Long-term variations of the erythema ultraviolet radiation in Siberian regions according to satellite data

M.A. Chernigovskaya, A.V. Mikhalev, and M.A. Tashchilin

Institute of Solar-Terrestrial Physics, Siberian Branch of the Russian Academy of Sciences, Irkutsk

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Long-term measuring runs (1979–1992 and 1996–2003) of exposition of the solar erythema ultraviolet radiation (EUVR) for Siberian regions nearby Novosibirsk, Tomsk, Krasnoyarsk, Irkutsk, and Gorno-Altaisk cities are analyzed on the basis of satellite data measured with a TOMS instrument (onboard Nimbus-7 and Earth Probe satellites) and processed with the help of specially developed software. The period under study makes almost 22 years. Normals for annual EUVR variations are obtained and EUVR inter-annual variations and trends are estimated for the above regions. The revealed peculiarities of time variations of all analyzed parameters are indicative of regional specific features in their behavior. Spectral analysis of time series of daily surface EUVR expositions has been carried out, which allowed the time periods indicating some correlation between the EUVR and solar activity to be distinguished in addition to the natural annual harmonic. Possible mechanisms of observed long-term EUVR variations are discussed.

Introduction

Solar ultraviolet radiation (UVR) flux is an important factor in atmospheric and earth phenomena, a participant of many photochemical, chemical-biological, and climate-forming processes.

It is clear today, that the enhanced UVR has a pronounced negative effect on biota (lesion of cell DNA, inhibition of plant photosynthesis, loss of phytoplankton capacity, eye-photolesion, carcinoma of the skin, immunodepression resulting in different epidemic explosions). At the same time, a lack of UVR as a stimulator of principal bioprocesses in human organisms is also dangerous. The most pronounced manifestation of "UV insufficiency" is avitaminosis, which results in phosphoric-calcium metabolism imbalance and hypostosis, as well as performance decrement and immunodepression. This is equally relates to latitudinal zones with UVR excess and areas with periodic UVR deficiency.

The intensity of the UVR flux to a particular Earth region depends on several factors: the latitude, restricting maximal diurnal and yearly sun elevation, the height above the sea level, the total ozone content (TOC), a presence of clouds or atmospheric aerosol, as well as other physical-meteorological factors.[1] Some southern middle-Russian and Siberian cities with moderate climate can be considered as areas of relative UV comfort, although with UVR deficiency in the middle of winter.[2,3] Negative manifestations of the UVR deficiency are characteristic of fall–winter seasons lacking of natural UVR ("solar starvation").

Global and regional (for Russia) spatial distributions of the most biologically active erythema ($\lambda = 300$–320 nm) ultraviolet radiation (EUVR) was analyzed for a 3-year period (1999–2001) based on the Earth Probe TOMS data.[4–6] In Russia, mesoscale inhomogeneities of EUVR fields were revealed, which turned to be regionally and seasonally dependent.

Long-term measuring runs of the surface EUVR for Irkutsk were analyzed based on the TOMS satellite data.[7,8] The period under study made almost 22 years and included the 21st, 22nd, and 23rd solar cycles. Normals of EUVR variations (long-term annual, seasonal, and month) were obtained; long-term trends of the surface EUVR were estimated. A seasonal EUVR trend, characteristic for Irkutsk, was revealed, possibly, reflecting specific features of local climate, physiographic location, etc.

Data and their analysis

To study spatiotemporal variations of the surface solar UVR, long-term EUVR runs measured with the spaceborne TOMS spectrometer[9] (Nimbus-7 in 1979–1992 and Earth Probe in 1996–2003) were analyzed (similarly to Ref. 7) for a series of Siberian regions: Novosibirsk (55°N, 83°E), Tomsk (56.5°N, 85°E), Gorno-Altaisk (51.5°N, 85.6°E), Krasnoyarsk (55.5°N, 91.9°E), and Irkutsk (52°N, 104°E) (Fig. 1). The TOMS data are diurnal (daytime) data on global distributions of the surface EUVR exposition with angular latitudinal and longitudinal resolution of 1×1.25°. So, further we mean that the data analysis was carried out for the areas (spatial cells of the above-indicated size) nearby the cities under study. Hence, the territory of 5° in latitude and 20° in longitude was analyzed.

For the above cities, the normals of annual EUVR variations were obtained. The conducted analysis revealed some specific features in their behavior.

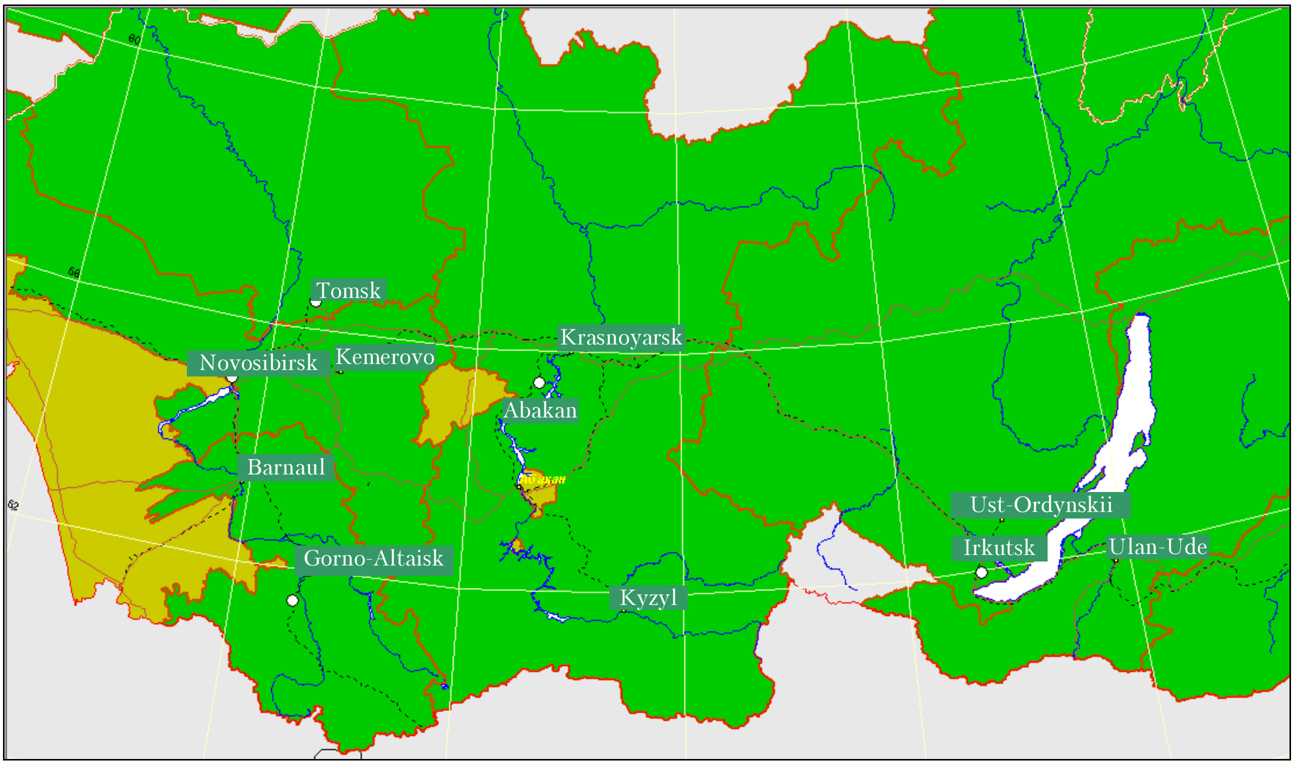

Fig. 1. Map of cities location.

Average annual (seasonal) EUVR variations resulting from averaging everyday measurements over each day of all years for periods 1979–1992 and 1996–2003 with further smoothing by moving average over 5 days are shown in Fig. 2 (middle curves). Top and bottom curves present, respectively, maximal and minimal values of daily EUVR doses for every day over all years of the above periods, which determine the region of scattering of everyday EUVR values (small dots). Thus, the curves illustrate probable interday EUVR variability, which depends, first of all, on cloudiness variations, as well as on variations of TOC and aerosol condition of atmosphere.

Knowledge of long-term normals allows one to find deviations in the values for individual months and years, i.e., to estimate the EUVR behavior as characteristic or anomalous. As an example, EUVR values for every day of 2004 are shown in Fig. 2 by dots. The majority of dots fall into the region bounded by maximal and minimal long-term curves. However, some days, especially in spring and summer, daily EUVR doses significantly exceed both average long-term level and long-term peaks, marked by big dots. As has been mentioned earlier,[10,11] sometimes there appear anomalously high EUVR values in the seasonal EUVR trend; they exceed EUVR values recorded in neighboring day under relatively clear weather. This can be caused by two reasons: first, decreasing of TOC level and, second, increasing of air transparency. Combination of such parameters, as large solar elevation angle, decreased TOC, and high air transparency can result in superposition of effects and essential EUVR peaks.

Average annual EUVR variations for different cities are shown in Fig. 3.

Since the solar elevation angle is the principal factor influencing UVR flux to the Earth surface, the surface UVR has clearly pronounced daily, seasonal, and annual trends.[1] Following the natural latitudinal EUVR trend depending on the solar elevation angle, average annual EUVR doses should be maximal in Gorno-Altaisk, gradually decreasing to Irkutsk, Novosibirsk, Krasnoyarsk, and Tomsk. The same tendency should manifest itself in maximal everyday EUVR values over all years of the period under study (Fig. 4). The maximal EUVR levels are registered in Gorno-Altaisk region (Figs. 3 and 4). This is connected not only to the southernmost position of the region, but also to its location in the Altay Mountains, where altitudes above the sea level can exceed 1000 m.

However, the above natural difference between average annual EUVR levels, clearly pronounced in winter, fall, and summer months, is virtually negligible in June (see Fig. 3). This can be interpreted as a manifestation of the longitudinal dependence in spatial EUVR distribution, which results in deviation from the latitudinal EUVR trend.

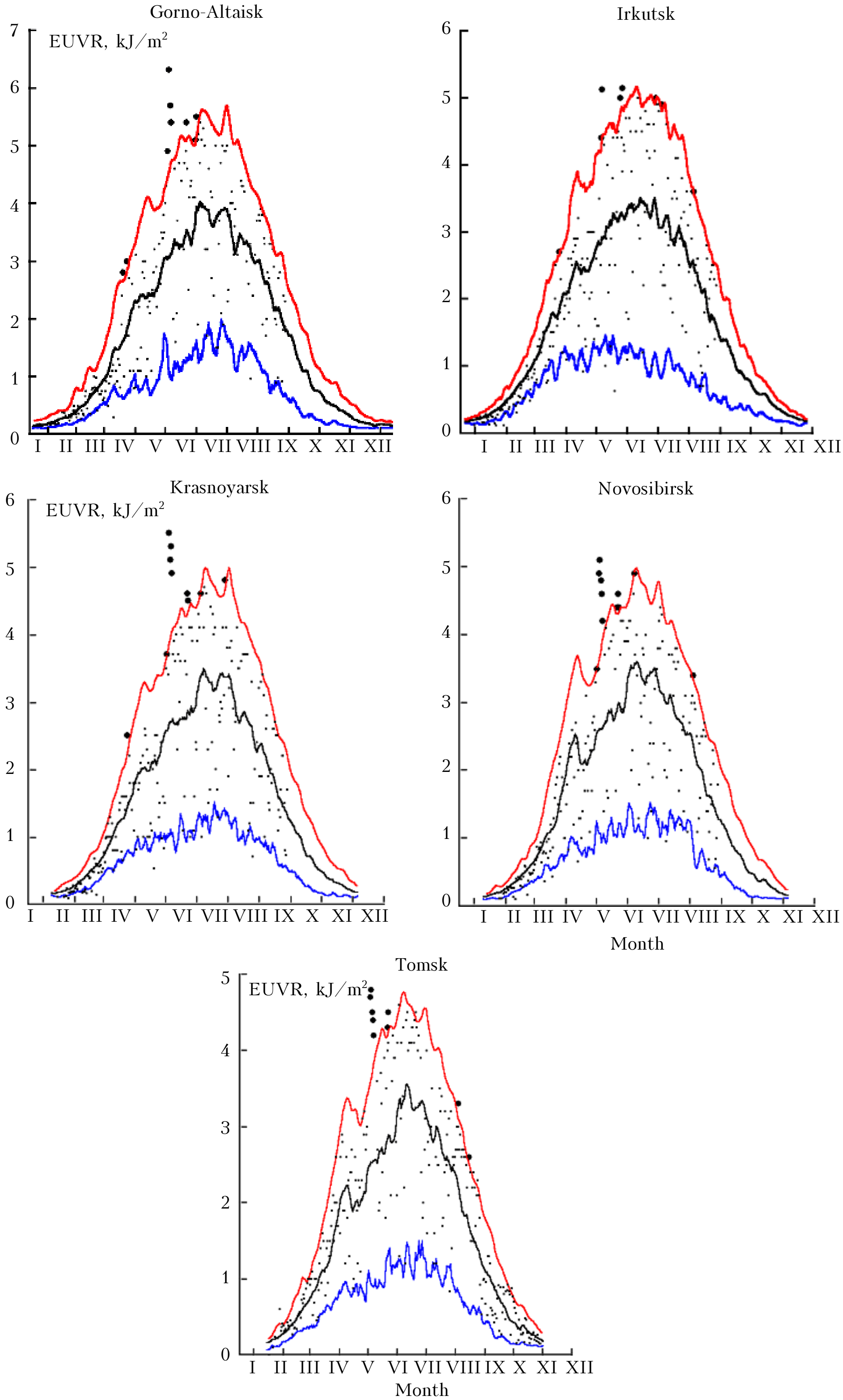

Fig. 2. Average annual variations, minimal and maximal many-year dozes, and daily values of EUVR for 2004.

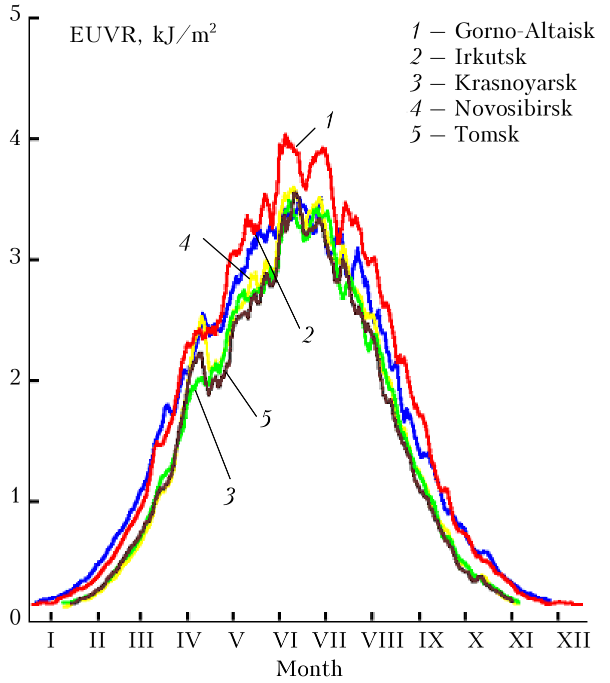

Fig. 3. Average annual (seasonal) EUVR variations resulting from averaging everyday measurements over all years with subsequent smoothing by moving average over 5 days.

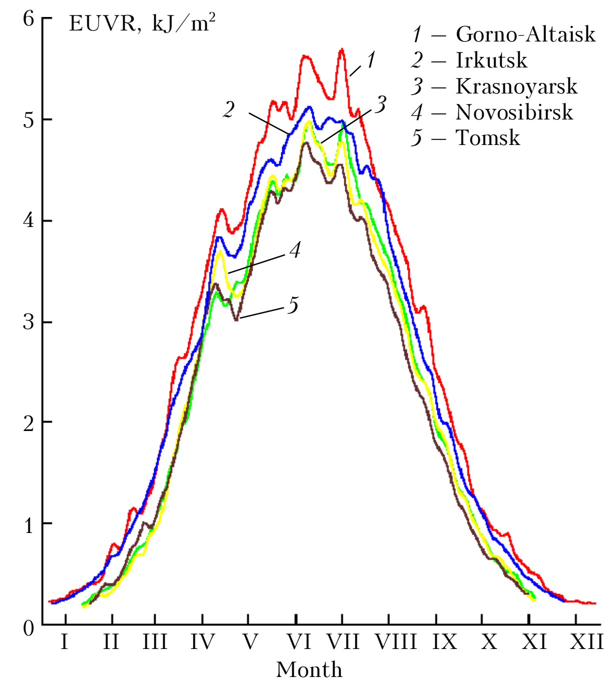

Fig. 4. Maximal everyday EUVR values over all years smoothed by moving average over 5 days.

As it was mentioned in Ref. 4, when averaging the TOMS EUVR data over a long time interval (more than 1 month), there appear mesoscale inhomogeneities in spatial EUVR distribution over Russia territory leading to deviations from the pronounced latitudinal EUVR trend. In summer, longitudinal EUVR inhomogeneities could attain 20–30%. Sometimes they could be associated with geographic structures, e.g. the East European Plain, the West Siberian Plain, Central Siberian Plateau with the boundary region mainland–ocean in the Far East.

Main parameters of UV climate on the territory of the former USSR, calculated by theoretical radiation atmospheric model are given in Ref. 1 together with maps of distribution of intensity and doses of direct, scattered, and total UVR for numerous spectral regions (including the erythema radiation) and different seasons. Both satellite data[4] and model results[1] show a significant difference between different EUVR meridian sections crossing the territory under study for a season: in June the differences can be 25%, while in September they did not exceed 10–15%.

This effect was mostly attributed to strong TOC effect on EUVR in the corresponding spectral region. Deviation of midday EUVR intensity contours observable southward the territories of Eastern Siberia and the Far East was related to the same reason due to the presence of high TOC there. In summer, the contours in the northwest of the European Russia deviated southward, because the high TOC zone in this season is there. In fall and winter, contours of EUVR intensity are almost parallel to latitude circles. The accounting for cloudiness effect on the EUVR intensity resulted in appearance of some inhomogeneity at the same latitude, but contours on EUVR intensity distribution maps kept smooth with some deviations from the latitudinal trend.

The spring increase in the average annual behavior of EUVR for Irkutsk at the end of April, noted earlier,[7,8] with the following drop in the beginning of May was related to the pronounced seasonal TOC trend over Irkutsk with the spring maximum.[12] This increase manifested itself to a greater extent in Tomsk and Novosibirsk, situated southwest of the West Siberian Plain (see Fig. 3). The average annual EUVR trend in summer (especially close to the summer solstice) is characterized by EUVR cycles of about 10–14 days (probably caused by lifetimes of principal synoptic objects, i.e., cyclones, anticyclones, and their combinations) with typical peaks for all the cities, including Irkutsk.[7] However, for Gorno-Altaisk and Irkutsk these cycles are more pronounced.

These peculiarities can be attributed to weather and climatic regimes of the region under study, which is characterized by seasonal distinctions in cloud and aerosol behaviors and in the TOC dynamics.[2]

Long-term variations of relative deviations of daily EUVR values from the average annual trend were analyzed for the considered regions in the same way as for Irkutsk.[7,8] Figure 5 shows relative deviations smoothed by moving average over the 3-month interval.

As is seen, mean relative EUVR variations attain ± 15–20% in the above averaging interval, although ± 30% overshoots are noticeable for the mountain Altai region and Novosibirsk city. Linear trends and curvilinear approximations with 5th degree polynomial fitting were determined. Bold curves in Fig. 5 correspond to such approximations; it is evident that different approximation methods can further result in different estimations of EUVR trends.

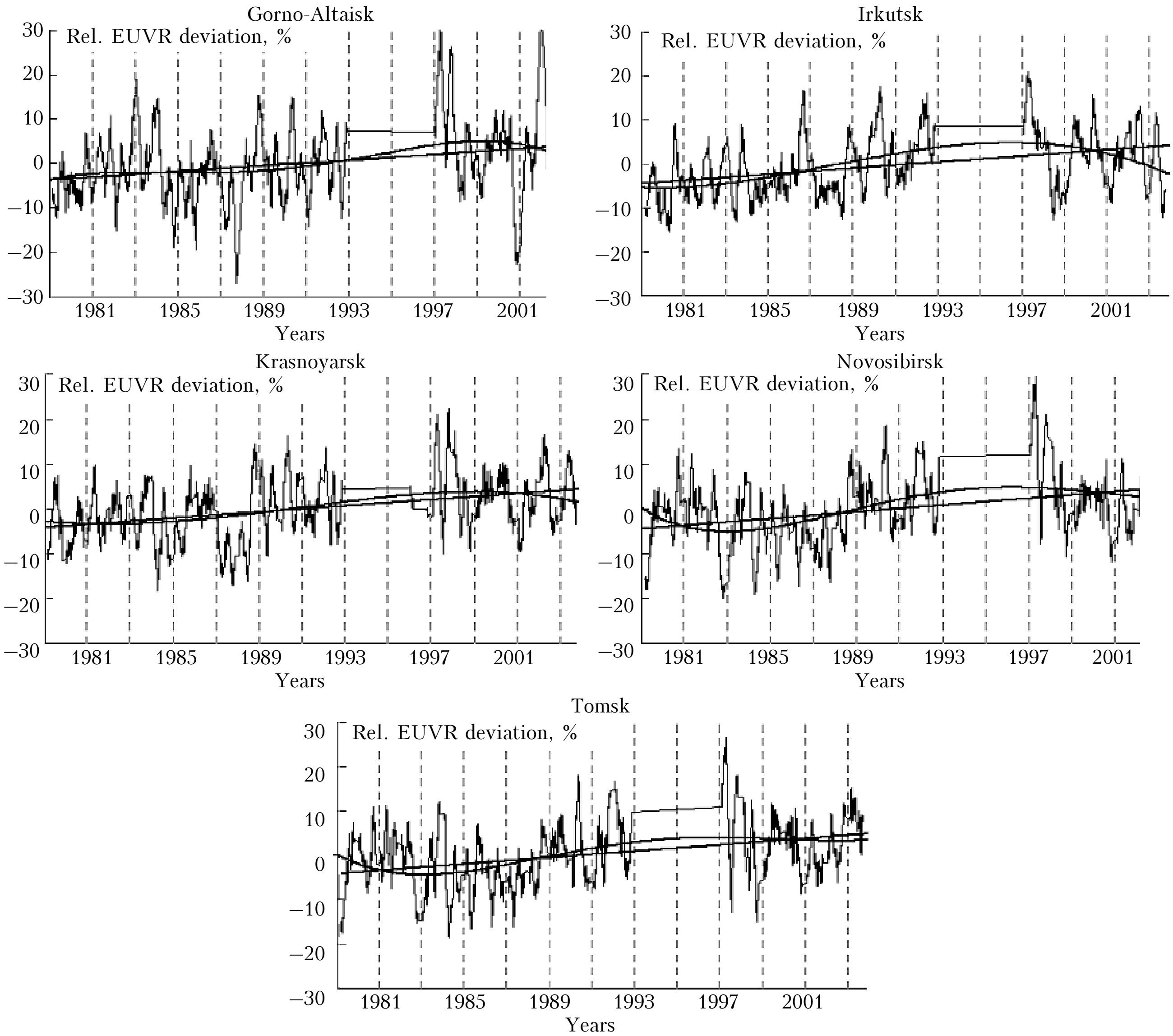

Fig. 5. Long-term variations of relative deviations of daily EUVR values from the average annual trend. The bold lines correspond to different approximations of variations of relative EUVR deviations.

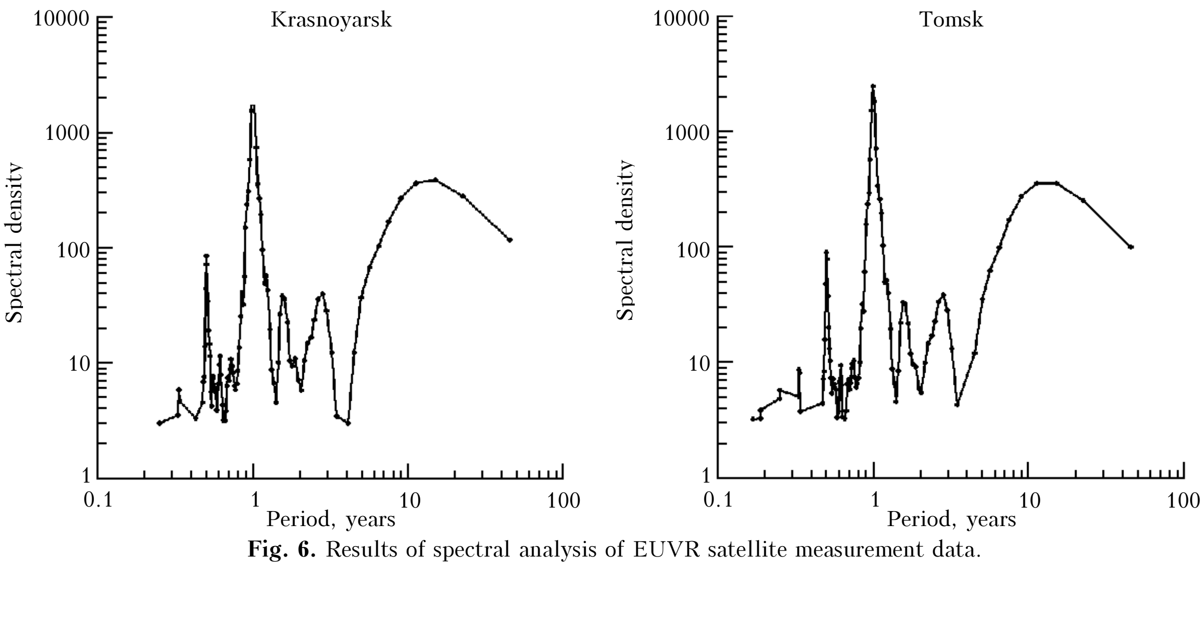

Fig. 6. Results of spectral analysis of EUVR satellite measurement data.

The linear trends point out to gradual increase of the EUVR within the period under study. If to accept the existence of such a trend, EUVR variations can be related to a negative time trend of the atmospheric ozone, which is observed in some regions of the globe and widely discussed in last decades.[13] At the same time, curvilinear approximations point to a tendency of the EUVR decrease in recent years. One of the reasons of such long-term tendency can be the existence of longer intervals ($\geq$10–20 years) of the EUVR variability followed from the results of spectral analysis presented below. Besides, the presence of the negative trend can be related to, for example, the presence of the positive 2-year-shifted correlation between solar activity and surface aerosol concentration[14] and, as a consequence, negative correlation between the solar activity and the atmospheric transparency.[15]

Spectral analysis of time series of surface EUVR daily doses, smoothed by moving average over 30 days, was carried out for 22 years (1979–1992 and 1996–2002 periods) for the above Siberian cities. As an example, the results for Krasnoyarsk and Tomsk are shown in Fig. 6.

There are oscillations of different periods in the analyzed time series. The highest maximum corresponds to the 1-year period (and close ones). This result is natural, because EUVR variations of maximal amplitude are connected with variations of solar elevation angle (seasonal variations), and the above period is principal. Of principal interest are periods concerned with the solar activity, for example, close to 11, 22, 5, and 2 years (i.e. periods of solar activity, with which many geophysical and meteorological parameters often correlate), and others.

These results bear evidence of correlation between EUVR and the solar activity, which is realized, probably, indirectly, through another atmospheric parameters, e.g. the atmospheric transparency, TOC, etc. The correlation between the spectral transparency of the atmosphere and solar activity in the 11-year cycle was marked in Ref. 15. A number of hypotheses of the solar activity effect on the atmospheric transparency[16] exist today, but the mechanism of the effect remains unclear as yet.

Hence, the conducted analysis has shown, that along with some general regularities in spatiotemporal distribution of the surface EUVR over the territory of Siberia, there is a number of regional distinctions in patterns of long-term variations. In general case, total EUVR fields are formed under the influence of many atmospheric factors, including cloud regime, aerosol, TOC, etc.; their distribution can be influenced by orographic conditions, degree of continentality, circulation processes, regional physiographic features, and the underlying surface albedo. The character and the degree of influence of these factors on the EUVR distribution need in additional study. The influence of many factors results in formation of spatial inhomogeneities in the surface EUVR distribution fields, as well as essential differences between different EUVR meridional sections, crossing the territory under study, for some seasons. This points to the presence of longitudinal dependence in the spatial EUVR distribution.

To illustrate this fact, we have built global spatiotemporal EUVR distributions for 2003 (Figs. 7 and 8).

Figure 7 presents annual EUVR variations at the Irkutsk latitude (52°N) for different longitudes of the

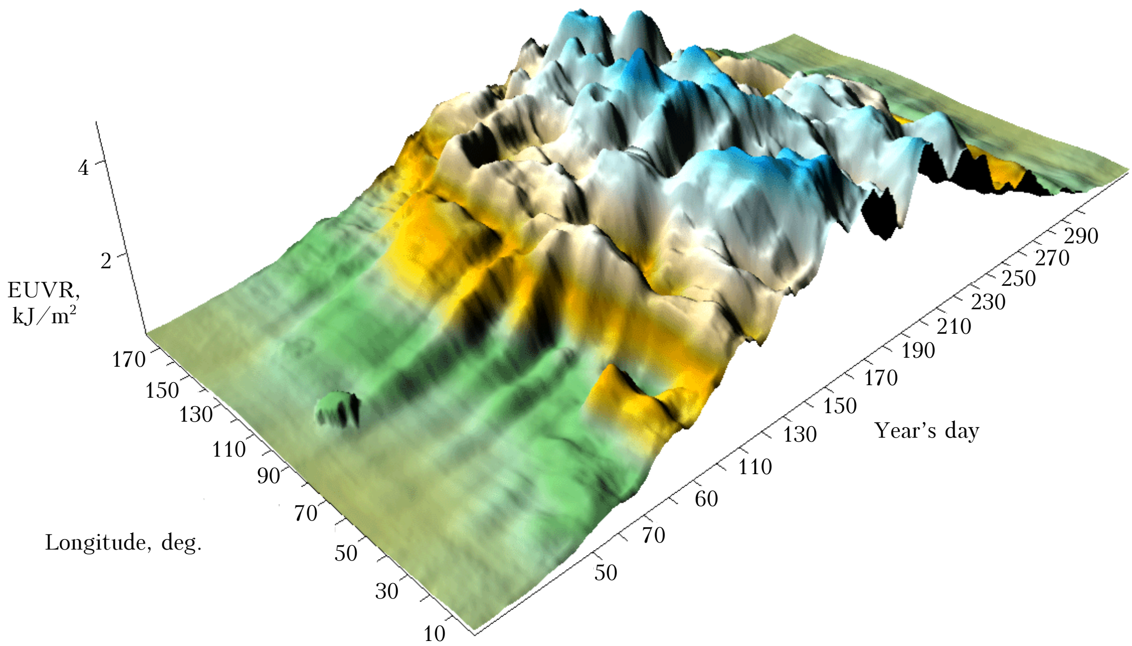

Fig. 7. Longitude-temporal distribution of the surface EUVR smoothed over 10 days for the Eastern hemisphere (Irkutsk latitude, 52°N).

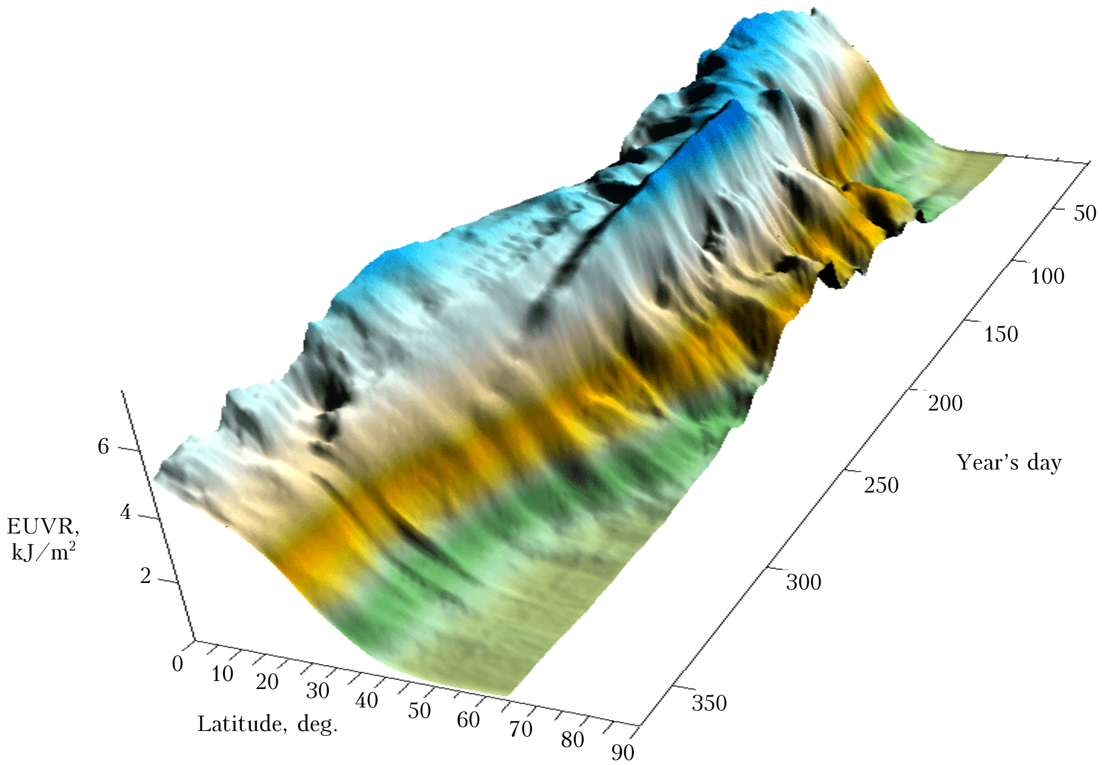

Fig. 8. Latitude-temporal distribution of the surface EUVR smoothed over 10 days for the Northern hemisphere (Irkutsk longitude, 104°E).

Eastern hemisphere. For example, the plane section (Irkutsk longitude, 104°E) of this surface gives the annual EUVR variation similar to Fig. 2. Moving longitudinally along the latitude circle, we obtain different patterns of annual EUVR variations. This proves once again the presence of longitudinal dependence in the spatial EUVR distribution. Therewith, based on similarity of peaks in Fig. 7, an existence of some wavy structure of 20–30 day periods moving westward along the latitude, can be supposed. Since the TOC is one of the factors affecting the surface EUVR level and, as is established, includes oscillations with periods close to planetary wave periods,[12] the spatiotemporal EUVR distribution probably reflects Rossby planetary waves in TOC variations.

Figure 8 shows the dependence of the surface EUVR level on the latitude, which restricted maximal solar elevation during a year. Deviations of annual variations from the natural latitudinal trend are well seen. Of particular interest is the peak within a limited latitudinal range falling on spring – beginning of summer, which can reflect the "spring anomaly" in the EUVR behavior well noticeable in Figs. 2 and 3.

Conclusions

Based on the performed analysis, the following conclusions can be formulated concerning the spatiotemporal EUVR distribution for Siberian regions.

The normals for annual EUVR variations have been obtained for several Siberian cities, which allow finding deviations based on available values for individual days, months, and years, i.e., to estimate the EUVR behavior as characteristic or anomalous.

General and distinctive features of average annual normals have been considered.

Long-term trends of the surface EUVR have been obtained. They reveal a gradual EUVR increase within 21st and 22nd solar cycles. The situation within the current 23rd cycle can be differently estimated depending on the particular approximation method.

The ambiguity in the results concerning possible further EUVR trends gives evidence of the necessity to accumulate experimental data in order to estimate the trends from longer observational series.

The spectral analysis of time series of everyday values of surface EUVR doses allows us to distinguish the periods of 11, 22, 5, and 2 years, which can be indicative of correlation between EUVR and the solar activity. Mechanisms and channels of this correlation have not been clarified yet and need additional studies.

A verification of the existence of mesoscale inhomogeneities in the EUVR distribution has been obtained. They are formed under impact of several atmospheric factors, including the cloud regime, aerosol, TOC, etc., whose distributions are influenced by orographic conditions, the degree of continentality, circulation processes, regional physiographic features, the underlying surface albedo, and the season. This fact can bear evidence of the presence of longitudinal dependence of the EUVR spatial distribution.

Acknowledgments

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