WIDEBAND SOLAR PHOTOMETER FOR STUDIES OF THE MARINE ATMOSPHERE

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A description of a multiwavelength (14 spectral channels) solar photometer for studying the atmospheric thickness in the spectral range from 0.4 to 12 μm onboard a ship is presented. In addition to two measurement channels there are an automated sun–tracker and a TV control system in the photometer. The system functioning control and recording of signals in a digital form can be carried out from a control desk or from a minicomputer.

The method of solar spectrophotometry of the atmosphere (determination of optical thickness) is one of a few methods which could be correctly used for studying the optical features of aerosol onboard a ship. The realization of this comparatively simple method under maritime conditions is hampered by the specific conditions of measurements onboard a ship––rolling and vibrating of the ship, a need for precise control of coordinate measurements, a limited field of view due to available masts and different constructions, and the use of long–wave communication lines. Some further difficulties emerge when the measurements are carried out within a wide spectral range which require several measuring channels. The familiar developments and investigations were confined to the shortwave 0.4–1 μm (see, e.g., Ref. 1) or in a single case 2–14 μm spectral range.[2]

Taking into account what has been said above, an automated marine solar photometer (AMSP) for the 0.4–12 μm spectral range was developed at the Institute of Atmospheric Optics. The photometer was designed accounting for experience of operation of a similar instrumentation (a shortwave photometer) onboard the research vessel "Akademik Vernadskii" in 1989 (see Ref. 3).

The solar photometer has been updated after a three–month run of the AMSP tests and of the atmospheric thickness measurements during the 43rd voyage of the vessel "Akademik Vernadskii" in 1991. Its last version is described in our paper.

The AMSP is intended for measuring the optical thickness of the atmosphere for the purposes of developing the methods of spaceborne sounding and of solving the climatic and ecological problems. In particular, during the integrated expedition SATOR (Tomsk, 1992) the AMSP was used to measure not only the aerosol optical thickness but also an integral content of water (0.94 μm absorption band) and ozone (9.5 μm absorption band).

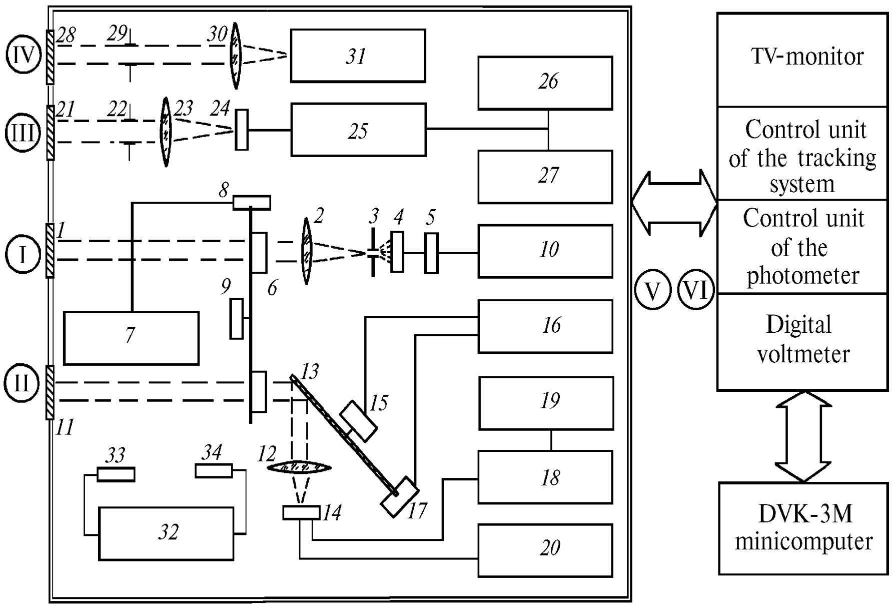

FIG. 1. Block diagram of a solar photometer: 1,11, 21, and 28) input windows; 2, 12, 23, and 30) single–lens objectives; 3, 22, and 29) diaphragms; 4) matt scatterer; 5, 14, and 24) photodetectors; 6) light filters; 7) scheme of filter switching; 8 and 17) optronic pairs; 9 and 15) electric motors; 10 and 18) preamplifiers; 13) mirror modulator; 16) modulator stabilization circuit; 19) selective amplifier; 20) stabilized supply circuit for photodetector; 25) mismatching signal circuit; 26 and 2) zenith and azimuthal electric drives; 31) commercial TV system; 32) thermostabilization circuit; 33) temperature–sensitive element; and, 34) electric heater.

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The AMSP general configuration (Fig. 1) incorporates four independent opto–electronic channels whose optical axes are aligned in a single direction:

– shortwave measuring channel (I),

– longwave measuring channel (II),

– aiming system and automated sun–tracker (III), and

– TV system for control of aiming (IV).

An opto–electronic part of the AMSP photometer (V) with a double–coordinate rotating desk is made as a separate construction (Fig. 2) and was positioned (during the 43rd voyage) at a direction–finding deck of the vessel. The photometer frame was made hermetic with automated heating for its protecting from sweating and humid air.

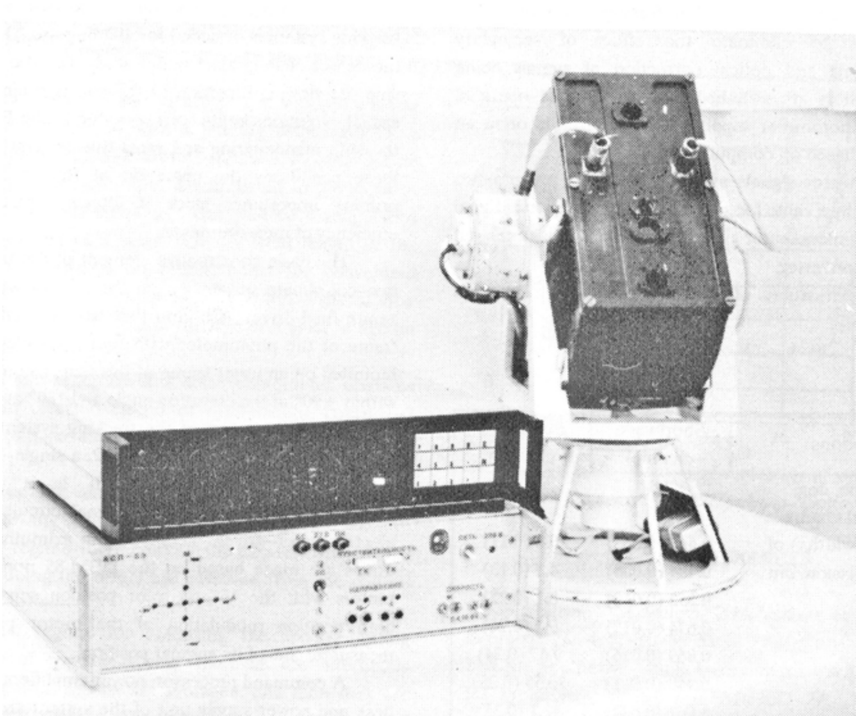

FIG. 2. Appearance of the AMSP photometer.

The AMSP control units with analog–to–digital converters (VI) and the DVK–3M minicomputer were mounted at the 15–20 m distance from the outlying part of the photometer at the vessel laboratory.

To eliminate the effect of long communication lines on informative and control signals all the electron boards subjected to the influence of noise were located in a hermetically screened frame of the photometer and their electromagnetic compatibility was provided.

The TV system incorporated into the AMSP was used for remote control of the measurements during which cloudiness and constructions of the ship could fall into the photometer field of view in the course of the ship manoeuvring and rolling. This is of particular importance when the signals are automatically recorded by the computer.

In developing the AMSP the field–of–view angles of the optical schemes were interconnected with dynamic characteristics of the tracking system (angular velocities and accelerations). The initial requirements for the AMSP operation were the mean angular velocities of the ship rolling below 6 deg/s and the range of angular rolling below ±15°. The error in the sun tracking must not exceed 0.2–0.5° in the working range of angles 180° (in azimuth) and 85° (at an angle of elevation). Taking into account these requirements as well as the need for minimizing the effect of scattered radiation in a shortwave channel[4] and background radiation of the sky in the IR channel, the field–of–view angles of the measuring channels were chosen as the optimal ones within the limits of 1.5–2°.

There arise difficulties associated with the development and combination of such opto–electronic schemes of four channels of the AMSP which, according to their weight and dimensional characteristics, could be applicable for a high–speed tracking system.

A shortwave measuring channel. An optical scheme of the short–wave channel of the photometer (Fig. 1) consists of an input window of a correcting light filter *1*, a single–lens objective *2*, a field diaphragm *3*, a matt scatterer *4*, and a PD–24K silicon photodiode *5*. The spectral selection of radiation is performed with seven interference filters *6* positioned in the wheel which is rotated (switches the filters) by signals generated with a filter switching circuits *7*. Code controlling signals are formed with optronic pairs *8* optically connected with the filter wheel.

The required filter is installed by bringing an engine (*9*) into stop at an appropriate position and is fixed with an electromagnetic holder from random displacements. In each spectral channel in addition to an interference filter there are pigmented glasses to eliminate the effect of secondary transmission maxima and optical correction of signals being measured. The filters are switched either in a hand–operated regime from the photometer supply and control units or in an automated regime based on computer instructions.

The photodetector signals are amplified with preamplifies *10* and transmitted by a cable for subsequent recording to a digital voltmeter or to a minicomputer after their smoothing by a ten–bit analog–to–digital converter.

The basic specifications of the AMSP measuring channels are listed in the table.

TABLE I.

Specifications	Shortwave channel	Longwave channel
Field–of–view angle, deg.	1.5	1.9
Number of spectral channels	7	7
Maxima (and halfwidths) of light–filter transmission, μm	0.447 (0.038)	3.8 (0.11)
	0.484 (0.008)	4.7 (0.13)
	0.552 (0.010)	8.1 (0.22)
	0.674 (0.012)	9.1 (0.24)
	0,869 (0.016)	9.47 (0.24)
	0.940 (0.011)	10.55 (0.25)
	1.061 (0.022)	12.1 (0.35)
Optical signal modulation frequency, Hz	0	140
Measurement error, % (not higher)	1	5
Time interval of a single run of measurements, min	1–2	

A longwave measuring channel. An optical scheme of the IR channel consists of a germanium input window *11*, a coated–menisc lens *12* made of optical ceramics PO–4, a mirror modulator *13*, and an MG–30 piroelectric photodetector *14*.

Two pairs of planes of the mirror modulator are deflected at an angle of 1° with respect to each other. As a result, during the modulator rotation the radiation from the sun and neighboring areas of the sky are alternately directed to the photodetector. Thus the contribution of the sky background radiation coming into the field of view of the IR channel is excluded from the recorded difference signal.

The rotational rate of a DPM–25 modulator engine *15* is stabilized with an electronic stabilization circuit *16* with feedback from an optronic pair *17*.

The spectral selection is performed with seven interference and disperse light filters positioned in the same wheel in pairs with filters of the shortwave channel. For optical smoothing of the measured signals the corresponding limiting diaphragms are positioned in front of every filter.

A signal from the photodetector after preamplifier *18* is fed to a selective amplifier *19* made of active low– and high–frequency filters and then it is transmitted by a long communication line for recording.

The aiming system and automated sun–tracker. The tracking system is intended for aligning the AMSP optical axes to the center of the object under study, i.e., the sun. Onboard the ship the viewing direction to the sun is subjected to substantial spatial evolutions being both slow due to the Earth's rotation and the ship manoeuvring and rapid due to angular rolling. Under these conditions the operation of the tracking system is of primary importance since it affects directly the error and efficiency of measurements.

The basic constructive element of the tracking system is a two–coordinate suspension on the axes of which azimuthal and zenith final drives with limit switches are mounted. A hermetic frame of the photometer with four opto–electronic channels is mounted on an inner frame of the suspension and can be moved within ±90° at the elevation angle and 180° at azimuth.

An outlying part of the tracking system includes an input window *21*, a limiting diaphragm *22*, a single–lens objective *23*, a sun–direction sensor *24* which is a FD–142 quadrant photodetector, a mismatching signal circuit *25*, and actuating electric direct–drives: zenith *26* and azimuthal *27*. The electric drives are made based on the DBM 85 noncontact dc electric motors with the VT–60 rotor–position sensors which provide both position modulation of the motor phase currents and measurements of its angular position.

A command processor, power amplifiers as well as a control desk and power supply unit of the system are placed in an self–contained body –– a control unit of the tracking system. Switches, which are mounted on a front panel of the control unit, change modes of the system operation (search/capture).

In the search regime the electric drives are closed with respect to an angular position of the corresponding axes of a suspension. A phase–modulated signal is fed to these electric drives as control signals. Its modulation depth and sign are assigned by the operator from the control desk and they determine the rate (including a zeroth one) and direction of electric drive rotation. Such a construction of a discrete phase closed electric drive enabled one to exclude multidigit converters usually used in digital control systems and to simplify the processing of signals received from angular position sensors.

A search for an object is performed using a control TV device and based on signals of a target LED indicator on the control desk. When the sun is detected the operator sets the regime "CAPTURE" that makes it possible to connect the electric–drive feedbacks to mismatching signal circuit of the sun direction sensor. By processing these mismatches the drives align the optical axes of the photometer to the sun. An angular zone of synchronization of the tracking system is ±3° about both of the axes and is quite sufficient for ensured capture and automated tracking of the target object.

The power amplifiers operate under conditions of two–stroke cycle pulse–duration modulation and provide regulation of electric–drive phase currents in the range of amplitudes ±6 A and in the band of working frequencies up to 2 kHz. In this case dynamic angular errors in the tracking system do not exceed 2 min of arc during two–coordinate sinusoidal disturbing effects by an amplitude of 15° and frequency of 1 Hz.

The tests of AMSP revealed the reliable operation of the tracking system with the angular error ±5 min of arc for the total field of view ~5°.

A TV control system of aiming consists of an input window *28*, a single–lens objective *30* with a limiting diaphragm *29*, a commercial TV system "PTU–Matritsa" *31*, and a TV set. Optical radiation entering the system input is attenuated to the value at which a semi–transparent cloudiness can well be distinguished against the background of a solar disk. A focal length of the objective was chosen based on requirements for convenient control of the tracking system operation. The total field of view of the control system was 3×4° and the size of a solar image on the TV screen was 50 mm.

Opto–electronic schemes of a solar photometer operates reliably due to an electron circuit of thermostatic control *32* which operates from an autonomous power supply in 24–hour regime.

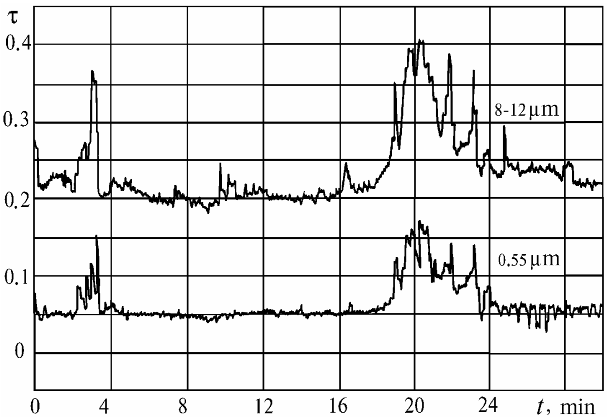

FIG. 3. Example of temporal variability of optical thickness of the atmosphere (September 8, 1991, polygon "Golfstrim").

Depending on the aims of the experiment and ambient conditions the following basic regimes of recording are used:

1. Mannual regime for recording the signals using digital voltmeters, in so doing the filters are switched from the control desk.

2. Automated regime for recording the spectra during which the filters of two measuring channels are alternately replaced, the measured signals are averaged, and then they are recorded on floppy disks. The signals are controlled and recorded by the instructions of a special program with the DVK–3M computer.

3. Automated "continuous record" of two selected spectral signals with required time of averaging.

As an example Fig. 3 depicts a 30–min fragment of continuous record of atmospheric optical thickness variability obtained during the 43rd voyage of the research vessel "Akademik Vernadskii". The records reveal quite well the instants of passage of weak semitransparent cloudiness (cirrus).

The AMSP photometer operation onboard the ship and after its modernization under continental conditions showed its efficiency for atmospheric optical studies and a small error within 0.01–0.02 in shortwave and 0.03–0.05 in longwave channels.

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