COMPARISON OF TOTAL COLUMN OZONE DATA FROM OMI MEASUREMENTS WITH GROUND-BASED OBSERVATIONS AT THE KISHINEV SITE, REPUBLIC OF MOLDOVA

A. Aculinin and V. Smicov

Institute of Applied Physics, Academy of Sciences of Moldova, 5, Academiei str., MD-2028, Chisinau, Republic of Moldova; e-mail: akulinin@phys.asm.md
(Received 16 August 2010)

Abstract

Total ozone content (TOC) data obtained from direct ground observations are used for validation of the ozone data from overpass ozone measurements performed with the Ozone Monitoring Instrument (OMI) on-board the Aura satellite platform. TOC ground data were obtained with a hand-held MICROTOPS II Ozonometer at the ground-based solar radiation monitoring station in Kishinev (Chisinau), Republic of Moldova during the period from 2004 to 2009. OMI TOC data were obtained by the OMI's team from OMI overpass observations and processed with using of the TOMS-like algorithm. OMI TOC instantaneous data and daily averages of the total ozone content retrieved from OMI overpass measurements are in full agreement with the ground observations with a correlation coefficient of ~0.99. Validation showed that OMI overpass data underestimate TOC data from ground observations for all sky and clear sky conditions. Biases for instantaneous and daily averages of TOC data retrieved from satellite and ground observations were –2.36% and –2.15%, respectively for all sky conditions. Seasonal variability of monthly averages of biases with values of –1.14% (in February) and –2.99% (in June) was observed.

1. Introduction

If all ozone contained in a column of atmosphere were brought down to the surface of the Earth at the STP conditions, it would occupy a layer, on an average, from 2 to 5 mm thick or in Dobson units (DU), from 200 DU to 500 DU. The thickness of the layer depends upon the season of year and geographical location on the Earth. Events with extremely low values of TOC with an equivalent layer thick up to ~0.9 mm (or 90 DU), as a rule, are observed over the Antarctic (phenomenon is known as the Antarctic ozone hole). Meanwhile, it is this thin layer of ozone that represents a natural powerful shield for protecting human health, flora and fauna, and ecosystems against the influence of harmful solar UV radiation. Both height distribution of the atmospheric ozone and the total column ozone content in a column of atmosphere demonstrates variability on regional and global scales during the diurnal and in a course of long-term observations [1]. To investigate total column ozone content variability on the spatial and temporal scales, both ground-based networks of spectral photometers and some satellite platforms with unique measuring instruments for remote sensing of ozone are used. The most known among them are TOMS-like on-board Meteor-3, Nimbus-7, and Earth Probe platforms, a GOME on-board ERS-2 platform, a SCIAMACHY on-board ENVISAT platform, and an OMI on-board Aura platform. Reliability of ozone data retrieved from satellite observations depends upon the accuracy of measurement by using unique optical equipment, applied models in computer modeling, and retrieving algorithms in data processing. In this connection, validation of satellite data through the ground-based direct ozone observations is an extremely important step and condition to improve the quality and accuracy of ozone data retrieved from satellites.

In this work, we carry out validation of the TOC data retrieved from OMI overpass measurements at the Aura satellite platform relative to ozone column data obtained from direct observations at the ground-based station in the Institute of Applied Physics, Kishinev (Chisinau), Republic of Moldova in the course of period from 2004 to 2006.

2. Measurement approach

TOC data retrieved from measurements of spectral components of solar radiation scattered from the Earth's surface or from the top of clouds by using an OMI instrument are utilized in this analysis. OMI is a nadir viewing ultraviolet/visible solar backscatter spectrometer and it is placed on-board the Aura satellite platform. TOC data were retrieved from satellite images of the Earth's surface with a high spectral and spatial resolution. The small pixel size of the image corresponds to dimension of 13 km x 24 km (for nadir viewing) of the area projected onto the Earth's surface. A more detailed description of the OMI instrument, some procedures of data processing, QC/QA procedures, calibration, and characterization can be find elsewhere [2]. Theoretical basis of the OMI ozone product algorithm for deriving the total column ozone from spectral scattered radiances is based on the TOMS-like algorithm (ver. 8 is the last one version) applied to OMI data processing, and it is described in detail elsewhere [2-5]. The data collected over period of satellite observations from 2004 to 2009 are used in this analysis. TOC datasets from OMI overpass measurements are compared with the data from ground observations carried out with a hand-held photometer at the ground-based solar radiation monitoring station in the Institute of Applied Physics.

Ground observations of the total ozone content in a column of atmosphere were regularly carried out using a hand-held MICROTOPS II ozonometer (Solar Light Co.) equipped with three high-quality interference filters (with a FWHM band pass of 2.4 nm and a precision of the peak wavelength of ±0.3 nm) in UV-B region of spectrum. Time-series of observations have been collected at the solar radiation monitoring ground station (φ=47.00°N, λ_o=28.82°E, h=205 m a.s.l.) since July 2003. The station is situated in an urban environment of Kishinev (Moldova) and mounted at the Institute‘s building roof. TOC values were derived from the ratios of direct solar ultraviolet radiances simultaneously measured at 3 discrete wavelengths of 305.5, 312.5, 320-nm within the UV-B spectral range. A detailed description of the hand-held ozonometer and measurement algorithm can be found elsewhere [6]. As a rule, measurements of the total ozone content were carried out during midday hours, when the small values of air mass m were the case. Observations were carried out for air masses m up to values m = 3–3.5 (for AM and PM). A MICROTOPS II ozonometer allows measuring the total ozone content with an accuracy of ~2% relative to the Dobson and Brewer spectrophotometers [6-8].

3. Data analysis

Regular direct observations of the total ozone content in a column of atmosphere at the ground station in the Institute of Applied Physics in Kishinev have been started by the Atmospheric Research Group (ARG) since July 2003 [9]. Respective TOC data from direct ground observations were processed and compiled into arrays of data; hereinafter, these datasets will be referred to as ARG. Multi-year series of TOC data acquired from the OMI overpass measurements at the Aura satellite platform since October 2004 are utilized in validation.

OMI overpass data for specific coordinates of ARG ground station are available at the Aura Validation Data Center (AVDC) web-site [10]. OMI gridded datasets composed of ozone daily means are available on-line through the NASA Goddard Space Flight Center archive. Data are presented in the ASCII form with the typical grid resolution of 1°-latitude x 1°-longitude [11]. Respective OMI ozone daily means corresponding to pre-selected coordinates (φ, λ_o) of the ARG station are computed by using a linear interpolation of gridded TOC daily means downloaded from the archive.

Summary of statistics concerning the TOC OMI validation results in comparison with the ARG ground observations is presented in Table 1. For each case, we report the number of pairs of ARG and OMI data or number of days of cooperative observations taken into account *n*; correlation coefficient between ARG ground and OMI overpass data *r*; the slope of regression line; the mean relative difference or bias *b* in %, $\frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i - x_i}{x_i}\right)\cdot 100$; the root mean squares (RMS) in DU, $\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)^2}$; and the RMS in % $\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i - x_i}{x_i}\right)^2}\cdot 100$, where variables y_i and x_i are the pairs of data from the OMI overpass and, respectively, ARG ground observations both for instantaneous and daily average measurements of TOC.

Datasets under consideration, collected at the ARG ground station for the period from October 2004 to November 2009, consist of instantaneous and daily means of TOC data both for clear sky and all sky conditions. The scatter plots and time series presented below consist of point data from the OMI overpass measurements versus the ARG ground-based direct ozone observations. Point data are defined as data which will be taken into consideration only if the region confined by projection of one pixel (12 x 24 km) onto the Earth's surface captures the point with coordinates of the ARG ground station. This is the condition of spatial homogeneity of measurements that characterizes the proximity of the OMI tracking line to the location of the ground station; hereinafter, respective data will be referred to as point one. It should be noted that 90% of point data fall in the time interval on the order of ±90 min defined for each OMI-ARG pair of data measurement as interval pertaining to time between the current instantaneous OMI overpass measurement and ARG direct ground observation. It is expected that in the course of that time interval TOC value at the site of observation does not undergo a significant variation. For example, from the series of observations, only those OMI-ARG pairs of data were chosen that are complying with the condition of synchronous point measurements within the time interval on the order of ±2 min. The regression line in this case was $Y = 12.25 + 0.94X$ with the correlation coefficient $r = 0.991$. Values of mean relative difference or bias and RMS were the following: $b = -2.21\%$ and RMS = 2.86%, which correspond to value of mean difference of TOC –7.7 DU.

Scatter plots of the TOC data derived from direct ground-based observations at the Kishinev site and retrieved by means of the TOMS-like algorithm from OMI overpass measurements are shown in Figs. 1 and 2, respectively. Datasets represent point measurements carried out for all sky and clear sky conditions, respectively. Scatter plots show a strong mutual dependence between the OMI and ARG TOC data with the correlation coefficient $r \approx 0.99$ both for clear and all sky conditions. There is a little difference between slopes derived from observations for these types of sky conditions. A comparison between scatter plots for ARG and OMI datasets reveals a good resemblance with respective values of the regression line slope of ~0.98 (for all sky) and ~0.96 (for clear sky) (see Figs. 1, 2 and Table 1).

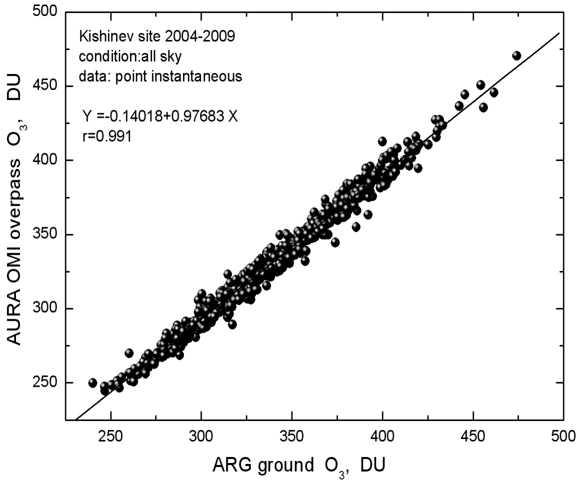

Fig. 1. Scatter plot of OMI overpass versus ARG ground TOC data from instantaneous observations for all sky conditions. The equation of regression line (solid line) is indicated. Period of observation from October 2004 to November 2009.

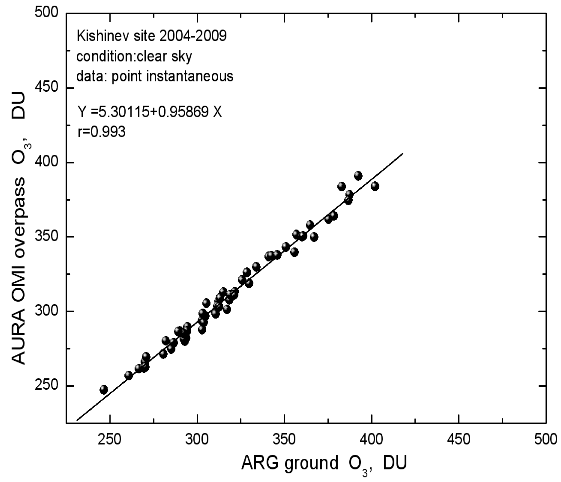

Fig. 2. Scatter plot of OMI overpass versus ARG ground TOC data from instantaneous observations for clear sky conditions. The equation of regression line (solid line) is indicated. Period of observation from October 2004 to November 2009.

Analogous behaviour of scatter plot is typical for daily averages of the TOC data retrieved from OMI overpass and ARG ground direct observations (see Fig. 3). In this case, the OMI daily means of total column ozone content were retrieved and linearly interpolated from respective gridded database [11].

ARG TOC daily means were derived from averaging of the set of multiple measurements of TOC fulfilled in the course of each appropriate day of observations. Derived statistical parameters were the following: bias *b*=–2.15% and RMS ~2.57%, which corresponds to value of mean difference of TOC ~ –7.2 DU. Respective equations of regression lines for the cases examined are indicated in each of Figs. 1-3. The slopes of regression lines for instantaneous and daily averaging observations for all sky condition are practically identical, but there is a little difference between the slopes for all sky and clear sky condition for instantaneous observations (see Table 1).

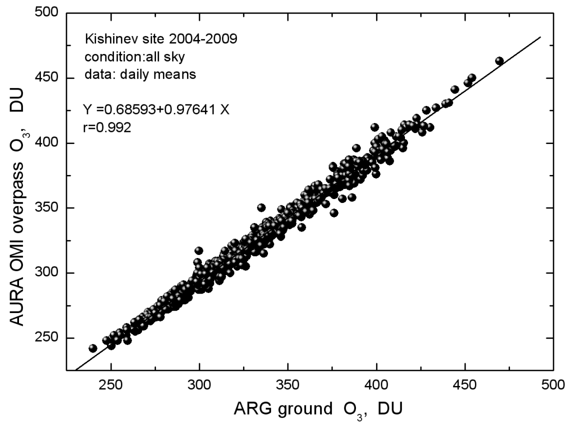

Fig. 3. Scatter plot of OMI overpass TOC daily means versus ARG ground TOC daily averages from observations for all sky conditions. The equation of regression line (solid line) is indicated. Period of observation from October 2004 to November 2009.

Taking into account the uncertainties of the OMI TOMS-like technique, a comparison between OMI overpass and ARG ground observations reveals a good agreement in cases of instantaneous and daily averaging observations both for all sky and for clear sky conditions. However, in all cases, note negative values of bias *b* (ARG TOC data overestimate OMI TOC ones); for example, for instantaneous measurements biases were *b*= –2.36% (for all sky) and *b* = –2.44% (for clear sky). These biases correspond to values of mean difference of TOC: -7.9 DU and –7.8 DU, respectively. For the case of daily averages of TOC from measurements for all sky conditions, the value of bias was somewhat less: –2.15%. In all cases of observations, root mean squares ranged from RMS ~2.54% to ~2.83% (see Table 1).

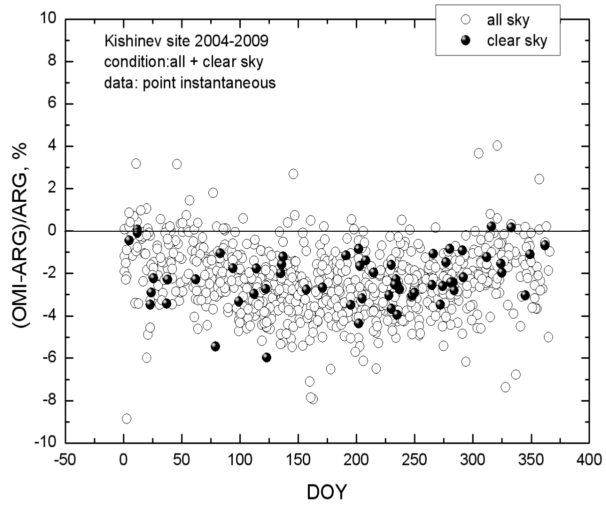

Fig. 4. Intra-annual variability of relative difference (OMI-ARG)/ARG (in %) versus day of year (DOY). Case of instantaneous OMI overpass and ARG ground TOC observations for all sky and for clear sky conditions. Period of observation: October 2004 to November 2009.

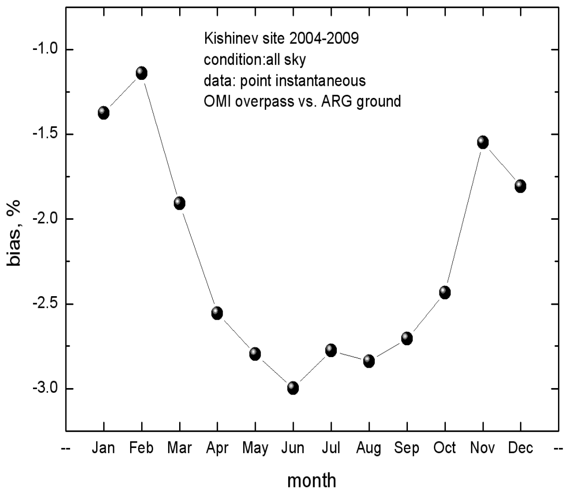

Fig. 5. Seasonal variability of multiyear means of relative difference *b* (in %) versus month. Case of instantaneous OMI overpass and ARG ground TOC observations for all sky conditions. Period of observation: October 2004 to November 2009.

Table 1. Summary of TOC OMI validation results (*n* is the number of days of observations taken into account in the comparison; *r* is the correlation coefficient between ARG ground and OMI overpass data; RMS DU (%) is root mean squares expressed in DU and in %, and *b* is the mean relative difference or bias, in %. OMI data were retrieved by using a TOMS-like algorithm. "Point" observation is defined for the selection of data by condition when coordinates of ARG site falls into the projection on the Earth's surface of one pixel of image and the distance between the ARG site place and the Aura platform line track is no more than ~12 km. Bias and RMS are computed for OMI overpass data relative to ARG data acquired from ground observations. Period of observation: October 2004 to November 2009.

	n	*r*	slope	RMS DU (%)	*b*, bias, %
clear sky instantaneous observations	60	0.993	0.959	9.0 DU (2.77%)	–2.44
all sky instantaneous observations	777	0.991	0.977	9.5 DU (2.83%)	–2.36
clear sky daily average observations	60	0.994	0.953	8.3DU (2.54%)	–2.22
all sky daily average observations	777	0.992	0.976	8.7DU (2.57%)	–2.15

Figure 4 shows time series of the relative difference defined as (OMI-ARG)/ARG (in %) for instantaneous OMI overpass and ARG ground observations for all sky (circles) and clear sky (black dots) conditions. For these types of sky conditions, we can clearly see the existence of negative relative difference throughout the year and the difference on an average is about –2.4%. Some discrepancies in bias observed in summer can be attributed to the influence of clouds and increased turbidity of the atmosphere, while days with clear sky conditions do not reveal a seasonal variability. The influence of the atmospheric turbidity on the TOC observations will be studied in a more detail in future investigation. Figure 5 shows the pattern of clear-cutting seasonal variation of monthly means of bias weighted by averaging over period from 2004 to 2009. The most discrepancies in bias variation were observed from March to October. The largest value of bias was observed in June and it was $b = -3.0\%$, corresponding to value of TOC mean differences of –10.4 DU. Minimum values of monthly means of bias were typical of winter. The seasonal variability of OMI TOC validation results for all sky conditions is presented in Table 2. We can see that winter is characterized as a season with the smallest negative value of bias, $b = -1.43\%$. The large value of seasonally means of bias $b = -2.86\%$ observed in summer can be attributed to the influence of cloudiness and to high atmospheric turbidity. Another reason both for seasonal variation of bias and for the direct value of bias can be associated with differences between the in-situ parameters of atmosphere and parameters applied in the climatic models of temperature and ozone content variability in the height of atmosphere (profiles of ozone absorption coefficients and their temperature dependence). The last parameters of climatic models were used in computer modeling by means of OMI ozone retrieving algorithms. These parameters used in standard models differ from the in-situ parameters, which generally depend upon the sky condition, season, and point of observation.

Table 2. Seasonal variability of OMI TOC validation results (key statistical parameters presented here are the same as in Table 1). Summary represents point OMI overpass vs. ARG ground observations of TOC for all sky conditions. Period of observation: October 2004 to November 2009.

	n	*r*	slope	RMS DU (%)	*b*, bias, %
Winter (D-J-F)	138	0.992	0.994	7.5 DU (2.23%)	–1.43
Spring (M-A-M)	230	0.986	0.987	10.3 DU (2.81%)	–2.46
Summer (J-J-A)	232	0.973	0.966	10.7 DU (3.22%)	–2.86
Fall (S-O-N)	177	0.982	0.937	8.1 DU (2.70%)	–2.28

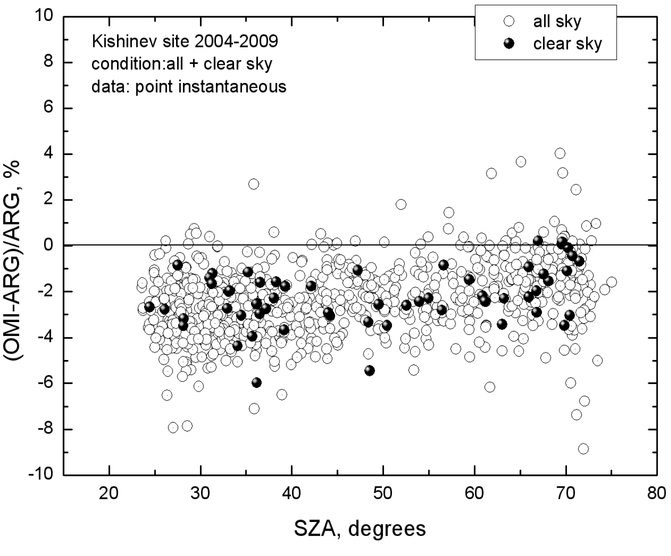

Fig. 6. Variability of relative difference (OMI-ARG)/ARG, (in %) versus solar zenith angle (SZA). Case of instantaneous OMI overpass and ARG ground TOC observations for all sky and for clear sky conditions. Period of observation: October 2004- November 2009.

Figure 6 presents variation of relative differences (in %) between OMI overpass and ARG ground TOC data versus the solar zenith angles (SZA) for all sky and clear sky conditions. Biases for clear sky (black filled circles) and all sky (open circles) conditions show good mutual resemblance in the course of SZA variation. The largest discrepancies of relative differences are observed in summer (for solar zenith angles corresponding to small values). The reasons of such discrepancies can be attributed to large values of atmospheric turbidity because of increased content of absorptive aerosols (dust, soot) in the atmosphere in summer and to specific profiles of ozone absorption coefficients (their temperature and altitude dependence). These parameters for the particular point of observation and time of year can differ from the analogous set of parameters which were taken into account in standard atmospheric models for evaluation of total ozone content in respective OMI ozone retrieving algorithms.

Climatic mean value of TOC retrieved from the TOMS overpass observations at the Meteor-3, Nimbus-7, Earth Probe, and Aura platforms for coordinates of the Kishinev site during period from 1979 to 2009 is 332.9 DU. The yearly mean values of TOC derived from MICROTOPS ozonometer measurements at the ARG ground station and from OMI overpass observations over period from 2005 to 2009 are 333.9 DU and 327.7 DU, respectively.

4. Summary and conclusions

The objective of the work was to fulfill validation of TOC data from the OMI overpass observations through the comparison with the column of ozone data obtained at the ARG ground station in Kishinev, Moldova. For this purpose, ground TOC data were derived from direct ozone observations of ozone using a hand-held MICROTOPS ozonometer at the ARG ground station. OMI ozone data were retrieved from overpass measurements on-board the Aura satellite platform. ARG ground and OMI overpass datasets suitable for coordinates of the ARG station consist of point instantaneous and daily means values of TOC. OMI TOC daily means data were obtained from linear interpolation of gridded data from respective OMI database for specific coordinates of the ARG ground station. Respective ARG and OMI TOC datasets were subdivided into two groups of measurements: for all sky and clear sky conditions. Time series of ozone data includes observations from October 2004 to November 2009.

It was found that instantaneous data and daily averages of total ozone content retrieved from OMI overpass measurements are in close agreement with the respective data obtained from direct ground observations; the values of correlation coefficients between these datasets, on an average, amount to ~0.992. The validation showed that OMI overpass data underestimate TOC data from ground observations (or biases were negative) in all cases: both for instantaneous and daily averages values of TOC at any sky conditions. Biases for the cases of instantaneous and daily averages of data retrieved from measurements for all sky conditions were –2.36% and –2.15%, respectively, which correspond to values of mean differences of TOC –7.9 DU and –7.2 DU.

Relative differences of TOC retrieved from OMI overpass and ARG ground observations show intra-annual variability. The maximum value of the relative differences was observed in the summer months and on an average it was about –2.15%. We also observed distinct seasonal variability of multiyear monthly averages of biases with values of –1.14% (in February) and –2.99% (in June). Multiyear seasonal means of biases ranged from –1.43% (in winter) to –2.86% (in summer).

A comparison of instantaneous measurements of TOC for all sky and clear sky conditions showed a weak dependence of relative differences on SZA. The largest discrepancies of relative differences were observed in summer (low values of SZA). For the cases of intra-annual and SZA variability, these relative differences may be due to distinctions of the parameters of atmospheric turbidity and profiles of ozone absorption coefficients in-situ from the set of parameters applied in standard models of atmosphere. These standard models were taken into account for modeling by means of respective OMI ozone retrieving algorithms.

Acknowledgements

We thank Dr. Christian Retscher, Aura Validation Data Center (AVDC), NASA Goddard Space Flight Center for the access to OMI overpass data at the site http://avdc.gsfc.nasa.gov/

and to Dr. Richard D. McPeters, Principal Investigator, Earth Probe TOMS at NASA Goddard Space Flight Center for the access to OMI daily means data at the site http://jwocky.gsfc.nasa.gov/.

References

[1] M.P. Chipperfield, V.E. Fioletovet et al., Global Ozone: Past and Present, Chapter 3 in Scientific Assessment of Ozone Depletion: 2006, Global Ozone Research and Monitoring Project–Report No. 50, World Meteorological Organization, Geneva, Switzerland, 572 pages, 2007.

[2] J.P. Veefkind, J.F. de Haan, E.J. Brinksma, M. Kroon, and P.F. Levelt, Geoscience and Remote Sensing, IEEE Transactions, 44(5), 1239, (2006).

[3] OMI Algorithm Theoretical Basis Document (ATBD), vol. 1, OMI Instrument, Level 0-1b processor, Calibration & Operations, Ed. by P.F. Levelt, ATBD-OMI-01, ver.1.1, 50 pages, August 2002, http://www.knmi.nl/omi/documents/data/OMI_ATBD_Volume_1_V1d1.pdf

[4] OMI Algorithm Theoretical Basis Document (ATBD), vol. 2, OMI Ozone Products, Ed. by P.K. Bhartia, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, ATBD-OMI-02, ver. 2.0, 91 pages, August 2002, http://www.knmi.nl/omi/documents/data/OMI_ATBD_Volume_2_V2.pdf

[5] P.K. Bhartia and C.W. Wellemeyer, TOMS-V8 Total O3 Algorithm: Algorithm Theoretical Basis Document (ATBD), http://toms.gsfc.nasa.gov/version8/v8toms_atbd.pdf

[6] M. Morys, F.M. Mims III, S. Hagerup, S.E. Anderson, A. Baker, J. Kia, and T. Wallkup, J. Geophys. Res., 106, 14573, (2001).

[7] U. Kohler, Geophys. Res. Lett., 26(10), 1385, (1999).

[8] D.H. Holdren, R.O. Olsen, and F.J. Schmidlin, Geophys. Res. Lett., 28(20), 3859, (2000).

[9] A. Aculinin, A. Smirnov, V. Smicov, T. Eck, and A. Policarpov, Mold. J. Phys. Sci., 3, 2, 204, (2004).

[10] Aura Validation Data Center (AVDC), http://avdc.gsfc.nasa.gov/index.php?site=2045907950

[11] Total Ozone Mapping Spectrometer (TOMS): Ozone Monitoring Instrument (OMI) Maps and Data, Ozone Processing Team – NASA/GSFC code 613.3, Greenbelt, Maryland, USA; ftp://toms.gsfc.nasa.gov/pub/omi/data/ozone/