MONITORING OF RADIATION FLUX WITH THE *SUN* AUTOMATED SYSTEM

V.A. Rozental', N.E. Chubarova, O.M. Izakova, and G.A. Sharaev

Meteorological Observatory at the M.V. Lomonosov Moscow State University

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The SUN automated system has been developed for monitoring of radiation flux. The SUN hardware and software corresponding to the standards of the Main Geophysical Observatory are described in detail in this paper. Two-year tests of the system conducted by the Meteorological Observatory at the Moscow State University have demonstrated its reliability and ease of use in radiation measurements. The data obtained and processed with the SUN system were used in analysis of spectral regularities of solar radiation extinction.

INTRODUCTION

Monitoring of solar radiation flux allows solution of a large number of problems in science and technology. It serves for estimation of geoclimatic resources of different geographic regions, validation of radiation parts of existing climatic models of the atmosphere, and solution of various applied problems. In particular, monitoring of solar radiation flux is of great importance under urban conditions. An urban area is a very powerful source of gaseous pollution of the environment. At the same time, it consists of various local sources, what forms a sufficiently nonuniform pattern of pollution and requires observations to be conducted at different sites. Monitoring of solar radiation in towns and neighboring rural regions can be used as an indirect measure of urban air pollution. Thus, for example, the direct solar radiation in Moscow is known to be lower, on average, by 9% than in the adjacent rural regions. In fall and winter, this difference may reach 17% (Ref. 3). Based on the calculated parameters found from long-term radiation flux measurements it was also shown that the mean annual values of the aerosol optical depth in Moscow is higher by 27% than in the nearest rural regions (within the 30–km zone) and by 75% higher than that measured at a distance of 100 km to the west from the city center.[3] Routine spectral measurements of solar radiation allow reconstruction of concentrations of the minor atmospheric gases (O_3, NO_2, and others) using the known methods as well. Thus, the type of pollution of the urban environment can be determined more specifically.

The nowadays radiation flux monitoring is conducted in Russia at the network of specialized stations in the form of periodic observations or in the form of recordings performed with a KSP–4 multichannel potentiometer.[5] According to estimates made in Ref. 2, manual processing of KSP–4 tapes introduces additional 5% error into the radiation measurement data. Periodic observations certainly cannot give the complete pattern, and they increase the measurement error by 3% on average (Ref. 2). A particular attention is now paid to an increase in the accuracy and reliability of radiation measurements.[9] The automated recording systems known as data loggers have long been in use for such purposes in foreign countries. However, they are inconvenient for use in the routine mode, because they do not allow an operator to look through plots of the parameters measured and to correct them when needed. These systems are very expensive (more than − 3 000), what restricts their use at all sites of the observational network. Russian laboratories are also dealing with the development of automated systems for gathering actinometric information. In particular, such systems are being developed at the Institute for Atmospheric Physics[6] and Institute of Atmospheric Optics.[4] However, their systems are intended basically for use in research radiation experiments, and the developed software does not provide for a convenient interface and standard output information corresponding to the requirements of the Main Geophysical Observatory (MGO). Thus, these systems do not allow unification of measurements all over the Russian network of actinometric stations. These circumstances have initiated the development of compact, reliable, and inexpensive equipment for acquisition and preliminary analysis of radiation measurements, which would allow monitoring of solar radiation in different regions, as well as software for processing the results obtained.

Such an automated system has been developed by the Meteorological Observatory (MO) at the Moscow State University mainly for monitoring of solar radiation flux, estimation of the overburden of anthropogenic origin coming from a town, as well as for use in radiation experiments.

DESCRIPTION OF THE *SUN* SYSTEM

The SUN system is a system for acquiring and preliminary analysis of the radiation measurement data. When necessary, it can be equipped with a set of supplementary sensors like, for example, temperature and pressure sensors, and others. The system is shown schematically in Fig. 1.

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The instrumental part of the system is interfaced to a computer and characterized by small size (20 × 30 cm) and mass (about 1 kg). Up to 15 various sensors can be connected to it by use of shielded twisted pairs.

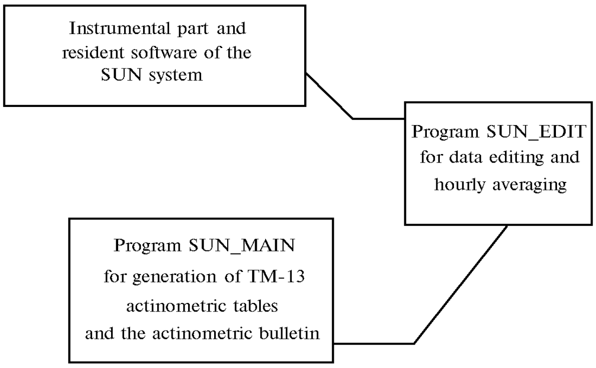


FIG. 1. Block-diagram of the SUN system.

As known, the devices that are used to measure components of the radiation balance are mostly thermoelectric and low-sensitive.[7] Among foreign devices, most reliable are also the thermoelectric ones, for example, Epply (USA) or Kipp&Zonen (Netherlands) devices. They are also characterized by low sensitivity (8 – 11 $\mu V/(W{\cdot}m^{-2})$ according to Ref. 8). Therefore, the SUN system was developed and adjusted for operation with sensors, whose output signals vary from 8 μV to 30 mV, what, in its turn, requires sufficiently wide dynamic range of the system about 70 dB. With an additional coupling unit, measurements can be conducted with the devices having an output signal higher than the 30-mV limit.

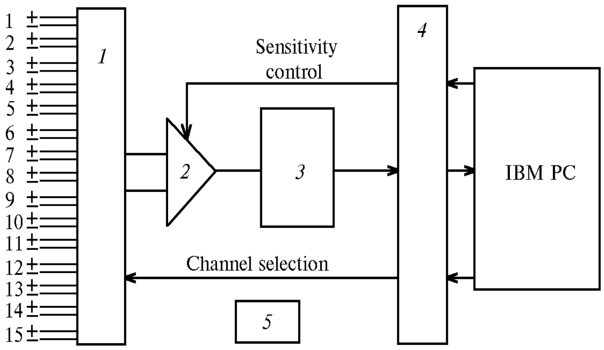


FIG. 2. Block diagram of the instrumental part of the SUN system.

The instrumental part of the system (Fig. 2) consists of a 16-channel input switch *1* (15 measuring channels and the channel for adjusting to zero), differential amplifier with a variable gain *2*, voltage-to-frequency converter *3*, optical interface to a computer *4*, and power supply *5*. In response to control signals coming from a computer, sensors are in turn connected to the amplifier *2* via the switch *1*. The gain factor of the amplifier *2* is set corresponding to the sensor sensitivity under the action of control signals. The possibility of using several levels of sensitivity is provided for in every channel. Thus amplified signal is converted into frequency in the converter *3*. Then it comes to the serial port of the computer through the optical interface *4*. In every cycle of sensor polling, the measurement system is automatically compensated for the drift of zero. The measurement error is below ±0.5%.

The system works with an IBM PC while being connected to it through the standard serial port with the help of the resident program, which is periodically activated for polling of sensors connected to the system. The measurement data are stored in the main and backup files to prevent data loss in the case of power supply failure. The resident part of the software occupies about 14 K. The polling period equal to 1 min was chosen with regard for the time lag of the Yanishevskii thermoelectric device widely used in the network of actinometric stations.[7] At midnight (00:00 L.T.) a pair of files is created with the unique name DDMMYY.dat (date, month, year). The main characteristics of the measuring system are presented in Table I.

TABLE I.

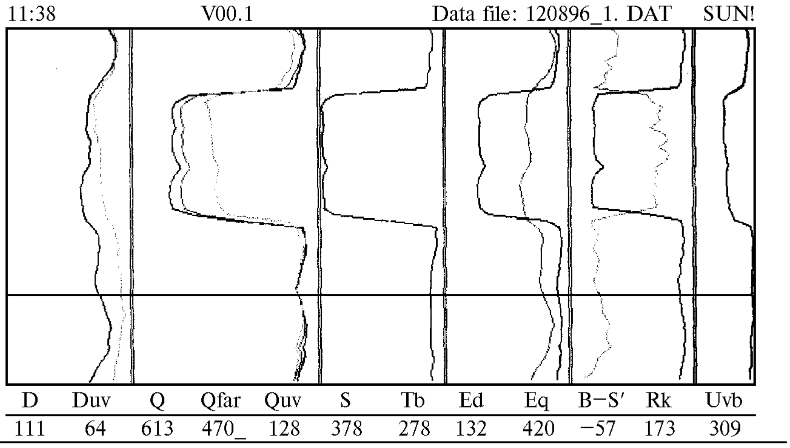
Polling period	1 min
Polling time for one sensor	0.11 s
Gain factors	K_1 = 3.5; K_2 = 10.5; K_3 = 32.2

For further viewing and editing the data prepared by the resident program, the program SUN_EDIT has been developed. It provides the convenient graphic interface for simultaneous viewing of records in all the spectral channels (Fig. 3).

The program allows real-time graphical presentation of the results of actinometric measurements. Besides, it allows an operator to edit curves and to print out data on the diurnal cycles. The program performs hourly averaging of the data measured every minute, determines the diurnal maximum values of radiation flux, and saves the information in text files.

All the main settings of the program storing the information about mutual positions of plots, zero position, and sets of the calibration coefficients are in the text configuration file (*.cfg), which can be viewed and edited with any text processor.

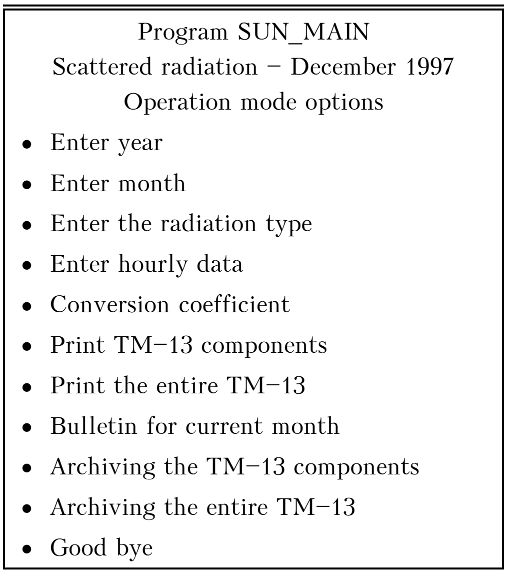
In the case of known calibration characteristics of the devices used, the program enables converting the data into absolute units at the stage of hourly averaging. Another possibility is to estimate the conversion factors by the MGO technique,[5] when a conversion coefficient for some measuring device is estimated from a comparison with the reference measuring devices during one month. The SUN_EDIT program creates the calibration files (*.cal) and fills them with the data from measuring devices corresponding to the time of observation with a reference device.



D	Duv	Q	Qfar	Quv	S	Tb	Ed	Eq	B−S′	Rk	Uvb
111	64	613	470_	128	378	278	132	420	−57	173	309

FIG. 3. Example of solar radiation flux records in different spectral ranges taken on August 12, 1996, in the Meteorological Observatory at the Moscow State University.

All text files created by the SUN_EDIT program are imported (with the help of a special program convert.exe) into the SUN_MAIN program intended for generation of the TM−13 standard actinometric tables and the actinometric bulletin. Figure 4 demonstrates the menu of the SUN_MAIN program.


Program SUN_MAIN
Scattered radiation − December 1997
Operation mode options

- Enter year
- Enter month
- Enter the radiation type
- Enter hourly data
- Conversion coefficient
- Print TM−13 components
- Print the entire TM−13
- Bulletin for current month
- Archiving the TM−13 components
- Archiving the entire TM−13
- Good bye

FIG. 4. Menu of the SUN_MAIN program for measurements of the scattered radiation conducted in December of 1997.

This program was developed for processing radiation flux values measured in MO (Table II). Besides, it provides the possibility of editing the number and types of radiation sensors and to change the latitude of the observation site, what makes it versatile for use in different geographic regions.

Upon converted, the imported data can be viewed by double clicking “show hourly dataB in the program menu. These data can be edited if needed.

The results of calibration by the MGO technique[5] can be presented graphically or edited, if necessary, by double clicking the “Conversion coefficientB option on the menu.

TM−13 tables consist of hourly data on the basic kinds of solar radiation. Daily, ten-day, and monthly sums of radiation are given in these tables, along with the monthly mean values. For some kinds of radiation, for example, UVR and FAR measured in MO, the provision is made for estimation of their part in diurnal sums of total and scattered integral radiation. The table of reflected radiation contains the values of the underlying surface albedo (%) calculated for daily periods. The TM−13 tables for the radiation balance b and total short-wave radiation Q are obtained by calculating, using known actinometric formulas.

To provide users with routine meteorological information for the standard observation period, the program also generates the bulletin of meteorological information, which includes, as its part, the data of radiation flux monitoring (select “Bulletin for the current monthB from the menu).

The program also provides the possibility of exporting data from the main TM−13 tables into ASCII codes (select (Archiving TM−13 components) or (Archiving entire TM−13) from the menu), as well as exporting data into the MGO format.

During two years, starting from 1994, the measurements were performed in parallel with a KSP−4 potentiometer and the SUN system. The results of these measurements show that transition to the SUN system does not violate the uniformity of series of solar radiation measurements. Since May of 1996 the measurements of solar radiation flux in MO have only been conducted with the SUN system. Besides application of the SUN system in routine actinometric observations, it was also used in scientific experiments, in particular, during Zvenigorod complex experiment in 1994 on studying spectral behavior of solar radiation extinction by cloud fields.[1] Figure 3 exemplifies the regularities revealed by the records of radiation flux acquired with the SUN system. In this case, the system operated in the mode superimposing the total radiation flux all over the spectral range (Q), as well as in the visible range (Q_{FAR}) and in the UV (Q_{UV}).

TABLE II. Characteristics of the solar radiation flux recorded in MO and processed with the programs SUN_EDIT and SUN_MAIN.

Radiation flux	Recorded characteristics	Calculated flux	Equation used for calculation
Direct radiation incident on the normal surface	S	–	–
Direct radiation incident on the horizontal surface	S'	–	$S' = S \sin h$
Scattered integral radiation	D	–	–
Reflected radiation	Rk	–	–
Radiation balance without direct solar radiation	$B - S'$	–	–
Radiation balance	–	B	$B = (B - S') + S'$
Total integral radiation	Q^1	Q	$Q = D + S'$
Total UVR	Q_{UV}	–	–
Scattered UVR	D_{UV}	–	–
Direct UVR	–	S'_{UV}	$S'_{\mathrm{UV}} = Q_{\mathrm{UV}} - D_{\mathrm{UV}}$
Total FAR	Q_{FAR}	–	–
Total irradiance	Eq	–	–
Scattered irradiance	Ed	–	–
Direct irradiance	–	Es'	$Es' = Eq - Ed$

[1] The total integral radiation is measured as a control quantity and is used only for reconstruction of direct or scattered integral radiation, when necessary.

It is clearly seen that the flux of UV radiation varies within a less wide range as compared with the visible and integral radiation, when no clouds obscure the sun disk and when the sun disk is obscured by a dense cloud (see the drastic decrease of the direct radiation S in the third column). This can be explained essentially by the nonlinear relation of the total radiation with the optical depth of the atmosphere. This relation manifests itself in the fact that at clear sky the fraction of direct radiation in the total UV radiation flux is far less than in the visible or integral radiation flux. With the increasing optical depth (because of cloudiness), the total UV radiation flux is slowly attenuated. Correspondingly, when the sun is obscured by a dense cloud, the direct radiation is fully screened, while the total UV radiation (Q_{UV}) is less attenuated than the visible and integral radiation.

CONCLUSIONS

We have developed a convenient system for acquiring and processing data on radiation flux. This system meets the basic MGO requirements. The system has successfully passed through a two-year verification and validation phase, and since May of 1996 is the basic system for radiation measurements in MO.

The SUN system may prove to be very helpful for routine monitoring in actinometric laboratories at various observation sites all over the Russia, as well as in various scientific experiments.

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