SPECTRAL MEASUREMENTS OF THE SOLAR NEAR-GROUND UV RADIATION DURING THE SOLAR ECLIPSE ON MARCH 9, 1997

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Results of spectral near-ground measurements of solar ultraviolet radiation, in the wavelength range 296–326 nm*, are presented for the period of the solar eclipse over Irkutsk on March 9, 1997. The changes revealed during the eclipse in the spectral distribution of the radiation recorded are discussed. It is supposed that the changes in the spectra observed at the moments close to the maximum phase of the eclipse may be caused by the effect of multiple scattering of the ultraviolet radiation.*

Information about the energy distribution over the solar radiation spectrum may be a determining factor in solving of a number of fundamental and applied problems in the field of investigation of solar radiation interaction with the Earth's atmosphere, for example, in modeling of photochemical processes in the Earth's atmosphere and ionosphere, or in measuring of the atmospheric ozone content by optical methods.[1] Intensity variations of solar radiation in the short-wave spectral region are of strongly important. The reason is that the outbursts of solar radiation in the X-ray and ultraviolet regions are the manifestations of solar activity. The ultraviolet radiation in the wavelength range from 220 to 310 nm plays an important role in the ozone generation processes, whereas the radiation of shorter wavelengths (extreme ultraviolet and X-rays) in the radiation processes in the D and E layers of the ionosphere. The intensity variations of the short-wave solar radiation have been revealed that are related to such short-time events as solar bursts, passage through sector borders of the interplanetary magnetic field, the 27-day rotational period of the Sun, as well as to the global variations in the solar activity cycle.[2,3] Such natural phenomenon as the total solar eclipse is a unique opportunity for studying the responses of the atmosphere and ionosphere to a short interruption of the influx of solar radiation. The amount and spectral composition of solar radiation vary during the solar eclipse (SE) events. The variations in the spectral composition are usually related either to the heliophysical factors (for example, darkening toward the solar disc edge,[4] or the presence of active formations on the Sun), or to the geophysical factors, like variation of the total ozone content (TOC) and nonphotochemical variations of optical properties of the atmosphere due to variations in pressure, temperature, air composition, and so on.

The contradictory situation takes place with measuring TOC during the solar eclipses. Thus, photochemical modeling of the SE influence on the composition of the stratosphere and mesosphere yields quantitatively consistent, on the whole, results that show that the TOC variations during the solar eclipse may not exceed the fractions of percent. However, in the experiment a wide spectrum of TOC variations, like the TOC increase, its periodic oscillations, or a decrease, with the amplitude up to units and tens of percents is observed during the solar eclipses (see Refs. 4 to 9 and references therein).

The account for darkening toward the edge of the solar disc does not necessarily make the agreement between the variations in the spectral composition observed during the SE quantitatively better. Moreover, the corrections that have been being used so far to TOC values measured during the SE for the influence of the solar disc darkening toward its edge, are based on the assumption of the invariance and symmetry of the distribution functions over the Sun disc. Meanwhile, the observational results, for instance, from Ref. 10 reveal certain unexpected effects. Thus, the West-to-East asymmetry of the darkening curves varying in time was observed in the epoch of minimum in the solar activity.

The intensity distribution over the disc varied everywhere in the spectral region (330–660 nm) analyzed with the amplitude of variations being of 1–2% during the time periods from minutes and up to hours. The magnitude of variations increased with the wavelength decrease. For a comparison, it should be pointed out that, according to Ref. 1, the accuracy of the TOC measurement using direct solar radiation is about one percent. This introduces an uncertainty into the atmospheric TOC data acquired during the SE events, and may, in part, explain the contradictions existing in the results on TOC variations observed that may be caused by the influence of solar eclipses, as well as by data interpretation. In this connection the spectral measurements of the near-ground solar UV radiation during the solar eclipse presented below can be of mutual interest for researchers in the field of the

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solar physics and in the physics of the Earth's atmosphere and ionosphere.

SOME CHARACTERISTICS OF THE SOLAR ECLIPSE

On March 9, 1997 the solar eclipse was observed over the Northern part of the East hemisphere with the band of full shade on the Earth's surface in the region starting from 50°N and 87°E, on the border between Russia and China.[11] Chita was the only big city within the full shade band with its largest width up to 370 km, whereas Irkutsk, Ulan-Ude and Ulan-Bator were in the immediate vicinity of the shade. A peculiarity of the solar eclipse observed over Irkutsk on March 9, 1997 (geographic coordinates are as follows: latitude 52° North and longitude 104° East) was low elevation angle of the Sun in the range from 5 to 20° that caused an essential variation of the optical mass of ozone and the atmosphere (from 2.5 to 10) during the SE. The spectral composition of radiation also changed because of different values of the absorption and scattering coefficients at different wavelengths. Full duration of the eclipse observed over Irkutsk was 2 h and 4 min. The time at which the onset of the maximum phase occurred at the observation point was T_{max} = 8:54 LT.

RESULTS OF OBSERVATIONS

The spectral measurements were carried out using an automated spectrophotometer, built on the base of a "KSVU–12B complex and an IBM PC/AT, in the wavelength range from 296 to 326 nm in 5 to 10 min intervals and, at some moments, in the wavelength range of 306–346 nm. The spectral resolution of the instrument used was 0.25 nm and the scanning speed of 8 nm/min. It was the scattered UV radiation that has been recorded in these measurements. The optical axis of the spectrophotometer was oriented horizontally along a fixed azimuth direction which thus viewed a portion of the sky below the visible trajectory of the Sun. To check the total illumination, the net flux of radiation (both direct and scattered) integrated over the wavelength range from 400 to 11000 nm has been measured with a detector of the net solar flux. Using a WAT–902 A CCD camera coupled with a Jupiter–37A objective of 135 mm focal length we have permanently recorded the solar disc image in the wavelength range 350–390 nm, the spectral portions being isolated with the color glass filters.

Time behavior of the radiation intensity at two wavelengths (323.8 and 315.4 nm) is shown in Fig. 1 along with those of the integral intensity and the eclipse phase Φ. The latter value being determined as the ratio of the shaded portion of the Sun's disc to its total area. Nonmonotonic trend of the integral flux in the first half of the eclipse is connected with cloudiness in the Eastern part of the horizon at this time. Low intensity of the UV radiation before the eclipse was caused by large optical masses of the atmosphere and of the ozone layer characteristic during morning hours.

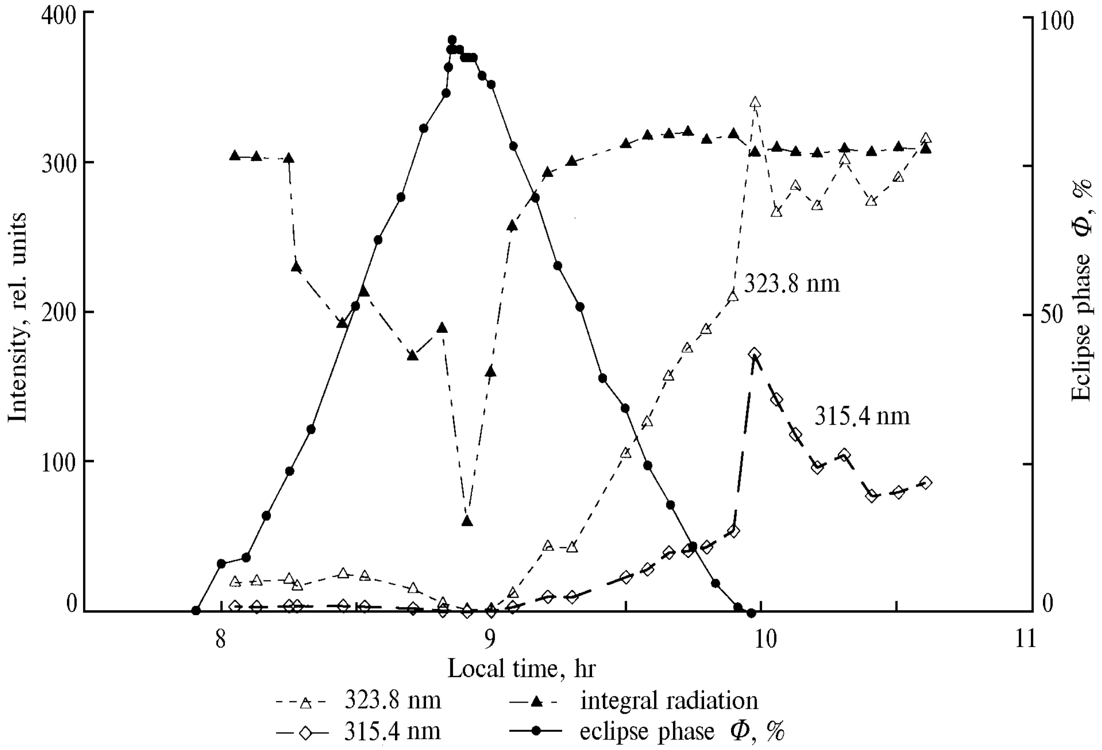

FIG. 1.

For a comparison it is worth noting here that the levels of integral flux before the eclipse and after it appear to be comparable. Stronger modulation of the short-wave portion of the UV radiation compared to that of the long-wave one is a peculiar feature of the UV radiation recorded. Thus, the ratio of the radiation intensity at 323.8 nm recorded in the beginning of the SE to its value during the maximum SE phase is about 11 while that of the intensity after the SE to the intensity during its maximum being equal to 180. Corresponding values at the wavelength of 315.4 nm are 15 and 720. At the same time these ratios for the integral intensity do not exceed 8 and 10, respectively.

The logarithm of the ratio between the intensities at 315.4 and 323.8 nm wavelengths, corrected for different measurement times, is shown in Fig. 2 as a function of time for March 8, 9, and 10, 1997. The intensity ratios are usually used as quantitative characteristics showing the spectrum change, for example, in the spectral transmission factor $\eta = \log (I_k/I_l)$, where I_k and I_l are the radiation intensities at the wavelengths λ_k and λ_l ($\lambda_k < \lambda_l$), or as a characteristic of a medium when, in particular, evaluating the ozone content by optical methods. The value η can conventionally be considered as a measure of relative spectral transparency of the atmosphere.

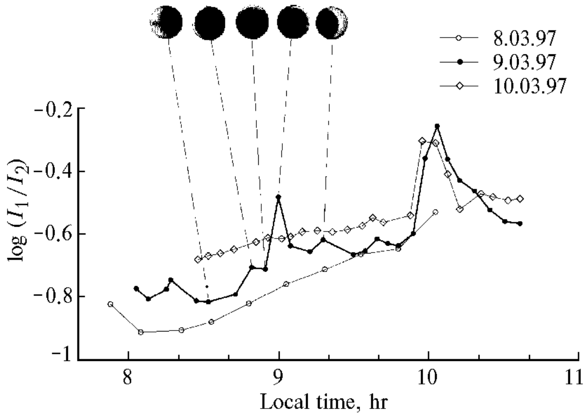

FIG. 2. Logarithm of the radiation intensity ratios and the SE phase images.

In Fig. 2 set out also are images of the SE phases as they have been recorded with the CCD-camera in the wavelength range 350–390 nm at the moments of taking the spectra. It is seen from the figure that the behavior of the factor η on the eclipse day differs from its time behavior on the days before and after the eclipse. This fact evidences that there is a deviation in the behavior of the spectral composition of the UV radiation during the eclipse as compared to its typical diurnal behavior, caused by variation of the optical mass of the atmosphere. This is especially true as regards the situation when approaching the maximum phase of the SE (T_{max} = 8 h 54 min), when an increase in the η value takes place. The increase in η value by the end of the SE (LT ~ 10 h 00 min–10 h 20 min) has been observed in two succeeding days as well. For this reason it was not considered to be directly related to the solar eclipse, at the stage of preliminary analysis of the results. However, in our opinion, such a behavior of the η factor requires special consideration and there are two reasons to do this. First, it is likely that the increases in η observed have common (or similar) mechanism, secondly, analogous behavior of η at the end of the SE was pointed out in Ref. 5 as well.

DISCUSSION

The variations of η factor that we have observed during the SE have also been pointed out earlier in Refs. 5 and 7, for example, there these variations have been treated as the ozone-eclipse effect. The effect manifested itself as a sharp change of relative transparency of the atmosphere in ozone affected region (310–330 nm) that corresponded to rise of the total ozone content in time when approaching the full phase of the eclipse. By time when these papers had been published the nature of the ozone-eclipse effect was yet unclear, and several possible explanations of this phenomenon were proposed. Among these there is the change in the balance between the portions of radiation in the spectrum of an extraterrestrial radiation source that cause the ozone-generation and destruction. Formation of aerosols in the atmosphere that may selectively attenuate radiation, temperature variations in the ozone absorption coefficient, and other causes have also been mentioned.

Unfortunately, we failed to find more recent papers on the ozone-eclipse effect in the literature. At the same time, the situation with TOC measurements during the SE, that, in fact, are the measurements of the ozone-eclipse effect, has been mentioned above. In this connection an attempt has been made to establish possible causes and mechanisms, other than those discussed in the literature, of η variation during the SE.

It is known that, besides the TOC value, many other factors as elevation angle and the state of the Sun disc, cloudiness, relationship between direct and scattered illumination, aerosol, and others influence the shape of the near-ground ultraviolet radiation spectrum and correspondingly the η value. Of the factors listed, the illumination, except for possible variations in the total ozone content in atmosphere, is the most dynamic one, especially when approaching the maximum eclipse phase.

The topology of the Earth's atmosphere illumination during SE, varying in time and space, may certainly explain sharp changes in the natural ratio between direct and scattered radiation, being, in shape, a combination of a converging cone of the full shade and a diverging cone of the half-shade. Possible schemes of forming the illumination of the atmosphere during the SE, at low Sun, for different positions of an observer, about the shade area, are shown in Fig. 3. The shade and half-shade (that is fixed eclipse phase) areas are denoted by Roman figures I and II, respectively. By *1*, *2*, and *3* are denoted the positions of three observers (or three moments in time $t_1 < t_2 < t_3$ for a fixed observer). It is seen that there exists the position, the observer *2* (shade or near-shade area), or the time moment (near the maximum phase of the eclipse) for a fixed observer when light multiply (doubly and higher-order) scattered from half-shade area contributes into the illumination of the atmosphere over the observer.

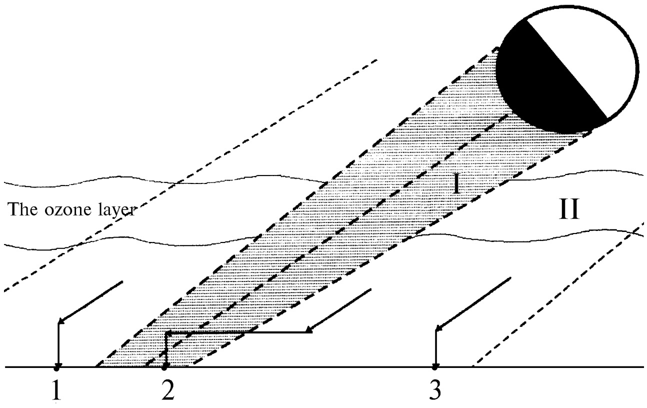

FIG. 3.

Subjectively, the essential increase of illumination due to multiply scattered light manifests itself in the absence of shadows from objects at time moments when approaching the maximum phase of the eclipse under clear sky conditions.

The so-called effect of ‘anomalous’ transparency of the atmosphere (see, for example, Ref. 4) can serve as the phenomenon that is most closely related to this situation. The effect is connected with an increase (variation), under certain geophysical conditions, of the fraction of multiply scattered light in the UV radiation recorded. This may change the shape of the UV portion of the spectrum thus being, in a certain sense, an instrumental effect. In particular, this effect is observed during twilight at low Sun.[12]

The increase of the scattered radiation fraction in the radiation recorded is accompanied by distortions occurring in the spectrum of the latter because of the enhanced portion of the short-wave radiation. For a comparison Fig. 4 presents data on calculated direct solar radiation spectrum, as well as on the spectrum of doubly scattered radiation in the ultraviolet region (curves *1* and *2*, respectively), taken from Ref. 4. The spectra of scattered UV-radiation we have recorded at two moments in time during the SE on March 9, 1997, are also shown in this figure. The calculated data refer to the Sun elevation angle of 12° that corresponds to the maximum phase of the SE on March 9, 1997. All spectra presented here have been normalized to the radiation intensity at the 325.4 nm wavelength, in the respective spectral distributions, thus being presented in relative units. The first of these spectra (curve *3*) has been recorded at 8:32 (LT) in the first half of the eclipse phase ($t \sim 0.5$) while the second one at 9:05 immediately after the maximum eclipse phase ($t \sim 0.8$), when the variation in the near-ground UV radiation spectral distribution takes place. The agreement between the calculated and measured spectra, that is qualitative quite good, at least for the wavelength range from 310 to 325 nm, has attracted our attention. The first, from the measured spectra, occupies in the figure the area corresponding to direct and singly scattered radiation, whereas the second one is shifted to the area of doubly (and higher-order) scattered radiation.

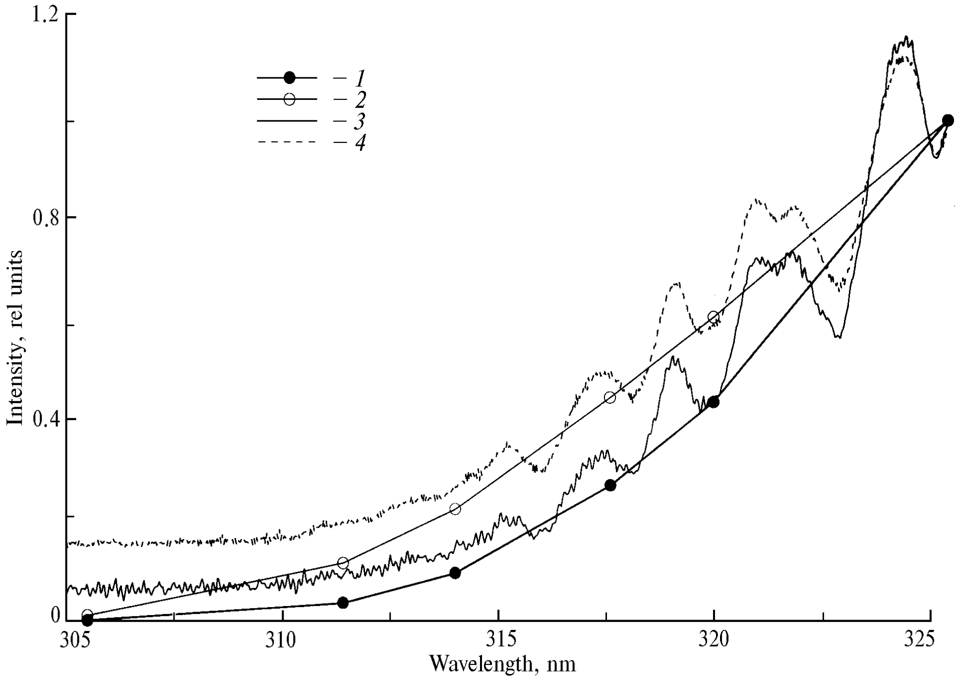

FIG. 4.

Thus, in authors' opinion, the variations in the spectrum of UV radiation (η variations) recorded during the SE, except for variations caused by the solar disc darkening toward edge, as well as by possible variations in the total ozone content and other optical and physical characteristics, can be related to nonuniform, with height, illumination of the atmosphere that varies during the SE and to the enhanced fraction of scattered UV radiation.

Similar effect in its full measure should, probably, manifest itself during the SE occurring at the low elevation angles of the Sun (illumination of the atmosphere at slant angles of incidence), and must disappear in airborne measurements[8] when no contribution comes from the scattering from the near-ground layers of the atmosphere.

The latter circumstances along with the fact that the effect discussed, like the 4anomalous' transparency of the atmosphere are, in a certain sense, of instrumental origin, depending, in particular, on whether the direct or scattered radiation is recorded, as well as on the angular aperture of optical receiver, can yield contradictory results of the total ozone content measurements. In some situations the effect may take place and be interpreted as the TOC variation during the SE, while in other situations it may be absent thus giving rise to the corresponding conclusions. So, if this effect of varying spectrum of the near-ground UV radiation is related to the TOC variation during a SE, then, according to preliminary estimates and being converted into the possible TOC variations, it should yield a 20%-decrease in TOC that exceeds the value of corrections to TOC for the solar disc darkening toward its edge. However, in accordance with data from Ref. 4, the corrections for the Sun disc darkening toward the edge do not exceed 11%, for the short-wave region of the UV radiation spectrum ($\lambda = 305$ to 332 nm) measured with a Dobson spectrophotometer. Besides, thus obtained correction would correspond to the apparent increase in TOC, in contrast to what we have from possible interpretation as the TOC decrease according to our experimental data.

As to the peculiarity in the behavior of η observed in the end of the SE (10:00 to 10:20, local time), it can be pointed out that it was observed when the elevation angle of the Sun was 20 to 22° over the horizon. Considering the fact that this peculiarity was revealed during two succeeding days as well, it seems to be natural to relate it to possible optical effects in the atmosphere or to the phenomena observed at some distances away from the Sun, under certain meteorological conditions. In this case the elevation angle of 22° coincides with the angular distance at which weak halo occurs as a result of light refraction and reflection on particles of some clouds. It is worth noting here that on the SE day (see Fig. 1) and on the succeeding days a thin stripe of cloudiness was observed in the east portion of the horizon during morning hours, whereas on March 8, when this effect was not observed, we had an overcast. In this relation the results published in Ref. 5 are of certain interest since similar η increase (wavelengths 310 and 330 nm) has been observed during the SE, after the 4th measurement session, when the Sun was at about 22° elevation angle (the optical mass ~2.5). The intensity behavior in this interval (see Fig. 1) exhibits a large relative increase in the short-wave UV radiation (for $\lambda = 315.4$ nm the increase amounted to about 300%) at a completely absent manifestations of the effect in the sum integrated radiation. Assuming that at certain elevation angles of the Sun light refraction and reflection may occur along the directions away from the Earth's surface as well, and taking into account that at the elevation angles of the Sun less than 20° the scattered UV radiation can be several times higher than the direct one, one can expect an essential local increase in the Earth's atmosphere irradiation in the spectral range from 300 to 320 nm. Such an increase can, in its turn, affect the photochemical processes at altitudes in the lower atmosphere, that involve the absorption of radiation of this spectral range, for example, in reactions of the ozone photodissociation.

CONCLUSIONS

During the Sun eclipse on March 9, 1997, over Irkutsk we have revealed the intensity variations of scattered radiation in the wavelength range from 296 to 326 nm as well as the solar disc images in the wavelength range from 350 to 390 nm.

We have recorded short-term variations in the spectrum of near-ground ultraviolet radiation at moments in time when approaching the maximum SE phase, as well as in the end of the SE.

Variations in the UV-radiation spectra detected within the maximum eclipse phase are interpreted as an increase in the fraction of scattered radiation during this time interval.

Variations in the UV radiation spectra in the end of the Sun eclipse are, likely to be caused by the halo effect, and are not directly related to the Sun eclipse.

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