FIRST PHASE OF CREATING THE SYSTEM FOR MONITORING OF THE UV RADIATION IN RUSSIA

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The first phase of creating the system for monitoring of the UV-B radiation over the territory of Russia has recently been completed and the instrumentation tested. The pilot operation of the system has revealed its good performance. The system has been designed to provide for real-time estimation of the field of integral (over the UV-B range) UV irradiance of the European part of the Russian Federation territory. It allows detection of regions, in which the level of UV-B irradiance departs significantly from the climatic norm. It was found during the pilot operation that 67% *of data given by the UV monitoring system differ from the results of the ground reference measurements by no more than* 20%, *and* 73% *of data differ by no more than* 25%.

The natural ultraviolet (UV) radiation comprises a small part in the total flux of solar radiation incident on the Earth's surface. However, reaching the ground it exerts a significant influence on the state and evolution of the Earth's biosphere. This influence of UV radiation upon biological systems (including human beings) is explained by its high photochemical and photobiological activity.

As known, the flux of the biologically active UV radiation near the ground essentially depends on the state of the Earth's ozone layer. The total ozone content (TOC) in the atmosphere varies widely in time and space. At present, it tends to a decrease (especially in polar regions). This tendency is now the subject of wide speculation, along with possible reasons for such a decrease and predictions of the total ozone content in the future. Extended studies aimed at revealing possible mechanisms of the ozone destruction and most active ozone-destructing substances are conducted. Systems for routine monitoring over the total ozone content are improved; and data banks and archives, which store information about TOC and ozone vertical distribution for many years, become more and more extensive.

However, we should clearly understand that the worldwide interest in the studies of the ozone layer is caused by the danger of an increase in the UV radiation intensity near the ground, which would result from the ozone depletion.

The total intensity of UV radiation near the ground is determined not only by the depth of the protective ozone layer, but also by cloudiness, the Sun height over the horizon, the albedo of the underlying surface, and many other factors. With this in mind, creation of a system to monitor directly the UV irradiance of the Earth's surface seems worthwhile. The decrease in the total ozone content not necessarily causes a sharp increase in the UV irradiance of a territory. It may be compensated for by an increased cloudiness or aerosol content, or other factors. Therefore, the measurement of the total UV radiation reaching the ground gives most objective information about the danger to living organisms on the Earth in the case of the ozone layer depletion.[1]

Different biological systems respond differently to changes in the spectral composition of UV radiation. That is why the spectrum of natural UV radiation also should be measured regularly. Such measurements are not easy. These require the expensive precision instrumentation and high-qualified service staff. Therefore, systematic spectral measurements of UV radiation with high spatial resolution covering large areas are still the task for the future.

Creation of a system for UV monitoring in the most biologically significant spectral range is now realistic and, at the same time, sufficiently informative. The b range of the UV part of solar spectrum (wavelengths from 280 to 315 nm) is just such a biologically significant spectral range. This range is characterized by the erythemic effect, the blastmogenous action, the action on animals, birds, and plants, the influence on biological equilibrium in water ecological systems, as well as on the rate of some photochemical reactions.

Physical parameters determining the intensity of total UV-B radiation near the ground vary widely on the scales from several kilometers to several hundreds of kilometers. Thus, the field of intensity of the natural UV-B radiation should be measured with the spatial resolution no less than several tens of kilometers.

Such a resolution can be achieved by using the satellite data on cloudiness, albedo, on the total content

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and vertical distribution of the ozone, in combination with the efficient algorithms for calculating the UV radiation transfer through gases, aerosols, and clouds. Systematic observations over the vertical ozone distribution are nowadays practically absent over the territory of Russia. Efficient algorithms for recognition of cloudiness type, estimation of cloud height and optical density are absent as well. The data on aerosol composition and altitude distribution are only a few. Nevertheless, the distribution of UV-B radiation over vast territories can be estimated with high spatial resolution and satisfactory error, if the main parameters influencing the total intensity of the natural UV radiation are separated out and the influence of each of them is estimated adequately. Among such parameters there are the total ozone content, the cloud fraction, and the albedo of the underlying surface. Influence of other parameters can be taken into account by using the data of statistical models.

The empirical dependence of the UV-B radiation intensity near the ground on TOC, the cloud fraction, and albedo of the underlying surface has been found in Ref. 2. It allows calculation of the field of the UV-B irradiance of the Earth's surface from satellite data on cloudiness, albedo, and TOC recorded with high spatial resolution. The data on TOC obtained at ground-based stations of the ozonometric network can also be used.

The authors of this paper have developed a system for monitoring of UV-B irradiance of the Russian territory, the first-stage instrumentation of which have successfully been tested and put into the pilot operation at the Central Aerological Observatory of the Russian Committee on Hydrology and Meteorology (Rosgidromet), and demonstrated good performance. The operation principle of the system uses this empirical dependence. The system is designed to provide for real-time estimation of the field of integral (over the UV-B range) irradiance of the ground in the European part of Russia and adjacent territories. It also allows detection of regions, where the level of UV-B irradiance differs abnormally from the climatic norms. The UV monitoring system includes the system for ozone monitoring,[3] the station for receiving satellite information about the state of cloud fields and the underlying surface (this station receives the data from orbital satellites and the stationary METEOSAT satellite), the center for information processing based on the algorithms developed, and the reference stations for measurements of the UV-B radiation. The coordinates of the edge points of the ground territory covered by the first stage of the system are the following: from left to right and from top down (71.0°N, 31.5°E), (42.4°N, 70.5°E), (48.2°N, 12.5°E), (31.5°N, 47.4°E). The already existing and new ground-based stations for measurements of the UV-B irradiance of the Earth's surface are needed as reference ones for calibrating the data of remote measurements.

To obtain the empirical dependence used in the UV monitoring system, statistical analysis has been performed based on the relations for the spectral density of the total radiation. These relations were obtained from the integro-differential equation for the UV radiation transfer through the atmosphere solved approximately using Schuster method.[4] After integration over the UV-B spectral range, the expression has been obtained, which relates the UV-B irradiance of the ground to the total ozone content, the Sun height above the horizon, the cloud fraction, and the albedo of the underlying surface.[2]

As the initial data for empirical analysis, we used the results of simultaneous measurements of TOC, UV-B irradiance, and the cloud fraction. Such measurements have been routinely conducted at the Ukrainian Scientific Research Institute of Hydrology and Meteorology (Kiev) since July, 1990. An M–124 device is used as the ozonometer, and the device of the same type modified at the Main Geophysical Observatory is used as a UV-meter. The latter allows integral measurements in the UV-A (315–400 nm) and UV-B (up to 315 nm) spectral ranges. The cloud fraction is estimated visually. For the time elapsed from the publication of Ref. 2, the amount of experimental data available has significantly increased. Based on the new data, we have refined the coefficients of the empirical dependence.[2] Toward this end, the experimental data were grouped by the cloud fraction value with a unity step. Then they were fit to the experimental dependence using the method of least squares.

To provide for a reliable operation of the UV monitoring system, current information is used in the form of maps of the cloud fraction and TOC over the analyzed territory. Current maps of the cloud fraction are reconstructed from pictures in the IR and visible spectral ranges received from the METEOSAT satellite being at the geostationary orbit. For one day, 48 images of the globe can be recorded in every spectral range. The TOC map is constructed from the data of the ground-based ozonometric network.[3] The Central Aerological Observatory receives these data daily via telegraph for compiling the "OzonometryB data bank.

Only snow has the large value of the albedo in the UV-B spectral range (for a new snow it achieves 80–85%). The albedo of other natural surfaces is low.[4] Therefore, the UV monitoring system uses the albedo of 70% for the cases, when the ground is covered with snow, and the albedo of 0% for all other cases (following Ref. 4). It may then be refined using satellite pictures of the Earth's surface.

The empirical relations used allow obtaining of both daily information about UV-B irradiance of the ground for any day and its climatic values. Climatic values can be obtained, if climatic databases on the cloud fraction and TOC will be used. Toward this end, the databases "Climatology of cloudinessB and "Climatology of the snow coverB were compiled within the framework of the UV monitoring system. These databases store the data on the cloud fraction and the dates of the snow cover establishment and melting off obtained from long-term ground-based observations and presented in Refs. 5 – 7. The climatic data on the total ozone content are stored in the "OzonometryB data bank.

The monitoring system is capable of calculating, on request, the daytime-mean integral total UV-B irradiance or the energy exposure at 1600 grid nodes of the map of a territory. The height of the Sun above the horizon is calculated for every such point by the astronomic formulas for one-hour intervals during daytime. The same formulas are used for calculation of the sunset and sunrise time and the duration of day at a chosen point. Then the intensity of total UV-B radiation at every point is calculated from satellite data on the cloud fraction, albedo of the underlying surface, and TOC. The calculated results are integrated over time to obtain the 24-hour mean energy exposure. To calculate the integral mean UV-B irradiance, the obtained value of the energy exposure is divided by the duration of day at the chosen point.

If satellite information about cloudiness comes in the intervals longer than one hour, then available data are linearly interpolated to the intermediate regions. This is required by the integration procedure for calculating the intensity of total UV-B radiation (the maximum interval between data cannot exceed one hour). When calculating climatic values of the UV-B irradiance, the diurnal behavior of the cloud fraction is neglected. However, the intensity of the total UV-B radiation from sunrise and until sunset is calculated hourly, as in the daily mode.

The UV monitoring system also calculates the rms deviations of climatic norms of the UV-B irradiance and energy exposure. This calculation uses data on the rms deviations of the daily mean cloud fraction from the “Climatology of cloudinessB database. The rms deviations of the daily mean TOC are taken from the “OzonometryB data bank. The rms deviations from the climatic value of the underlying surface albedo are taken equal to 0.1.

The output information of the UV monitoring system is formed in two files. These files include the information about the daytime mean integral total UV-B irradiance and the energy exposure to the total UV-B radiation during a day. They also contain, along with the current data for a day selected by an operator, the information about climatic values, rms deviations, and deviations of the current data from the climatic norms. Besides, these files include the information about the territory, for which the fields of natural total UV-B radiation are presented on a chosen day.

The visualization programs allow the mapping to be done with the isolines corresponding to the irradiance levels for twelve types of fields (the six types of maps for the fields of the daytime-mean integral intensity of the total UV-B radiation and the six types of similar maps for the fields of energy exposure of the Earth’s surface to the total UV-B radiation): (1) fields of current irradiance values of the territory; (2) fields of the climatic norm of the irradiance; (3) fields of rms deviations (standard deviations) of the climatic norm of the irradiance; (4) fields of deviations of the current irradiance from the climatic norm in the absolute units; (5) fields of deviations of the current irradiance from the climatic norm in the units of standard deviations; (6) fields of deviations of the current irradiance from the climatic norm in per cent. As an example, Fig. 1 presents the map of the daytime-mean integral intensity of the total UV-B radiation on April 10, 1997. Maps may be colored (areas between isolines colored in accordance with the color scale).

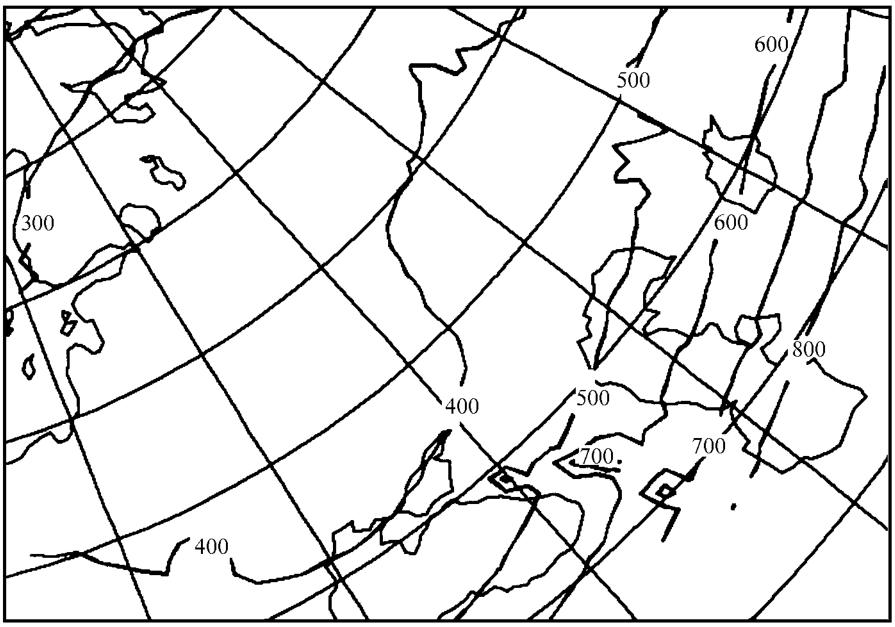

FIG. 1. Map of the field of daytime integral mean intensity of the total UV-B radiation on April 10, 1997.

The first stage of the system for UV monitoring of the Russian territory was in pilot operation in spring and summer of 1995. The data of the UV monitoring system were compared during the pilot operation with the results of reference measurements. As reference meters of UV radiation, M–124 type instruments modified at the Main Geophysical Observatory were used. These devices allow integral measurements in the UV-B spectral range. The measurement error of such a device is about 20%.

The reference meters were located at the following sites: the station "Sankt-PeterburgB (59.97°N, 30.30°E); the station "UkrNIGMI,B Kiev (50.40°N, 30.45°E).

At both stations of the reference network, UV radiation was repeatedly measured simultaneously with the measurements of TOC and cloud fraction during the period of pilot operation of the UV monitoring system. The measurements were conducted every day (depending on the meteorological conditions) at different time of a day. For a comparison of the data of the UV monitoring system with the data of reference measurements, we took such days, when no less than five measurements of UV-B radiation were conducted with the devices at the reference network. In this case, the devices gave the error about 18–20% in determination of the energy exposure of the ground for 24 hours or the daytime-mean integral intensity of the UV-B radiation at a reference point. For the station "UkrNIGMI,B there were 106 such days during the period of pilot operation. For the station "Sankt-Peterburg,B we succeeded to obtain such data for only 53 days.

The data of the system for UV monitoring, being compared with the data of reference measurements during the pilot operation, demonstrate quite good agreement in the latitudinal range covered by the first stage of the system. The results obtained with the system for UV monitoring were reconstructed using the technique for reconstruction of UV-B irradiance fields exploited in the system. For the period of pilot operation, 67% of data of the monitoring system differ from the results of reference ground-based measurement by no more than 20%, while 73% of data differ by no more than 25%. The average absolute value of the difference between the results compared is about 22% for the period of pilot operation. Taking into account that the error of reference measurements themselves is also about 20%, the data reconstructed by the system for UV monitoring can be considered as representative.

The results of a comparison between the data acquired with the UV monitoring system and the results of reference measurements at the stations "UkrNIGMIB and "Sankt-PeterburgB are shown in Fig. 2. Distribution of the number of cases by the difference between the measured results and the results reconstructed by the monitoring system is shown in the form of a histogram. The number of cases is given in relative units (normalized to the maximum value).

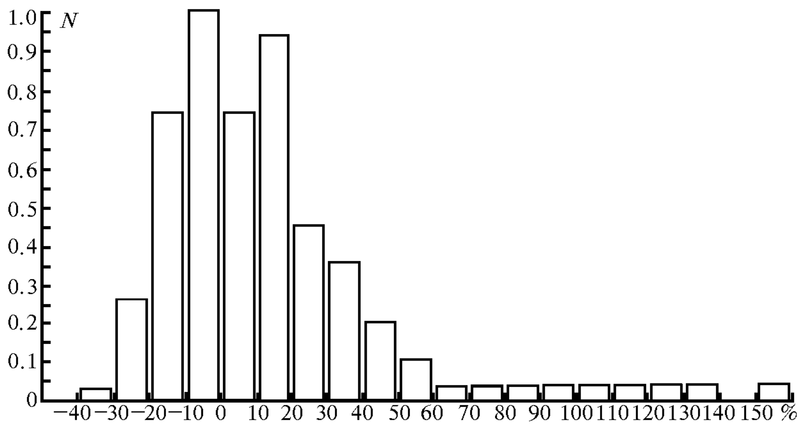

FIG. 2. The results of comparison of the reference measurements with the data acquired with the UV monitoring system in the form of a distribution histogram.

For the period of pilot operation, the monitoring system did not record cases of false alarm or missed target. (As an alarm situation, we consider the case, when UV-B irradiance of the Earth's surface exceeds the climatic norm by 2.5–3.0 standard deviations.)

In the future, it is planned to extend the UV monitoring system operation onto the territory of Siberia and Far East thus allowing the monitoring of the UV-B irradiance of the ground all over the Russian Federation. To do this, the possibility of receiving and processing pictures taken from other satellites, which give the information about cloudiness for these territories, should be studied thoroughly. Another necessary item is the development of a specialized software for the use of ground-based data on cloudiness for regions not covered with the satellite observations. Given the spectroscopic devices measuring the UV radiation from the Sun operate routinely, the monitoring system could be converted into the monitoring of irradiance in narrower spectral ranges.

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