Irregular variations of UV radiation at the ground level

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The paper presents and analyzes the data on daily observations of ground-level near-noon solar ultraviolet radiation (UVR) in the wavelength range from 295 to 345 nm in Irkutsk (Eastern Siberia, 52°N, 104°E) over a period from 1998 to 2000. The study revealed asymmetry of seasonal variation of the UV radiation with respect to the summer solstice as well as its wavelength dependence in the spectral range under consideration. Irregular variations of the ground-level UV radiation, typical of this region and depending on the season and spectral range selected, are determined. The detected features of the irregular variations are interpreted in terms of the existence of a pronounced annual variation in the total ozone content, the variation (during different seasons) of the proportion between the Rayleigh and aerosol scattering contributions to extinction of UV radiation as well as absorption by ozone and specific climatic weather conditions in Eastern Siberia.

Introduction

One of the most important problems in the field of the investigation of solar-terrestrial relations is the study of a possible variability of ground-level solar ultraviolet radiation (UVR). These variations can be associated with climatic variations of some atmospheric parameters observed in the last decades, in particular, the existence of negative time trends and (or) many-year variations of atmospheric ozone.[1$4] The variations of ground UVR due to the changes of the total ozone content in some cases are found to be comparable with or even smaller than the variations of UV radiation of different time scales connected with other helio-geophysical and meteorological factors.

The highest amplitude variations of UV radiation are due to the variation of the solar elevation (daily and seasonal variations) as well as the presence of cloud cover. In midlatitudes these variations of UV radiation depending on a wavelength can reach tens and hundreds percent and more. Seasonal variations may be of two types. First, regular variations due to seasonal variation of the solar elevation (depend on the latitude of an observation point). Second, irregular variations connected with the peculiarities of the regional climatic conditions (i.e., depend on geographic position and physical-geographic characteristics of a region). It is precisely these irregular seasonal variations that are of special interest as a climate characteristic of the UV radiation field of the region under study. These variations are also an important parameter, which determines the dispersions of monthly and annual amount of UV radiation, whose consideration is necessary when determining the trends of UV radiation. The existence of physical-geographic peculiarities of regions under study motivates the necessity of conducting simultaneous observations of ground UV radiation in many Earth regions.[1,5$10] Among them, of special interest is the Antarctic region where the highest-amplitude total ozone content variations are observed.

This paper presents the results of observations of the ground-level UV-radiation in Irkutsk. A peculiarity of the observation point is associated with the fact that the Siberian region is the area of stable Asiatic anticyclone where anomalously low values of TOC were observed in specific periods until recently.[2,3,10,11]

Results of observations and discussion

In Irkutsk (region of Eastern Siberia, 52°N, 104°E) daily measurements of near-noon values of UV radiation have been carried out in the wavelength range from 295 to 345 nm since fall 1998. The measured values correspond to the flux of direct radiation with the possible extra contribution of scattered radiation (about 5 to 15%). Thus, the analyzed relative UVR variations smaller than this value may be attributed to mutual re-distribution of the direct and scattered components in the measured flux.

Figure 1 shows the results of daily observations of UV radiation from September 24 of 1998 to December 31 of 2000 for a wavelength of 309 nm. The day of summer solstice is indicated by a vertical dashed line. Figure 1 shows that the annual variation of UV radiation is clearly determined by the solar elevation. A strong daily variation of UV radiation is observed. Its value is affected by cloudiness variations as well as aerosol state of the atmosphere and TOC variations. More careful analysis of time variations reveals asymmetry in annual variation of UV radiation at phases of spring growth (first half year) and fall decay (second half year) due to variations of solar elevation, i.e., the presence of seasonal variations.

For biennially estimation of this effect, Fig. 2 shows mean variations of UV radiation for half years (from December 23 to June 22 and from June 23 to December 22) depending on the sun angle elevation *i* for wavelengths 309 nm (*a*) and 344 nm (*b*).

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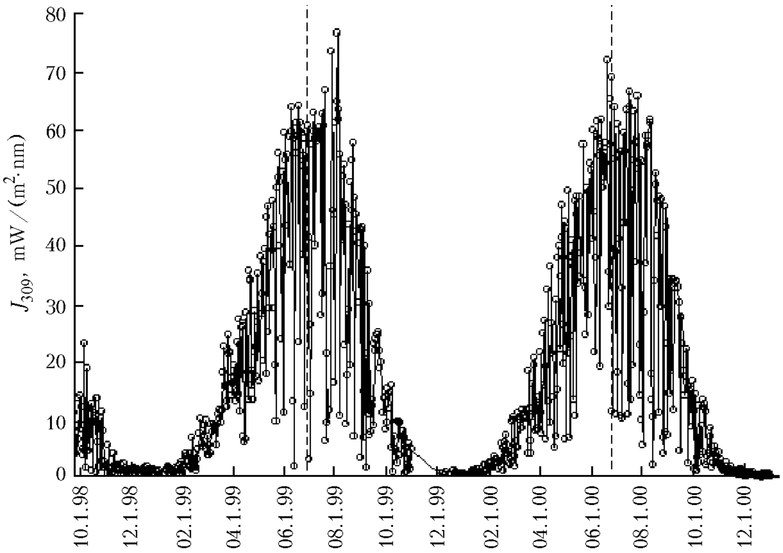

Fig. 1. Daily near-noon intensities of observed UVR at wavelength of 309 nm.

Variations for the first half year of 1999$2000 are shown by thin lines, and those for second half year are shown by thick lines. The values of *J*(309 nm, *i*) for the second half year in the range of solar elevations from 30° to 60° (June$September) systematically exceed the corresponding values of *J*(309 nm, *i*) for the first half year (March$June) (see Fig. 2*a*). The excess reaches 40$50%. For a given intensity of UV radiation *J*(344 nm, *i*) in Fig. 2*b*, the excess of values for the first half year of 1999$2000 is noted relative to the corresponding values of the second half year in the range of angles from 15° to 40° (corresponds to periods January$March and September$ December). An essential increase of *J*(344 nm, *i*) in the 30°$40° angular range was observed in the spring period of 1999.

The mentioned differences of seasonal dependences of *J*(309 nm, *i*) and *J*(344 nm, *i*) are caused by the peculiarities of spectral dependence of basic factors affecting the incoming UV radiation. It is known that in the considered spectral range the main effect on the UVR extinction is produced by the Rayleigh and aerosol scattering and ozone absorption. In the wavelength range from 345 to 350 nm the principal contribution to the radiation extinction is due to aerosol scattering and Rayleigh scattering, while the ozone contribution is about 0.1%. In the shortwave range of UV spectrum, the contribution of ozone to extinction increases and at a wavelength of 280 nm it is about 85% (Ref. 12).

Asymmetry of seasonal variation of UV radiation relative to summer solstice in the shortwave spectral range of 309 nm can be caused by the pronounced annual variation of TOC over the region[4] with maximum in the first half year. The behavior of UV radiation at a wavelength of 344 nm is likely connected with the different cloud and aerosol conditions of the atmosphere in different seasons.

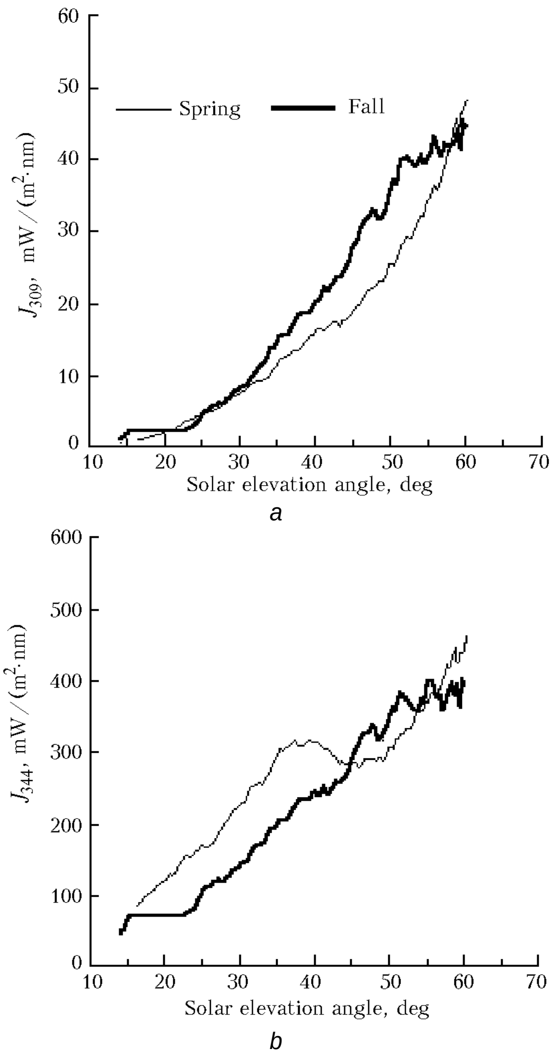

Fig. 2. Biennially averaged smoothed variations of the UV radiation at the wavelengths of 309 nm (*a*) and 344 nm (*b*) for two seasons depending on the solar elevation angle.

The removal of annual behavior of UV radiation makes it possible to separate out irregular variations due to climatic and meteorological characteristics of the region and the dominating regimes of atmospheric circulation at the observation point (Fig. 3). The annual UVR variation determines the low-frequency component of the time series. However, it is not a simple harmonic with a one-year period, because the annual variation includes large-scale synoptic variations during a year. Therefore, the annual variation was approximated by a five-order polynomial of the whole time series. So, it was different for different years and different wavelength.

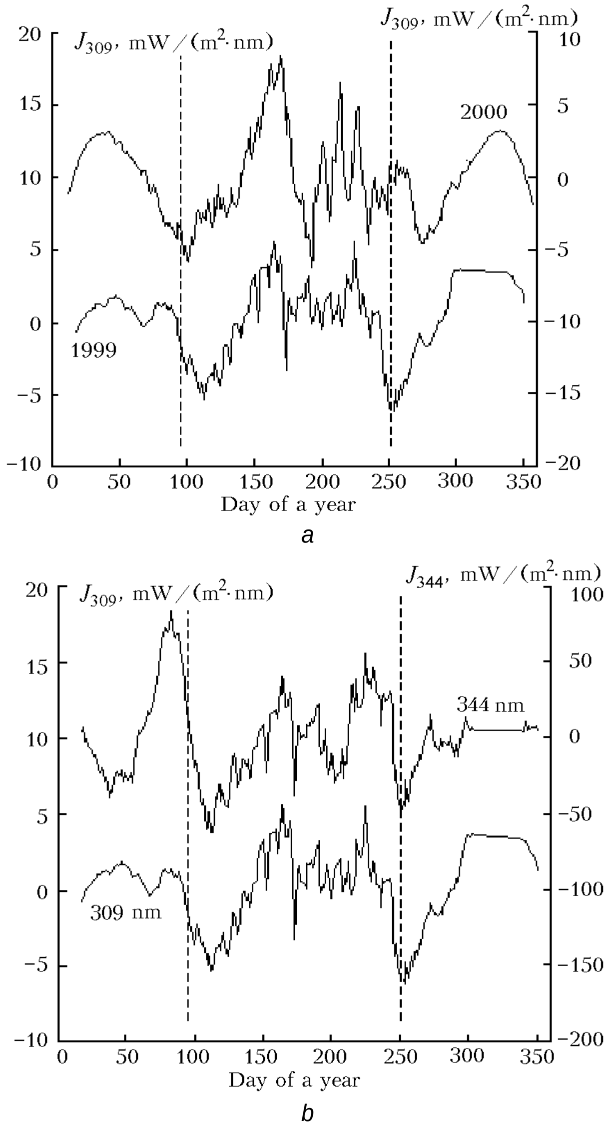

Fig. 3. Irregular variations of UV radiation after removal of the annual variation at the wavelength of 309 nm in 1999 (left scale) and 2000 (right scale) (*a*); at the wavelengths of 309 (left scale) and 344 nm (right scale) in 1999 (*b*).

The region of Eastern Siberia is characterized by the presence of the Asiatic anticyclone in the first winter months of a year (in Figs. 3*a* and *b*, it is a period from 1st to 80th day) with a large number of fine days.[13] Subsequently the spring intensification of cyclone activity is observed with a predominance of transformed air masses coming from the regions of Arctic seas (the period of 80th–120th day).

The late spring and the early summer are characterized by dry weather with a large number of days with clear skies and high temperatures (~120th–180th day). The late summer is characterized by abundant precipitation and, hence, by cloudy weather (~180th–240th day) due to the cyclone activity over Mongolia and arrival of southern cyclones to the southern Baikal region. The fall period is characterized by the cyclone activity from the west with a relatively short period of stable weather.

Figure 3*a* shows annual variations of UV radiation at 309 nm for 1999 and 2000 after removal of the annual trends and averaging over 21 days. As would be expected, repetition of irregular variations is seen. Some distinctions in amplitudes and time shifts of these variations are likely connected with the specific manifestations of the mentioned meteorological peculiarities of the region in different years.

Figure 3*b* shows the averaged irregular variations for the wavelengths of 309 and 344 nm for 1999. Different correlation of UV radiation variations is visually observed at two wavelengths for different seasons. For ~100th–280th day period (the Sun elevation angles $i > 30$–$40°$) we can see high similarity of curve shapes for both wavelengths (with the presence of a high-frequency component). At the same time, for ~1st–100th and ~280th–365th day periods ($i < 44°$ and $i < 30°$, respectively) some differences are already seen in dynamics of irregular variations of UV radiation up to anticorrelation (see, for example, the time interval ~1st–80th day period).

This peculiarity is probably conditioned by different contributions to UVR extinction due to Rayleigh and aerosol scattering and ozone absorption in different seasons at different solar elevation (optical masses). At low solar elevation angles (large optical masses), the great contribution to direct radiation extinction due to large value of optical mass is introduced by the "Rayleigh" and "ozone" atmospheres, which are less irregular than the aerosol component. At large elevation angles and, respectively, low optical masses, the variations of aerosol component (and cloudiness) become decisive. This component has weak spectral dependence of scattering coefficients resulting in high correlation of UVR variations at the wavelengths of 309 and 344 nm.

The pronounced annual behavior of TOC in the region under study[4] with maximum at the beginning of the year and minimum in fall, is responsible for the different dynamics of irregular UVR variations in ozone-dependent spectral range (309 nm) as compared with the longwave spectral range (344 nm) where the TOC effect becomes negligible. This circumstance can be explained by the fact that the transition from the section with high correlation to the section with lower correlation on the curves of irregular variations occurs at different solar elevation angles. Early in a year, when the TOC value is the highest, this limit could be determined as the solar elevation angle ~42$44°, while in the fall it can be determined as ~30$32° (in Figs. 3*a* and *b* these conditional limits are marked by vertical dashed lines).

Daily variability of the ground near-noon UVR has also seasonal dependence. Figure 4 shows the coefficients of the recorded UVR variations for the wavelengths of 309 and 344 nm.

These coefficients are determined as the monthly averaged ratio of standard deviation to the monthly mean value of the UVR. It should be noted that maximum values of the variation coefficients are observed in October and minimum ones are observed in June. In this case the variation coefficients for 309 nm in the first months of a year (February$April), when the largest TOC values are observed, exceed the corresponding values of the variation coefficients for the wavelength of 344 nm. This can be explained by the fact that the observed UVR variations in the ozone-dependent spectral range are determined both by variations of the aerosol and Rayleigh components and by the TOC variations. On the other hand, during summer months the coefficients of UVR variations at the analyzed wavelengths practically coincide. This can be conditioned, as was noted above, by the predominant contribution of variations of the atmospheric aerosol component.

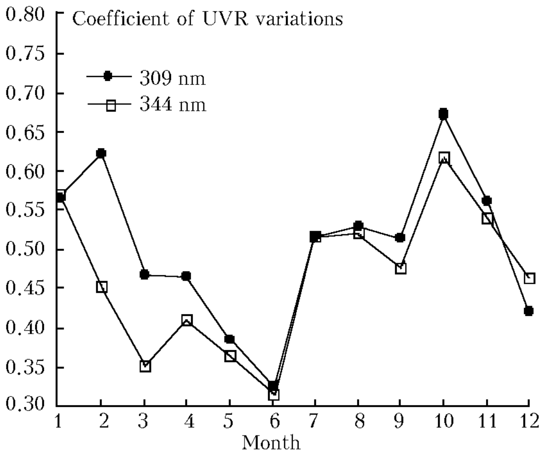

Fig. 4. Coefficients of UVR variations at the wavelengths of 309 and 344 nm over the observation period.

Thus, irregular UVR variations in different seasons can be explained by different causes (dynamics of TOC, aerosol component, cloudiness, albedo) and can be of various character for different parts of the considered spectral range. The mentioned peculiarities of the UVR variations should have distinctions in the other regions with different latitude of an observation point, TOC dynamics, and climatic and meteorological condition.

Conclusion

For the region of Eastern Siberia the asymmetry of seasonal variation of UV radiation (295$345 nm) about the summer solstice was revealed. This asymmetry was determined by the presence of a marked seasonal variation of total ozone content and meteorological peculiarities of the region.

Irregular variations of the ground UV radiation and their peculiarities characteristic of the observation region were determined. For variations in the shortwave spectral range, their repetition from year to year was noticed, while the differences are connected with short-term manifestations of meteorological peculiarities in different years. For simultaneous UVR variations in different spectral regions, the similarity at high solar elevation and dissimilarity at low solar elevation was observed during one year. This was connected with the varying contributions of Rayleigh and aerosol scattering and ozone absorption to spectral UVR extinction at different solar elevation.

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