Geophysical station of the IOM SB RAS for monitoring the climate and ecological changes

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The current state of observation facilities at the geophysical station of the IOM SB RAS is considered. In addition to a certified meteorological station of the second category, the geophysical station includes observation stations for monitoring of the scattered UV radiation, electric field strength, and mercury content in the environment. The observational facilities and some results obtained at them are briefly described. The prospects for the further development of these observation facilities are considered.

Introduction

The cause-and-effect relationship between the global changes of climate and the environment, as well as the effect of regional peculiarities and anthropogenic factors on these changes are among the today's basic problems in the Earth sciences, whose solution call for a correct revision of the research methodology[1] and technology of long-term field measurements.

Taking into account that the list of climate-forming and anthropogenic factors is continuously revised and many factors are multiparameter ones, one can obviously realize that the problem of climate and ecological monitoring has a complex character. This problem is solved with the use of various ground-based, spaceborne, airborne, shipborne, and balloon-borne observation facilities for obtaining space and time resolved observation data.

The scientific and methodical bases of regional climate and ecological monitoring were developed by one of the authors of this paper and published in Refs. 2–4. These references formulate the priority problems of monitoring concerning the conditions of field observations, physical and mathematical modeling of atmospheric processes and phenomena, application of geoinformation technologies at accumulation, systematic analysis, and generalization of the information on various natural formations.

The main task to be achieved by stationary observation stations is obtaining of long-term uniform series of parameters characterizing the fields of various geophysical characteristics. These observation series can be used for determination of the variability characteristics, such as trends, explicit and implicit periodicities important from the point of view of coming changes.

It should also be noted that the information obtained at stationary observation sites is used as input information in climate and global circulation models, as well as for verification of satellite measurements.

Besides, observation series obtained at stationary sites are efficiently used in establishing statistical relationships among various meteorological and geophysical characteristics, what favors revealing of the physical mechanisms of climate variability under the effect of natural and anthropogenic factors.

Purpose of the geophysical station of IOM SB RAS

The geophysical station of the IOM SB RAS is situated in eastern suburbs of Tomsk Akademgorodok and occupies the area of 4.9 ha. This area includes an assembly-and-testing building, control terminal, electric power supply substation, and other auxiliary buildings.

The geophysical station has been put into operation in connection with the formation of the “Climate and ecological monitoring of Siberia” research project in 1993. The executors of this project are academic and higher educational institutes of Siberia, and the Project's coordinator is the Institute of Optical Monitoring. The major task of this Project is to reveal long-term climate and ecological changes based on systematic and complex monitoring of the physical and chemical state of the atmosphere with the allowance for the growing anthropogenic impact and to timely give recommendations on the effect of these changes on the social and economic development of Siberia. This Project received significant support connected with the agreement signed by Academician V.A. Koptyug, former Chairman of SB RAS, and V.M. Kress, Governor of the Tomsk Region, on the joint efforts aimed at realization of the Project on the territory of the Tomsk Region. This agreement assumed organization of Tomsk basic center for long-term monitoring of the air basin in Siberian region, supply the ecological and hydrometeorological technical facilities with meteorological data, and geoinformation and analytical support of monitoring. In many aspects thanks to this support, a certified meteorological station of the second category was opened in 1994 at the IOM and the observation stations described below were developed.

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The main functions of the geophysical station are the following:

1. Monitoring of geospheric processes under conditions of anthropogenic impact.
2. Testing of new devices, systems, and monitoring technologies under field conditions.
3. Training ground for students and specialists.

Active observation facilities

The geophysical station includes the following units operating in the monitoring mode: the certified meteorological station of the second category, the station for observation of the scattered UV radiation, the station for measuring the electric field strength in the atmosphere, and the station for measuring the mercury pollution of the environment.

Meteorological station

The meteorological station in the standard (8 times a day) mode determines meteorological parameters of the atmosphere tabulated below.

Parameter	Measurement accuracy
Atmospheric pressure (barometer), mbar	0.1
Air temperature at barometer, °C	0.1
Air temperature (mercurial thermometer), °C	0.1
Maximum air temperature, °C (mercurial thermometer)	0.1
Minimum air temperature, °C (alcohol thermometer)	0.1
Relative humidity, %	
psychrometer (above −10 °C)	1
hair hygrometer (below −10 °C)	1
Surface temperature, °C	0.5
Maximum surface temperature, °C (mercurial thermometer)	0.5
Minimum surface temperature, °C (alcohol thermometer)	0.5
Temperature of soil under the natural and ploughed cover, °C	0.1
Wind speed, m/s	1
Wind direction, deg.	
wind indicator	1
weather vane	5–10
Cloud bottom height, m	
PBO	5–10
visually	50–100
Rainfall, mm	0.1
Snow cover, cm	1
Cloud amount (10-grade scale)	1
Haze cover of reference point (rel. units)	1

Station for observation of scattered UV radiation

The selection of the scattered component of the solar UV radiation on the Earth's surface as a parameter for monitoring was motivated by the circumstance that Tomsk is characterized by prevalence of cloudy days, therefore accumulation of representative observation series for direct radiation using ground-based observation facilities is problematic.

Observations are conducted with a filter UV spectrophotometer.[5] As a receiving antenna, it uses a KU-2 quartz hemisphere with the convex part facing upwards. This antenna provides for collection of radiation in a solid angle, with the plane angle at vertex equal to 110°. At the sun elevation larger than 35°, the receiving antenna of the spectrophotometer installed horizontally receives both the direct and scattered solar radiation, and at the sun elevation less than 35° it receives only scattered solar radiation.

The spectral part of the spectrophotometer is made as a unit including two filters for the UV-A and UV-B spectral regions. The characteristics of the used filters are given in Fig. 1.

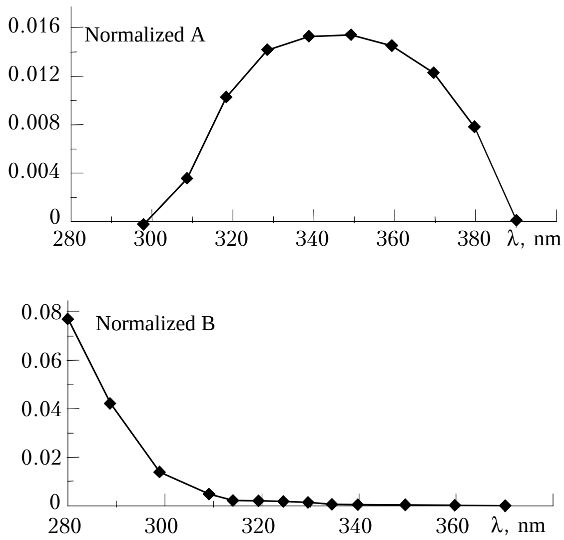

Fig. 1. Spectral sensitivity curves normalized to unity for A and B channels of the spectrophotometer.

A FEU-170 photomultiplier tube with a tellurorubidium photocathode is used to detect the monochromatic radiation. This photomultiplier was selected because of the following circumstance. The radiation flux from the sun and the sky within B region is several orders of magnitude lower than that of the region A. Therefore, the detector's sensitivity in B region should be much higher than that in the A region. The tellurorubidium photocathode well satisfies this requirement.

To measure the electric current from the photomultiplier, a measuring digital unit with a liquid crystal display (LCD) indication was used. The spectrophotometer can be connected to a personal computer.

Figure 2 depicts the typical diurnal behavior of the flux of UV-B scattered radiation obtained under cloudy conditions of observation on 06.30.99.

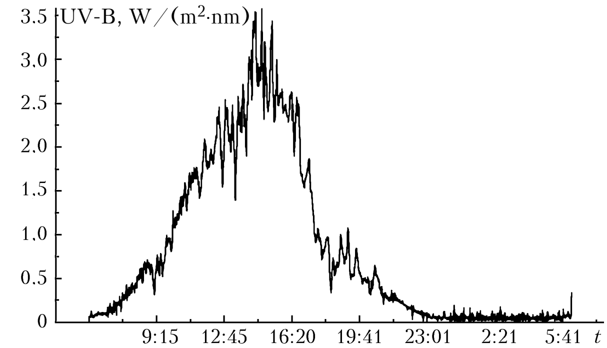

Fig. 2. Diurnal behavior of the UV-B radiation flux.

Monitoring of UV radiation have been conducted since 1994 in three regular world days of every month. Accumulated observation series were used for estimating the effect of such factors as surface albedo, cloudiness, and total ozone on the radiation fluxes.[6,7]

Station for measurement of electric field strength in the atmosphere

An instrumental system with an automated processing of measurement data, whose layout is shown in Fig. 3, is used to measure the electric field strength.

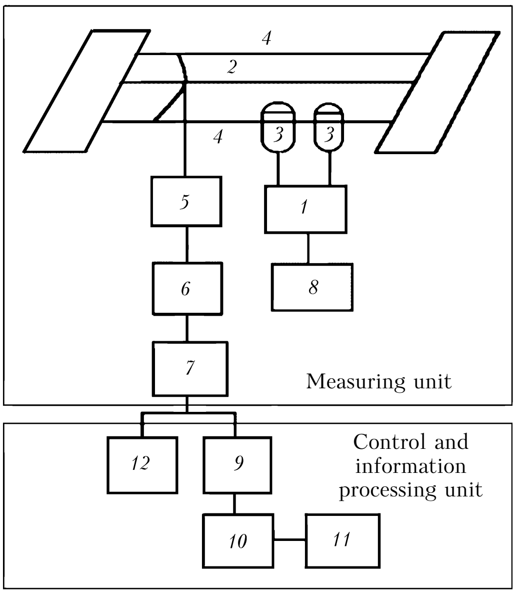

Fig. 3. Layout of ELEFIELDS instrumental system.

The system consists of the measuring unit *1–8*, which is a string sensor of electrostatic field,[8] and a control and information processing unit *9–12*, including digital voltmeter *12* for visual control of the sensor readouts, analog-to-digital converter *9*, IBM PC *10*, and a disk drive *11*. The string sensor operates as follows. A master clock *1* excites oscillations with the frequency of 400 Hz in a steel string *2* through coils *3*. An electric field induces a charge proportional to the field strength on this string grounded through the sensor body. The electric field at the measuring string *4* varies periodically with at a given frequency due to oscillations of the charged string. The variable electric strength in the measuring circuit is amplified by the pre-amplifier *5*, then rectified by the detector *6*, and amplified at the output dc amplifier *7*. Then it comes to the control and information processing unit. The constant voltage proportional to the strength of the electric field sought is measured at the output. To calibrate the sensor and draw the calibration curve $E = f(V)$ V/m (where V is the voltage at the sensor), a $50 \times 50 \times 50$ cm plane capacitor with compensation of edge effects is used, and the voltage from a calibrated power supply is applied to its plates.

Figure 4 shows the results (processed by Yu.A. Pkhalagov, IAO) of synchronous observations of the UV radiation flux and the electric field strength measured under the clear sky conditions of observation on 05.26.2000. It can be seen that the maximum value of the flux corresponds to the minimum electric field strength. This dependence was also observed on the days with overcast and suggests the hypothesis on the photochemical mechanism of the effect of solar UV radiation on the atmospheric conductivity.

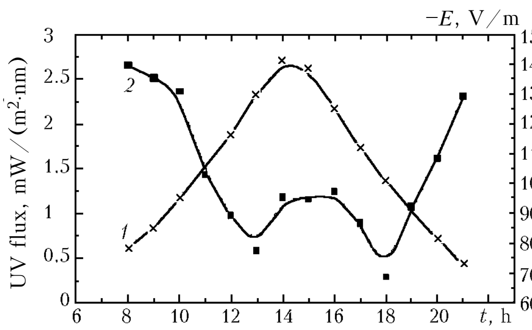

Fig. 4. Diurnal behavior of UV radiation flux (*1*) and electric field strength (*2*) under clear sky conditions on 05.26.2000.

The accumulated array of observation data allowed us in cooperation with the Siberian Physical Technical Institute and the Institute of Atmospheric Optics to check experimentally the validity of the so-called electro-optical relationship determining the relation between the electric field strength E and the aerosol extinction coefficient α as $E \sim \alpha \sim S_{\mathrm{m}}^{-1}$, where S_{m} is the meteorological visual range.

Station for measurement of the environment contamination with mercury

The operating principle of the RGA-11 gas analyzer is based on the differential absorption method with the use of the Zeeman effect and the effect of isotopic splitting of the mercury resonance spectral line at $\lambda = 253.652$ nm (Ref. 9).

The gas analyzer consists of two parts: multipass optical cell and measuring unit, and operates in the following way. The radiation from a VSB-1 monoisotopic mercury lamp placed in the longitudinal magnetic field generated by a permanent magnet leaves the emitter and consists of two Zeeman components having circular polarization. These components are separated in time with a resonance photoelastic polarization modulator and a Glan prism of Iceland spar. The photoelastic modulator consists of a fused quartz plate and a quartz resonator glued to it.

Oscillations excited by a piezoelectric oscillator at the resonance frequency ~50 kHz induce mechanic stresses in the fused quartz plate, which lead to birefringence modulated at this frequency in the plate. Varying the amplitude of the electric signal applied to the piezoelectric oscillator and turning the Glan prism, we can obtain the linearly polarized σ^+- and σ^--components emitted in turn by the modulator at its modulation frequency. The lamp radiation separated in this way is directed into the optical cell through a three-lens system. The radiation passed through the six-pass optical cell is recorded with a photodetector. If a mercury vapor is present in the cell, the photodetector outputs a variable signal, which comes after amplification to the digital processing unit. The result is displayed on a digital display. There is an analog output for connection of the gas analyzer to an external computer.

The gas analyzer does not require sample preparation and pre-concentration of mercury on sorbents and has very high sensitivity: from 30 to 10000 ng/m^3 in air and from 0.1 to 50 ng in water in a 2-ml sample. Besides, all spectroscopic effects used for modulation of radiation are done in the 0.004-nm wide spectral range, what provides for very high selectivity of gas analysis.

Figure 5 shows the depth distribution of mercury in a peat column of the Samara deposit in the Great Vasyugan Marsh.[10] The analysis shows that the peak in the upper half-meter peat layer is caused by industrial activity. Fluctuations of the mercury content in deeper layers are likely caused by different sorption capability of the corresponding peat layers.

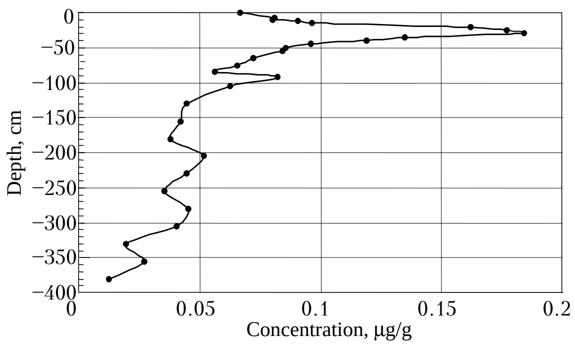

Fig. 5. Depth distribution of mercury in peat.

Planned observation facilities

When developing and installing new facilities at the geophysical station, we proceed from the fact that some geophysical parameters are already measured with the corresponding devices in other Tomsk organizations. Thus, monitoring of atmospheric aerosol is conducted at IAO, many-year ionospheric observations in the radio wave region are conducted at Siberian Physical Technical Institute, and technical facilities for remote sensing of atmospheric radioactivity are developed at Tomsk Polytechnic University and Tomsk University of Control Systems and Radio Electronics. Therefore, new technical facilities for the geophysical station are planned so that they complement rather than duplicate the already available devices.

Thus, in the nearest future we plan to equip the geophysical station with the following facilities: actinometric station, AMK-01 automated meteorological system, station for recording the Earth's natural pulsed electromagnetic field, and acoustic station for monitoring the atmospheric boundary layer.

The specialized program of automation of measurements is now active at the geophysical station. Standard and nonstandard measurement facilities are connected to IBM PCs through specially developed controllers for collection and processing measurement data. It is planned to send these data through a modem connection to the server of the climate and ecological observatory. It is important here for the program tools for processing of measurement data to provide not only mean values, but also the data on the first derivatives of the measured parameters (within the justified time interval) in accordance with the scientific and technical requirements on monitoring of natural and climate changes.

Actinometric station is a standard tool in both domestic and world practice. It allows observation of the following elements of radiative conditions:

– *direct solar radiation* coming directly from the sun and the circumsolar zone with the radius of 5° (measurements by an AT-50 Savinov–Yanishevsky actinometer);

– *scattered solar radiation* incident on a horizontal surface from all the firmament points, except for the sun disk and the circumsolar zone with the radius of 5° due to molecular and aerosol scattering in the atmosphere (measured by an M-80 shaded Yanishevsky pyranometer);

– *net solar radiation* equal to the total amount of the direct and scattered radiation incident on a horizontal plane (measured by an unshaded pyranometer);

– *reflected radiation,* i.e., a part of the net solar radiation, which was reflected from the active surface (measured by a pyranometer, whose head is turned to the active surface).

The values of the net and reflected radiation are used to calculate *albedo,* i.e., the ratio of the reflected radiation to the net flux; albedo is expressed in fractions of unit or in percent. The difference between the net and reflected radiation determines the *shortwave radiation balance.*

Observations are conducted at the level of 1.5 m at any weather except for heavy shower or snow storm. In this case the measurement term is cancelled or shifted. The observation time (LT): 08:50, 11:50, 14:50, 17:50, and 20:50.

AMK-01 automated system[11] is designed to record the main meteorological parameters of the atmosphere: wind speed and direction, air temperature and relative humidity, atmospheric pressure. The system can be installed on the ground (open land), on a roof, and in premises. It is produced as a backpack device and therefore can be applied as both stationary and movable meteorological station.

To measure the temperature, wind speed and direction, the AMK-01 uses the ultrasound method, which significantly improves the measurement speed and information content, accuracy and sensitivity, as well as stability of obtaining information under the effect of unfavorable external climate factors. The key part of the AMK-01 is an acoustic thermoanemometer (Fig. 6). It executes the following functions:

– transmission and reception of acoustic signals passed through the monitored air volume in four directions with four pairs of piezoelectric converters (ultrasound sensors);

– measurement of time intervals t_i (i = 1, ..., 4), for which the acoustic signal passes the distance between each pair of ultrasound sensors separately;

– conversion of the measured time intervals t_i into the digital code entered through the RS-232 standard interface into the external device (PPU-25 and/or PC).

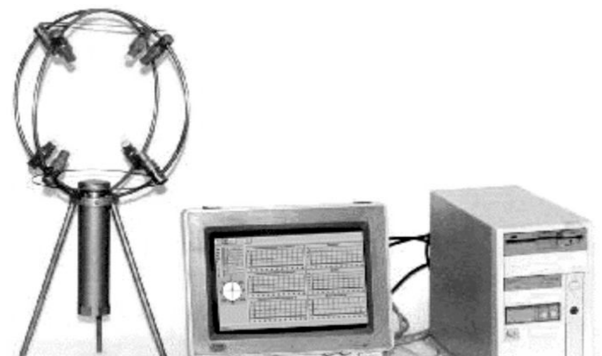

Fig. 6. AMK-01 system.

The acoustic thermoanemometer is used for measuring the temperature and three orthogonal components of wind velocity based on the application of the well known dependence of the group sound velocity in air on these meteorological parameters. To easure the atmospheric pressure and air humidity, extra sensors are used, whose output voltages U_D and U_B depend functionally on these parameters.

The AMK-01 provides for measurement and calculation of the mean values of the following meteorological parameters:

– wind speed from 0 to 30 m/s with the error of ± (0.2 + 0.02V) m/s, where V is the measured wind speed, in m/s;

– wind direction from 0 to 360° with the error of ± 4°;

– air temperature from −50°C to +50°C with the error of ± 0.5°C;

– atmospheric pressure from 560 to 800 mm Hg with the error of ±1 mm Hg;

– relative air humidity from 10 to 100% with the error of ± 4%.

The station for recording the Earth's natural pulsed electromagnetic field includes the sensors for measurement of the magnetic and electric components of the Earth's electromagnetic field, the unit for collection and pre-processing of analog signals, and the power supply unit. It has the following characteristics of the measuring channels. The channels for measurement of the magnetic H component: the sensor is a ferrite antenna with the resonance frequency at 14.5 kHz; the maximum gain factor is 96 dB or 63000 times; the gain factor varies from 0 to 63000 in a unity step; the input sensitivity is 5 μV; the bandwidth of the amplification circuitry is from 1 to 30 kHz; the analog-to-digital converter has a capacity of 12 bit. The channel for measurement of the electric E component: capacitive differential sensor; the maximum gain factor, variability of the gain factor, input sensitivity, and ADC capacity are the same as for the H component; the bandwidth of the amplification path from 500 Hz to 200 kHz. Depending on the problems to be solved, the system can include a control computer (Notebook or desktop personal computer).

The structure scheme of the unit for collection and pre-processing of analog signals is shown in Fig. 7 (Ref. 12). The unit consists of a microcontroller control unit, two measuring channels for the magnetic component H, and one measuring channel for the electric component E. It is possible to connect up to five extra measuring channels (not shown on the diagram).

Figure 8 shows examples of winter and summer 24-hour motion of the Earth's crust in the Baikal Region as judged from the intensity of signals reflecting the dynamics of the Earth's crust motion.[13]

This station is planned to be used for long-term measurement of characteristics of electromagnetic fields aimed at revealing possible relations between the atmospheric and lithospheric processes.

Acoustic station for monitoring of the atmospheric boundary layer is intended for monitoring of the structure and dynamics of the lower atmospheric layer with a high-frequency small-size acoustic radar (minisodar) developed in the IOM.[14] The MS-1 minisodar is a handheld three-channel Doppler sodar. Each channel operates in a monostatic pulsed successive mode providing for transmission, reception, and real-time processing of primary information, as well as in the bistatic pulsed and continuous-wave modes.

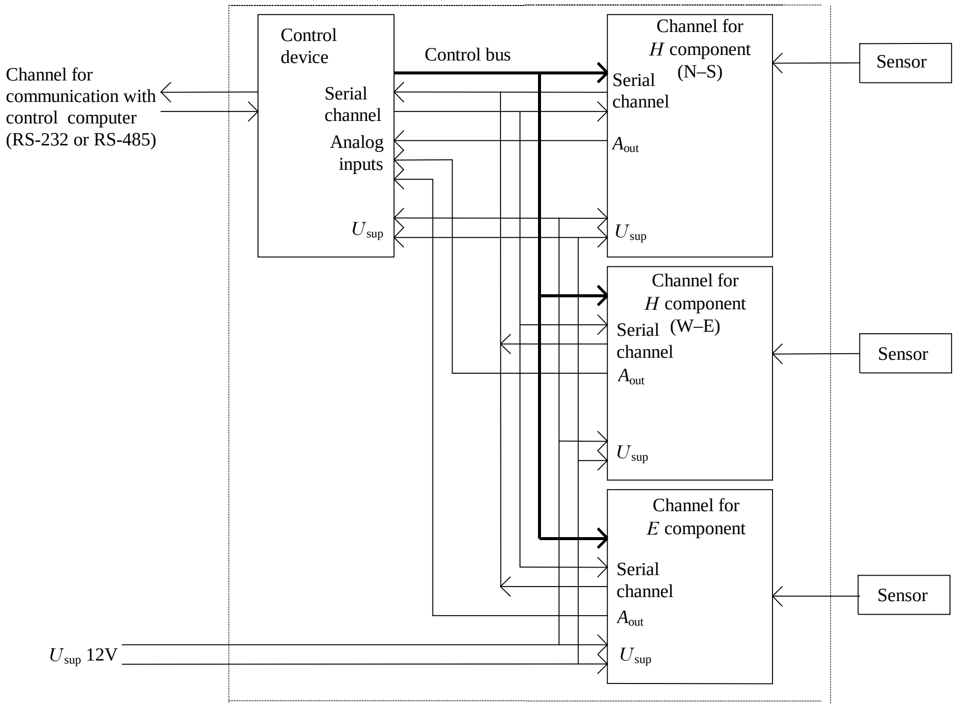

Fig. 7.

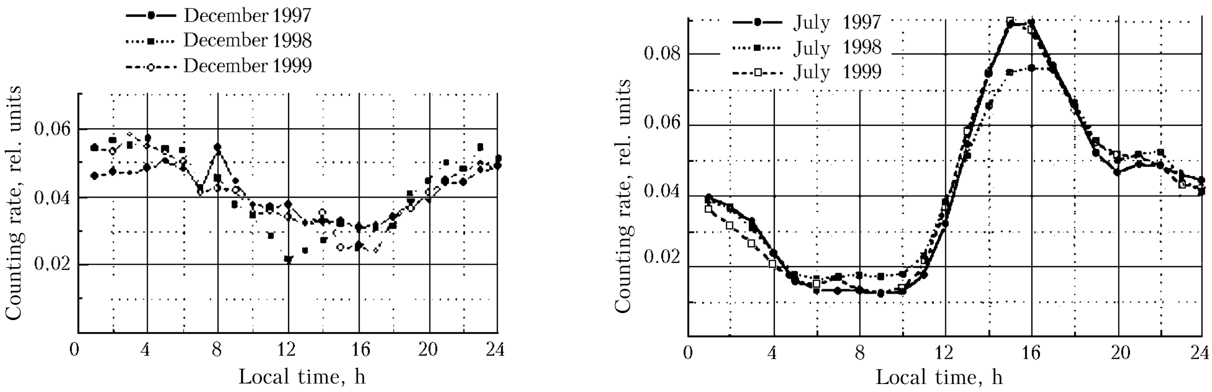

Fig. 8. Examples of typical winter and summer 24-hour rhythms of the Earth's electromagnetic field measured in Baikal Region and reflecting the 24-hour rhythms of motion of the Earth's crust.

Once a measurement cycle is completed, the wind velocity components and other parameters of the atmosphere are determined. The sensing height in the monostatic mode is from 8 to 200 m, and the resolution is 8 m. The sodar operation, including formation, reception, processing, and output of the final results, is controlled by a computer.

In the future, it is planned to equip the geophysical station with the instrumentation for measurement of minor atmospheric constituents (main biogenic, greenhouse, and carcinogenic gases). Thus, the capabilities of combined monitoring of the atmosphere will be significantly extended. A FTIR K-300 gas analyzer is planned to become the basic measuring facility.

Conclusion

The active and planned new measurement facilities at the geophysical station of the IOM SB RAS form a rather powerful experimental basis for field studies of meteorological, actinometric, and atmospheric-electric processes and phenomena. Concentrated in one place and operated consistently, these facilities already allowed solution of some scientific problems on revealing regional features in radiative, electro-optical, and thermodynamic conditions in the surface atmosphere.

The further development of the geophysical station is dictated by new methodological requirements to thorough studies of the regional climate and ecological changes.[2,15] One of these requirements is simultaneous monitoring of climate and ecological changes for estimation of the role of anthropogenic factors in them. Thus, the extension of the list of measuring facilities is inevitable, but this cannot promise too much if only simple mechanical pile-up of the number of parameters is considered. As earlier, development of the geophysical station should consist in coordination of field observations with new and traditional measuring facilities, as well as creation of conditions favorable for a wider and more efficient cooperation with Russian and foreign scientists.

Another requirement is connected with the studies of regularities in observed climate and ecological changes. It states the necessity of systematic monitoring of not only static parameters characterizing the state of the natural chemical system, but also its dynamic parameters characterizing change of states (at least, the rate of changes). This requirement gives rise to a new, in principle, field in the hydrometeorological and ecological instrumentation. Some technologies developed at the IOM and planned for operation already meet this requirement both in their physical-technical and information-technological potential. This upgrade of the geophysical station with the up-to-date technical facilities including the devices for remote sensing of the environment opens up new promises for successful solution of the urgent problems in monitoring and modeling changes in nature and climate.

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