System for the network monitoring of the atmospheric constituents active in radiative processes. Part 1. Sun photometers

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We discuss basic principles of organization of the information and measurement system for an automated monitoring in Siberia of the atmospheric properties governing the radiative processes. A sun photometer with a built-in microcontroller for measurement of atmospheric transmittance in 18 spectral intervals of the 0.3 to 4 μm region is described. As compared with other similar devices, this photometer has a wider spectral range and is capable of regularly measuring the meteorological parameters at the observation site and self-controlling its basic characteristics (noise, thermostat operation, and others). A brief characterization is presented of the software for the unattended operation of the photometer.

Introduction

The investigations into the global warming have been intensified in the last decade because of the need to explain the current processes and predict their development. In this connection, many experts (see, for example, Ref. 1) emphasize the necessity of developing observation systems for regular long-term monitoring of climate characteristics on the global, regional, and local scales. Aerosol, water vapor, ozone (most variable atmospheric constituents), and other greenhouse gases play an important role in the radiative–climatic processes.

One of the efficient and rather simple methods to determine their total content is solar spectrophotometry of the atmosphere (measurement of atmospheric transmittance). Among modern tools for monitoring of the spectral transmittance, to be noted are the precision filter radiometer (PFR) (http://www.pmodwrc.ch), MS-120 sun photometer (http://www.eco.co.jp), SPUV-6 filter spectrometer, and MFR-7 (Multifilter Rotating Shadowband Radiometer; http://www.yesinc.com).

The AERONET network (http://aeronet.gsfc.nasa.gov) employing the CE 318 sun photometers (www.cimel.fr) and including more than 100 stations on all continents of the globe meets the requirement of measurement consistency and the global coverage to the highest extent.[2] Actually, AERONET is still the only example of an automated monitoring network. Its important advantages are the fast processing of observations, the presence of the INTERNET-accessible database of aerosol data, and high information content. The use of contemporary methods and algorithms for solution of the inverse problems, the parameters retrieved include, in addition to the aerosol optical depth (AOD), the aerosol scattering phase function, the aerosol microstructure, and the single scattering albedo.

In Russia, the network monitoring is being carried out only for the total ozone content in the mode of manual measurements,[3] while observations of the atmospheric AOD were terminated more than 10 years ago. The regular measurements of the total content of greenhouse gases are conducted only at three to four sites in the European part of the Russia (see, for example, Ref. 4). Thus, in terms of the network observations of the atmospheric transmittance, the vast Siberian territories remain a "blank spot," in spite of their very important role in the global climate and aerosol–gas exchange processes.

To fill this gap, we have carried out the study aimed at the development of multichannel sun photometers, the algorithms for automation of the measurements, and the techniques for determination of the AOD and the content of gaseous atmospheric constituents.[5–8] This paper presents the latest version of the SP-6 sun photometer designed for operation as a part of the information-measurement network.

1. Concept of a network system

The new SP-6 sun photometer was developed on the basis of the SP-4 photometer, which has been long operated in the mode of round-the-year measurements.[6] Recall that, for the unattended operation of the SP-4 photometer, the functions of automatic detection of the fact of "cloudless sun" and search of the sun until its lock-on by the precise tracking system were additionally implemented. The transition to the network mode of observations of the

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atmospheric spectral transmittance required some changes to be made both in the operating algorithms of the measurement system and in the engineering solutions of the photometer itself. Some principles of organization of multi-site measurements were borrowed from the AERONET network.

The monitoring of the content of gaseous and aerosol atmospheric constituents based on the data on spectral transmittance must meet the following requirements.

1. Functioning of the system in the form of an automated network, which includes a set of "sensors" with remote access (SP-6 in different Siberian regions) and the common center for data acquisition, processing, and archiving. The composition of the information system from photometers to databases will be considered in Part 2 of this paper.

2. Unattended operation of SP-6 photometers, including:

(a) detection of "cloudless sun" situations and pointing of the photometer to the sun;

(b) measurement and accumulation of spectral transmittance signals;

(c) at night and in cloudy situations, switching of the photometer to the standby mode (parking), in which the input optics is reliably protected against precipitation and dust;

(d) self-diagnostics of the photometer, including periodic measurements of noise in the measuring channels, thermostat temperature, supply voltages, etc.;

(e) use of a built-in microcontroller with an ADC and digital transmission of signals (photometer–computer) to reduce the number of communication lines and improve the noise immunity.

3. Additional measurement of the weather parameters (temperature, humidity, pressure), which are needed to improve the accuracy of reconstructing the optical characteristics and the following analysis of observations.

4. Every-year calibration of the photometers under the mountain conditions (Mondy observatory, Institute of Solar–Terrestrial Physics SB RAS).

Below we describe the photometer designed and characterize its software.

2. Photometer design

The model SP-6 sun photometer includes the following basic units:

1) multichannel sun photometer with a built-in microcontroller;

2) guidance and sun tracking system;

3) unit of sun sensors and sensors of meteorological quantities;

4) power supply and control unit, personal computer.

The appearance and the design of the optical part of the rotatable photometer are shown in Figs. 1 and 2. To measure the atmospheric transmittance in the wide spectral region ~ 0.3 to 4 μm, three measurement channels are used: ultraviolet (UV), shortwave (SW), and longwave (LW), which are oriented to the sun during the operation. The features of the photodetector systems are explained in Table 1.

Fig. 1. Appearance of the SP-6 sun photometer.

Table 1. Characteristics of the optoelectronic channels

Channel	Input window	Optical system; spectral range	Photodetector
UV	Quartz	Quartz lens f = 81 mm; 0.3–0.4 μm	Silicon carbide solar-blind photodiode and a dc amplifier
SW	PS-5 glass	Field of view is formed by the input diaphragm; 0.4–1.1 μm	FD-24k silicon photodiode and a dc amplifier
LW	Silicon	Field of view is formed by the input diaphragm; 1.1–4.6 μm	Modulation of optical signal – MG-32 pyroelectric detector – synchronous detection

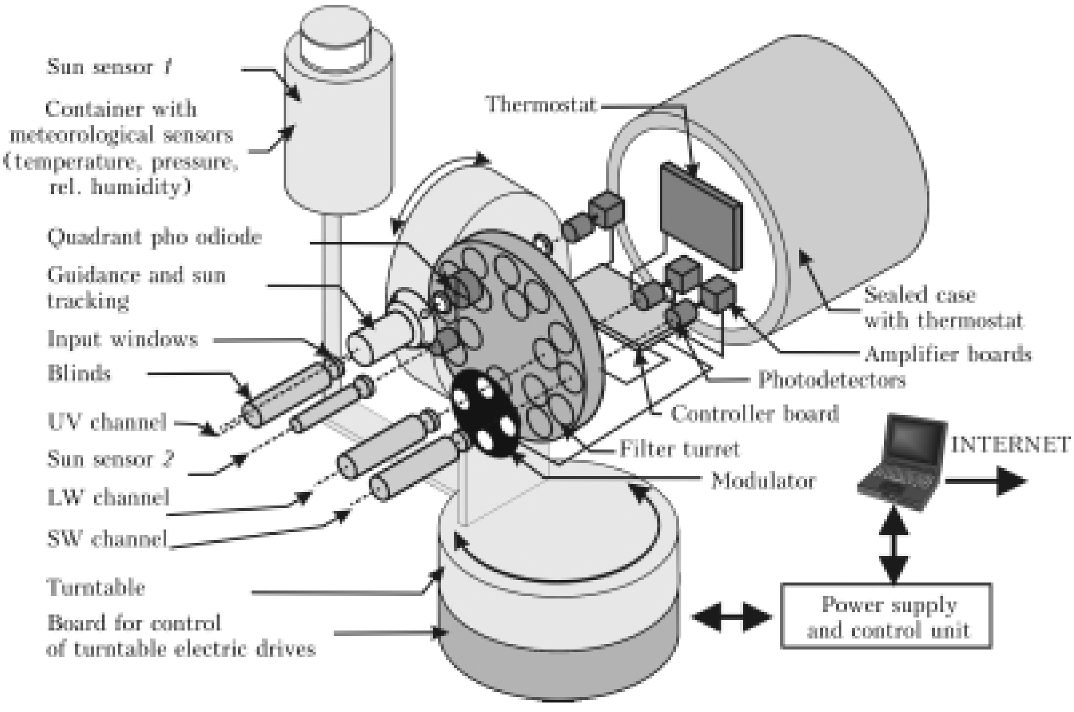

Fig. 2. Design of the sun photometer.

The spectral ranges of received radiation are separated out using turret-mounted interference filters: 12 UV and SW filters on the outer diameter and 6 LW filters on the inner diameter. Filters are set in front of the photodetectors through turret rotation by a stepper motor in response to the controller command.

The sensors of meteorological parameters are located in a separate vented container, protecting the sensitive elements from the direct solar radiation. The temperature and pressure are measured using a PDTK-0.1-1R quartz transducer (ElPA Specialized Design Bureau), and the relative humidity is measured with an HIH 3602 sensor (Honeywell). The sun sensor *1*, being a silicon photodiode with a scattering attachment is installed in the top part of the container and is used for detection of the "cloudless sun" situations. The decision-making is performed by comparing the sensor signal $U_{S1}(Z)$ with the predetermined threshold value $\Delta_1(Z)$ for every solar zenith angle Z (see Ref. 6).

The photometer is installed on a two-coordinate (zenith/azimuth) rotatable platform designed based on the UN-79 guidance system (Rastr Scientific Research Institute of Industrial Television). The guidance and tracking system includes also the module of coordinate photosensors (MCS) located on the front panel of the photometer. The MCS includes four photodiodes of the rough guidance circuit and the FD-142 four-sector photodiode (at the lens focus) of the precise tracking system, which controls the electric drives of the rotatable platform with the aid of the electronic circuits of difference signals.

The main part of the electronic circuitry of the photometer (Fig. 3) is the controller board, which includes the ADS7824P 4-channel 12-bit ADC (Texas Instruments), the driver for control of the stepper motor of the filter turret, the ATMEGA163 8-channel 10-bit ADC built in the RISC AVR microcontroller (ATMEL; www.atmel.com), which has all the attributes inherent in a standard computer (Fig. 4).

The 12-bit ADC converts the photodetector signals into the digital form, while self-diagnostic signals characterizing the SP-6 state and external conditions come to a 10-bit ADC. The microcontroller executes the following procedures: (*a*) synchronous detection of the modulated signal of the LW channel with its accumulation; (*b*) formation of the commands to turning-on of the guidance system and parking of the photometer; (*c*) diagnostics of the photometer position "operation—parking" and setting of the filter turret into the "0" position. The controller is controlled through the RS-232 serial interface, which is connected to the serial asynchronous transceiver of the microcontroller. The rate of exchange is 56 Kbit/s.

To meet the requirement of round-the-year open-air operation of the photometer, its sealed case houses a container with a silica gel drier and a double-circuit thermostat is used. The specifications of the model SP-6 sun photometer are summarized in Table 2.

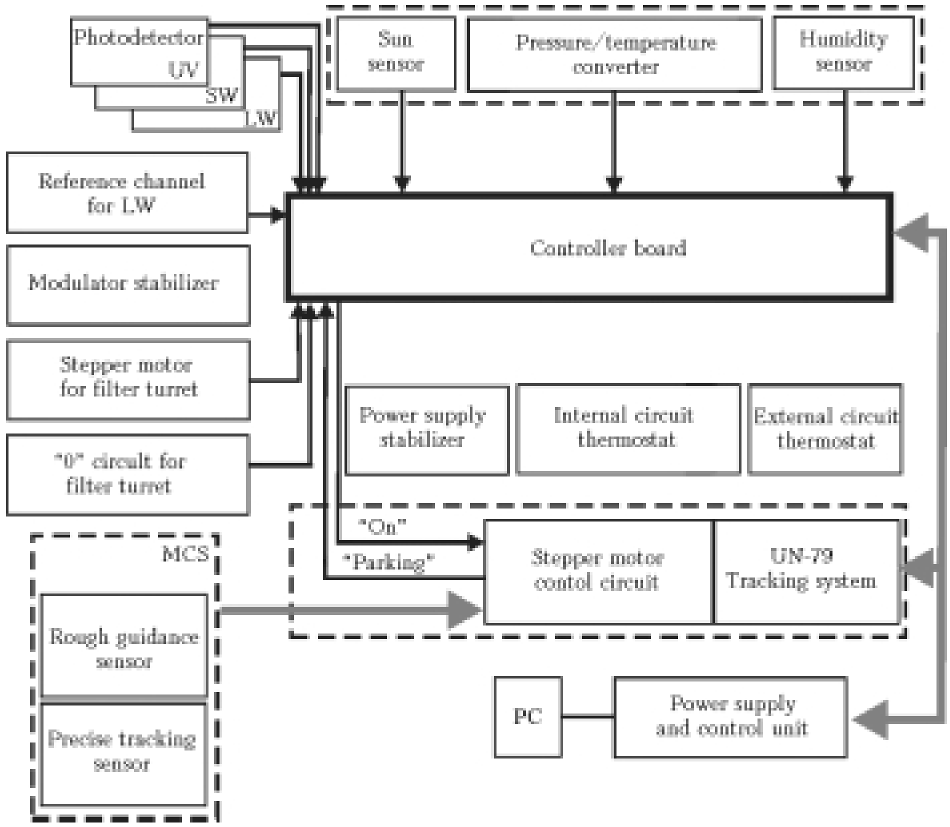

Fig. 3. Electronic circuitry of the model SP-6 sun photometer.

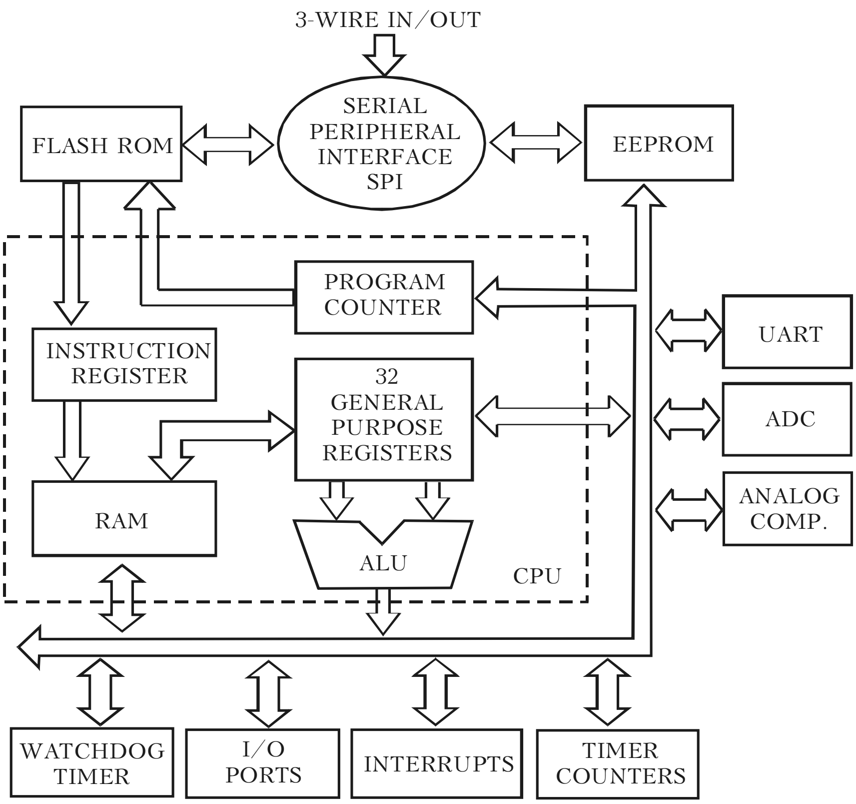

Fig. 4. Block diagram of the ATMEGA163 microcontroller.

Table 2. Specifications of the SP-6 sun photometer

Characteristic	UV channel	SW channel	LW channel
Field of view, deg	0.9	1.4	2
Number of wavelengths	5	7(8)	6
Filter pass bands, μm	0.31, 0.32, 0.34, 0.37, 0.41	(0.41), 0.44, 0.5, 0.55, 0.67, 0.87, 0.94, 1.05	1.25, 1.55, 2.06, 2.2, 3.3, 4.0
Halfwidth of the filter pass bands, nm	5–8	5–10	15–30
Sun tracking error, deg	0.2		
Time for measurement of a single spectrum, s	40		
Range of guidance angles (zenith×azimuth), deg	90 × 300		
Thermostat temperature, °C	(32–35) ± 0.3		
Ambient temperature, °C	–50 to +35		
Power supply (50 Hz), V · A	220 × 1		
Overall mass (estimated), kg	30		

3. Software and photometer operation

The photometer is intended for 24-hour round-the-year operation. The most operations are performed by commands from the program of the computer controlling the operation of the built-in microcontroller. Its software includes a set of procedures needed for maintaining the measurement process and pre-processing of signals from photodetectors and pressure and temperature sensors, as well as for control of the photometer mechanisms. To improve the reliability of operation, the microcontroller works in the mode with a watchdog timer, which resets the controller in case if some procedure does not respond and then turns it into the terminal mode, allowing the control program to keep the control. There is also a set of service procedures for self-testing. All the software is made in the Assembler of ATMEL AVR controller. The program consists of 877 strings.

The software for the computer is written in the Builder C++ environment and includes two programs: measurement and testing.

The measurement program is intended for controlling the photometer in the automatic operation mode, recording the measurement results into files, and displaying the experimental data for visual control. The diurnal cycle of the program includes two modes:

standby mode: (a) round-the-clock: every hour diagnostics of the photometer characteristics and meteorological parameters, including the control of ADC inquiries and filing the data into F_1; (b) daytime ($Z < 80°$): continuous inquiry of the solar sensor *1*, calculation of the zenith angle, making of the decision ($U_{S1} > \Delta_1$) to transition into the next mode;

active mode: (c) by the controller command (at $U_{S1} > \Delta_1$), automatic pointing of the photometer to the sun and setting of the filter turret into the "0" position; (d) comparison of the signals from the photodiode of the solar sensor *2* with the second threshold ($U_{S2} > \Delta_2$) and making of the decision to start measurements; (e) programmed control of the stepper motor rotating the filter turret and measurement of the signals in the UV, SW, and LW channels; (f) filing the data into F_2 with time registration; (g) in the situation of "sun covered by clouds" ($U_{S2} < \Delta_2$), switching the photometer into the standby mode.

Notes

1. At the scheduled diagnostics time, the active mode is interrupted for the inquiry of meteorological sensors (~30 s).
2. If the condition (d) fails, the photometer is turned into the parking state for the preset time (1 min), and the threshold Δ_1 increases by 5% to avoid following false activations of the guidance system.
3. To enhance the photometer efficiency under the conditions of broken clouds, the photometer is turned into the parking state with a lag of 1–2 min.
4. The experimental data, including both the measurement results (in the graphical and digital forms) and the additional information (current operation executed by the photometer, number and character of errors in the photometer operation during the day) are displayed in real time.

The content and the sequence of the procedures included in the measurement program are explained in Fig. 5.

The test program intended for setting and testing the operation of individual units of the photometer allows the simulation of the measurement process in the step-by-step mode.

Note that the information about the photometer (its geographic coordinates, the coefficients of the equations for calculation of the thresholds and meteorological characteristics, the sequence of the filters in the turret, and others) is included in the ini-file read at the start of both of the programs. This allows the programs to be fast adapted for operation with different photometers.

The appearance of the user interface is shown in Fig. 6, and the content of the F_1 and F_2 data files is given in Table 3.

The comparison with the CE-318 photometer operated in the automated network shows (Table 4) that SP-6 has the following advantages: (1) wider spectral region; (2) determination of the total ozone content; (3) meteorological data during the observations; (4) higher immunity to variations of the ambient temperature; (5) exclusion of false operation under the cloudy conditions. The AERONET network, due to application of the well-developed algorithms for solution of the inverse problems,[2] wins in the number of the aerosol characteristics reconstructed. Therefore, it is an important task for the next stage to develop the algorithms for inversion of the optical data: spectral AOD and the aureole scattering phase function in the solar almucantar, allowing automatic processing of the data arrays.

The operation of the SP-6 photometer only together with a computer can be considered as a disadvantage in comparison with the AERONET, but it is an interim measure. After finalizing of the measurement technology, more powerful microcontroller with a sufficiently large storage capacity and the network interface will be installed.

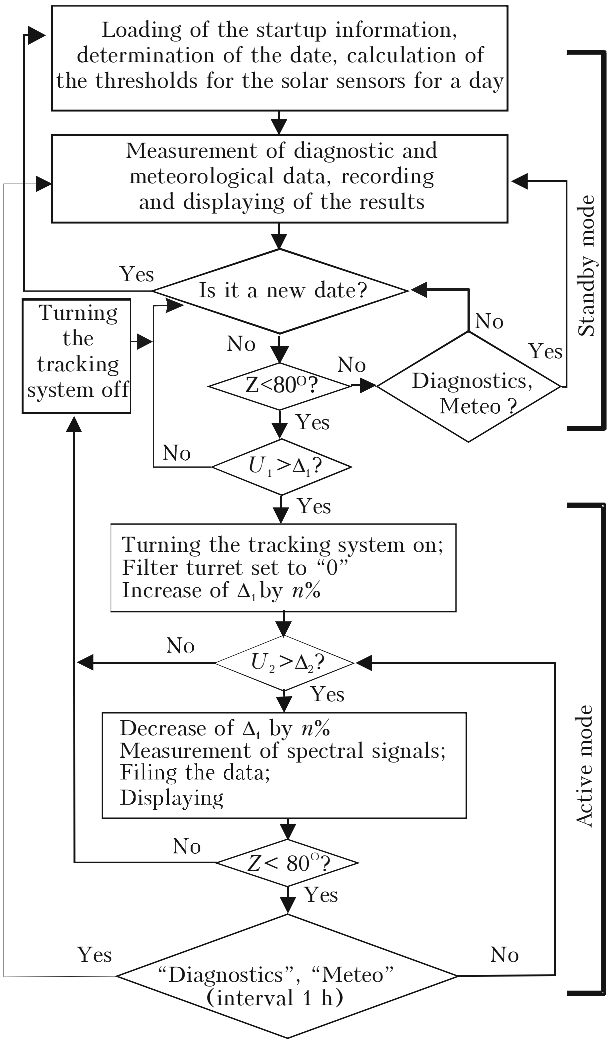

Fig. 5. Diagram of the measuring program.

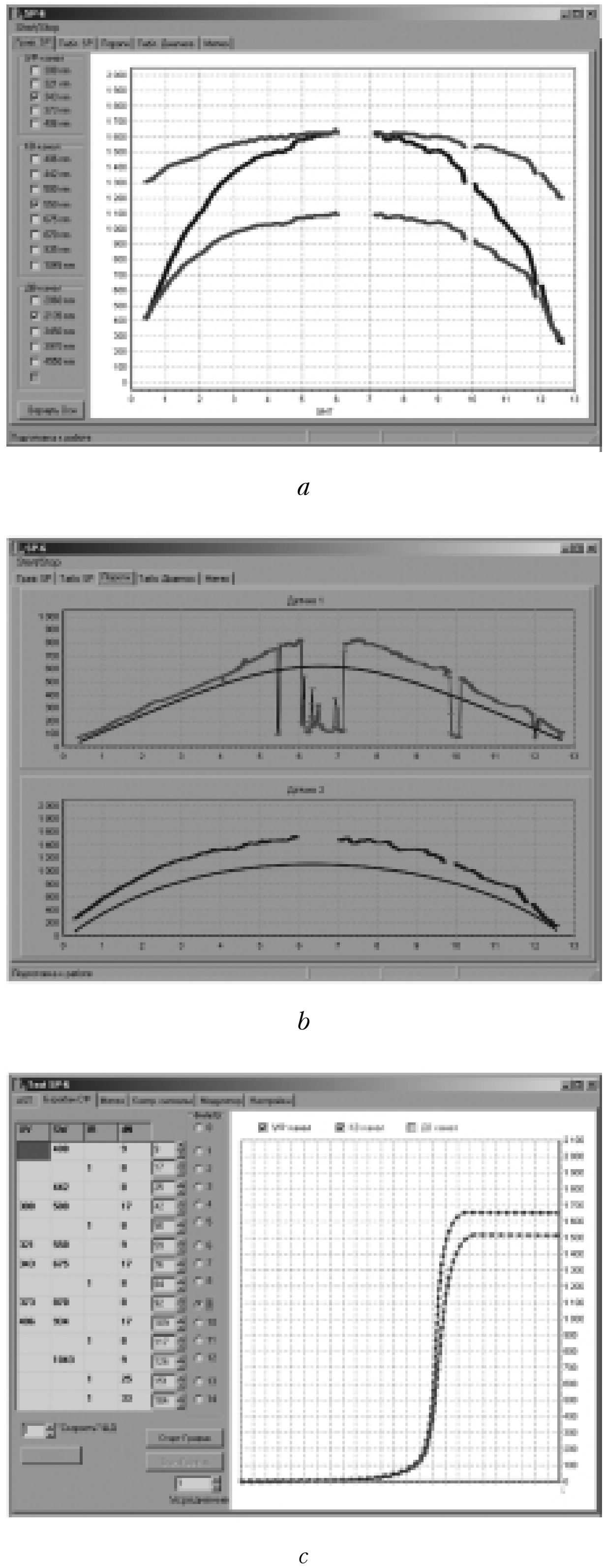

Fig. 6. Appearance of the user interface: measurement program in the mode of browsing the signals of the UV, SW, and LW channels (*a*) and signals from the solar sensors (*b*); test program in the mode of control of the filter turret and browsing of optical signals (*c*).

Table 3. Characteristics of the data files

File F_1									
		Meteo			Diagnostics				
#	1	2	3	4	5	6	7	8	9
Characteristic	Date, GMT	T, °C	P, mbar	RH, %	θ_1, °C	θ_2, °C	U_{sup}, V	F_{mod}, Hz	0 (1)*

File F_2																	
Channel		UV				SW				LW				Solar sensor *2*, modulator frequency	
#	1	2	3	…	6	7	8	…	15	16	17	…	22	23	24
Characteristic	Date, GMT	U_{noise}	U_{308}	…	U_{408}	U_{noise}	U_{408}	…	$U_{1.05}$	U_{noise}	$U_{1.25}$	…	$U_{4.0}$	$U_{(S2)}$	F_{mod}, Hz

* 0 denotes parking, 1 denotes operation. Meteo and Diagnostics are presented in the form of mean, minimum, and maximum values, and rms deviations.

Table 4. Comparison of network photometers

Photometer	CE-318 (AERONET)	SP-6
Measured radiation	direct and diffuse	direct
Spectral region, μm	0.34–1.02	0.3–4
Number of channels //filters	2//8	3//18
Determined characteristics	aerosol optical depth (0.34–1 μm); total content of H_2O; aerosol microstructure; single scattering albedo	aerosol optical depth (0.3–4 μm); total content of H_2O and O_3; temperature, pressure, humidity
Protection against ambient conditions	sealing	sealing and thermostat
Automation facilities	microcontroller	microcontroller + PC

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