INSTRUMENTATION COMPLEX FOR RADIATION INVESTIGATION

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The description and specifications of an instrumentation complex consisting of two sun photometers, a spectral pyranometer operating in the 0.3–1 μm *wavelength range, a remote pyranometer-reflectometer, a photoelectron meter of the sunshine duration, and a sky brightness photometer are given. It is noted that the developed instrumentation-software complex consisting of six meters connected with personal computers provides obtaining of real-time data on all key characteristics of shortwave radiation.*

Integrated radiation investigation is connected with long-term often continuous measurements of a relatively large amount of diverse parameters of the atmosphere and underlying surface. Among the principal characteristics, one should mention the integral and spectral components of the shortwave radiation (total, direct, scattered, and reflected ones), albedo of the underlying surface, spectral transparency of the atmosphere, total content of aerosol and gas components, etc.[1–3]

The necessity of continuous measurements is caused by the fact that the radiation parameters are characterized by very high variability of their amplitude and frequency range of oscillations. The maximum variations are caused by the motion of cloudiness typical of the majority of mid-latitude regions. For example, August in Tomsk is characterized by only two days with clear sky (the cloud amount $N_{cloud} \le 2$) and two days of continuous cloudiness,[4] the rest of the time the variable cloudiness is observed with corresponding variations of the incoming radiation components. Naturally, slower oscillations of the total content of aerosol and water vapor are superposed on the variability of cloudiness, thereby creating the complex structure of variations of radiation fluxes in the range from several seconds to a day and more. We mean the diversity of the parameters as not only the difference in the objects under investigation (aerosol, clouds, gases, and radiation), but also the difference in instrumentation, techniques for investigation, and regime of observations. Below we give some considerations that should be taken into account when creating modern radiation complexes.

1. Traditional investigation of the components of integral fluxes does not provide the complete understanding of the complex processes of energy exchange in the atmosphere–ocean–land system. The selective nature of interaction of gases, vegetation, and aerosol determines the corresponding transformation of the radiation budget components and “inner” redistribution of energy, which is not always manifested in the integral parameters.

2. The correct investigation of the reflected radiation, albedo, and shortwave budget can be carried out when the instruments are suspended over the underlying surface typical of the region rather than over the test section of an actinometric site.

3. To fulfill the requirements of modern measurement technologies, the general procedure of the integrated experiment should be optimized and individual instruments should be adapted to personal computers and field conditions.

To investigate the peculiarities of the radiation regime of Western Siberian region, a complex was developed at the Institute of Atmospheric Optics. It consists of six meters, the data from which are transmitted to two work stations of operators-researchers.

The following meters are included into the radiation complex (Figs. 1 and 2): AMSF–3 and –4 sun photometers, a remote suspended pyranometer-reflectometer (RPR), the SPUR spectral pyranometer, a photoelectron heliograph (PEH), and a sky radiance photometer (SRP). The common design feature of the instruments is that they are made as two modules: remote optoelectronic meters and control panels with a common power supply unit integrated into one block. The individual instruments are from 20 to 40 m from the control panel. The amplification and conversion of photodetector signals, sufficient for interference-proof data transfer through a long communication line, are realized in the remote blocks. The number of the primary measurable parameters is 68 and the number of the data channels is 24 (without taking into account communication lines of tracking systems, thermostats, power supply systems, etc.).

The integrated experiment is separated into two stages according to the following principle: meters with continuous recording (RPR, SPUR, PEH, and SRP) and instruments with discrete (on cycles) regime of observation (AMSF–3 and 4).

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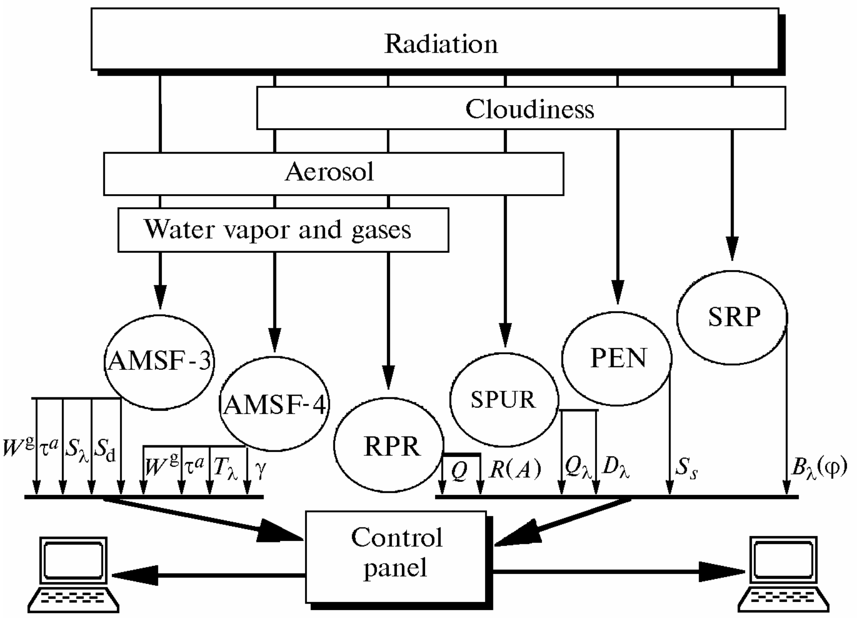

FIG. 1. Block-diagram of investigated parameters and meters. Here, W^g is the total content of gaseous components (H_2O, CO_2, CH_4, and N_2O); τ^a is the aerosol optical thickness (AOT) of the atmosphere; S_λ and S_d are the values of spectral and total direct solar radiation, respectively; T_λ is the spectral transparency of the atmosphere and cloudiness; γ is the aureole scattering phase function; Q, R, and A are the total and reflected radiation and albedo, respectively; Q_λ and D_λ are the spectral total and scattered radiation; S_s is the sunshine duration; $B_\lambda(\varphi)$ is the energetic brightness of the sky (clouds) at the viewing angle φ.

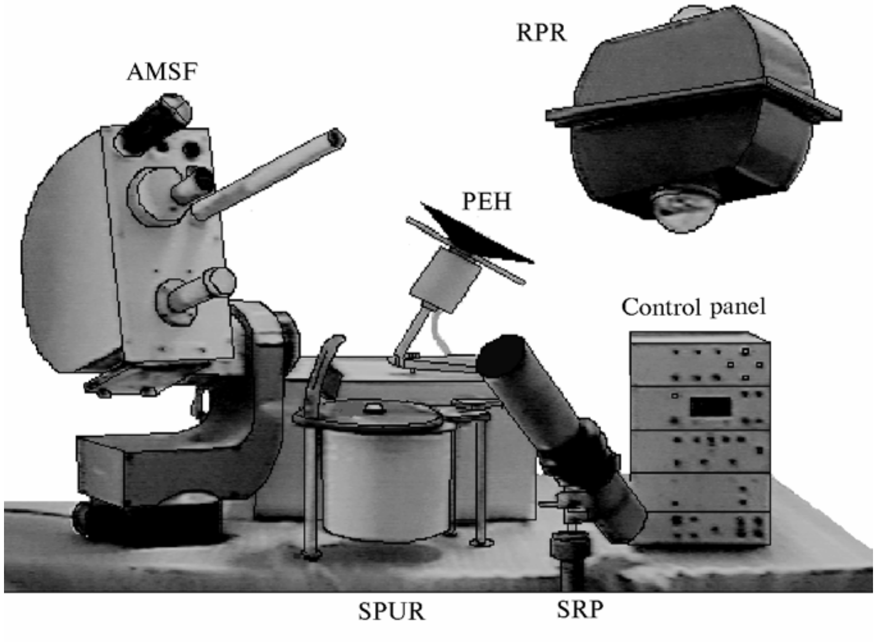

FIG. 2. External view of the radiation complex.

The data on 20 primary parameters are transferred in the continuous measurement group by 12 data channels. Three parameters (scattered radiation, albedo, and shortwave budget) are additionally reconstructed taking into account the data of the actinometric channel of AMSF–3. The number of measurable parameters and data channels is shown in Fig. 1 in the form of the fraction N_{par}/N_{chan}.

AMSF–3 and 4 sun photometers duplicate each other in measuring some characteristics, thereby increasing the reliability of investigations. At the same time, they solve two different problems.

The AMSF-3 (λ = 0.3–4 μm) is oriented toward measurement of the spectral aerosol optical thickness (AOT) of the atmosphere, total content of water vapor and gas components (TGC), spectral and integral direct radiation. The AMSF-4 is aimed at measuring the spectral optical thickness of semi-transparent cloudiness, spectral aureole scattering phase functions of the atmosphere and clouds, spectral transparency in wider range from 0.35 to 12 μm. The description and operation principle of the sun photometers were considered in detail in Refs. 5 and 6. We present here only the specifications of the photometers (Table I). The main regimes of operation of sun photometers are continuous cycles 15–30 min long every 1–2 hours at the solar elevation angle larger than 15°. Now we consider the instruments with continuous data recording during a day in more detail.

TABLE I. Photometer specifications.

Parameter	AMSF-3		AMSF-4	
	SW-channel	IR-channel	SW-channel	IR-channel
Angle of the field of view, deg	0.75	1	0.75	1.9
Number of spectral channels	12	6	8	8
Maximums and band half-widths of light filters, μm	0.37 (0.022) 0.409 (0.03) 0.425 (0.013) 0.439 (0.006) 0.485 (0.007) 0.514 (0.022) 0.553 (0.008) 0.638 (0.005) 0.673 (0.010) 0.870 (0.011) 0.940 (0.010) 1.061 (0.019)	2.182 (0.029) 2.32 (0.04) 2.06 (0.04) 3.9 (0.04) 4.0 (0.04) AP-1: 0.3–3.0 *	0.368 (0.019) 0.438 (0.008) 0.485 (0.008) 0.552 (0.008) 0.633 (0.009) 0.869 (0.015) 0.934 (0.010) 1.06 (0.020)	2.06 (0.04) 2.19 (0.03) 2.32 (0.04) 3.8 (0.11) 3.9 (0.04) 4.75 (0.13) 10.55 (0.24) 12.1 (0.35)
Frequency of modulation of IR-channel, Hz	–	180	–	280
Error in photometric evaluation, no more, %	0.3	0.7	0.3	0.7
Aureole angles, deg	–	–	0.75 – 6	
Angular resolution, deg	–	–	0.25	
Thermostat temperature, °q	35 ± 0.5		35 ± 0.5	
Output signal level, V	1–10			
Time of a measurement cycle (10–20 revolutions of a drum filter), min	1–2			
Error in tracking the Sun, deg	0.2			

* Spectral characteristics are given for the AP-1 actinometric channel[7] of the photometer.

SPUR spectral pyranometer is designed for automated multiwave measurements of the total and scattered radiation in the 0.36–1.06 μm wavelength range. Unlike the standard integral pyranometers,[2,8] the principal elements of the spectral instruments[9,10] are a diffusely-scattering or integrating attachment providing the cosine dependence of radiation reception within the hemisphere, a block of spectral selection (a monochromator, light filters, etc.) and a detector of photoelectric type.

The external view and block diagram of the remote block of the SPUR spectral pyranometer are shown in Fig. 3. When developing the instrument, some technical solutions of the AMSF sun photometers were used and improved.

The spectral pyranometer operates as follows. The fluoroplastic integrating attachment *1* provides reception of the total all-sky radiation and the quartz lens *2* focuses the rescattered radiation to the FPU-21 photodetector (developed at the Special Design Bureau of the A.F. Ioffe Physical-Technical Institute[11]). The FPU-21 (its hybrid-integral modification) consists of a siliceous photodiode and an amplifier with a gain switch. An additional matching amplifier serves for amplifying the FPU signals up to the level sufficient for their transfer through the long communication line and analog-to-digital conversion. Spectral selection of the received radiation is performed by means of the interference filters *4* mounted in the rotating drum. Automated control of the filter change is realized by the electron scheme *6* with synchronization from the optron *7*. Unlike the analogous block in the AMSF photometers, the drum filter rotates with variable rate – it slows when filters cross the optical axis and accelerates in the "dataless" intervals between the filters.

The scattered component of the radiation D_λ is measured by means of the shadow screen *8* which shields the scatterer *1* from the direct solar radiation when oriented toward the Sun. The correction factor introduced by the screen which shields a part of the sky does not exceed 2%. In the regime of a search for the Sun, the shadow screen with the Sun sensor *9* rotates about the vertical axis by the electric driver *10*. When the Sun comes into the view of the sensor ($\omega = 2°\times90°$), the "stop" signal is generated and is fed into the control scheme *12*. Rotation of the shadow screen is resumed after two measurement cycles (two revolutions of the drum filter). The threshold of the Sun sensor is set by the level of the minimum direct radiation under conditions of the cloudless Sun. This means that the shadow screen stops and D_λ is measured only for the open Sun disk.

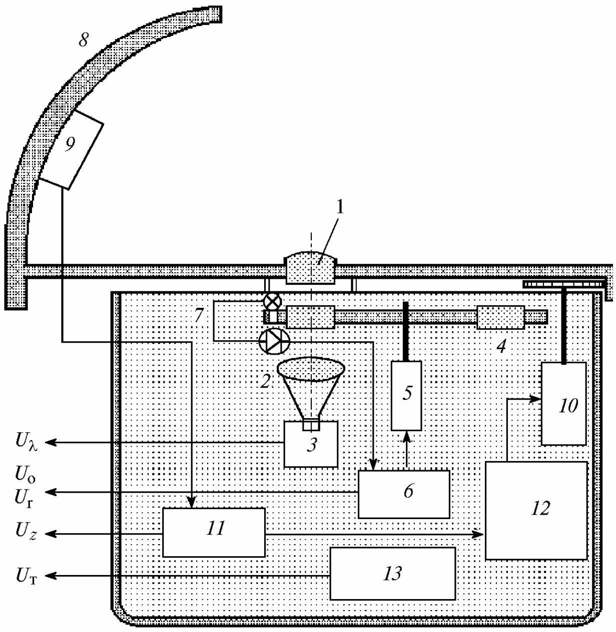

FIG. 3. Block-diagram of the spectral pyranometer: 1) scatterer; 2) lens; 3) FPU with a matching amplifier; 4) drum with filters; 5) and 10) electric drivers; 6) control scheme of the drum rotation; 7) optron; 8) shadow screen; 9) sun sensor; 11) generator of the Sun location signal; 12) control scheme of rotation of the shadow screen; 13) thermostat scheme; U_λ are signals of radiation fluxes Q_λ and D_λ; service signals: U_r is "reading"; U_0 is drum revolution ("cycle"); U_z is a stop of the shadow screen "toward the Sun"; U_T is thermostat operation indication.

To prevent sweating of the optical elements and to provide the normal conditions of operation of electronic boards, the inner cavity of the spectral pyranometer is thermostated.

Taking into account that the optoelectronic channel of measurable signals (FPU, amplifier, and ADC) is identical to that of the AMSF photometer, we did not study specially the error of photometric evaluation and it was estimated as 0.3% (for relative measurements).

The specifications of the spectral pyranometer are presented in Table II.

TABLE II. Specifications of the spectral pyranometers.

Parameter	SPUR	MFRSR–6
Number of spectral channels	8	6
Maximums and band half-widths of light filters, nm	370 (24) 440 (7) 484 (7) 550 (4) 692 (14) 869 (14) 940 (10) 1065 (11)	415 (10) 500 (10) 610 (10) 665 (10) 862 (10) 940 (10)
Time of a measurement cycle, sec	5–10	15
Error of photometric evaluation, %	1	1
Deviation from the cosine dependence at angles 0–80°, no more, %	18*	5
Overall dimensions of the remote block, mm	244×326×290	332×364×274

* Results of pilot experiments (not net results).

The specifications of the best modern analog – the MFRSR–6 multifilter radiometer[10] – are also presented here for comparison. The MFRSR–6 was developed at the Center for Atmospheric Researches of the New-York University for implementation of a number of radiation programs.

We note that both pyranometers, SPUR and MFRSR–6, have the water content measuring channel at a wavelength of 0.94 μm and allow the installation of any other light filters in the limits of sensitivity bands of their photodetectors.

Remote suspended pyranometer-reflectometer was developed for investigation of the short-term variations of the principal standard components of the solar radiation-total, scattered, and reflected – as well as of the albedo of the underlying surface and the shortwave budget (Fig. 4).

Two PP–1 thermoelectric pyranometers[8] oriented toward the upper and lower hemispheres are used in the RPR as radiation receivers. The remote part of the RPR includes amplifiers of pyranometer signals, schemes for heating of protective valves of pyranometers, an electromechanical block for semi-automated closing (opening) the housing, an illumination sensor "day-night," a two-coordinate suspension with a balance (counterbalance) for self-positioning of RPR by a horizontal level. Large distance of remote operation (no less than 40 m) allows to install the RPR on a mast or to suspend it over the area to be investigated at an altitude of 10–20 m. Development of the pyranometer-reflectometer as a remote instrument was caused by the necessity of carrying out measurements over the forest, the typical underlying surface of the Western Siberian region.

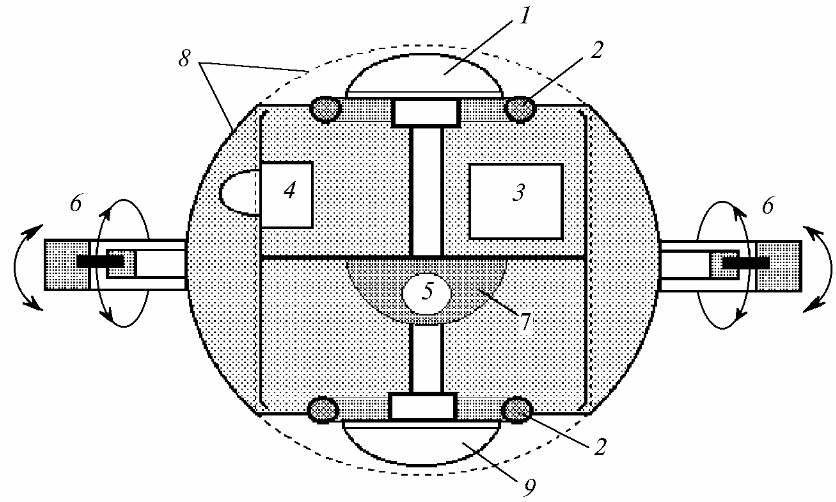

FIG. 4. General block-diagram of the RPR: 1) pyranometer; 2) heating schemes; 3) amplifiers of signals of pyranometric sensors; 4) illumination sensor "day-night"; 5) electromechanical block for closing (opening) the housing; 6) two–coordinate suspension; 7) balance; 8) protective housing; 9) reflectometer.

Automation of the RPR envisages bringing of the radiation block instruments into operation and switching on the computer with "on duty" program of measurements every morning. The RPR specifications are the following:

– range of shortwave radiation fluxes, kW/m^2 .... 0.01–1.5
– total conversion coefficient of the pyranometer, $V{\cdot}m^2/kW$ 6.5
– total conversion coefficient of the reflectometer, $V{\cdot}m^2/kW$ 27
– operation distance of the remote block, m 40
– relative acceptable principal error of the sensors, no more than, % 6
– overall dimensions of the remote
– block, mm .... 370×180×320.

Photoelectron heliograph is the most simple instrument of the radiation complex destined for measuring the sunshine duration (SSD) during any given time or the day as a whole. High correlation of the SSD with the total radiation[1–3] and the daytime average cloud amount makes this simple parameter very useful for carrying out the integrated experiments.

Physical and methodical basis of measuring SSD is separation of the direct solar radiation component from the total flux of incident radiation, its comparison with the threshold value (corresponding to the open Sun), and then determination of the instant when it exceeds the threshold. The external view and block-diagram of the PEH are shown in Fig. 5.

To separate the direct radiation flux, screens and diaphragms are used that decrease the scattered radiation contribution. The screens *1* and *2* form the field of view of the photodetector *3* in the plane of solar equatorial with linear angle of view in the vertical plane ~27°. The photodetector includes three photodiodes *4* with diaphragms oriented so that their total angle of view in the equatorial plane is no less than 270°. When the Sun moves in the sky, it always remains in the field of view of one of the photodetectors. Solid angle of view of each detector is 0.785 sr, which provides the decrease of the effect of the scattered radiation approximately 8 times. The additional decrease of the background radiation is obtained by substracting the minimum signal ("background") from the maximum one ("background+Sun"). The current value of SSD is displayed by a 4-bit indicator of the control panel and simultaneously is transmitted to the computer.

The PEH specifications are the following:

– measurement range of SSD, h 0–99.99
– resolution, h 0.01
– sensitivity threshold of the photodetector is set equal to the threshold of the GU–1 heliograph, W/m^2 100
– minimum solar elevation angle corresponding to the threshold, deg 3
– overall dimensions, mm .... ∅170×220

Sun radiance photometer is included into the radiation complex for measuring the energetic brightness of the sky and clouds along individual viewing directions.

The SRP is constructed by the simple scheme using the Gelios–40–2 commercial photoobjective, a changeable interference filter, the FD–24k siliceous photodiode, and the amplifier with gain switch. The photometer is mounted on a support or on a two-coordinate turntable for orientation in the given direction of the upper hemisphere.

The SRP specifications are as follows:

– input window diameter, mm 57
– linear angle of the field of view, deg 1
– wavelength range, μm 0.55
– azimuth viewing angles, deg .... 0–360.
– zenith angles, deg............ 0–90
– error of photometric evaluation, % 0.3
– overall dimensions, mm .... ∅80×360

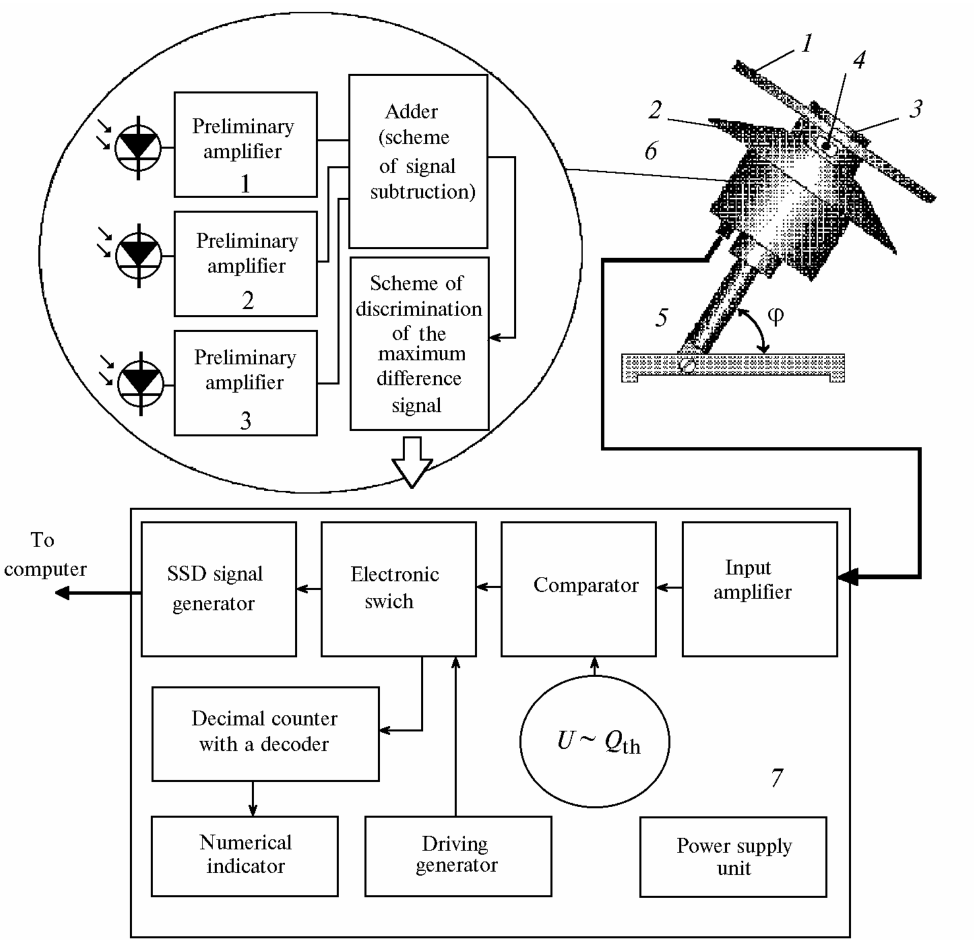

FIG. 5. External view and block-diagram of the photoelectron heliograph: 1) and 2) screens; 3) photodetector block; 4) photodetector; 5) axial rod for latitude installation; 6) electronic board of preliminary processing of SSD signals; 7) indicator block diagram.

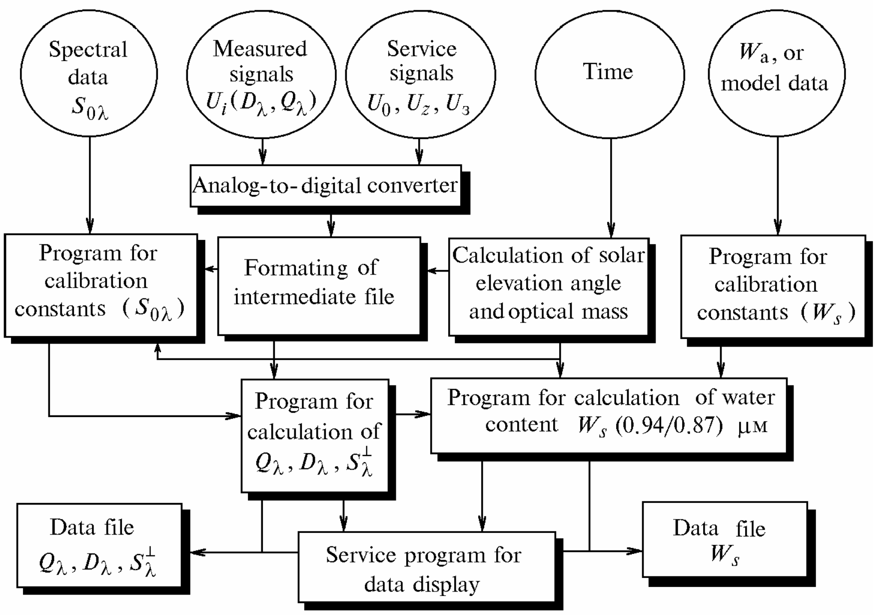

FIG. 6. Schematic diagram of signal processing when measuring the spectral components of shortwave radiation and water content.

Signals from individual meters are transmitted to their own control panels (blocks) and then to the analog-to-digital converters built in the computers PC–386 (486). The created software provide primary data processing in real time, display of graphic and numerical data on the computer screen to control the experiment. One of the programs is shown in Fig. 6.

We note in conclusion that individual meters have different degree of readiness. The AMSF and SSP photometers were used in field experiments and yielded good results before updating. A prototype of the photoelectron heliograph was tested in 1995 under real conditions, resulting in its further development. Finally, two last instruments, RPR and SPUR, were created in 1996 and were tested and adjusted under laboratory conditions.

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