INVESTIGATION OF THE SPECTRAL ATTENUATION OF DIRECT SOLAR RADIATION BY MEASUREMENTS IN THE VISIBLE RANGE

E.G. Golovina, L.A. Sokolova, and A.V. Shashkin

Hydrometeorological Institute, Leningrad
Received December 2, 1988

The paper describes a multi-channel prism spectrometer that allows one to perform simultaneous measurements in 15 channels within the range 402 to 766 nm. The minimum time interval between successive measurements is about 1 sec. Results of a set of spectral measurements of the attenuation of direct solar radiation spectra for various types of translucent clouds are presented.

As of present, a large body of experimental data has been gained on the spectral optical thickness of the atmosphere — one of the most important parameters of the Earth's atmosphere. But most of data were obtained under cloudless conditions.[1–5] Because the likelihood of such a weather state for the middle belt does not exceed on average 50%. Investigations in the presence of cloudiness remain a problem of current interest.

The difficulty of such investigations is connected with the high temporal and spatial variability of clouds[9], and also with the lack of apparatus which would make it possible to measure the spectral optical thickness under unstable atmospheric conditions. Many authors have directed their efforts to various model calculations and experimental laboratory-scale investigations of artificial clouds.[6–8] But papers devoted to the measurements of spectral cloud transmission of direct solar radiation are significantly fewer due to the difficulty of carrying them out. Moreover, the results of many experimental investigations are rather contradictory.[10,11] This can be explained by both the low accuracy of measurements and the deficiency of information (small number of recording wavelengths over a wide spectral range), thus preventing a study of the finer structure of the spectral optical thickness of the atmosphere. Under clear sky conditions, one of the main factors limiting the further increase of the accuracy of measuring the spectral optical thickness is its short-term variability $\sim \pm 0.01$ sec^{-1}).

With the goal of carrying out investigations of the spectral optical thickness of the atmosphere under unstable conditions, a ground-based multichannel prismatic spectrometer (MCS) was built in the chair of meteorology, climatology and atmospheric conservation in the Hydrometeorological Institute of Leningrad. This device can produce simultaneous spectral counts in 15 channels in the range 402 to 766 nm, making it possible to obtain instantaneous values of the spectral optical thickness of the atmosphere. The minimum time interval between spectra is 1 sec. The specifications of the MCS are given below. The optical scheme of the device (an autocollimation scheme with mirror output slits) is shown in Fig. 1. Fifteen F-17 and F-23 vacuum photoelements are employed as the radiation detectors.

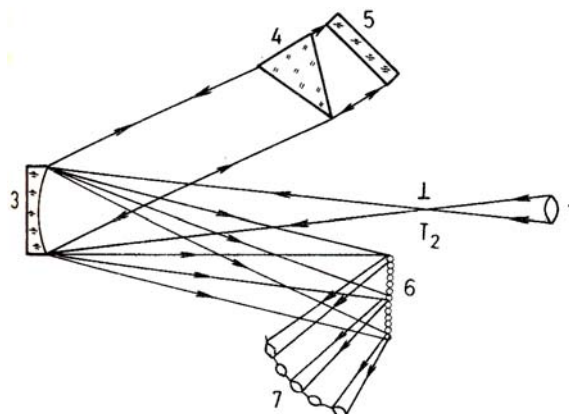A block diagram of the electronics of the MCS is shown in Fig. 2.

FIG. 1. Optical scheme of the electronics of the multichannel spectrometer: 1 collimator objective; 2 — input slit; 3 — parabolic mirror; 4 — prism; 5 — flat mirror; 6 — mirror output slits; 7 — spherical base with photodetectors.
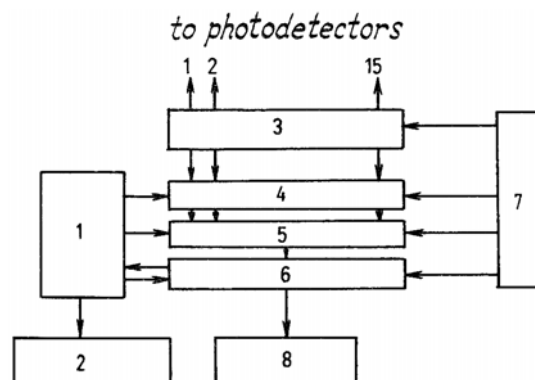

FIG. 2. Block diagram of the electronics of the multichannel spectrometer: 1 — microcomputer; 2 — numerical record on magnetic tape; 3 — 15-channel amplifier; 4 — sample-and-store device; 5 — 15-channel switch; 6 — analog-digital converter; 7 — power supply; 8 — recorder.

The photocurrents are amplified by a 15-channel constant-current amplifier 3, are sent from there to a sample-and-store device 4 and from there to a 15-channel switch 5. A microcomputer 1 is used to control the processes of measurement, recording, and processing and output of information. The alignment of the MCS to the Sun is achieved using a heliostat equipped with a clock mechanism of 3′ accuracy. The temperature of the MCS during the measurements was held at $30 \pm 1°C$. The variability of the spectral sensitivity did not exceed 1%.

SPECIFICATIONS OF THE MULTICHANNEL SPECTROMETER

The number of channels is 15.
Spectral characteristics of the channels:

Channel number	Wavelength, nm	Half-width of spread function, nm
1	766	60
2	702	40
3	644	30
4	600	24
5	566	19
6	538	16
7	514	14
8	494	12
9	476	10
10	460	9
11	446	8
12	433	7
13	422	6
14	412	5
15	402	5

The temporal spread of the counts in the channels during one measurement does not exceed 10^{-3} sec.

The minimum interval between measurements is 1 sec.

The dynamical range (without changing the sensitivity setting) is 4096.

The random measurement error (for a maximum signal) does not exceed 0.05%

The viewing angle is 15′.

The memory storage capacity of the control computer is 1000 spectra.

The thermostabilization accuracy of the MCS is ±1°C.

The solar alignment accuracy is 3′.

A series of measurements of the attenuation spectra of the direct solar radiation by translucent clouds of different shapes were carried out using the MCS in a weather station situated at a height of 2100 m above sea level in the settlement Rodionovka

of the Akhalkalakskii region of the Georgian Republic during July-August, 1988. The measurements were made in series of 8–64 spectra with intervals of from 2 to 30 sec between the spectra. Thus, the series of measurements did not last more than 30 min. During such a short time, any changes in the sensitivity of the MCS are negligibly small and, consequently, the error in determining the variations of the direct solar radiation spectra in one series depends only on the noise of the receiving-recording path and the errors of the analog-digital converter. The experimentally obtained value of the error is 0.05% of the maximum signal.
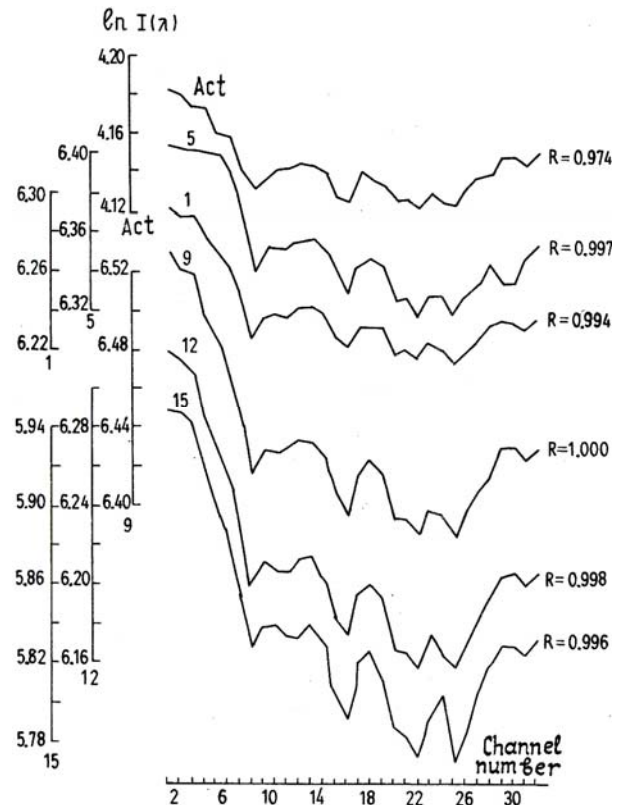

FIG. 3. The logarithm of the intensity of the direct solar radiation.

To illustrate the performance of the MCS, Figure 3 plots on a semi log scale the temporal variations of a direct solar radiation spectrum (data taken with the MCS) and the integrated solar flux (using the thermoelectric actinometer) obtained on 8 August, 1988 at 18:27 with a weak cirrus cloud covering the Sun's disk with a time interval of 30 sec between spectra. The synchronism of the variations is noticeable. The correlation coefficients of the curves, R, with repsect to the data of the 9th channel ($\lambda = 476$ nm) are given in the same figure. It should be noted that the data obtained by means of actinometer correlate well with the data obtained using the MCS. Here and in the figures that follow, the curve numbers correspond to the channel numbers.

The instability of the optical conditions during the measurements did not permit us to calibrate the

MCS to the exo-atmospher ic values with sufficient accuracy. Nevertheless, the results of the calibration can serve as an approximate estimate of the optical thickness of the atmosphere. During the investigations of the spectral attenuation of the direct solar radiation by translucent clouds, the optical thicknesses reached several units. Under such conditions multiply scattered solar radiation can influence the results of the measurements. Therefore to simplify the interpretation of the measurements data and to obtain more accurate measurements, cases were chosen for which the optical thickness of translucent clouds did not exceed 0.5. The influence of multiply scattered light was checked experimentally. Towards this end, the signals obtained for accurate alignment and for deviation of the axis of the device from the center of the Sun by 2° were compared. It was found that even for optical thicknesses of the translucent clouds near unity the spectra of the circumsolar aureole were equal to not more than 1% of the direct solar radiation spectrum. Thus, we will assume Bouguer's law to be valid for our case, and neglect the contribution of scattered light to the measured spectrum.

To find the variations of the spectral optical thickness of the atmosphere $\tau(\lambda)$, the spectra measured under conditions of maximum transparency of the atmosphere in the absence of clouds over the Sun's disk were chosen from each series of observations, and the logarithms of these spectra were averaged:

$$\overline{\ln I_{max}(\lambda_i)} = \sum_{j=1}^{M} \ln l_{max}(\lambda_i)/M,$$

or

$$\overline{L_{max}(\lambda_i)} = \sum_{j=1}^{M} \ln l_{max}(\lambda_i)/M,$$

where $i = 1,2,..., 15$; $j = 1,2,..., M$; and M is the number of the chosen spectra with maximum level of spectral intensity distribution in the series of observations.

Next, the differences are calculated for all of the spectra in the series

$$\Delta L_j(\lambda_i) = \overline{L_{max}(\lambda_i)} - L_j(\lambda_i),$$

where $j = 1,2,...,N$; N is the number of spectra in the series.

Using Bouguer's law, we have

$$L_j(\lambda_i) = L_0(\lambda_i) - \tau_j(\lambda_i)m,$$

where $j = 1,2,...,N$, $L_0(\lambda_1)$ is the logarithm of the exo-atmospheric spectrum from the MCS measurements, and m is the optical mass of atmosphere.

Equation (3) can now be written in form

$$\Delta L_j(\lambda_i) = (\tau_j(\lambda_i) - \overline{\tau_{min}(\lambda_i)})m = \Delta\tau_j(\lambda_i)m$$

where $i = 1,2,...,15$ and $\overline{\tau_{min}(\lambda_i)}$ are the mean optical thickness corresponding to the values $\overline{L_{max}(\lambda_i)}$

Thus, apart from a factor of m, the quantity $\Delta L_j(\lambda_i)$ describes the variations of spectral optical thickness of the atmosphere, i.e.,

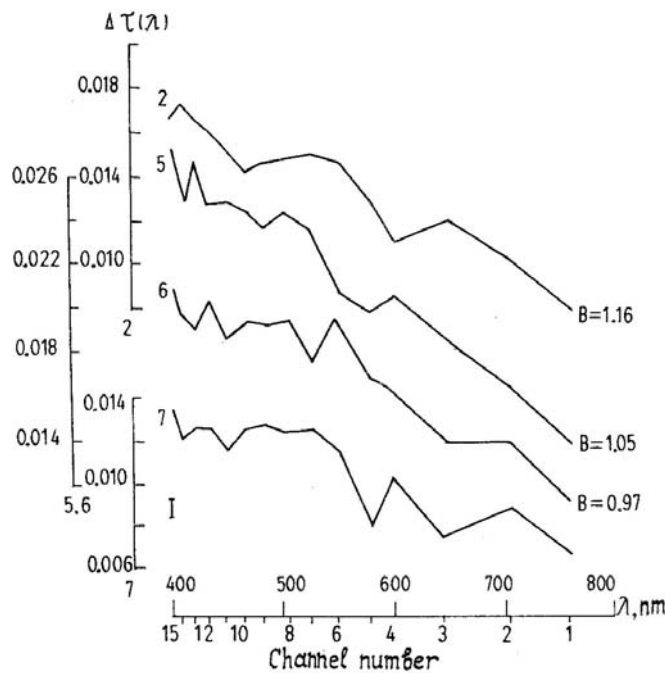$$\Delta L_j(\lambda_i) \sim \Delta\tau_j(\lambda_i),$$

where $j = 1,2,...N$.

FIG. 4. Variations of the optical thickness of the atmosphere under cloudless conditions for different Angstrom indexes B. Here, and in Figs. 5 and 6, the ordinate axes correspond to the maximum error in determining the variations of the optical thickness of the atmosphere.

Figure 4 presents $\Delta\tau(\lambda)$ dependences measured under conditions of high transparency. The time interval between the spectra was 2 sec. The pronounced spectral dependence (the Angstrom index $B \approx 1.1$) is observed in the variations of the atmospheric optical thickness under cloudless conditions on August 17, 1988 at 10:24. The random error in measuring the variation as can be seen from figure is $\pm$ 0.001, which is in good agreement with the calculated and experimental data obtained from the tests of the MCS under laboratory conditions. The observed variations under cloudless conditions can be connected with the presence of invisible aerosol "clouds".[10] In the presence of cumulus cloudiness, the measurements were made through the thin edges of the clouds. Measurements of $\Delta\tau_j(\lambda_1)$ performed on August 17, 1988 at 11:23 are plotted in Fig. 5.
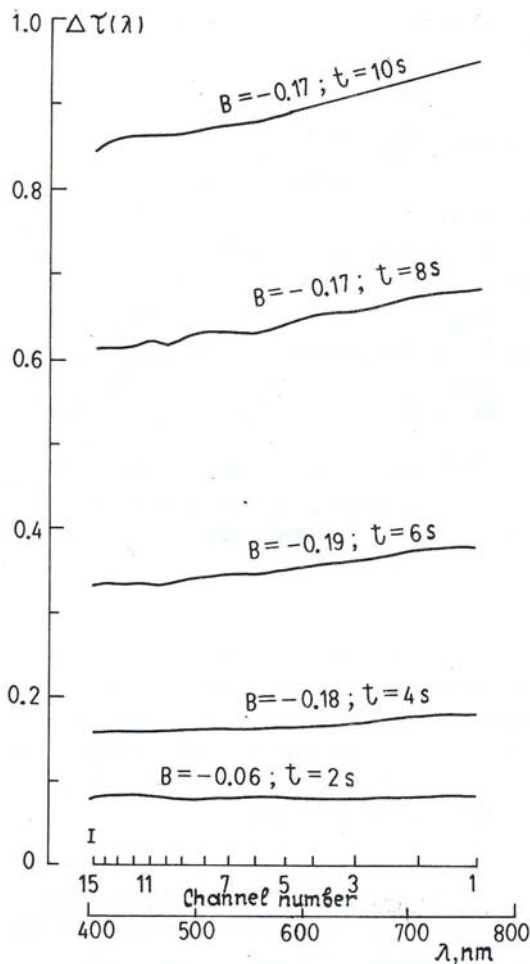
An increase in solar radiation is observed with an increase in the wavelength (the Angstrom index $B = -0.18$). The variations of the spectral optical thickness obtained at the 8th and 10th seconds exceed the limit established earlier, which takes account of the influence of scattered light ($\Delta\tau < 0.5$). Nevertheless, the spectral dependence of $\Delta\tau_\psi(\lambda_1)$ observed at smaller optical thicknesses (the observation times were 2.4 and 6 sec) is preserved in these two cases. This indicates that in the presented data on the spectral optical thicknesses in translucent clouds the influence of multiply scattered light is not substantial. For haze conditions (Fig. 6), the spectral dependence of $\Delta\tau_j(\lambda_1)$ has a more complicated form, which is probably associated with the relatively fast size redistribution of the haze aerosol particles and the change of the optical aerosol characteristics caused by the condensation of water vapor on the aerosol particles.
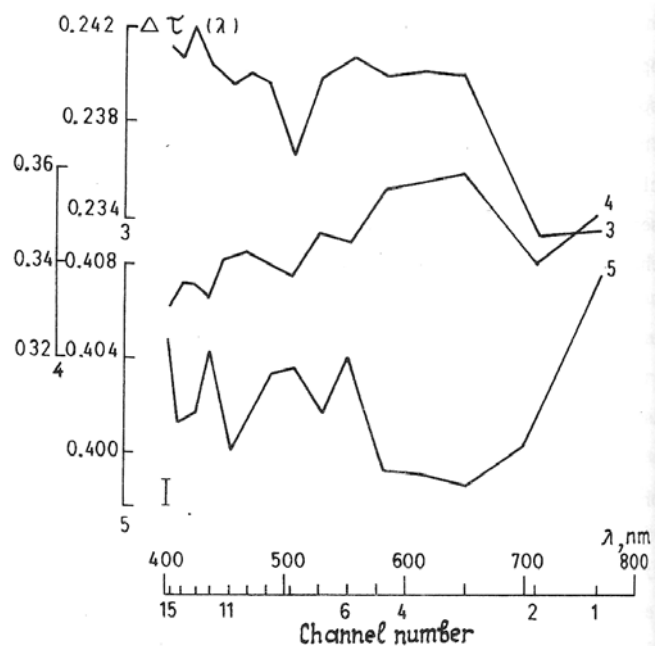

FIG. 5. Variations of the atmospheric optical thickness, measured through the edge of a cumulus cloud.

FIG. 6. Variations of atmospheric optical thickness under haze conditions.

In conclusion, we note that

1. The multichannel spectrometer permits one to study the variations of the spectral optical thickness under unstable atmospheric conditions in the range 402–766 nm.

2. A technique for estimating the variability of the optical thickness of the atmosphere using measurements of direct solar radiation has been developed.

3. The measurements enable one to find the spectral dependences of the atmospheric optical

thickness that are characteristic of different optical conditions.

REFERENCES

1. Yu.S. Georgievskii, Izv. Akad. Nauk SSSR, FAO, **2**, No. 5, 494 (1965).

2. V.L. Filippov and S.O. Mirumyants, Izv. Akad. Nauk SSSR, FAO, **7**, No. 6, 641 (1970).

3. K.A. Tavartkiladze, Izv. Akad. Nauk SSSR, FAO, **12**, No. 6, 596 (1976).

4. K.S. Shifrin, V.M. Volgin, B.N. Volkov, et al., Issled. Zemli iz Kosmosa, No. 4, 21 (1985).

5. Yu.S. Georgievskii and A.Kh. Shukurov, Izv. Akad. Nauk SSSR, FAO, **2**1, No. 4, 397 (1985).

6. E.M. Feigel'son [Ed.], *The Radiation in Cloud Atmosphere* (Gidrometeoizdat, Leningrad, 1981).

7. A. Slingo and H.M. Schrecker, J. R, Met. Soc. **108**, No. 456, 407 (1982).

8. A. Hence, *Workshop on Radiation and Cloud-Radiation Interaction in Numerical Modeling,* ECHWE, Reading, March, 41 (1981).

9. V.E. Zuev and M.V. Kabanov, *Optics of Atmospheric Aerosols. Current Problems of Atmospheric Optics,* **4** (Gidrometeoizdat, Leningrad, 1986).

10. G.P. Guschin, *Methods, Devices, and Results of Measurements of the Spectral Transmittance of the Atmosphere* (Gidrometeoizdat, Leningrad, 1988).

11. A.Kh. Shukurov and P.P. Anikin, *Abstarcts of Reports at the Eleventh All-Union Conference on Actinometry and Atmospheric Optics,* Part V, 105, Tallinn, 1980.