# Long-term variations of erythemal ultraviolet radiation in Irkutsk based on data of satellite measurements

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The analysis of temporal variations of erythemal ultraviolet radiation (EUVR) in Irkutsk is given on the basis of data of satellite measurements of solar EUVR using TOMS instrument (Nimbus-7, Earth Probe) processed by means of a specially developed complex of programs over the periods 1979–1992 and 1996–2003. Results of the analysis of the long-term homogeneous measurement series carried out and processed by unified techniques enable us to establish climatic norms of variations of different time scales (interseasonal, interannual, within a cycle of solar activity). The possible reasons of the observed temporal variations of near-ground EUVR in Irkutsk are discussed.

## Introduction

The ultraviolet radiation (UVR) is a climate-forming factor, making a direct impact on the Earth's biosphere. This refers both to the latitude zones with UVR excess and to zones where UVR deficit can be observed over specific periods. Siberian region is usually related to the latter category. From the entire range of the solar ultraviolet radiation reaching the Earth's surface the spectral region from 300 to 320 nm is the most biologically active for living beings (including a human being). This is the so-called region of erythemal ultraviolet radiation (EUVR) (in Latin “erythema” is reddening).

The investigation of a possible variability of the ground EUVR is one of the important problems in the studies of solar-terrestrial relations. Problems of the investigation of EUVR variations in Siberian region, their regional peculiarities and tendencies are still not clearly surveyed. Time variations are a very important parameter, which determines the variances of monthly and annual sums of EUVR, whose consideration is necessary in determining trends of EUVR. Great interest in the currently available EUVR trends is conditioned by its dependence upon the total ozone content (TOC) in the Earth's atmosphere. The investigations of TOC have been carried out intensely in the past few decades in relation to the recorded negative trends of TOC on the global scale and observations during certain periods in some regions of short-term anomalies of TOC.[1,2,3]

In the papers written previously[4,5] the authors investigated the peculiarities of diurnal, seasonal (regular and irregular) variations of the ground UVR in Irkutsk based on data of the ground-based measurements of the intensity of the surface UVR curve in the wavelength range from 295 to 345 nm using an ultraviolet spectrophotometer for the period of 1997–2000. Because the satellite techniques of UVR measurement have improved information content and are useful for solving the problems of investigating global variations in space and time, the authors have invoked these data for extending the range of possible problems being analyzed. A comparative analysis of the results of ground-based measurements of the ground EUVR intensity in Irkutsk with the EUVR data assessed from the TOMS satellite data[6] has shown good agreement of these data with high correlation coefficients.[7] This has made it possible to use extensively the satellite data of UVR measurements in studying global and regional (for Russia) spatial EUVR distribution. In the global distributions of monthly and annual EUVR dosages the continental “structures” and large mountain masses are manifested.[8] On examination of the EUVR distribution on the territory of Russia the mesoscale inhomogeneities of the EUVR fields are manifested depending on the region and season considered.[9]

It is obvious that when describing the peculiarities of space–time distribution (typical and anomalous) of the ground EUVR, as any other parameter characterizing the atmospheric processes, it is necessary, first of all, to have the information about the climatic norms of the characteristic behavior. By the anomaly it is meant the deviation of characteristics from their mean values in time and space.

The climate (*klima* (Greek) denotes the tilt, i.e., the tilt of the Earth's surface with respect to solar rays) is the long-term conditions of weather typical of one or another locality on the Earth and being one of its geographic characteristics. With the development of physics of the upper atmosphere and ionosphere the concept of climate was extended to the characteristics being studied by these Earth sciences. To determine specific features of the climate, both typical and rarely observed, the long-term observation series are required. The long-term mean

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values of meteorological elements (annual, seasonal, monthly, daily and so on), their sums, frequencies of occurrence, etc. are said to be climatic norms, the appropriate magnitudes for particular days, months, years, etc. are considered as the deviation from these norms.

This paper presents some results of the analysis of long-term homogeneous measurement series of the ground EUVR, performed and processed using integrated methods, for the purpose of determining climatic norms of EUVR variations on different time scales (interseasonal, interannual, inside the solar activity cycle) in Irkutsk (52°N, 104°E).

## Data and results

We used the data of satellite measurements of the ground integrated EUVR obtained by the scanning spectrometer TOMS (Total Ozone Mapping Spectrometer), mounted onboard the Nimbus-7 satellite (over the period from 1979 until 1992), then mounted onboard the Earth Probe satellite (over a period from 1996 until 2003). Thus, with consideration for an interval in the measurements of three-year duration and a half (from 1993 to August 1996) the time interval of 22 years was analyzed. This time interval covers 21, 22 and 23rd cycles of the solar activity.

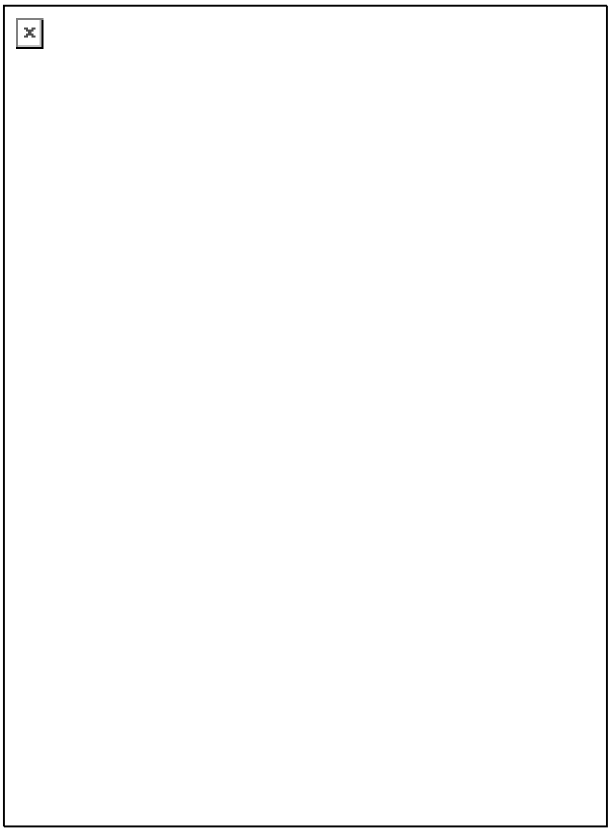
Satellite data are presented by daily (day-time) global distributions of EUVR display of the Earth's surface at the angular resolution of 1°×1.25° in latitude and longitude, respectively. The data are reconstructed by a combined analysis of TOC measurement data using TOMS, the data on the state of atmospheric cloudiness, the albedo of underlying surface, as well as the data on extraterrestrial UVR solar flux.[10,11] For extracting the values from data files of EUVR measurements using TOMS and their subsequent processing, a complex of programs has been developed.[12]

This complex of programs consists of the set of modules and enables one to obtain daily data on the sum EUVR distribution, to develop the proper data base of EUVR values, to construct the maps of global distribution of UVR intensity values, both for the Earth's surface, as a whole, and for the territory of Eurasian continent, obtained by averaging during chosen observation interval. To analyze EUVR in Irkutsk the TOMS data were selected with the coordinates nearest to the city (52.5°N, 103.75°E).

Figure 1*a* shows the daily EUVR values, obtained by superimposing the daily measurement data for the entire observation period from 1979 to 1992 and from 1996 to 2003.

As in the preceding papers, we notice that there exists a strong diurnal EUVR variability, whose value is first affected by the variations of cloudiness as well as the TOC variations and aerosol state of the atmosphere.[4,5,13] Here the mean annual variation, denoted by heavy line, is given obtained by averaging over all years of daily data for each month. The points are centered relative to the middle of each month.

Figure 1*b* shows the annual mean (seasonal) variation of EUVR, obtained as a result of averaging of measurements for each day of a year over all the years with a subsequent smoothing by a moving average over 5 days, and the curve for the sun elevation angle. The previously detected[13,14] asymmetry of EUVR seasonal behavior relative to the summer solstice, which consisted in exceeding EUVR in the second half a year as compared with the first half at the same elevation of the sun and connected with a pronounced seasonal variation of TOC over Irkutsk with its maximum in spring manifested itself in the annual mean only slightly. This is connected, evidently, with the fact that the EUVR data were analyzed over all days of observations without separating into fine and cloudy days. The effect of asymmetry in the papers[13,14] was clearly defined only with the use of days with fine weather. The presence of cloudiness compensated strongly for the value of seasonal asymmetry.



*b*

**Fig. 1.** Daily values of EUVR for the observation periods from 1979 to 1992 and 1996–2003 and the annual mean EUVR variation obtained using monthly mean data (*a*); the annual mean EUVR variation obtained using daily mean data on all the years (heavy line) and the curve for the sun elevation angle for Irkutsk (thin line) (*b*).

In the annual mean behavior in summer (especially close to the period of the summer solstice) the variations are observed with periods of 10–14 days (i.e., are determined by the life times (and their combinations) of the main synoptic objects, cyclones and anticyclones) with the typical peaks, corresponding to 17 and 29 June, 13 and 24 July, 7 August (Fig. 1*b*). A spring burst of EUVR in late April with a subsequent decay in early May is observed, which was previously noted in analyzing the UVR ground-based measurement data in the short-wave spectral region.[4] These peculiarities are most likely connected with the meteorological and climatic regime of the investigated region of Eastern Siberia, characterized by the distinctions in the TOC dynamics and in the behavior of the cloudy and aerosol conditions of the atmosphere during different seasons.

After compiling the annual mean curve of EUVR using the daily mean data during all years (Fig. 1*b*) the analysis was made of long-term variations of relative deviations of diurnal EUVR values from the annual mean behavior. Figure 2 shows the curve of relative deviations smoothed by a moving average over a three-month period. The upper curve shows similarly smoothed long-term variation of the solar flux of radio-frequency radiation at a wavelength of 10.7 cm.

**Fig. 2.** Long-term variations of relative deviations of daily values of EUVR from the annual mean behavior (lower curve); the solar radio radiation flux at a wavelength of 10.7 cm (upper curve), smoothed by a moving average over three-month interval. Trends of variations of relative deviations of EUVR, obtained by two different methods, are shown by thick lines in the bottom plot.

Figure 2 shows that the mean relative variations of EUVR reach the value of ±15–20%, although the diurnal variations on some days can be up to ±90% (strong diurnal variability can be seen from Fig. 1*a*). Great interest is provoked by a vital question on the long-term trend of relative variations of EUVR, since in such a way one can evaluate the tendency of behavior of values of the quantity being studied in the future. The linear trend was determined by the least squares method and the curvilinear trend was determined with the use of smoothing by a polynomial of the fifth power. The results of such approximations are given in Fig. 2 (heavy lines). Figure 2 shows that different approximation methods can point to the opposite tendencies of EUVR behavior in the future. The linear trend shows a gradual increase of EUVR as compared with the annually mean behavior. When it is considered that such a positive trend exists then the EUVR variations can be connected with the negative time trend of the atmospheric ozone observed in some regions of the world and widely discussed in the past decades.[1–3] Having applied the polynomial approximation, we obtained a tendency to EUVR decrease in a few past years.

The existence of negative trend can be associated, e.g. with the occurrence of the positive correlation with a 2-year shift between the solar activity and the aerosol concentration in the ground atmospheric layer,[15] and, as a consequence, the negative correlation of solar activity with the atmospheric transmittance.[16] In accordance with these conclusions by the period of 2003–2004 (see the upper curve in Fig. 2 about the time variation $F_{10.7}$) the aerosol concentration in the ground layer must reach its maximum, consequently, the atmospheric transmittance tends to decrease. This, in its turn, signifies a possibility of a tendency toward reduction of the ground EUVR that can be obtained at the polynomial smoothing of relative variations of EUVR. But both of the trends obtained make it possible a gradual growth of EUVR in 21st and 22nd cycles of solar activity. One of the reasons for such a long-term time variation may be the existence of longer periods (e.g., 22nd cycle).

In the present 23rd solar cycle the situation can be evaluated variously depending on the approximation method. Contradictory opinions exist in the literature about the long-term trends in the ground UVR and the above-mentioned example, testifying to a possibility of obtaining the opposite time trends in approximating the time series by different methods, confirm a the grounds for debates in solving a given problem at the present time. Obviously, to draw justified conclusions on this problem it is necessary to analyze the longer time series and to have a more detailed information on the behavior of the entire intricate complex of factors, determining the EUVR level on the Earth's surface as well as to be careful in tackling the problem of interpreting the results of statistical data processing.

We have analyzed the long-term time variations of the mean values of daily expositions of EUVR for every months of the year (Fig. 3). On plots the monthly mean values of EUVR for different years are denoted by points and the monthly mean values of EUVR obtained by averaging over all years are denoted by a dashed line (Table 1). These values were used for the construction of the annual mean variation in Fig. 1*a*. On plots (see Fig. 3) the linear trends obtained by the least squares method are denoted by solid lines. From this figure we notice that the character of variations of monthly mean EUVR values from year to year is different for different months.

For most of the months (January, February, March, April, July, August, October, November and December) the character of behavior of time trends is the same: the growth of EUVR over a period from 1979 to 1992 and the decay of EUVR over a period from 1996 to 2003. For June the pattern of trend is opposite. In May the growth of EUVR is observed from 1996 to 2003, and for September the decay of EUVR is characteristic over a period from 1979–1992. Of special interest are the time variations in May, summer months and in September, when the values of EUVR exposition as well as their variability are maximum (see the data in Table 1). As indicated in plots of Fig. 3, the behavior of the ground EUVR of a unified character for these months was not observed.

**Table 1. Climatic monthly norms of EUVR and measures of variability**

| Month | Mean, kJ/m$^2$ | Dispersion | Variation coefficient, % |
|---|---|---|---|
| January | 0.24 | 0.001 | 0.2 |
| February | 0.50 | 0.001 | 0.3 |
| March | 1.16 | 0.014 | 1.2 |
| April | 2.12 | 0.069 | 3.2 |
| May | 2.75 | 0.081 | 2.9 |
| June | 3.33 | 0.146 | 4.4 |
| July | 3.19 | 0.116 | 3.6 |
| August | 2.60 | 0.042 | 1.6 |
| September | 1.48 | 0.018 | 1.2 |
| October | 0.74 | 0.005 | 0.7 |
| November | 0.35 | 0.001 | 0.4 |
| December | 0.21 | 0.001 | 0.4 |

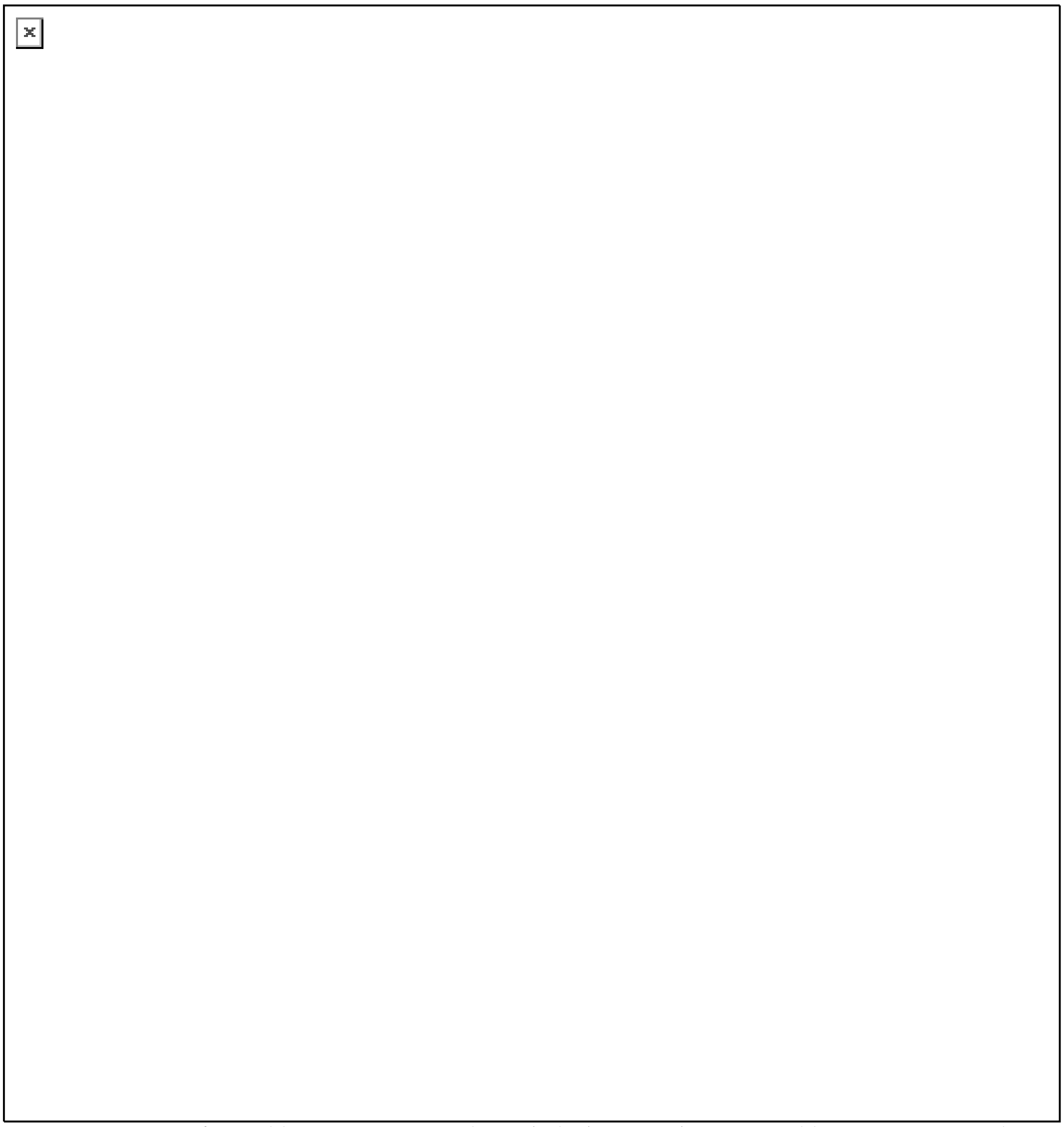


**Fig. 3.** Long-term variations of monthly mean EUVR values; dashed curves denote monthly mean EUVR values, obtained by averaging over years; solid curves denote linear trends obtained by the least squares method.

Figure 4 shows the statistical distribution (histogram) of daily EUVR values in a given time interval. It indicates that the most probable values fall in the range of minimum values of EUVR, 0–1 kJ/m$^2$. This is also evident from the superposition of daily values of EUVR in Fig. 1*a*. The least variability of EUVR (i.e., the largest density of points) is just in the region of minimum values of EUVR and can be observed in winter months: November, December, January, and February. In the rest months the points with equal probability can take the values falling practically within the entire range of possible values from 1 to 4 kJ/m$^2$. It is possible to explain such a distribution by that in winter months the level of ground EUVR is mainly determined by the change of the sun elevation angle.

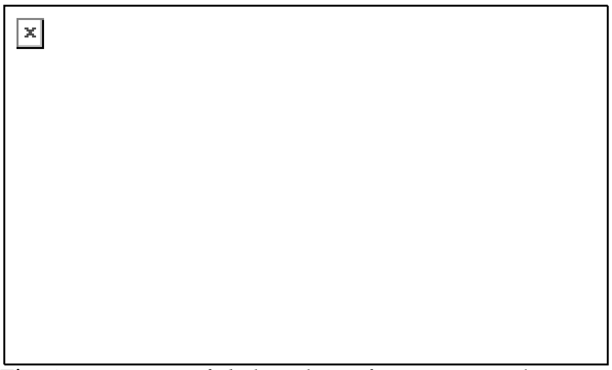


**Fig. 4.** Histogram of daily values of EUVR over the entire period under study.

In cold season in Irkutsk the fine cloudless weather is often observed, since the region of Eastern Siberia is characterized by the presence of the Asian anticyclone during winter period (about 1–80 days correspond to this period in Fig. 1, where the greatest point concentration is observed). Then we notice the spring strengthening of cyclonic activity. The end of spring and the first half of summer are characterized by dry weather with a large number of fine days and high temperatures. In the second half of summer heavy rains are observed, and, hence, the cloudy weather connected with the activation of cyclonic activity over the Mongolia. The autumn period is characterized by the activation of cyclonic activity in the west with a relatively short period of stable weather.[17]

The presence of cloudiness, as noted above, very strongly affects the level of the ground EUVR making a strong diurnal variability. Besides, the TOC makes an impact on the EUVR, characterized by a marked annual variation with a maximum in spring and a minimum in autumn, as well as the atmospheric aerosol content. The effect of these competing factors can, evidently, result in such a complicated distribution of EUVR values shown in Fig. 4.

We have performed a spectral analysis of the time series of daily values of exposition of the ground EUVR over the entire 22 years smoothed by a moving average over 30 days. For a statistical analysis of time series the program package Statistica for Windows was used. The results of the spectral analysis of the EUVR measurement data are depicted in Fig. 5.

The spectrum of analyzed time series includes a wide range of oscillations with different periods. The largest maximum corresponds to a period of one year (and close to it). This result is quite natural, because the greatest in amplitude UVR variations are connected with the change of the sun elevation angle (seasonal variations) and this period is basic. Of interest are the periods connected with the solar activity. In the range of time series of EUVR the periods are observed close to 11, 22, 5, and 2 years (i.e., the periods of a manifestation of solar activity, with which many geophysical and meteorological parameters often correlate) and other periods (see the data in Table 2).

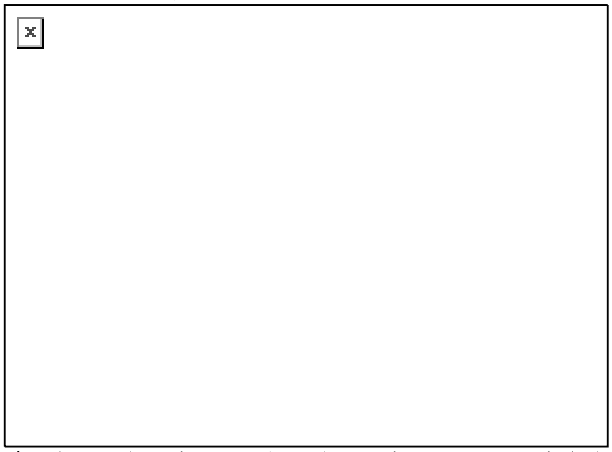


**Fig. 5.** Results of spectral analysis of time series of daily values of exposition of the ground EUVR over all the years, smoothed by the moving average during 30 days.

**Table 2. Basic most significant periods determined by spectral analysis**

| Period, days | Period, years | Spectral density |
|---|---|---|
| 364 | 1.0 | 2901.0 |
| 372 | 1.0 | 2092.4 |
| 356 | 1.0 | 1762.8 |
| 381 | 1.0 | 775.3 |
| 349 | 1.0 | 596.4 |
| 390 | 1.1 | 316.9 |
| 4096 | 11.2 | 315.9 |
| 5461 | 15.0 | 311.1 |
| 8192 | 22.4 | 207.1 |
| 2731 | 7.5 | 179.1 |
| 2341 | 6.4 | 133.6 |
| 1820 | 5.0 | 128.6 |
| 2048 | 5.6 | 123.9 |
| 1638 | 4.5 | 105.4 |
| 1489 | 4.1 | 64.5 |
| 683 | 1.9 | 38.2 |
| 712 | 2.0 | 37.1 |
| 655 | 1.8 | 30.7 |

This result testifies that EUVR, probably, through the other atmospheric parameters, for example, the atmospheric transmittance, TOC and so on, is related to the solar activity. The paper[16] describes the possibility to have the dependence of spectral atmospheric transmittance on the solar activity in the 11-year cycle. Some hypotheses have recently been proposed relating to the solar activity effect on the atmospheric transmittance[18] but the mechanism of this effect was not determined.

Previously we recognized 26-day variations based on data of ground-based measurements of the short-wave UVR, which, by our assumption, could also be dictated by variations of the atmospheric transmittance at quasi-periodic variations of solar activity close to a typical time of 27 days.[19]

## Conclusions

In analyzing the long-term homogeneous data of satellite measurements of the ground total EUVR in Irkutsk, obtained and processed using unified methods over a period of two cycles of solar activity, we have obtained the following results:

1. Climatic norms of EUVR variations have been obtained – many-year, seasonal, monthly means and their repetitions. Knowledge of these norms makes it possible to consider the appropriate analyzed values for separate months, years, etc. as a deviation from these norms, i.e., to judge on the typical and anomalous behavior of EUVR.

2. The seasonal behavior of EUVR for Irkutsk with typical features has been obtained (local, representing local peculiarities of climatic conditions, physical-geographic location, and so on).

3. The long-term trends of ground EUVR have been obtained, which give a progressive growth of EUVR in the 21st and 22nd cycles of solar activity. In the current 23rd cycle the situation can be assessed variously depending on the approximation method. Indefiniteness of obtained results of relativity of possible future EUVR trends is indicative of the necessity of accumulation of experimental data for estimating trends on more long-term series of observations.

4. Spectral analysis of a time series of daily values of exposition of the ground EUVR has made it possible to separate out, in addition to the natural annual harmonic, the periods of 11, 22, 5, and 2 years, which can be an evidence of the relation existing between the EUVR and solar activity. Mechanisms and channels of this relation, up to now, have not been determined and require further investigation.

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