Spatial and temporal inhomogeneities of erythemal ultraviolet radiation fields over the territory of Russia

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Received July 17, 2003

Using data of satellite (Earth Probe TOMS) measurements of erythemal ultraviolet radiation (EUVR) we analyze the global and regional (for Russia) spatial distribution of EUVR. An examination of the EUVR distribution in the territory of Russia reveals mesoscale inhomogeneities of EUVR fields depending on the region and season under consideration. We discuss the competing contribution from meteorological (cloud cover, aerosols) and other factors of influence on EUVR in the effects observed. Generally the EUVR fields are produced under the influence of many atmospheric factors, whose distribution can be affected by orographic conditions, the degree of continentality, circulation processes, and physical-geographic characteristics of the region.

Introduction

One of the main factors determining the levels and variations of the surface ultraviolet solar radiation (UVR) is the angular altitude of the sun, which forms the latitude dependence of UVR. However, there exist other factors, such as the total ozone content (TOC) in the Earth's atmosphere, the presence of cloud cover and atmospheric aerosol, which take part in formation of UVR fields and are connected with distributions of stratospheric and tropospheric meteorological parameters, albedo of underlying surface, and others. These factors, being the most variable, may have some peculiarities connected with physical-geographic and climatic conditions of regions.[1] For example, in Ref. 2, when analyzing satellite data of TOC, the global inhomogeneities of TOC were revealed coinciding with the contours of continents and large mountain masses. These circumstances can cause inhomogeneities in spatial UVR distributions disturbing their latitude behavior, and the occurrence of longitudinal or regional peculiarities of UVR distributions, which in the general case do not coincide with the TOC inhomogeneities.

Problems of research of spatial inhomogeneities of UVR, regional peculiarities, and their tendencies have not been adequately elucidated in the literature. However, the papers are available indicating that the effects in UVR, connected with regional peculiarities, can be significant. Thus, in Ref. 3 it is noted that the biologically active (erythemal) UVR in New Zealand (45°S) is twice as large as that in Germany (48°N) practically at the same latitudes. Taking into account these facts, the solution of the problem of UVR increase due to the ozone layer depletion, widely discussed in the last ten years, is impossible without consideration of regional peculiarities of UVR and their tendencies. It should be noted that due to the effects of multiple scattering[4] the formation of the UVR field may differ from the solar radiation distribution in the long-wave optical range.

Satellite techniques of UVR measurement are very valuable for solving the problem of global spatial UVR variations despite some unsolved methodical questions (the effect of aerosol component, albedo, and so on), limiting the precision of UVR determination.[5] Comparison of data of satellite and ground-based measurement technique favors a fundamental understanding of dynamics and morphology of UVR behavior, as well as the increase of accuracy of procedures[6] for measuring UVR.

In this paper, based on the data of satellite measurements of erythemal ultraviolet radiation (EUVR), we have analyzed the regional (for Russia) spatial distribution of EUVR. Erythemal radiation is the most biologically active spectral region of ultraviolet solar radiation in the range from 300 to 320 nm. An increased interest in EUVR is caused by the fact that EUVR is subjected to a greater (as compared with UVR in the other spectral ranges) TOC influence in the Earth's atmosphere; as well as EUVR is an important climate-forming factor.

Processing procedure for EUVR

Satellite data of the Earth Probe TOMS (Total Ozone Mapping Spectrometer) (http:/toms.gsfc.nasa.gov/ery_uv/euv.html) are the data of one-day (diurnal) global distributions of EUVR exposition of the Earth's surface with an angular resolution $1° \times 1.25°$ in latitude and longitude, respectively. They are restored through the joint analysis of TOC measurements obtained with TOMS instrument, the information on the state of atmospheric cloudiness, albedo of underlying surface, and data on extraatmospheric solar flux of UVR.[5,7]

One-day data of EUVR distributions show the running values of distributions of cloud fields, TOC,

0235-6880/04/01 70-04 $02.00

aerosol, and albedo of the underlying surface. Summing or averaging of EUVR data over longer intervals of observation enable one to investigate the EUVR distributions stipulated by seasonal variations of atmospheric parameters and physical-geographic peculiarities of the region under study.

To investigate relative contributions of TOC, cloudiness, and albedo to the observed effects of global EUVR distribution, the data array on erythemal radiation for 1999 was subdivided into fine and cloudy days. This has made it possible to recognize the days when the TOC distribution (fine days) was the determining factor for EUVR, as well as the days when the atmospheric cloudy conditions (cloudy days) could be the determining factor in the distribution of erythemal radiation.

To distinguish fine days for each nodal point from all days of a chosen month, the maximal values of EUVR were found. Based on the totality of these values, the global EUVR distribution for fine days was constructed. It should be noted that the obtained distribution for fine days is a combined daily EUVR distribution. To distinguish cloudy days in the distribution of erythemal radiation, the monthly data for every nodal point were first averaged by the method of sliding mean over three days. Then for every day from the initial data the averaged value for this day was subtracted. If the obtained value was less than the averaged one, that day was considered as a cloudy day. The values of EUVR for each coordinate were averaged over the cloudy days revealed during a month. The values of EUVR, obtained using this method for fine and cloudy days, were used for constructing images of the global EUVR distribution.

We selected for analysis the monthly and annual intervals of averaging over a period from 1999 to 2001. The procedure of obtaining and processing data consisted in extraction of information from the EUVR data arrays of the Earth Probe satellite, its processing, and construction of a final bit matrix containing 288×180 nodal points in latitude and longitude, respectively, reflecting the EUVR spatial distribution on the Earth's surface. Global distributions of the erythemal radiation averaged over months and years during the above-mentioned period were obtained.

Below we analyze the spaceborne averaged data of EUVR of Earth Probe TOMS to reveal the regional peculiarities of EUVR in the territory of Russia.

Results of data analysis and the discussion

To assess the effect of cloudiness on the distribution of the integrated EUVR based on the satellite data, the longitude variation of the daily mean EUVR along the latitude circle 20°N for January 1999 is shown in Fig. 1, as an example, for all initial data (curve *a*), as well as for fine (*b*) and cloudy (*c*) days. In this case we used the above technique of recognizing fine and cloudy days from the initial data array.

As is seen from the Fig. 1, the distribution by cloudy days to a greater extent correlates with the initial data distribution. The correlation coefficient for initial data and cloudy days equals 0.96, for initial data and fine days it equals 0.65. This fact can be indicative of a decisive role of a cloud cover in the formation of inhomogeneities in EUVR distribution when averaging on large time scales.

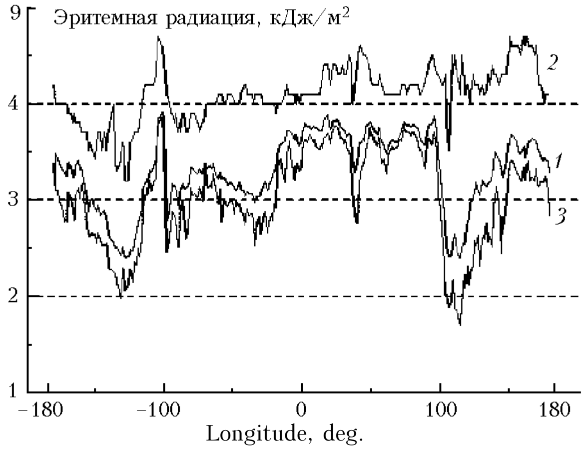

Fig. 1. Exposition (dose) of EUVR along the latitude 20°N for January 1999: all initial data (*1*); all fine days (*2*); all cloudy days (*3*).

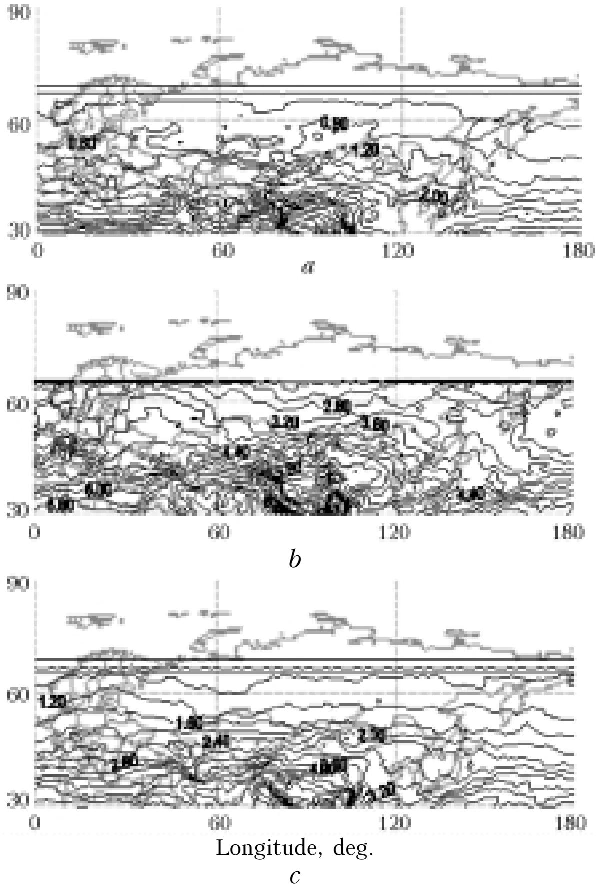

Fig. 2. Isolines of daily mean expositions of the integrated EUVR for 1999: March (*a*), June (*b*), September (*c*).

To analyze spatial variations, we construct the monthly mean maps of isolines of total erythemal radiation for a latitudinal-longitudinal region including the territory of Russia (longitude > 20°E) and longitudinal variations of EUVR for fixed latitudes. Figure 2 shows the maps of EUVR isolines for individual months of different seasons.

Figure 3 shows the longitudinal variations of total EUVR for the latitudes 52°N (top curve) and 60°N (bottom curve) averaged for Junes of 1999–2001.

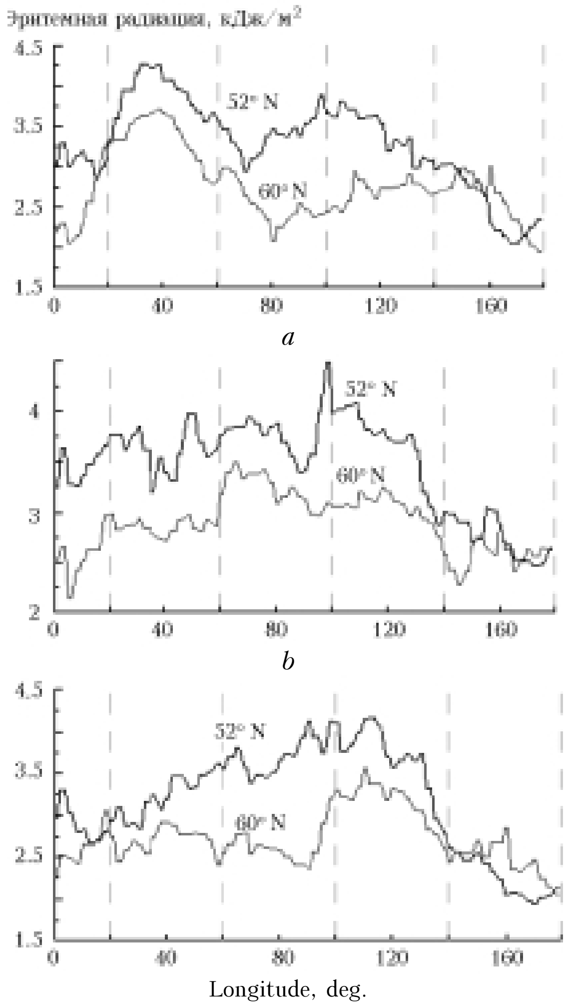

Fig. 3. Longitudinal variations of the total EUVR averaged for June: 1999 (*a*), 2000 (*b*), 2001 (*c*).

It is evident from the Fig. 3 that in the averaged over a month daily expositions of total EUVR the deviations from the natural latitudinal variation of EUVR due to different elevation angles of the sun are observed. These deviations result in the longitudinal variations of EUVR at the latitudes under study, which may reach 20–30% in June. The region of Primorski Krai and the Far East (longitudes > 130°E) is characterized by the least mean values of EUVR that, probably, is connected with the increased cloudiness in this region. The enhanced EUVR values characterize the Central Siberian plateau (90–130°E).

Monthly mean daily EUVR expositions in the territory of Russia show the large-scale and mesoscale EUVR field inhomogeneities, which are probably due to regional peculiarities (physical-geographic, orographic, climatic, etc.). In some cases the large-scale EUVR inhomogeneities can be compared with geographic structures, i.e., East-European plain, West-Siberian lowland, Central-Siberian plateau, Primorski Krai, and the Far East.

Interannual variations of EUVR distribution are also observed in the territory of Russia. For 52°N latitude in June 1999 we can recognize the greatest EUVR values in the European part of Russia and a tendency to its decrease in the direction to the Far East (Fig. 3*a*). For June 2000 we observe the EUVR increase when passing from the European part to the region of Central-Siberian plateau, i.e., the character of longitudinal dependence varies (Fig. 3*b*). The greatest EUVR values in the region of Central-Siberian plateau and their decrease in the direction to the Far East are recorded. In 2001, a tendency to the EUVR increase when passing from the European part of Russia to the region of Central-Siberian plateau is more pronounced (Fig. 3*c*).

Interannual variations of the longitudinal EUVR distribution at 60°N are also seen with all their peculiarities. The greatest EUVR values are observed in June 1999 in the European part of Russia; in June 2000 they pass to the region of the West-Siberian lowland; and in June 2001 they characterize the region of Central-Siberian plateau.

Some conditional angular velocity of transfer of regions of EUVR maximal values, which can be revealed from Fig. 3, is about 30–40 degrees per year for the cases under consideration that corresponds to periods of 9–12 years.

An example of mesoscale inhomogeneities may be the variation of EUVR at 60°N in June 2000 in the longitude range from 90 to 100°E (Fig. 3*b*) when the value of mean daily exposition of EUVR varies from ~ 3.4 to 4.4 kJ/m^2. At different seasons the levels of mesoscale inhomogeneity can be different. Thus, for March 1999 (Fig. 2*a*) the latitudinal-longitudinal EUVR distribution is more structurized as compared to September (Fig. 2*c*) that is due to the spring reconstruction and instability of circulation regime of the atmosphere, as well as peculiarities of the TOC annual variation.

The data on basic characteristics of the UV climate in the territory of the former Soviet Union calculated by the theoretical radiation model of the atmosphere were presented in Ref. 8. They involve the maps of distributions of intensity and doses of direct, scattered, and total UV radiation for different spectral ranges (including erythemal radiation) for different seasons. The satellite EUVR data, presented in this paper, and the model calculations[8] reveal a considerable difference between different meridian profiles of EUVR observed in the territory under study for one and the same season. In June the difference could reach 25%, in September it did not exceed 10–15%. The authors connected that effect with a significant influence of TOC on the UVR in this spectral range. The same explanation they attributed to the observed deviation of the intensity isolines of the EUVR meridian values to the south over the territory of Eastern Siberia and the Far East for the spring season due to the presence there of the region of high TOC. In summer, the isolines deviated to the south at the northwest of European territory of Russia, i.e., when the increased TOC zone was in that region. In fall and winter the EUVR intensity isolines were almost parallel to latitudinal circles.

The account for the effect of cloudiness on the EUVR intensity resulted in the appearance of some inhomogeneity at one and the same latitude, but isolines at the maps of UVR intensity distributions remained smooth with some deviations from the latitude behavior. That is, along with the similarity in describing the total EUVR behavior (a manifestation of the longitudinal effect, deviation from the latitudinal behavior of UVR) satellite data give new and more precise information on the radiation distribution such as a more structurized latitude-longitude EUVR distribution with revealing mesoscale inhomogeneities and interannual variations of the EUVR distributions.

Finally, it should be noted that in the general case the fields of the total EUVR are formed under the effect of many atmospheric factors, including the cloud regime, aerosol, TOC, and others; and their distribution may depend on the orographic conditions, degree of continentality, circulation processes, physical-geographic characteristics of the region, albedo of underlying surface. The character and the degree of influence of these factors on the EUVR distribution require further investigations.

Conclusions

1. When averaging satellite data of TOMS EUVR over large time intervals (≥ 1 month), in spatial EUVR distributions above the territory of Russia the mesoscale inhomogeneities appear that, in some cases, results in some deviation from the pronounced latitudinal behavior of EUVR.

2. In summer the longitudinal EUVR inhomogeneities in the territory of Russia can reach 20–30%. In some cases these inhomogeneities can be comparable with the geographic structures – East-European plain, West-Siberian lowland, Central Siberian plateau, with the boundary area continent–ocean in the Far East.

3. Interannual variations of EUVR distributions are observed in the territory of Russia (based on the 1999–2001 data for Junes).

Acknowledgments

This work was supported by the Integration Projects of the Siberian Branch of the Russian Academy of Sciences (Nos. 95 and 130), as well as the Grant No. NSh–272.2003.5 in the framework of the government support of leading scientific schools of the Russian Federation. One of the authors was supported by INTAS (Grant 00–189).

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