Development of ozone monitoring instruments in Belarus

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Abstract

Several instruments for ozone layer investigation were engineered or modified in Belarus at NOMREC (National Ozone Monitoring Research &Education Centre) created in 1997. The spectrometer-ozonometer "PION" was successfully tested with a set of net instruments and started operating regular total ozone measurements in 1997. Some special features are a narrow field of view of the spectrometer (about 40 angular minutes), multiwavelength method of total ozone calculation (up to 20 wavelengths in 295-317 nm region) and high speed of measurements (up to 1000 measurements per day). The instrument can operate in the mode of classical spectroradiometer with 0.35 nm spectral resolution and about 10 seconds per one scan. An automatic tracking system traces the Sun with an error not exceeding 2 angular minutes. All mentioned above and low level of internal scattered radiation permit making total ozone measurements at Sun zenith angles up to 80 degrees.

The new UV-spectroradiometer complying with the WMO recommendations to UV-monitoring at GAW stations was engineered at NOMREC in 2000. The fully automated UV-spectroradiometer PION-UV has a spectral assembly, optimized to all kinds of UV radiation measurements: a portable double holographic grating monochromator in range of 280-450 nm with the spectral resolution of about 0.8 nm and stray light reduction >$1*10^6$, a teflon cosine-corrected irradiance collector, an entrance radiant flux attenuator and shadowband total-diffuse horizontal irradiance selector. Potentially PION-UV can measure total ozone as well as estimate a cloud cover.

Both these instruments have been used at Minsk ozone station to measure the total ozone value and global downward irradiance.

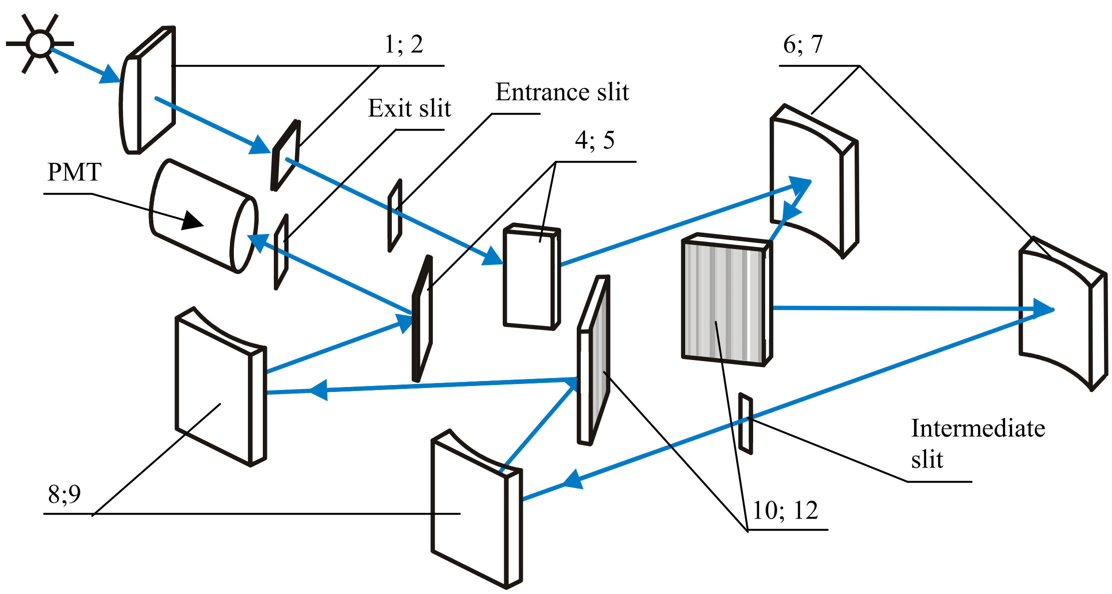
Introduction

The global ozone layer depletion causes increasing the UV-B component in solar surface irradiance. Besides increasing solar UV radiation at the Earth's surface, Belarus has an additional problem - a boosted radiation background as a result of the Chernobyl catastrophe. These two factors have a negative impact on human health. As a consequence total ozone amount and UV radiation monitoring have been organized in Belarus to estimate the aftermath of its change. The monitoring aims at providing information about UV levels, the UV index, UV climatology and total ozone trends using an equipment of high spectral resolution and sensitivity.

Automatized ultraviolet solar spectrophotometer-ozonometer "PION"

Being made in 1985, the spectrometer-ozonometer "PION" was constructed using and developing ideas set forth in the article R.D. Saunders et al., 1984[1]. As noted in this paper, the high-precision ozone measurements may be achieved using the short wavelength between 290 and 305 nm, but there will be some additional problems meaning the shorter the wavelength, the smaller the solar spectral flux and signal-to-noise ratio, the greater spectral scattering in monochromator is. To solve these problems a compact double grating monochromator was engineered featuring the construction specially designed for reducing the level of internal scattering radiation. To conduct measurements of total ozone amount at the great Sun zenith angles the instrument is equipped with a special input objective with very narrow field of vision (about 40 angular minutes). One of the factors providing long-term stability of monochromator characteristics is practically full absence of the moving details, thus realization of spectral distribution is accomplished by scanning the intermediate slit. For reducing a dynamic range of input signals the spectral range is chosen within 295-320 nm. The multi-wave procedure of calculation of total ozone amount values allows to use an optimal set of wave lengths depending on current conditions of observation [2]. An optical scheme of the instrument is given in Figure 1. The monochromator consists of two consistently functioning shoulders (with a focal distance of 180 mm), has two turning mirrors (4; 5), four reflecting objectives (6; 7 and 8; 9 - in each shoulder), two diffraction grating (10; 12) with the size of 35*35*8 mm; 1200 /mm; the working order - I, and three slits, one of which – the intermediate - serves as an exit slit for the first and an entrance slit for the second shoulder of the monochromator.

Spectrometer-ozonometer "PION" has precise automatic tracking system traces the Sun with an error not exceeding 2 angular minutes, multi-wavelength method of total ozone calculation (up to 20 wavelengths in 295-317 nm region) and high speed of measurements (up to 1000 measurements per day). The instrument can operate in the mode of classical spectroradiometer with 0.35 nm spectral resolution and about 10 seconds per one scan. A double monochromator and reduced field of view of the spectrometer provide the possibility of total ozone observations at low sun inclination angles (~8^0). Processes of measurement and data storage are fully automated under the control of an external computer. The instrument has portable construction (see Fig. 2). "PION" was successfully tested during the comparisons to the regional WMO standard (Dobson spectrophotometer №108, Atmosphere Remote Sensing Research Center, Voeikovo, Russia) in July-August 1996 according to WMO recommendation. In the following years the device was passed through the series of intercomparisons. Since 1997 total ozone observations have been carried out every sunny day. In 1998 the ozone station of the Center received an identification number of №354. The data are being submitted to the WMO Data Center (Canada). A new modification of the instrument is being created to measure ozone concentration by means of zenith sky observation.



Extended Langley calibration of total ozone sun spectrophotometer

Determination of extraterrstrial constants to calculate total ozone on the base of measured direct sun UV intensities is one of the most important tasks to provide adequacy of measurements. Recently one of us has reported [3] an extended version of Langley calibration method applicable to use at sites with unstable ozonosphere. Since 1997 a new spectrometer-ozonometer PION is operating at Minsk ozonometric station. For the first time the instrument was calibrated with the regional WMO standard Dobson N 108 spectrophotometer at S.Petersburg in 1996. Next comparison in 2001 showed that instrument's calibration had been preserved. We were quite sure in such result, as the parameter stability of the device in a gap between calibrations was checked using the proposed method.

A similar approach for the first time was applied by Dobson [4] and was grounded on a hypothesis that random diurnal variations of total ozone do not contain a systematic component and vanish if averaged on a sufficient number of days. The procedure, utilised by us, is founded on less strong restrictions, namely, guesses that predominantly a linear diurnal trend of ozone is watched in middle latitudes.

Figure 2. The PION-ozonometer

PION instrument provides in the automatic mode more than 1.000 direct sun single measurements of total ozone content per clear day. A narrow field of view of the spectrometer permits observations at sun zenith angles up to 80 degrees without any visible μ-dependence of results.

We investigated diurnal records of total ozone measurements for clear days from 1997 till 2001 and have concluded that *constant total ozone values throughout a day is a rare phenomenon for the region of Minsk station location*. *Approximately linear diurnal trends occur in most cases, and parabolic ones (when total ozone goes through a minimum or a maximum) have been observed only for a few days of the period.* Examples of usual and rare diurnal total ozone records are given in figs. 3-6.

To see the influence of changing cloudiness on total ozone values, which are calculated from direct sun measurements, signals from the sun tracking system of PION instrument are plotted together with total ozone data. The sun tracking system registries sunlight in spectral region 700-1000 nm where ozone doesn't absorb radiation. Thus, its using is conveniently adapted to detect clouds and to monitor overall atmosphere stability with ozone contribution excluded. Registered data show that fluctuations of the atmosphere transparency in this region don't affect total ozone value in most cases.

Langley plot method can not directly be applied when total ozone changes. In spite of this we have worked out a procedure to monitor the preservation of calibration and to correct it when necessary, using a hypothesis of predominantly linear diurnal trend of total ozone. The method is statistical by nature and frequent total ozone measurements are desirable for its use.

Standard formula for total ozone calculation [5] (valid for Dobson, Brewer or PION instruments as well) is

$$X = (F_0 - F - m\Delta\beta)/(\mu\Delta\alpha), \quad (1)$$

where F is a linear combination of logarithms of measured intensities at a number of fixed wavelengths λ_i; $\Delta\beta$ is the same linear combination of Rayleigh scattering coefficients $\beta(\lambda)$; $\Delta\alpha$ is the same combination of the ozone absorption coefficients $\alpha(\lambda)$; F_0 is the instrumental extraterrestrial constant; μ, m are ozone and air relative masses respectively; X is the total column amount of ozone in the atmosphere.

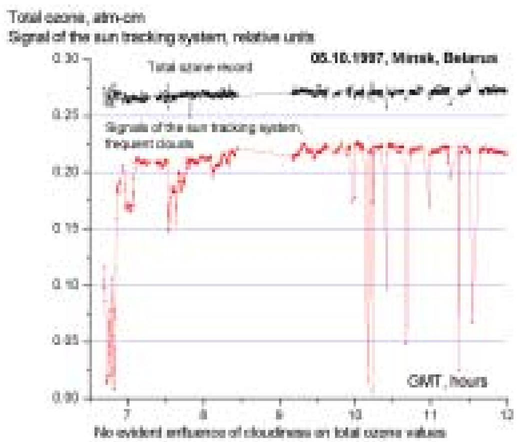


Figure 3. An example of total ozone daily record made by PION spectrometer-ozonometer. Total ozone is slightly rising. Very frequent phenomenon.

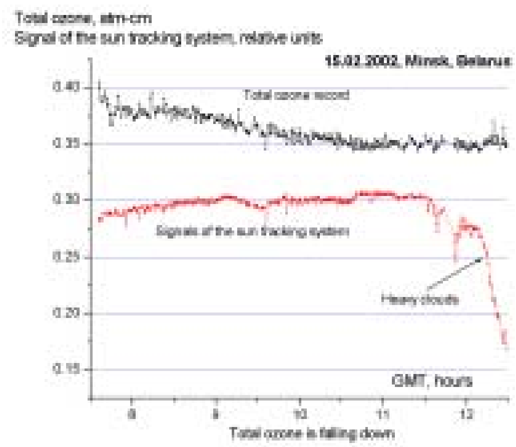


Figure 4. An example of total ozone daily record made by PION spectrometer-ozonometer. Total ozone is falling down. Frequent phenomenon.

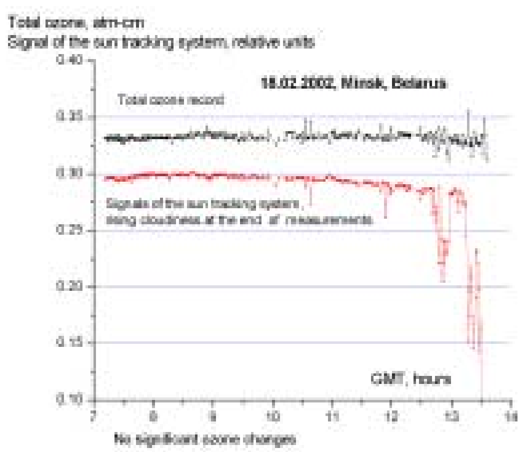


Figure 5. An example of total ozone daily record made by PION spectrometer-ozonometer. Total ozone does not change. Very rare phenomenon.

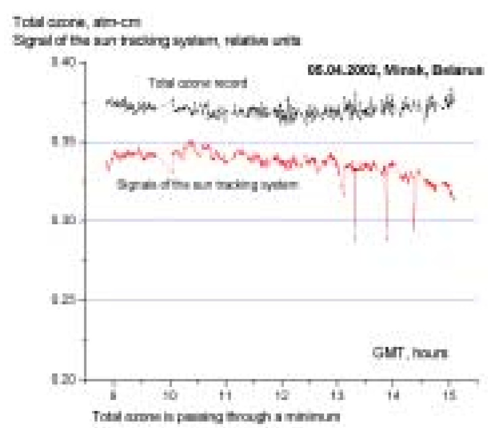


Figure 6. An example of total ozone daily record made by PION spectrometer-ozonometer. Total ozone passes through a minimum. Very rare phenomenon.

We will suppose further, that conditions of observations are restricted to the case, when relation (1) works well. This means that no corrections due to scattered light for large zenith angles are needed; no significant deviations from the Bouguer-Lambert-Beer law are expected; etc. We shall suppose also that wavelength setting is adjusted precisely and doesn't drift. Assume, that the measured value of total ozone is

$$X_i = X_0 + \gamma(t_i - t_n) + \varepsilon/\mu + \delta X_i, \quad (2)$$

where $t_i - t_n$ is the difference between time of observation and time of local noon, γ is the slope of the linear diurnal trend, $\varepsilon = \delta F_0/\Delta\alpha$, δF_0 is an unrevealed error in the value of the extraterrestrial constant, and δX_i ($\overline{\delta X} = 0$) is a random error of measurements (the designates averaging over sufficiently large number of measurements). Then, if measurements are taken rather frequently, and the period of observations is almost symmetrical relative to local noon, it can be shown (see details in [3]), that the diurnal averaged square deviation of measured total ozone from its daily mean value $\overline{X}$

$$\sigma^2 = \sum(X_i - \overline{X})^2 = \varepsilon^2\sigma_\mu^2 + \gamma^2\sigma_t^2 + \sigma_r^2 > 0 \quad (3)$$

achieves a minimum for the correct value of the F_0 constant ($\varepsilon = 0$). Following designations are used in eq. (3):

$$\sigma_\mu^2 = \overline{(1/\mu)^2} - \overline{(1/\mu)}^2, \; \sigma_r^2 = \overline{(\delta X)^2}, \; \sigma_t^2 = \overline{(t - t_n)^2}.$$

Thus, minimization of the dispersion of calculated total ozone leads to the correct value of the extraterrestrial constant.

Direct estimating of δF_0 (or ε) from eq. (3) is impossible due to unknown characteristics of total ozone trend and σ_r^2. Further manipulations [3] lead to

$$\varepsilon = \left[\overline{(X/\mu)} - \overline{X}\,\overline{(1/\mu)}\right]/\sigma_\mu^2. \quad (4)$$

Having in mind, that the value of ε defines an error in X caused by $\delta F_0 \neq 0$, and restricting the allowed error to a definite value, say, 1.5 D.U. ($\Delta X/X \approx 0.5\%$), one can get a convenient criterion of the current consistency of the instrument's calibration.

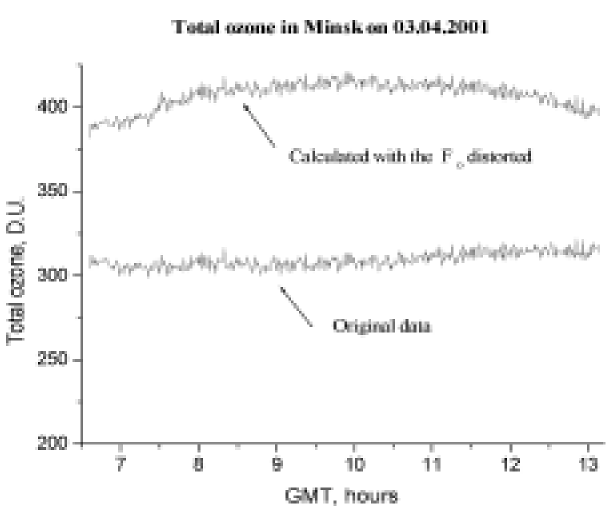


Figure 7. A computer simulated example of correcting of the extraterrestrial constant.

Obviously, there is a reason to average the latter estimation over a sufficient number of days of observations in order to avoid significant contributions of rare days, which have symmetric ozone trend and lead to the procedure failure.

Summarizing, the proposed method includes monitoring of ε, averaged on a number of days with rather good observational conditions. When the calculated value systematically drops out of the stated limits, correcting of the F_0 constant should be made.

A computer-generated example of using the method is given in fig. 7. The lower curve is a real daily total ozone record of the PION instrument in Minsk 03.04.2001.

The higher curve represents values of total ozone, which were calculated with the intentionally distorted F_0 constant.

Calculating of ε with eq. (4) and introducing the resultant correction of δF_0 almost exactly corrects the distortion and puts total ozone curve closely to the initial one.

The fully automated UV-spectroradiometer PION-UV

In accordance to WMO recommendations on UV-monitoring at GAW stations [6], the new UV-spectroradiometer has been engineered at National ozone monitoring research and educational center (NOMREC). The automated UV-spectroradiometer PION-UV has a spectral assembly, optimised for a variety of UV radiation measurements: a portable double holographic grating monochromator (see. Fig. 8) with stray light reduction $>1*10^6$, a teflon cosine-corrected irradiance collector (2), an entrance radiant flux attenuator (3) and shadowband global-diffuse horizontal irradiance selector (1). It has fully automated processes for measurement and data storage under the control of an external computer and has the potential to address a variety of other ultraviolet atmospheric optics problems with some reprogramming. There is a completely hermetic and temperature-stabilised box designed for all-weather operation. The monthly verification of instrument parameters and calibration at the meteorological testing setup is carried out in accordance to WMO guidelines [7].

The basic spectral characteristics of the PION-UV device and its long-term stability are defined to a large extent by the chosen optical scheme and the way in which the monochromator is being technically designed. The monochromator, which consists of two consistently functioning shoulders (with a focal distance of 180 mm) located one on top of the other, has four reflecting objectives (5; 6 and 7;8 - in each shoulder), a double dispersive system, a holographic diffraction grating (4), with the size of 35*70*8 mm; 2400 /mm; the working order - I, used independently in both shoulders of a monochromator, and three slits, one of which – the intermediate - serves as an exit slit for the first and an entrance slit for the second shoulder of the monochromator. The characteristics of the monochromator are determined by the configuration of optical elements, which are in turn the result of a compromise between energy and, spectral parameters of the device, and a choice of optimum kinematic parameters. Both shoulders of the monochromator are constructed under the horizontal asymmetrical Ebert scheme and are divided by a shield to reduce the amount of diffuse light.

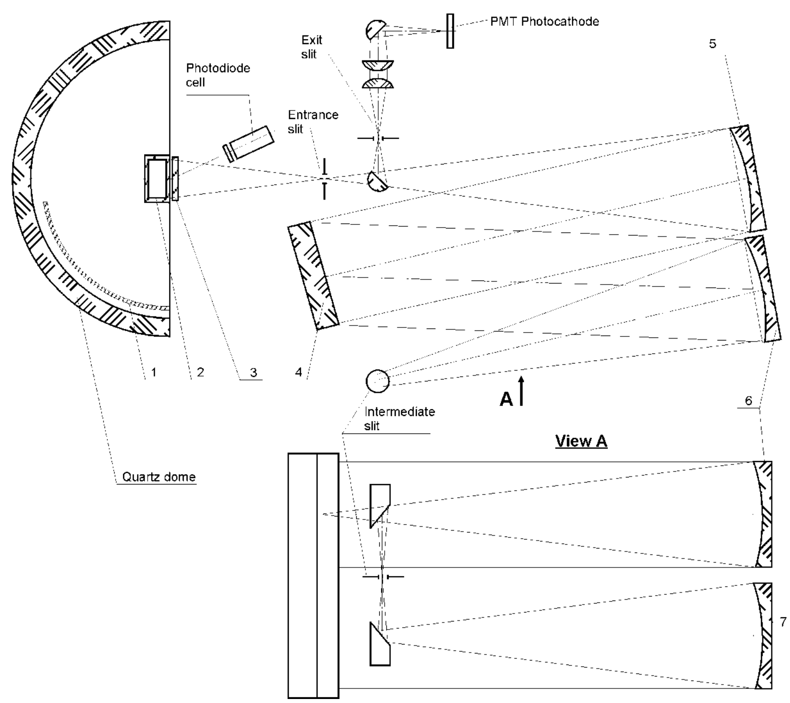


Fig.8. PION-UV optical scheme

There are different integration times for solar irradiance measurements in four spectral ranges: 1.0 s – (285-295 nm); 0.6 s - (295-305 nm); 0.2 s – (305-320 nm); 0.02 s – (320-450 nm) and 2.0 s at mean PMT "dark" current measured every scan in the range 282-285 nm.

To minimize a non-linearity uncertainty in entrance irradiance in the 10^6 dynamic range, three attenuator transmission values (τ_1=100 %, τ_2=10 % and τ_3=1 %) are used. The linear range is extended and the signal-to-noise ratio is improved as a result of changes made to the PMT high voltage. Global and diffuse irradiance measurements can be made every 10 minutes. The measurements (sunlight spectra) will be recorded in an external computer in the form of textual data files.

PION-UV GENERAL SPECIFICATIONS

- spectral range	285-450 nm;	- wavelength precision	0.01 nm
- spectral resolution	0.8 nm;	- wavelength accuracy	0.1 nm
- detection threshold	$<1*10^{-5}$ W $m^{-2}nm^{-1}$	- scan time	< 5 min
- saturation threshold	>3 W $m^{-2}nm^{-1}$	-calibration accuracy below 300 nm	< 10%

- stray light reduction degree (at λ=441 nm) $<1*10^6$

The external view of spectroradiometer PION-UV and its spectral module are given in Figs. 9 and 10.

Figure 9. Spectral module of ultraviolet spectroradio-meter PION-UV

Figure 10. Spectroradiometer PION-UV

Regular observations of the horizontal ultraviolet irradiance in the spectral range 285-450 nm have been realized at the NOMREC ozone station since September 2001. Parallel total ozone and ultra-violet radiation measurements are used in a tentative estimation of seasonal changes in natural UV radiation in the Minsk area and their dependence on the total ozone distribution. The estimation of seasonal changes in natural UV radiation and daily doses has been achieved using the results of regular observations at the Minsk ozone station. A total daily dose, expressed in terms of the biological effects of erythema and DNA damage, has been assessed.

Typical distributions of the horizontal spectral irradiance derived from the combination of direct and diffuse sun radiation, which are characteristic of various seasons, are given in fig.11. The data used for comparison have been chosen on the base of conditions, under which the measurements have been made. The CIE weighted irradiance measurements obtained using the PION-UV are illustrated in fig.12. The value of total ozone has been a variable one and has been chosen close to a monthly average where possible.

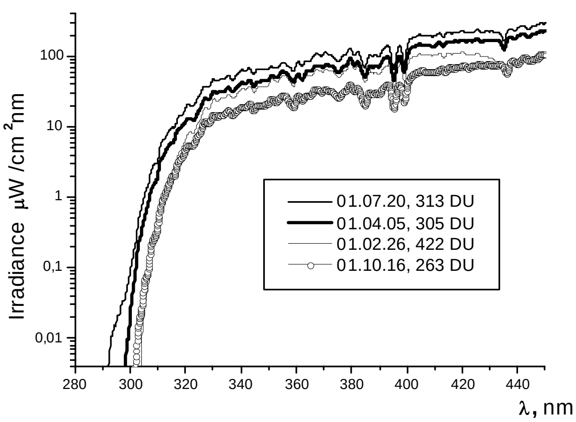


Fig.11. Sun spectra.

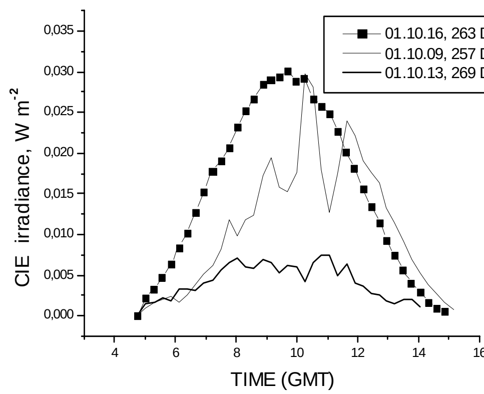


Fig. 12. Time series of the CIE weighted irradiance measurements obtained using the PION-UV for selected days in October 2001. 10.09.2001 and 10.13 - full and partly cloudy sky, 10.16.2001 - clear sky.

Ozone column retrieval

If the direct Sun measurements of the total ozone amount are not available, the global irradiance (i.e. sum of the diffuse and direct irradiance components) data may be applied. For the retrieval of the total ozone amount from UV spectral global irradiance measurements we used the same approach, which have proposed by *Knut Stamnes et al*.[8] and then developed by *M. Houët et al*.[9]. In our case only two wavelength's pairs has been applied now. The $E_{340\ nm}/E_{305,5\ nm}$ and $E_{323,5\ nm}/E_{305,5\ nm}$ ratios then compared to the same values computed by libRadtran for the various ozone abundances and solar zenith angles. By means use the input parameters typical for the spring-summer season in Minsk, the deviation within 5% of the daily mean ozone amount with the direct Sun measurements has been assumed. The first results are presented on Fig. 13.

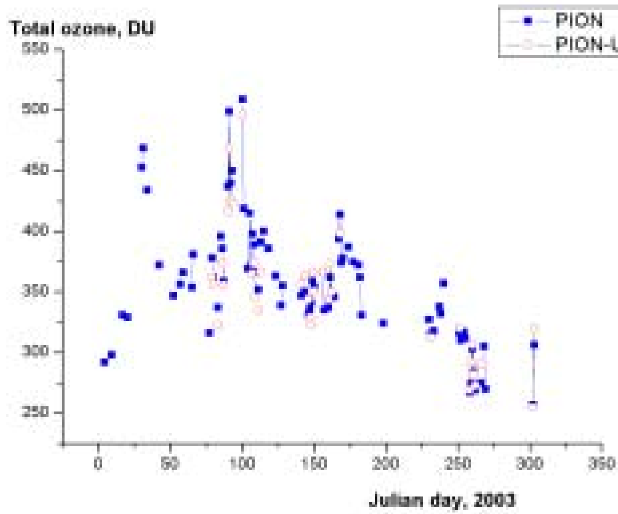


Fig.13. The total ozone amount measured by the direct Sun radiation and global irradiance.

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