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COMPARISON OF REMOTE SPECTROPHOTOMETRIC AND LIDAR MEASUREMENTS OF O_3, NO_2, AND TEMPERATURE WITH DATA OF SATELLITE MEASUREMENTS

Bazhenov O.E., Burlakov V.D., Grishaev M.V., Gridnev Yu.V., Dolgii S.I., Makeev A.P, Nevzorov A.V., Salnikova N.S.

V.E. Zuev Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences

Russia, 634021, Tomsk, Academician Zuev square, 1, E-mail: dolgii@iao.ru

ABSTRACT

We consider the results of remote spectrophotometric and lidar measurements of the total ozone and nitrogen dioxide contents and temperature, obtained at the Siberian Lidar Station (SLS) of V.E. Zuev Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences (Tomsk: 56.5°N; 85.0°E) in comparison with the results of analogous satellite measurements.

The ground-based measurements of the total ozone (TO) content are performed with the help of M-124 ozonometer; and the measurements of the nitrogen dioxide (NO_2) content are carried out with automatic spectrophotometer. The ground-based lidar measurements of temperature are conducted on the basis of SLS measurement complex. These measurements are compared with data of balloon-sonde and satellite measurements. The satellite measurements are performed by the TOMS and IASI instrumentation.

1. TO MEASUREMENTS

TO measurements have been performed with the help of ozonometer M-124 since 1993. To compare our data, we used satellite measurements of TO, which are retrieved with the help of two algorithms: OMI-TOMS and OMI-DOAS [1]. The first algorithm is based on the version TOMS V8. The measurements are performed in four discrete spectral regions centered at 313, 318, 331, and 360 nm. The second algorithm uses the hyperspectral feature of Ozone Monitoring Instrument (OMI). It is based on the principle of Differential Optical Absorption Spectroscopy (DOAS). The retrievals are performed using measurements in the wavelength range 331.1-336.6 nm. The key difference between the two algorithms is that DOAS removes the effects of aerosol, clouds, sulfur dioxide, and underlying surface by spectral fitting; while TOMS algorithm does that through empirical correction. In addition, TOMS algorithm uses a cloud height climatology, derived with the help of infrared satellite data; while the DOAS algorithm uses cloud information derived from OMI measurements in the O_2-O_2 absorption band at wavelength of 470 nm. A single well-established algorithm of the satellite data processing has not yet been commonly accepted. Qualitative behavior of the long-term TO variations differs little between different algorithms used.

Figure 1 shows the observation time series for the first half of 2013, performed with M-124 device and processed by the OMI-DOAS algorithm. **Figure 2** compares the M-124 ozonometer measurements for 2005 – 2013 with satellite data, processed with different algorithms. We present the relative differences between M-124 values and results of satellite measurements; the differences are smoothed using sliding average over 365 days. At the Aura Validation Data Center (AVDC) website, the OMI data processed by the OMI-TOMS algorithm are abbreviated as OMTO, and data based on the OMI-DOAS algorithm are abbreviated as OMDO.

The relative discrepancy between ground-based and satellite data, retrieved with the help of OMI-DOAS algorithm, and averaged over the year, has been 13 DU (3.5% of the annual average) in 2010 and 16 DU (4.7%) in 2011. Recall that 2012 was very dry, with many fires at summertime, which probably influenced the accuracy of measurements. As a result, the discrepancy between the satellite and ground-based measurements grew from the middle to the end of 2012. Seemingly, until August 2012 this was due to the increased turbidity and smoke pollution of the atmosphere. In late 2012, the satellite measurements indicated the decreased total ozone content; while ground-based observations reported the usual seasonal TO growth. As a consequence, the discrepancy had been 18 DU in the first half and 23 DU in the second half of 2012. In 2013, the disagreement between ground-based and satellite data decreased and became 16 DU over the first half-year.

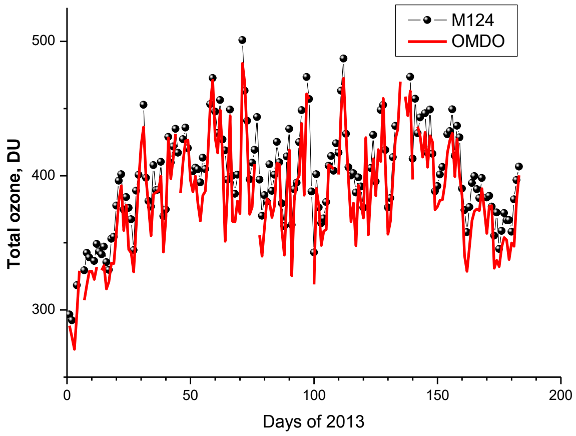

Figure 1. **Comparison of measurements of the total ozone content with the help of M-124 ozonometer and TOMS instrumentation (satellite measurements are retrieved with the use of the OMI-DOAS algorithm) for the first half of 2013.**

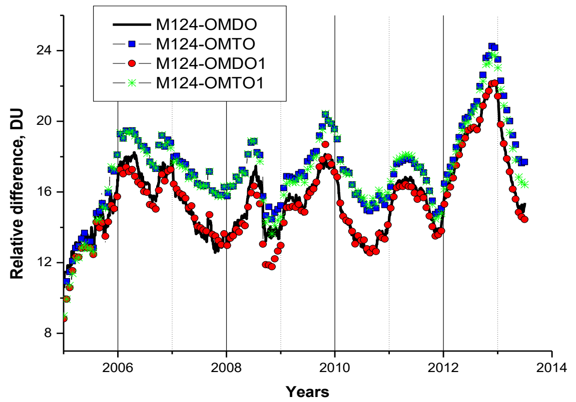

Figure 2. Relative discrepancies between measurements of the total ozone content with the help of M-124 ozonometer and on the basis of TOMS instrumentation for period of 2005 – 2013.
The satellite data are retrieved with the help of two algorithms for two closely lying geographic points: Tomsk (OMDO, OMTO) and Tomsk 1 (OMDO 1, OMTO 1).

2. MEASUREMENTS OF NO_2 CONTENT

The NO_2 content is measured with automatic spectrophotometer, which records the spectrum of zenith-scattered solar radiation in the wavelength range of 430 – 450 nm with the spectral resolution of 0.9 nm. The deformation of the spectrum is used to determine the nitrogen dioxide content in the slant atmospheric column as a function of the solar zenith angle. The measurements are performed at twilight time of the day, when the solar zenith angle varies from 83° to 96°. By solving the inverse problem, the data on the slant nitrogen dioxide content in the atmosphere are used to retrieve the vertical distribution of nitrogen dioxide in 10 layers, each 5 km thick, in the altitude range from 0 to 50 km [2]. For determining the NO_2 content, the satellite instrument OMI uses the DOAS method, by recording the spectrum of solar radiation, scattered by the Earth's atmosphere, in the wide wavelength range in the ultraviolet and visible parts of the spectrum with the spectral resolution of 0.5 nm and spatial resolution of 13x24 km^2 at nadir [3]. The wavelength range of 415 – 465 nm is used to determine the NO_2 content in the vertical atmospheric column. In the report we use OMI data for period from October 2004 to December 2012. For comparison, we took the data sample of OMI measurements of the total NO_2 content in the stratospheric column over Tomsk; these data are publicly available at AVDC website [4].

The ground-based measurements are performed at twilight time of the day; therefore, interpolation method was used to reduce them to the time of satellite measurement, taking into consideration the photochemical processes. The satellite measurements over Tomsk were performed twice daily at different times; therefore, the results of both measurements were used for comparison purposes, while the ground-based measurements were interpolated to the times of satellite measurements.

Figure 3 presents the values of the total NO_2 content in the stratospheric column according to measurements from satellite (OMI instrument) and ground-based measurements, interpolated to the times of observations from satellite. As can be seen from the figure, these satellite measurements coincide quite exactly with data of ground-based observations. The time series show annual behavior, with maximal values in summer and minimal values in winter.

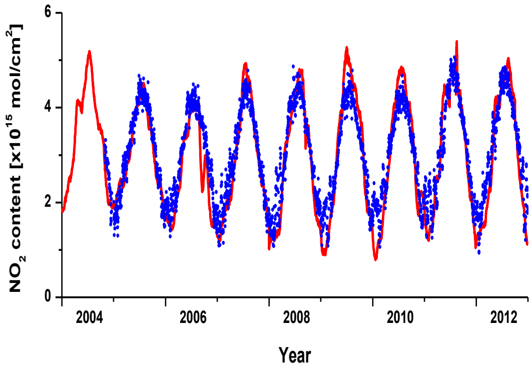

Figure 3. The NO_2 content in the vertical column of the stratosphere (10 – 50 km) over Tomsk according to measurements with the help of satellite (OMI instrument) and ground-based measurements, interpolated to the time of observation from satellite

Figure **4** presents the difference between ground-based measurements and satellite observations (grey circles). The standard deviation of the values is $0.53x10^{15}$ mol/cm^2. The average difference is positive and is equal to (0.19 ±0.01) mol/cm^2. The values of NO_2 content in the stratosphere according to data of ground-based observations are somewhat higher than satellite measurements; however, the average difference is low and is within the error of ground-based and satellite measurements. The sliding average over 30 days (thick line) demonstrates a pronounced seasonal behavior. The correlation coefficient for this observation period is 0.91.

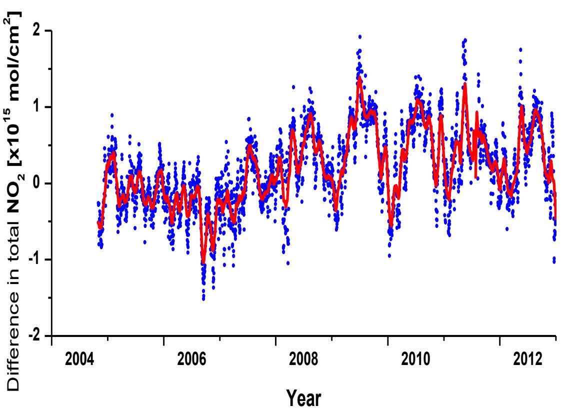

Figure 4. Difference in the diurnal values of NO_2 content in the stratosphere between ground-based and satellite measurements, performed over Tomsk.

3. TEMPERATURE MEASUREMENTS.

At heights larger than 30 km, where aerosol is practically absent (under the background conditions), the intensity of Rayleigh lidar signal (at the wavelength of the sensing radiation 532 nm) is determined by purely molecular scattering, thus making it possible to retrieve the molecular density and temperature of the middle atmosphere from these signals, because the density depends linearly on the temperature, and because Raman scattering (RS) signals from molecular nitrogen (at the wavelength of 607 nm) also have no direct contribution from aerosol scattering, i.e., the number of recorded scattered photons is directly proportional to the molecular density of the atmosphere, making it possible to retrieve the profiles of the vertical distribution of temperature.

We compared the results of lidar measurements of temperature with the simultaneous balloon-sonde measurements in Tomsk and with measurements of altitudinal temperature profiles by Infrared Atmospheric Sounding Interferometer (IASI) on MetOP satellite, ESA. The measurements and processing of IASI data can be used to obtain the profiles of temperature, humidity, and content of certain atmospheric gases.

The temperature profiles are retrieved on the basis of standard EUMETSAT and NASA methods [5]. The data on the simultaneous lidar, balloon-sonde, and satellite measurements of temperature are presented in **Fig. 5.**

From the figure, we can see that the profiles of the vertical distribution of temperature in the lower stratosphere from data of lidar measurements according to Raman scattering signals from molecular nitrogen at the wavelength of 607 nm and balloon-sonde data nearly coincide. It is noteworthy that a well-defined tropopause is observed at height of about 11 km. The satellite measurements of temperature fix the tropopause not as sharply and exceed the balloon-sonde observations. The reasons for this are both due to differences in the spatial resolutions of satellite, lidar, and balloon-sonde measurements, and because these measurements have different uncertainties.

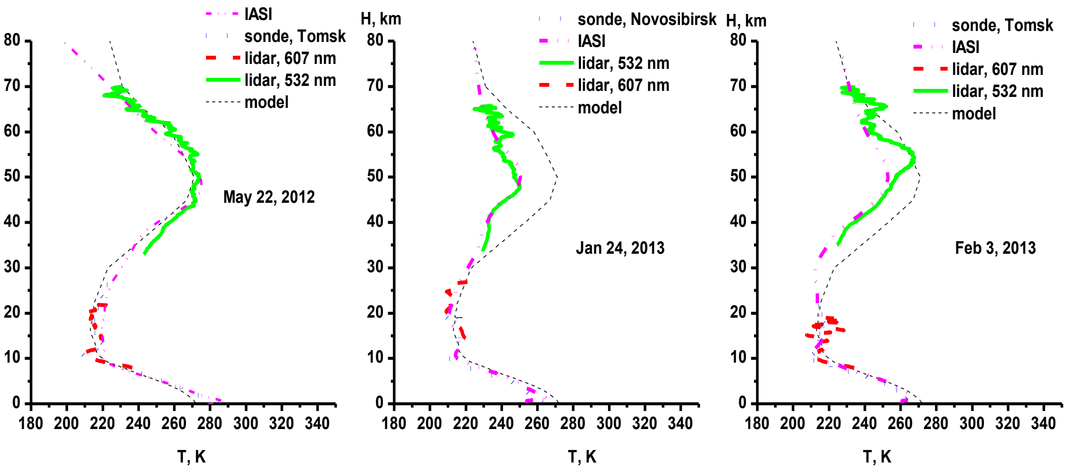

Figure 5. Examples of simultaneous lidar, balloon-sonde, and satellite measurements of temperature

4. CONCLUSIONS

When TO data are compared, M-124 ozonometer measurements best agree with data on the basis of OMDO algorithm. As a rule, the M-124 measurements exceed the satellite data.

Comparison of ground-based measurements of NO_2 at SLS with satellite (OMI instrumentation) observations showed that the wintertime (summertime) values of NO_2 content according to satellite observations are larger (smaller) than those obtained from the ground-based observations. However, the statistically average discrepancy for the stratosphere is small and is within the measurement errors.

In the upper stratosphere – mesosphere, the profiles of temperature, obtained from data of satellite and lidar measurements, do not totally coincide. The discrepancy reaches 7-8 K, probably due to the uncertainties of both instruments and spatiotemporal separation of measurements. For instance, the lidar and balloon-sonde measurements of temperature on January 24, 2012 in Tomsk (56.5°N; 85.0°E) were performed from 12:20 to 13:00 GMT (balloon-sonde was released at the location of lidar), and satellite measurements were performed at 13:53 GMT at the point with coordinates 56.447°N; 84.608°E.

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