THE PION UV SPECTROMETRIC OZONOMETER: REZULTS OF LABORATORY AND FIELD TESTS AND EXPERIENCE OF THE FIRST OPERATION

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Results of the first tests of the noval Pion UV solar spectrometer-ozonometer are discussed in comparison with data of the Brewer ozonometer No. 43. A new measurement technique, based on automatic optimization of the working wavelength range, is proposed for minimization of the recording error.

The overall design concept of the Pion spectrometric ozonometer, developed at the A.N. Sevchenko Scientific–Research Institute of Applied Physics Problems at the V.I. Lenin Belorussian State University, was given in Ref. 1. A series of laboratory and field tests of the two prototypes of that ozonometer was performed in Minsk, Kislovodsk and Dolgoprudnyi in the 1988–1990. During these tests in the last two cities, measurements performed with the Pion ozonometer could be compared with the readings of the standard measuring instruments: the Brewer ozonometer No. 43 placed at the High–mountain scientific station of the Institute of Atmospheric Physics of the Academy of Sciences of the USSR (Kislovodsk), the Dobson ozonometer No. 107, and the Brewer ozonometers No. 45 of the Central Aerological Observatory of the State Committee on Hydrology and Meteorology of the USSR (Dolgoprudnyi). As a result of these tests, the recording system of the new instrument and its measurement procedure were modified. In this present paper we discuss the results from these tests, the drawbacks identified in the use of the ozonometers, and the possible ways of their eliminating.

During the laboratory tests of the ozonometers, the following technical characteristics were obtained:

Performance	Instrument No. 1	Instrument No. 2
Wavelength range, nm	294–316.4	295.5–316.7
Instrumental half–width, nm	≈ 0.44	≈ 0.55
Scanning step, nm	≈ 0.022	≈ 0.021
Total number of scanning steps	1000	1000
Wavelength referencing error, nm	< 0.01	< 0.01
Dispersion (the dependence of wavelength on the number of channel)	close to linear dependence	

The spectral sensitivity of ozonometer decreases approximately linearly at longer wavelengths, because the solar–blind photomultiplier FEU–142 is used in it.

As can be seen from the obtained data, the realistic characteristics do not differ significantly from the values prescribed at the design stage.[1] The brief description of the design and of the overall view of the Pion spectrometric ozonometer can be found in Ref. 1. Note the two important features of its design that differ it from the well–known Dobson and Brewer instruments. First, it has a substantially reduced field of view of the objective (40′×40′), which imposes a stringent limitation on the performance of its pointing system; however, measurements at larger solar zenith angles become possible.

Another important difference is the absence of attenuators of radiation which are otherwise mechanically inserted into the beam to control the strength of the signal. Instead of this, the original measurement procedure is applied, according to which the working wavelength range of the ozonometer scans the spectral range depending on the conditions of observations, so that to select the optimal strength of the signal.

The recording system envisages automatic control of the period of signal storage, depending on its strength, within the limits 0.5 ms – 0.5 s. As a result, the actual dynamic range of the ozonometer signal exceeds four orders of magnitude. An additional opportunity to regulate the sensitivity is the control of the voltage applied at the FEU. However, such a regulation is permissible only between the measurement series, because of the long time needed for setting up the working regime of the photoelectronic unit.

In the course of the initial field tests in December, 1989 (Kislovodsk) the pointing system was tuned, the efficiencies of individual units were tested, some solar UV spectra were recorded, and the measurement procedure was updated. As has already been noted above, the Brewer ozonometer No. 43 operated in a routine regime at the field station of the Institute of Atmospheric Physics of the Academy of Sciences of the USSR and its readings were used to adjust the parameters of the calculational technique.

About 200 solar spectra were recorded, on the whole, more than 70 among them were recorded in ample detail with minimum spectral step. They were used to calculate the exoatmospheric solar spectrum in the wavelength range from 303 to 316.4 nm (during the tests the shorter wavelengths in that spectrum could not be recorded because of small angles of elevation of the sun above the horizon). The calculated results are shown in Fig. 1. The same graph shows the positions of the spectral lines of Hg, used for referencing the ozonometer wavelength scale. The lower part of the plot shows graphically the number of the recorded spectra used for the calculations at each wavelength.

First, the noticeable shift of spectra along the wavelength scale concentrates our attention on the short wavelengths. While the difference found between the amplitudes may be referred to the particular computational procedure employed, the authors have no doubts concerning the wavelength referencing. Generally speaking, similar

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discrepancies are encountered in other comparisons of exoatmospheric solar spectra published by various authors.[2–4] Thus, it should be recognized that the problem of the solar UV exoatmospheric spectrum has not yet been solved.

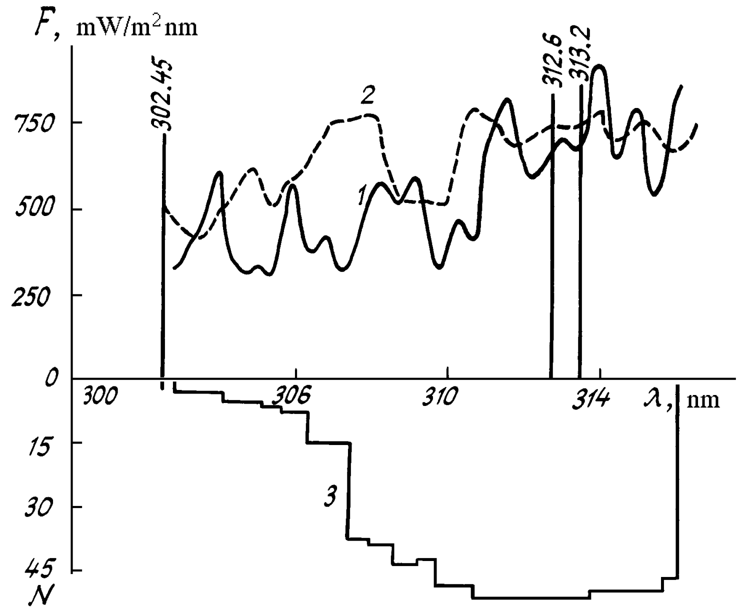

FIG. 1. The exoatmospheric solar spectrum: 1) after processing of the measurements performed with the Pion UV spectrometric ozonometer; vertical bars show the positions of spectral lines of Hg used to calibrate the wavelength scale, 2) data from Ref. 2, and 3) the number of spectra used to plot curve 1 in different spectral ranges.

High functional stability of the opto–mechanical unit has made it possible to do without referencing the wavelength scale prior to each measurement. The instrument design was simplified: a built–in mercury lamp was removed. The periodic check of the reference accuracy can be performed with an external radiation source mounted onto the objective.

One of the variants of the multiwavelength technique[5–7] was used as the basic for retrieval of the total ozone content (TOC). It was based on measurements at 200 wavelength pairs. A concurrent technique was tested, its multiwavelength character was aimed at expanding the working range of the instrument (it was chosen for a routine regime of measurements). The entire spectral range of the spectrometer was divided into overlapping working regions, and ten wavelength pairs were selected within each of these regions for calculating the TOC. With the sun being high over the horizon and the TOC remaining relatively small, the strength of signal, sufficient for accurate measurements, was obtained at the short wavelength edge of this range. Meanwhile, the photomultiplier could be illuminated at longer wavelengths, so that no readings were taken there. As the observational conditions deteriorated, the signal optimal in their strength shifted toward the long wavelength part of the working spectral range of the instrument. As a rule, the TOC could be calculated simultaneously for several adjacent working ranges (their total number was 23). The TOC, averaged over all these working ranges in a given recording, was taken as the value of TOC for the given individual measurement. In the case in which the standard deviation exceeded 1%, the two extreme readings from the set, with the largest absolute deviation from the mean value, were excluded from the averaging procedure.

The technique for adjusting the parameters of the formula, used to calculate the TOC, needs additional explanation. We assume that the aerosol extinction remains nonselective. Then the relation for finding the TOC from measurements in the individual working wavelength region takes the form

$$X = \frac{1}{\mu\alpha} [R - L - m\beta\, p/p_0] ,$$

were μ and m are the relative ozone and air masses, respectively; α is the parameter of absorption of radiation by ozone; R is the exoatmospheric parameter; β is the parameter of molecular scattering (it is calculated beforehand for every working wavelength region according to the well–known empirical formulas); p/p_0 is the ratio of air pressure at the place of measurement to standard air pressure; L is the sum of the logarithms of the ratios of recorded signals over the wavelength pairs. The parameters α and R were determined from a comparative calibration against a reference instrument. In addition, the problem was to minimize the discrepancies of the TOC, obtained in different working wavelength regions. The values of α and R thus found appeared to be rather close to those theoretically calculated from the experimental data on the absorption coefficient of ozone and on the exoatmospheric solar spectrum. However, we chose the parameters retrieved from comparative calibrations in our experiments.

By way of example Fig. 2 shows the TOC measured on December 14, 1989, in comparison with the measurements performed with the Brewer ozonometer No. 43. An important advantage of the Pion ozonometer consists in its efficiency at large air masses due to small field–of–view angle and high sensitivity of the instrument.

One of the dificiencies is poor reproducibility of the results in comparison with the Brewer ozonometer. It can be partially compensated at the cost of transition from individual measurements to a measurement series with subsequent averaging of results (see below).

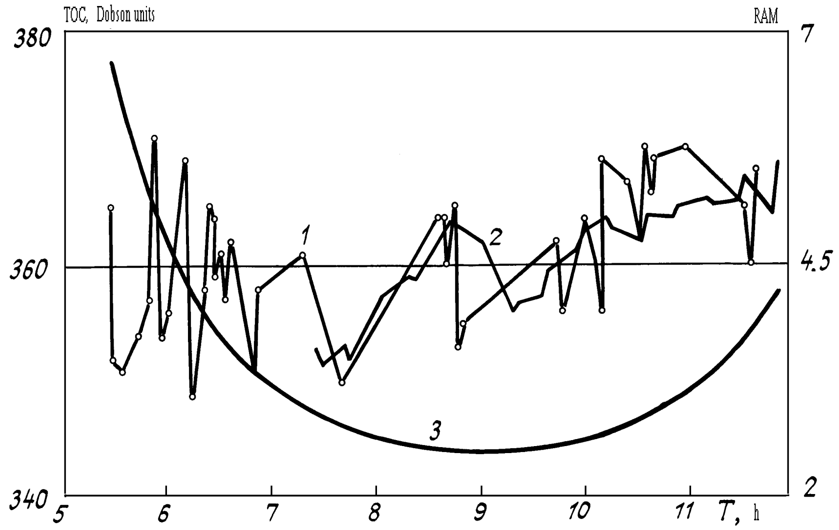

FIG. 2. Results of TOC measurements in Kislovodsk on December 14, 1990: 1) Pion No. 1, 2) Brewer No. 43, and 3) Relative air mass (RAM) as a function of time. Greenwhich time is plotted as abscissa.

In the course of the field tests in 1990, the second ozonometer was calibrated, and the measurement procedure and the software providing for it were updated. By the last tests in Kislovodsk in December, 1990 that work had been mostly completed. As a result was developed a program to control the performance of the Pion ozonometer in semi–automatic mode during the entire day. Since the programmable control of the drives of the pointing system was unavailable, the operator still had to control the performance of the instrument: when the pointing system failed because of clouds appearing in its field of view, the instrument was switched to the idle mode, waiting for the operator command to start it up again. As the data were accumulated, all information was automatically stored on a floppy disk; after the termination of the measurements, the protocol of observations might be printed.

Figure 3 shows measurements in Kislovodsk on December 15, 1990. They are averaged over a series of seven individual measurements. It can be seen that the spread of readings turns to be much smaller as a result of application of such a procedure. Discrepancies in the daily averaged TOC, measured with different instruments, are explained by insufficient length of the period of measurement used to adjust the parameters of the calculational technique implemented in the Pion ozonometer. They will be eliminated in the course of subsequent calibrations. The spread of readings of repeated measurements made wichthe help of different ozonometers was equal to about 1.5% and was mainly caused by errors in the performance of the pointing system.

Unfortunately, the available technical solution makes any improvement in the performance of the pointing system impossible. The apparent way to solve this problem is to introduce program processing of the signals from the sighting head and programmable control of the pointing mechanisms. Such a solution is envisaged in the modified version of the Pion ozonometer which is currently under development. Simultaneously measures are taken to improve the performance of the receiving and measuring channels. Such updating is expected to open possibilities of estimating systematic errors in the measurement of the TOC with the Pion ozonometers, so that the final inference on the fruitfulness of the overall design concept, proposed in Ref. 1, may be made.

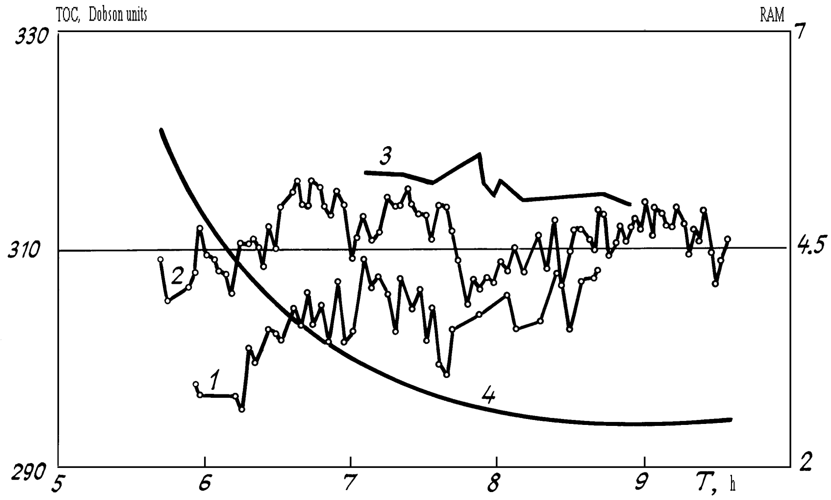

FIG. 3. Measurements of the TOC in Kislovodsk on December 15, 1990: 1) Pion No. 1, 2) Pion No. 2, 3) Brewer No. 43 located at the station of the Institute of Atmospheric Physics, and 4) relative air mass vs time.

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