THE PION UV SPECTROMETRIC OZONOMETER: MEASUREMENT PROCEDURE AND RESULTS OF THE COMPARATIVE TESTS

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The unique procedure for measuring the total ozone content in the atmosphere with the help of the Pion solar uv spectrometric ozonometer is discussed. The results of intercomparison of the Pion readings and the data obtained with the Brewer No. 45 and Dobson No. 107 spectrometers are presented for the spring—fall seasons of 1991. It is shown that the accuracy of the average daily measurements performed with the Pion ozonometer is close to the accuracy of readings of the Brewer and Dobson instruments.

Since 1989, the Pion uv solar spectrometric ozonometer developed at the Scientific—Research Institute of Applied Physics Problems at V.I. Lenin Belorussian State University has been tested intensively. Three instruments has been produced by the present time. The last instrument included a number of modified units developed with an account of the test results and detected defects of the first two prototypes. Design peculiarities of the device were briefly described in Refs. 1 and 2, the general approach to the design of the precision spectrometric ozonometer was stated in Ref. 1, the theoretical aspects of uv solar ozonometry were discussed in Refs. 3–6, and a detailed description of the design and characteristics of the device will be given in an individual publication.

The results of the laboratory and field tests of the Pion ozonometers Nos. 1 and 2 were presented in Ref. 2, where the advantages and disadvantages of the instruments were also discussed in comparison with the well—known Dobson and Brewer ozonometers. Unique procedure for measuring used in the Pion ozonometers and results of comparative tests with the Dobson and Brewer ozonometers in spring, summer, and fall of 1991 carried out at the station of the Central Aerological Observatory of the State Committee on Hydrology and Meteorology of the USSR (in Dolgoprudnyi, Moscow region) are described below in detail.

Primarily, to measure the total ozone content (TOC) in the atmosphere with the Pion ozonometers we were going to use one of the variants of the multiwave technique[4,7–9] based on measurements at 200 pairs of wavelengths. However, the analysis performed in Ref. 6 has shown that the direct generalization of the usual few—wave techniques for the case of many working wavelengths is not the optimum way for increasing the accuracy of the TOC measurements. At the same time, the idea of using the redundant number of the working wavelengths proved to be promising from the viewpoint of extending the range of measurable conditions. The aspects of this problem were discussed in Ref. 6 in detail. Here we describe an individual realization of the developed technique which preserves to some degree the features of the standard multiwave approach to the TOC measurement.

Prior to each measurement a mobile spectral slit of the monochromator of the spectrometric ozonometer was placed at the beginning of the spectral range (293-317 nm). For measuring the TOC, the spectral range was devided into 13 uniformly spaced working parts (see Fig. 1) incorporating 10 wavelengths with one scanning step (0.02 nm). The very short—wave part was used for measuring the background signal F and evaluating its standard deviation DF.

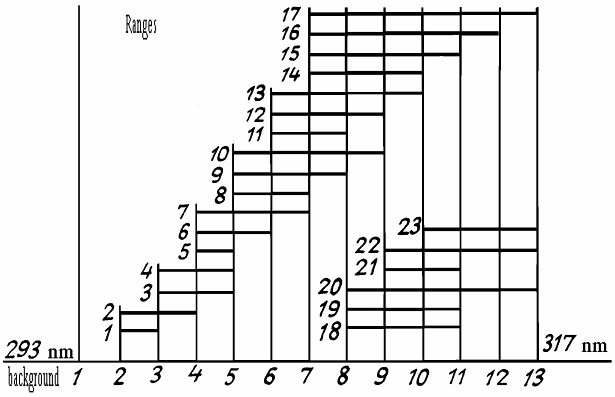

FIG. 1. Wavelength distribution of the working parts and working spectral regions of the Pion spectrometric ozonometer.

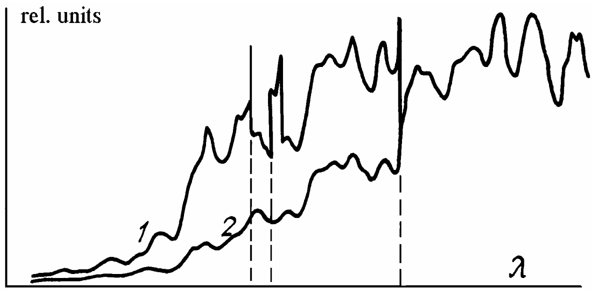

FIG. 2. Recorded solar UV spectrum: 1) with the variable integration time depending on the signal amplitude (the vertical lines denote the points of the double increase of the integration time) and 2) the spectrum converted to the standard integration time.

An electronic channel of the control and recording unit was capable of stepwise controlling the signal integration time t_i of an integrator within the limits 0.5 ms – 0.5 s. The data processing algorithm automatically adjusted t_i as a function of the output signal of the photomultiplier to provide the optimum mode of operation of an analog–to–digital converter (ADC). The adjusted integration time was then used as an input parameter for optimization when measuring in the next channel. In addition to the change of the signal integration time, a possibility of several measurements (up to 30) in each of the channels with subsequent averaging of the result was assumed. Figure 2 shows the solar spectrum (curve *1*) recorded with optimization of the integration time and the result of its conversion to the standard time (curve *2*) as an example.

The procedure for measuring included the stage of the rough estimate of the signal in every working part. To this end, the measurements were carried out in the first channel of each working part with small integration time. If the estimate of the signal amplitude did not exceed $S_{\min} = F + 50\sqrt{DF}$, then the measurements were not performed and a transition to the next working part was made. If there occurred the overflow of the ADC in the long–wave–region with minimum integration time, the scanning of the spectrum was terminated to avoid the illumination of the photodetector.

The Pion spectrometric ozonometer was equipped with a servounit operating in an independent automatic mode and controlling the engine used to rotate the instrument in the vertical and horizontal planes.

The successive measurement started with switching off the servounit determining the noise level and its variance, adjusting the spectrometer at the beginning of the second working part, switching on the servounit, and waiting (over the course of 2–5 s) for the final training of the spectrometric ozonometer on the sun. After the signal "the sun has been caught" the servounit was switched off and the scanning of the spectrum started with the estimate and measurement of the signal amplitude in the working parts (2–13). After termination of scanning the servounit was switched on again and the spectrometer was adjusted at the beginning of the spectral range. To avoid the additional interferences during scanning and measuring the noise level, the thermostat was also switched off. The total scanning time varied within the limits from 2 to 10 s as a function of the maximum integration time, the number of repeated measurements, and the signal amplitude.

Single scanning gave the average noise level and its variance, the serial numbers of the first and last informative parts, the ADC records in each of 10 channels of every informative part, and corresponding integration time. Conversion of the measurements to the standard integration time (0.5 ms), subtraction of the noise, logarithmic operation, and summation of the signals obtained in each of 10 channels of the working part were then performed. From 12 working parts (2–13) 23 pairs of overlapping working regions were formed (see Fig. 1). The serial numbers of regions in which the TOC determination was possible were found depending on the first and last informative working parts.

The TOC in the individual spectral region was calculated from the formula

$$X = \frac{1}{\mu\Delta\alpha}(\Delta R - \Delta L - m\Delta\beta p/p_0) , \qquad (1)$$

which is one of the versions of the multiwave technique[6] based on the assumption on nonselectivity of aerosol attenuation. In formula (1) μ and m are the relative ozone and air masses, respectively[10]; $\Delta\beta$ is the difference between the sums of the scattering coefficients at all the wavelengths of the first and second working parts of the examined region; $\Delta\alpha$, ΔR, and ΔL are the analogous values calculated for the coefficient of ozone absorption, the logarithms of the density of extra–atmospheric solar radiation flux, and the logarithms of the recorded signals, respectively; p/p_0 is the ratio of the pressure at the measurement point to the standard atmospheric pressure. The parameter $\Delta\beta$ was calculated from the well–known semiempirical formulas[11] with the referencing of the spectrometer channels to the wavelength scale. Generally speaking, the parameters ΔR and $\Delta\alpha$ could be calculated starting from the experimental data on the extra–atmospheric solar spectrum, ozone absorption coefficient, and referencing of the spectrometer channels. However, we preferred to determine these parameters by means of a comparative calibration against the standard ozonometer. This approach is more laborious but it makes it possible to avoid the additional errors due to the errors in the initial experimental data.[3] Measurable signals were shifted along the scale toward one or other end depending on the real TOC, the measurement conditions, and the instrumental sensitivity (which could be controlled in the given limits by changing the high voltage applied to the photomultiplier). The application of many overlapping working ranges distributed over the entire wavelength scale of the instrument opens the possibility of obtaining the result (the TOC measurement) in a wide range of the observational conditions without extremely high reguirements to the dynamic characteristics of the electronic channel of the recording system. Perhaps, it is the only real advantage of using many wavelengths to determine the TOC (in the case in which the other gases were not measured).[1,6]

As a rule, in each measurement the TOC was obtained simultaneously in several spectral regions. An averaged value was determined over all the measurable regions except two most distant from the average value, if the relative standard deviation exceeded 1%.

In order to decrease the errors and to eliminate the random overshoots the measurement runs were divided into the series incorporating several individual measurements. The results obtained in the series were averaged according to the above–described procedure and the standard deviation being interpreted as the error of the TOC measurement in a series were determined. The results of comparison of the daily record sheets of the measurements performed with the Pion ozonometers Nos. 1 and 2 with the Brewer standard ozonometer (in Kislovodsk at the High–Mountain Scientific Station of the Institute of Atmospheric Physics of the Russian Academy of Sciences) were given in Ref. 2.

In spring of 1991 the Pion spectrometric ozonometer No. 1 was transported to the station of the Central Aerological Observatory and installed on the same platform along with the Brewer No. 45 and Dobson No. 107 ozonometers. The results of simultaneous measurements are shown in Fig. 3. The daily average records of the instruments are shown for the days in which the Pion ozonometer was switched on. The calculated standard deviations of the readings of two instruments were as follows: the Dobson and Brewer ozonometers – 10; the Dobson and the Pion ozonometers – 10; the Pion and Brewer ozonometers – 14 Dobson units. Thus, taking into account the daily average readings, the Pion ozonometer has nearly the same accuracy as the Brewer and Dobson ozonometers. However, in this case it is necessary to take into consideration that the Brewer and Dobson instruments possess a much better reproducibility of the readings in the course of the daytime observations[2] but the Pion spectrometric ozonometer opens the possibility of measurements in a wider range of the observational conditions (in particular, for greater air and ozone masses[2]). As to improving the reproducibility of the readings (decreasing the random measurement errors), in the third prototype of the instrument the servounit and electronic channel of the recording system has been modified in order to eliminate this disadvantage. One can judge the achieved effect after testing the Pion No. 3 spectrometric ozonometer.

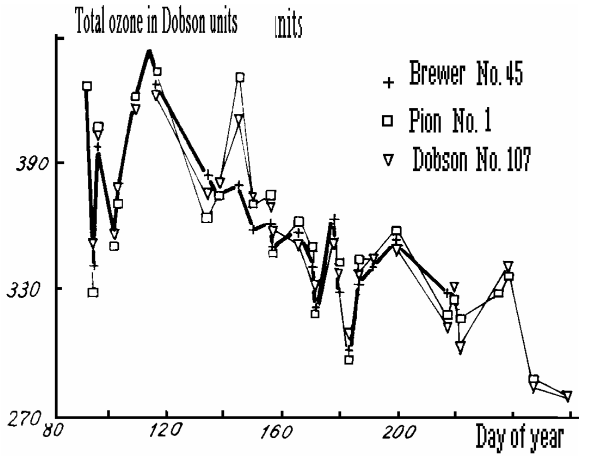

FIG. 3. Measurements with the Brewer No. 45, Dobson No. 107, and Pion ozonometers in spring, summer, and fall of 1991 at the station of the Central Aerological Observatory.

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