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Measurement Of Stratospheric Ozone Layer Thickness Using 0.65 Nm Resolution Micro Spectrometer

Results of ozone layer thickness measurements are presented. Instead of expensive Dobson or Brewer spectrometers an UV microspectrometer was used. Obtained results are compared to the results from satellite measurements. This comparison showed agreement inside 10 % in average.

1. Introduction

Since 1925. when Dobson constructed the first spectrometer for measurements of stratospheric ozone layer thickness [1] several types of instruments have been developed. Some of them are based on Sun spectrum measurement, like Brewer spectrometer which is equipped with diffraction grating or prism, while other are based on optical filters. In the last time some hand held instruments which can be used for these purposes appeared [2]. On the other hand monitoring of ozone layer thickness is regularly performed by the satellites, like TOMS [3].

All of these instruments are less or more expensive, especially spectral ones. One of the possibilities is to use classical laboratory UV spectrometers, but this solution is also expensive and is not mobile at all.

In this paper we present results of stratospheric ozone thickness measurement using small UV spectrometer with 0.65 nm spectral resolution specified by producer. The measurements are based on the absorption at one pair of wavelengths, e.g. at 305.5 nm and 325.4 nm. This procedure is well known and is described in several references (Refs. 2 and 4 for example). Results obtained in this work are compared with the results obtained from the TOMS measurements.

2. Theoretical base

The theory of absorption of UV part of Sun spectrum is based on Lambert-Beer law which can be expressed in the form [4]:

$$F_{dir}(z) = \mu_0 F_\infty \exp(-\tau(z)/\mu_0) \quad (1)$$

where $F_{dir}(z)$ is flux density at the horizontal surface at latitude *z*, μ_0 is cosine of solar angle, F_∞ is extrareresstrial flux and $\tau(z)$ is optical depth of atmosphere along *z*-axes. All processes of absorption and scattering at different particles influence the value of τ. Following this model the spectral intensity at wavelength λ can be expressed as:

$$I_\lambda = I_{0\lambda} \exp(-\alpha_\lambda \mu \Omega - \beta_\lambda m \frac{p}{p_0} - \delta_\lambda \sec Z) \quad (2)$$

where I_λ is direct perpendicular radiation spectrum at the ground surface, $I_{0\lambda}$ is radiation spectrum at the upper atmosphere, α_λ is ozone absorption coefficient at wavelength, μ is ratio between actual and perpendicular path, Ω is ozone layer thickness expressed in Dobson Units (DU), β_λ is Rayligh scattering coefficient at wavelength, *m* is "airmass", *p* is station pressure, p_0 is pressure at sea level, δ_λ is scattering coefficient of aerosol particles at wavelength and *Z* is solar zenith angle (SZA).

When method for ozone layer thickness determination based on one pair of wavelengths is applied, the expression for ozone layer thickness in Dobson units [DU] is [4]:

$$\Omega(\mathrm{DU}) = \frac{1000[L_{12} - \ln((I_1/I_2) - \beta_{12} m(p/p_0) - \delta_{12} \sec Z)]}{\alpha_{12}\mu} \quad (3)$$

where:

$\alpha_{12} = (\alpha_1 - \alpha_2)$, $\beta_{12} = (\beta_1 - \beta_2)$, $\delta_{12} = (\delta_1 - \delta_2)$,

$L_{12} = (L_1 - L_2) = \ln(I_{01}/I_{02})$ - extraterrestrial constant.

Values for α and β can be calculated as:

$$\alpha(\lambda) = 2.1349 \cdot 10^{19} \exp(-0.14052\lambda) \quad (4)$$

$$\beta(\lambda) = (16.407 - 0.085284\lambda + 0.00011522\lambda^2) \quad (5)$$

where λ is in nm. From expression (3) the ozone layer thickness can be deduced using one pair of wavelength from recorded sun spectrum. In this case λ_1=305.5 nm and λ_2=325.4 nm.

3. Experimental set up and measurements

Experimental set-up consists of optical fiber equipped with the collimator, UV spectrometer, lap-top or desk-top computer and tripod holder. The block scheme of the experiment is presented in Figure 1. The collimator is mounted at entrance end of optical fiber. The geometry of collimator provides $1.5 \cdot 10^{-3}$ srad solid angle of view. During the Sun spectrum recordings the collimator was directed to the Sun. The other end of the optical fiber is mounted at the 10 μm wide entrance slit of the spectrometer. The spectrometer used in this work is Ocean Optics HR2000 model equipped with 1200 g/mm grating and with the spectral range 200-400 nm. After diffraction on the grating the spectrally resolved light is focused on the CCD detector with 12-bit A/D converter. The spectra are recorded by computer through USB port and using producer's interface for controlling the spectrometer and data acquisition. Integration time was chosen in this way that part of the spectrum up to 350 nm covers 12-bit levels in order to record the spectrum with the resolution as high as possible.

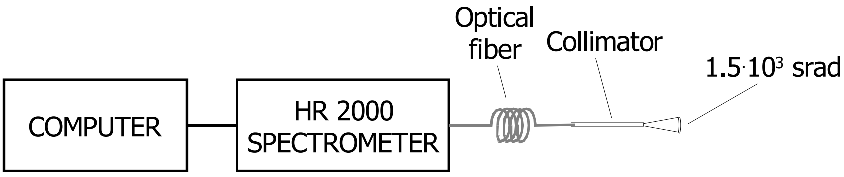

Figure 1. Block scheme of the measurement set up.

Measurements of the Sun spectrum were done at different dates during the spring 2005. at the city of Novi Sad and Kopaonik mountain, Serbia and Montenegro. The geographical data for Novi Sad are: latitude 45.3° longitude 19.8° and altitude 82 m. This is the city with the average pollution. One measurement was done at Kopanik meteorological station with the following geographical data: latitude 43.2°, longitude 20.5°, and altitude of 1711 m. This location was chosen because of height and the fact that around this site in the circle of about 60 km no pollution centers exists. Under these conditions we supposed clear atmosphere above the measuring site. In this way the comparison between the results obtained from the site with the medium polluted atmosphere with the ones obtained from clean atmosphere was enabled. The example of recorded spectra are presented in Figure 2 a and b. In Figure 2 a the whole spectrum between 200 and 400 nm is presented while in Figure 2 b, the part of the spectrum is presented. This is example of the part-spectrum which is used for ozone layer thickness determination.ext of the section.

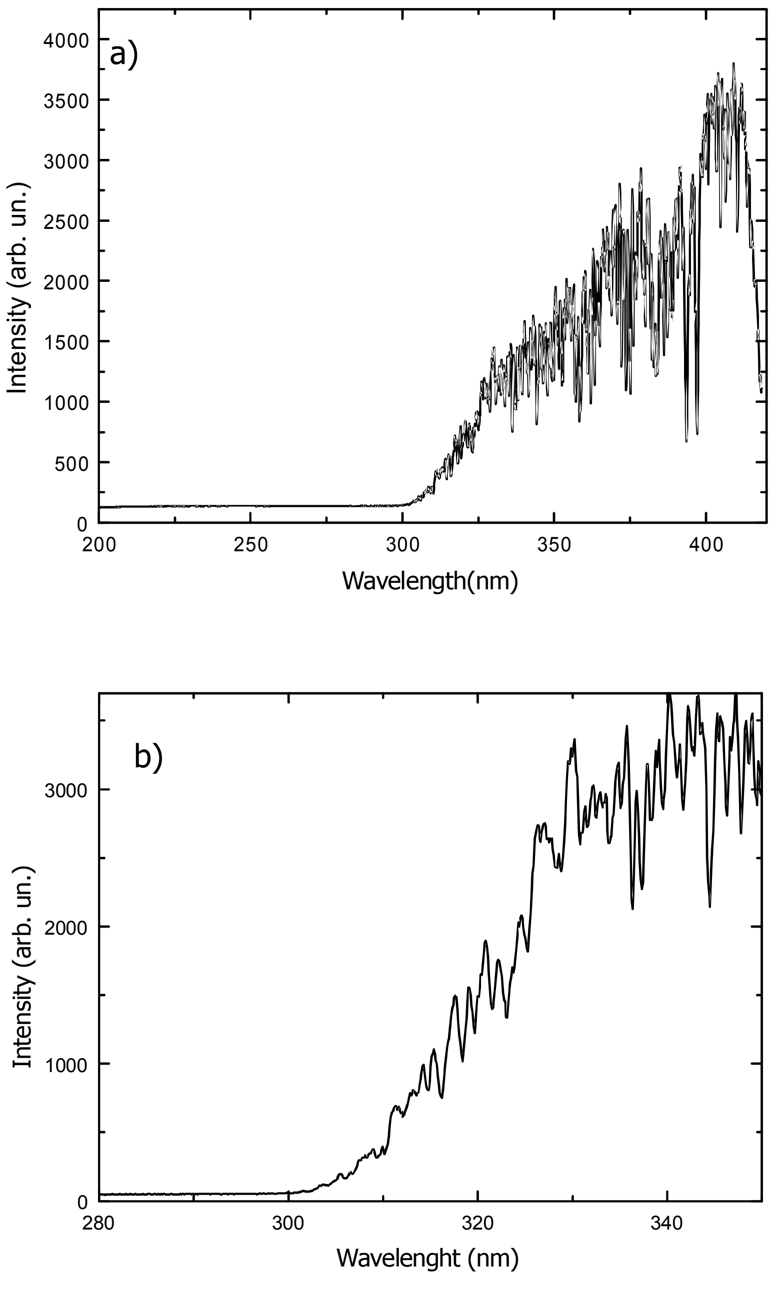

Figure 2. Recorded Sun's spectra.

4. Results and discussion

Results of ozone layer thickness are obtained from at least three spectra respectively recorded under the same conditions (inside time interval of 10 minutes). These spectra are used for the ozone layer thickness in conjuction with Eq. (3). The wavelength bandwidth of 1 nm around the central wavelengts (305.5 nm and 325.4 nm) was used as input data for I_1 and I_2. The other input data were calculated in accordance with Eqs. (4) and (5). Meteorological data were taken from the local meteorological stations at the times of measurements. The withdraw of this measurements is the lack of the data for the aerosols since these measurements are not performed at the location of measurements. So, some average values for these locations were supposed.

Results of ozone layer thickness measurements are summarized in Table 1.

Table 1.

Date and time	Ozone layer thickness (spectrometer)	Ozone layer thickness (TOMS)	Relative deviation
01.03.2005. 10:00	224 DU ± 1 DU	259 DU	13.5 %
21.03.2005. 10:00	254 DU ± 2 DU	279 DU	8.9 %
13.04.2005. 14:00	381 DU ± 15 DU	378 DU	0.8 %
04.05.2005. 13:00	357 DU ± 1 DU	339 DU	5.3 %
09.05.2005. 12:00	366 DU ± 6 DU	365 DU	0.3 %
10.05.2005. 10:00	338 DU ± 4 DU	370 DU	8.6 %
10.05.2005. 12:00	369 DU ± 1 DU	370 DU	0.3 %

This table contains the date of measurement, the time, results of ozone layer thickness obtained in this work, results from TOMS and deviation of these measurements from TOMS results expressed in percents. Disagreement between these two methods is between less than 1 % and 14 %. The lowest deviation is for the date April 13, 2005. This measurement was done at Kopaonik. One can expects this since the atmosphere above the site at Kopaonik is almost clean. Namely, the main source of error in the measurements was lack of the data about the aerosols present above the cities like Novi Sad. Nevertheless, these measurements agree with the TOMS results inside 10 % in most cases. Just for example, seven measurements of Sun’s spectrum at May 10, 2005, performed inside 20 minutes time interval, resulted in ozone layer thickness of 366 DU with the standard deviation of 6 DU. This standard deviation is deeply inside the estimated error of measurements in range 7-12 %.

5. Conclusion

Results of these measuremnts show that ozone layer thickness measuremnts can be done using simple experimental set up as one described in the paper. Attained precission is quite acceptable what is confirmed by comparison with the satellite measurements.

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