On satellite measurements of the total ozone in the IR region

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Advantages and disadvantages of satellite measurements of the total ozone at the wavelength of 9.59 μm are considered. Investigations of the total ozone using ultra-violet ground-based / satellite and infrared satellite data of 1998 for Siberia are compared. The ultra-violet ground-based / satellite data are practically identical but the infrared data have the +20 D.u. bias and the correlation coefficient of 0.72. Assuming water vapor to be a possible reason of this discrepancy, we corrected the infrared satellite data using the NOAA HIRS information.

The study of the Earth's ozone layer is among the priority ecological problems. The main methods used for measurement of the total ozone content (TOC) are optical ones that are based on estimation of absorption of electromagnetic radiation by the atmosphere at certain wavelengths in the region of electronic transitions of the ozone molecule. From the ground, the total ozone content is determined by measuring extinction of the UV solar radiation in narrow spectral intervals at two wavelengths with the different ozone extinction coefficient, for example, at $\lambda = 300$ and 348 nm. Satellite ozonometers operating in the UV region measure the solar radiation backscattered by ozone molecules. The TOMS spectrophotometer (USA) uses two pairs of wavelengths: 0.3125 and 0.3312 μm, 0.3175 and 0.3398 μm for this purpose.[1]

The TOMS data on TOC are published in the Internet[2] the next day after measurement; every file contains the global information on TOC with the resolution of 100$120 km. A month later, the corrected data are published.[3] The data are corrected in the following aspects:

$ albedo of the surface and the atmosphere is taken into account;

$ absorption by atmospheric aerosol is taken into account;

$ wavelength is calibrated;

$ the mutual position of the satellite, Sun, and ground site is taken into account.

Figure 1 shows the daily TOMS data on TOC for 12 months of 1998 for Krasnoyarsk: the data smoothed by a polynomial approximation with a third-power polynomial (curve *1*) and the data smoothed and corrected (*2*), as well as the ground-based data (*3*) obtained with an M-124 ozonometer in Krasnoyarsk. The TOC values in Dobson units (D.u.) are plotted as ordinate. The daily satellite data are biased by 9 D.u. with respect to the ground-based data for 1998, the correlation coefficient is 0.57, and the corrected daily data are biased by 8 D.u. with respect to the ground-based ones with the correlation coefficient of 0.92. Similar results were obtained in comparing the ground-based data with the TOMS data dated to 1998 for Tomsk: the satellite data were biased with respect to the ground-based ones by 11 D.u. with the correlation coefficient of 0.53, while the corrected data were biased by $0.8 D.u. with the correlation coefficient of 0.95. The ground-based and satellite measurement methods in the UV region are thought rather stable and accurate. However, TOC can also be measured in the IR and radio wave regions.[4]

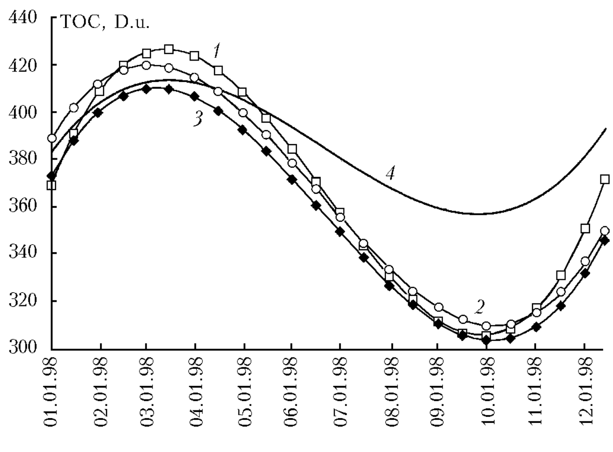

Fig. 1. Smoothed daily TOC values for Krasnoyarsk.

NOAA satellites (USA) are equipped with the TIROS Operational Vertical Sounder (TOVS) intended for vertical sensing of the atmosphere. The data obtained with the HIRS being a part of the TOVS and operating in the IR region allows reconstruction of the vertical profiles of air temperature and humidity in the troposphere and the lower stratosphere and estimation of TOC and some other atmospheric parameters.

The Krasnoyarsk HRPT station for reception of the NOAA information has the TOVS software package for radiometric calibration, geographic reference, and calculation of the vertical profiles of the atmosphere and TOC through solution of the inverse problem. The output data are an inhomogeneous grid of points, whose number is from 400 to 600 for one satellite passage, and the spatial resolution is equal to 20$80 km.

To determine TOC, the TOVS software uses inversion of the radiative transfer equation with the reconstructed temperature profiles of the atmosphere and the data on the surface temperature. Actually, the expected intensity of radiation of the surface and atmosphere in the ozone absorption band (λ = 9.59 μm) is calculated with the Planck's equation, and the difference between the calculated and measured intensity gives the estimate of TOC. The wavelength λ = 9.59 μm 30 times exceeds the wavelengths used in the UV region. Therefore, in the IR region the scattering of electromagnetic waves by air molecules and aerosols, as well as other interfering factors, produces smaller effect. Besides, round-the-clock operation in the IR region is possible, while the measurements in the UV region are realizable only on the illuminated part of the Earth. Reception of the TOC information on regional HRPT stations from NOAA satellites is possible six to eight times a day (with two satellites); in Krasnoyarsk, TOC can be estimated over the territory from 80 to 120°E and from 40 to 80°N. At the secondary processing, we used the technique described in Ref. 5.

In Ref. 5 it was noted that the TOC data obtained in the IR region exceed the results of ground-based measurements, and the same conclusion was drawn in Ref. 6. Figure 1 (curve *4*) shows the smoothed daily TOVS data on TOC for 1998 in Krasnoyarsk. The bias of the curve *4* with respect to the curve *3* on the average for the year is 20 D.u., and the correlation coefficient of daily values is 0.72. The TOC values are markedly higher as compared with the ground-based data, especially in the summer-fall period. In addition to Krasnoyarsk, the TOC behavior in 1998 was studied at other sites in Siberia: Irkutsk, Tomsk, Tura, Igarka, and Dickson. For Tomsk the TOC data obtained in the IR region were compared with the ground-based data, and the bias was 20 D.u. with the correlation coefficient of 0.72. For Irkutsk, Tura, Igarka, and Dickson, the IR data were compared with the corrected TOMS data. In all these cases, the IR data exceeded the UV data, and the bias and the correlation coefficient had the values similar to those for Tomsk and Krasnoyarsk.

In Ref. 5 it was assumed that the discrepancy between the UV and IR data is caused by the effect of atmospheric water vapor, the edge of whose absorption band falls just at λ = 9.59 μm. Fortunately, the HIRS device allows determination of the column water vapor just at the same points as TOC. This, in principle, allows correction of the HIRS data. Two ways are possible: the use of the transfer equation with the data on water content substituted in it and correction based on regression equations. In this paper, we exemplify the use of the latter approach.

To find the correction coefficient, let us use the equation

$$y = ap + b,$$

where y is the difference between the HIRS data and the data of the ground-based ozonometric station; *!* is the water vapor column density (in mm). The coefficients a and b in the equation were found from the learning sample based on the data for July 1998 in Krasnoyarsk (at almost cloudless atmosphere): = = = $1.3687 D.u. / mm, b = 81 D.u.

Figure 2 shows the daily ground-based TOC data for Krasnoyarsk (curve *1*) in August 1998, the initial HIRS data (curve *2*), and the results of correction of the HIRS data (curve *3*). The data were obtained at roughly the same time $ near the local noon, largely for the cloudless atmosphere. Before correction the bias was 49 D.u. (16.1%) with the correlation coefficient of 0.64, and after correction the bias was $ 4 D.u. ($1.3%) with the correlation coefficient of 0.51. The corrected HIRS data were biased from the corrected TOMS data by $11 D.u. with the correlation coefficient of 0.31. Note that there is close agreement between the corrected TOMS data and the ground-based data: the bias of 7 D.u. and the correlation coefficient of 0.91.

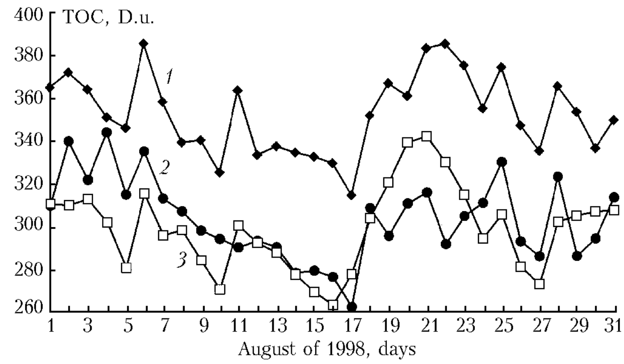

Fig. 2. Correction of TOC measurements in the IR region.

Thus, the allowance for the moisture content in the atmosphere markedly decreases the bias between the TOC data obtained with the HIRS in the IR region and the ground-based data, as well as the satellite data obtained in the UV region. It is interesting to understand the causes of this discrepancy between the IR and UV data, in particular, the low correlation between the TOC values. Analysis of satellite images obtained in the visible region showed that on August 10, unlike other days of the month, overcast conditions were observed in Krasnoyarsk and the days of August 5 and

19$22 were characterized by weak cloudiness. Possibly, just on these days the HIRS data on the humidity had a significant error (the accuracy of vertical sensing of the lower atmosphere with the use of HIRS was analyzed in Ref. 7).

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