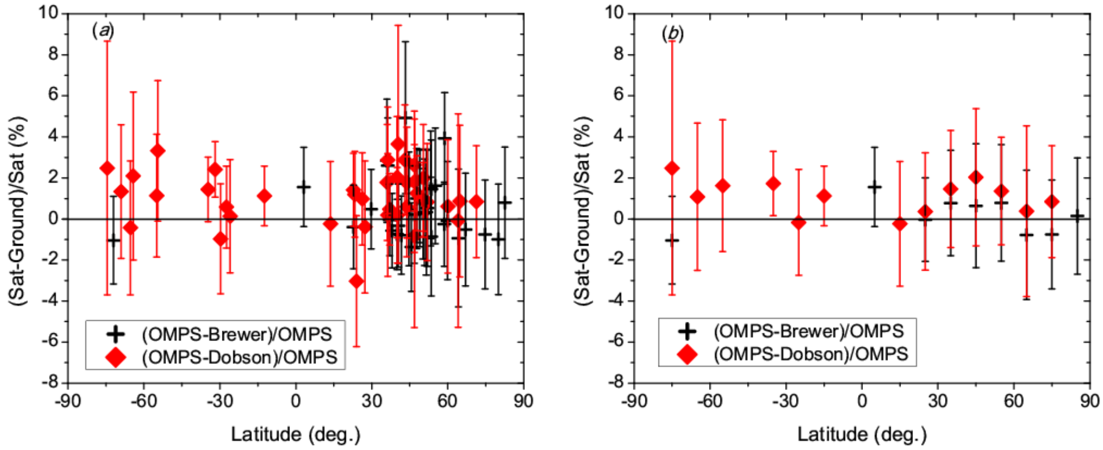

Figure 3. Mean relative differences between OMPS TC ozone and ground measurements as a function of each ground station latitude (*a*) and 10° latitude bins (*b*).

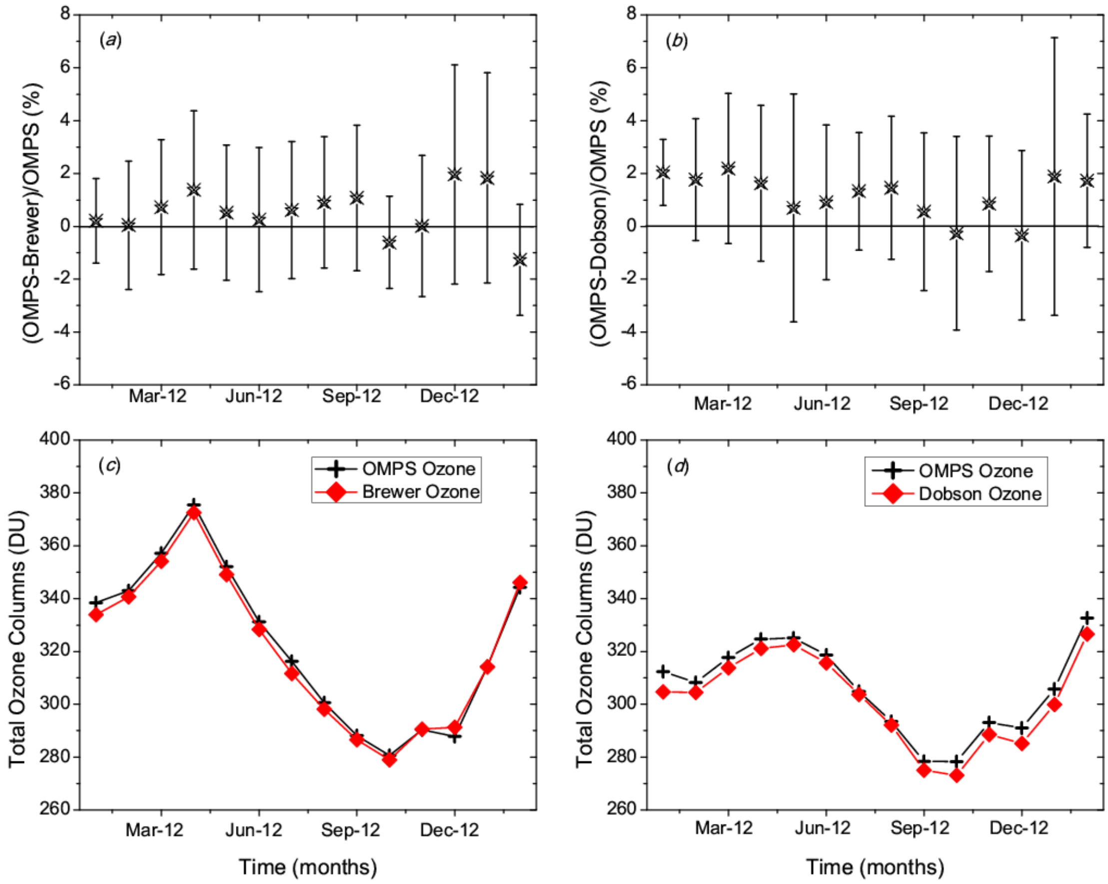

Figure 4. Time series of the monthly mean relative differences (top) and TC ozone values (bottom).

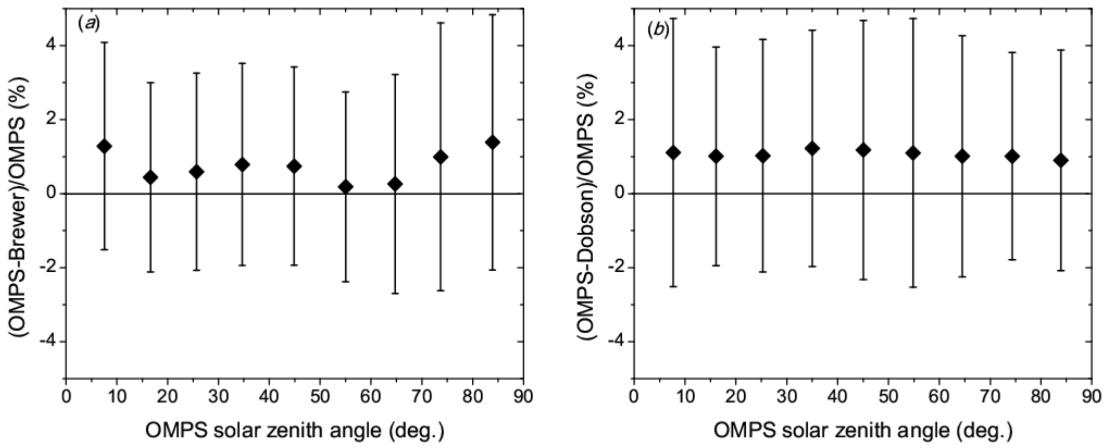

Figure 5. Investigation of the relative differences dependence on OMPS solar zenith angle (bins of 10°).

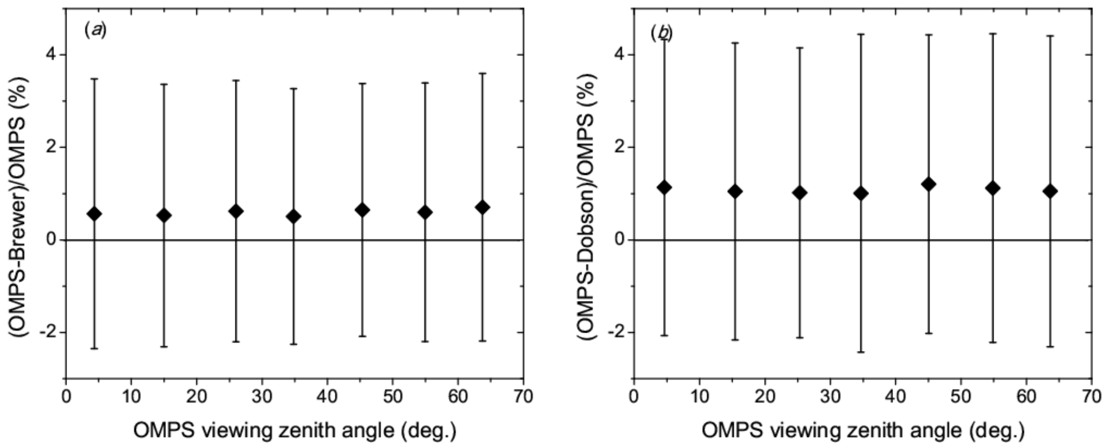

Figure 6. Same as Fig. 5 but for OMPS viewing zenith angle.

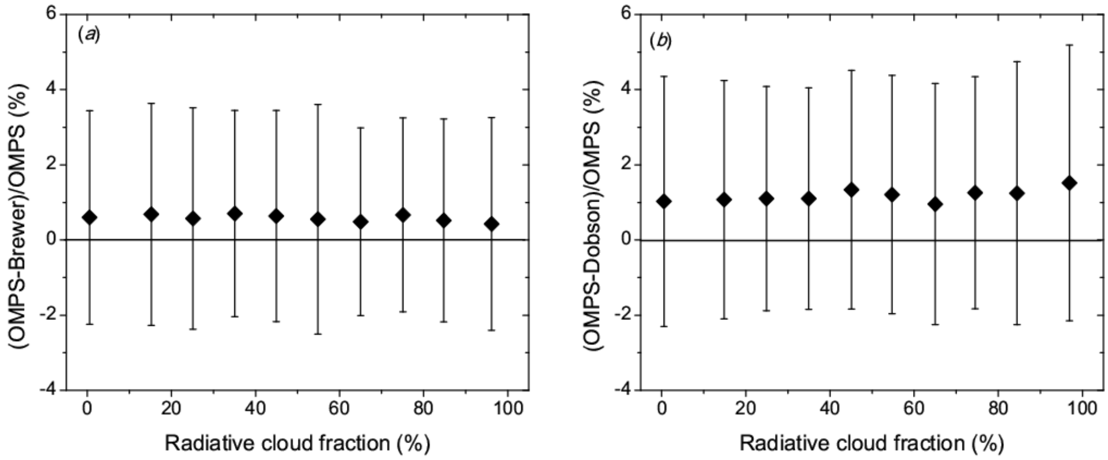

Figure 7. Investigation of the relative differences dependence on radiative cloud fraction (bins of 10%).

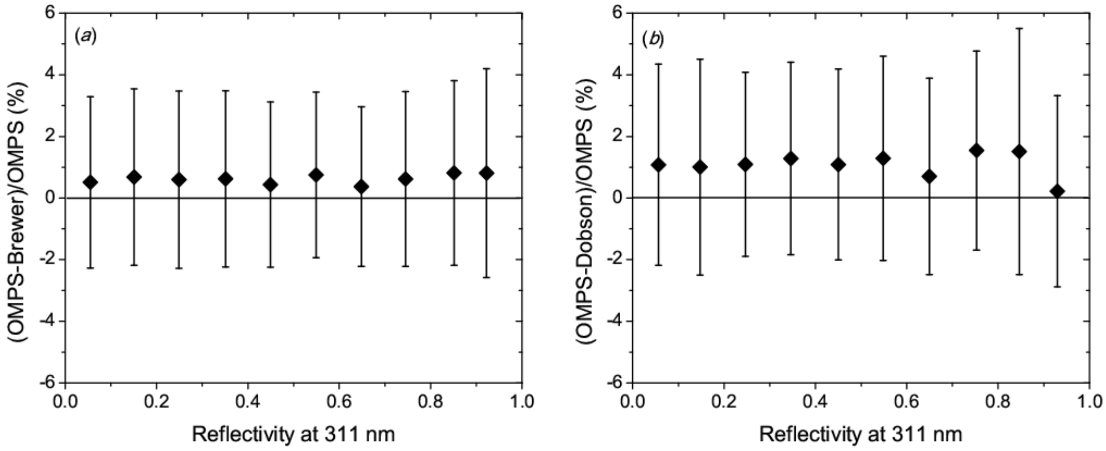

Figure 8. Mean relative differences versus reflectivity at 311 nm (bins of 0.1).

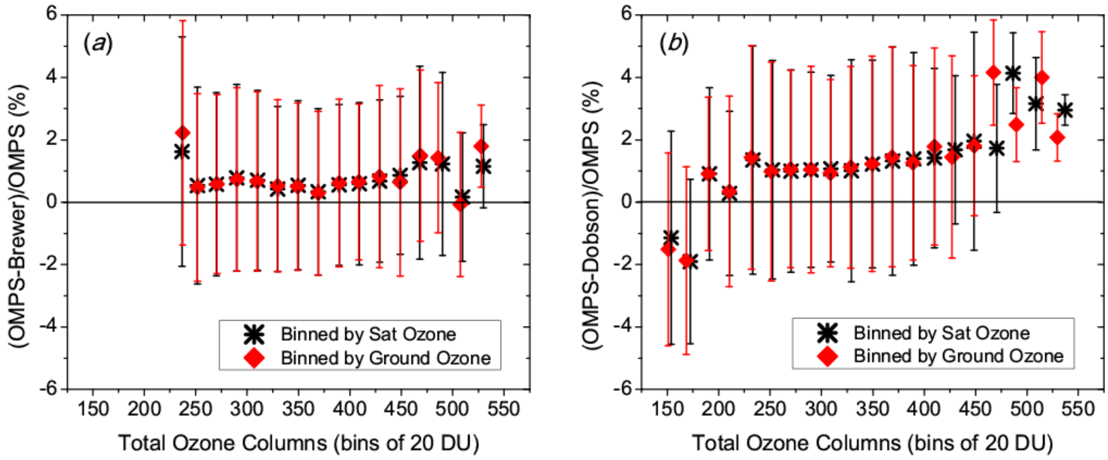

Figure 9. The relative differences of OMPS and ground-based measurements as a function of the total ozone column: Brewer dataset (left) and Dobson dataset (right).