Characteristics of optical flares in night-time atmospheric radiation according to data of observations with a multispectral photometer and a TV-camera

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The results of experimental studies of tens to hundreds millisecond long optical flares in the nighttime atmospheric emission in mid-latitudes are presented. Luminous emittance of optical flares in different regions of the optical spectrum was estimated, and distributions of the flare duration and the probability of their observation during a night were obtained. The moments of optical flares occurrence in time were compared with those of the gamma-ray bursts according to data from the BATSE catalog. It was concluded that the questions on the nature and sources of optical flares are still open.

For a sufficiently long time, the existence of irregular bursts was noticed in a number of papers devoted to the study of light effects against the background of the nighttime sky (see, for example, Refs. 1–7). These bursts were interpreted as optical flares (OF).

Analysis of characteristics of possible OF sources and mechanisms of OF occurrence allows us to separate out several types of OFs and pulsations, which originate from different phenomena, in the nighttime atmospheric emission in mid-latitudes. The possible OF sources include X-ray and gamma-ray bursts,[8] high-altitude lightning discharges,[9] pulsed ionospheric–magnetospheric processes,[10] and artificial optical phenomena. The presence of several possible OF sources, which have similar characteristics in optical manifestation, poses the problem of their identification.

In this paper we analyze the results of experimental studies of optical flares with a ground-based photometer and those obtained from observations of the upper atmospheric emission with a TV-camera in mid-latitudes. The observations were conducted in 1987–1993 and 1997–1999 at the Geophysical Observatory of the Institute of Solar–Terrestrial Physics SB RAS, Irkutsk (52°N, 103°E).

Instrumentation and observation technique

In 1987–1993, optical radiation from the upper atmosphere was measured within the spectral portions of the atomic oxygen [OI] emission lines at 557.7 and 630.0 nm isolated with spectrometers and photometers with the tilted interference filters ($\Delta\lambda_{1/2} \sim 1$–$2$ nm). In 1997–1999, besides the radiation at 557.7 and 630.0 nm, the infrared radiation (720–830 nm), the radiation in the blue (360–480 nm) and the UV (360–410 nm) spectral regions, and, in some periods, the integral radiation were measured. The measurements in 1997–1999 were conducted by a four-channel zenith photometer connected to a personal computer with the time resolution up to 8 ms.

In some periods, TV-camera observations with the use of image-converter tubes were used. The sensitivity of the TV system with the image converters of different types allowed the background component in the integral radiation of the nighttime sky to be reliably recorded, as well as point-like objects up to 8–9 star magnitude under clear sky conditions. Besides, TV-camera observations allowed optical flares caused by meteors and satellites with varying luster to be separated out.

Results of observations

Figure 1 shows characteristic signals from optical flares in different spectral regions. Optical flares have a duration about tens to hundreds milliseconds or, in some cases, several seconds. By now OFs were observed in several spectral regions: in the region of atomic oxygen forbidden lines [OI] 557.7 and 630.0 nm and in the near infrared (720–830 nm), blue (360–480 nm), and UV (360–410 nm) spectral regions.

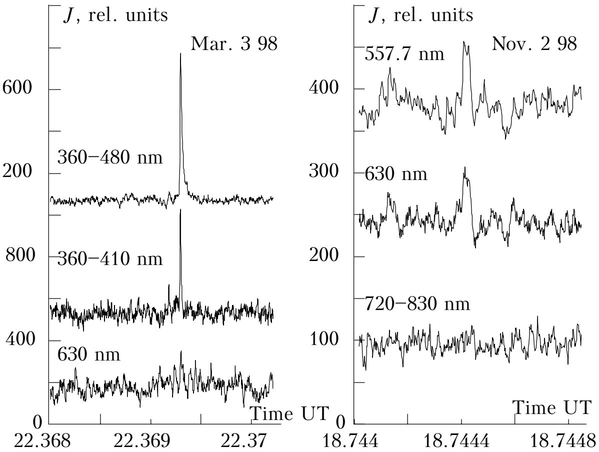

Fig. 1. Examples of optical flares in the nighttime sky emission as measured with a photometer: high-intensity (*a*) and low-intensity (*b*) flare.

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Except for most intense flares, the OF luminous emittance is comparable with the natural background radiation flux of the nighttime sky, and so they are at the sub-visual level. The characteristic values of OF emittance in the wavelength ranges of 557.7, 630.0, 720–830, and 360–410 nm are respectively $\geq 10^{-4}$, $\geq 3{\cdot}10^{-5}$, $\geq 10^{-3}$, and $\geq (1.5\text{–}7){\cdot}10^{-3}$ erg/cm^2·s. Below we give a description of the optical flare observed at 02:50 L.T. on March 1, 1998. This flare was one of the most intense flares and, what is especially important, it was recorded by Cherenkov atmospheric telescope of the Scientific Research Institute of Applied Physics at the Irkutsk State University[7] which was located about 750 m far from the observation site.

Figure 2 shows the signals in the three channels of the photometer: integral channel (300–830 nm), channel of 557.7 nm, and channel of 630 nm from the optical flare recorded on March 1, 1998. The intensity is given in relative units with a shifted zero level of the signals. The upper panel of this figure shows the three TV frames corresponding to the moments before, during, and after the flare. The effective field of view of the TV system was about 40°.

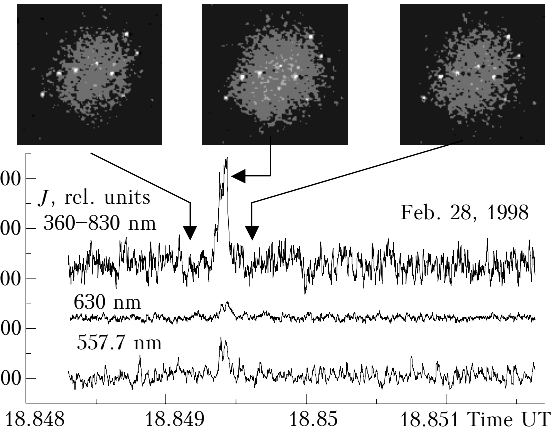

Fig. 2. Optical flare of March 1, 1998 (02:50 L.T.), as recorded with a photometer (intensity is given in relative units with shifted zero levels of signals) and a TV camera.

The estimation of photometric signals gives the following luminous emittance of the optical flare of March 1, 1998: ~ $(4\text{–}8){\cdot}10^{-3}$ erg/cm^2·s by the integral channel and about $3.5{\cdot}10^{-4}$ and $1.26{\cdot}10^{-4}$ erg/cm^2·s in the channels of 557.7 and 630 nm, respectively. The relative excess of the flare signal over the current mean was about 65, 115, and 90%, respectively.

The TV-camera data presented above evidence that the optical flare of March 1, 1998, was characterized by the increased brightness of the entire nighttime sky image. This evidence supports the conclusion[4] that optical flares are extended objects with a characteristic angular dimension of tens of degrees.

The duration distribution of the optical flares and the probability to observe an optical flare during a night were of interest as well. The most probable values of OF duration were obtained to be 100–200 ms for the region of 360–480 nm, 20–60 ms nearby 557.7 and 630 nm, and 40–240 and 400–520 ms in the region of 720–830 nm. Figure 3 shows the histograms of OF duration for the spectral regions of 360–480 and 630 nm. Figure 4 gives the OF observation probabilities for two observation periods: May–November 1987 (data of Ref. 6, curve *1*, 200 hours of observation), December 1998 – January 1999 (curve *2*, 176 hours of observation). The data of Ref. 2 are given for comparison (curve *3*, more than 10 000 hours of observation). In one case, an optical flare was detected simultaneously at sites separated by about 100 km.

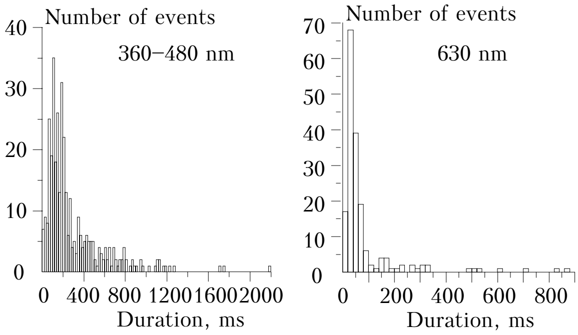

Fig. 3. Distribution of optical flares by duration.

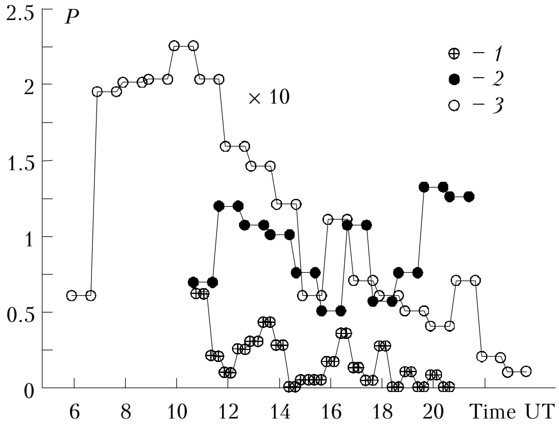

Fig. 4. 24-hour distribution of the probability to observe an optical flare (number of flares observed per one hour): May–November 1987 (*1*), December 1998 – January 1999 (*2*), data of Ref. 2 (*3*).

Discussion

In Ref. 6 it was noted that optical flares with the above characteristics, which were observed first in the auroral zone,[1] later in the subauroral zone,[4] and then in mid-latitudes, are the same geophysical phenomenon. Initially, the origin of optical flares was believed to be due to the emission at the atomic oxygen forbidden lines at 557.7 and 630 nm (Refs. 1 and 2). The results of Ref. 6 and this paper allow the assumption that the OF spectrum probably has a complex structure, including a sufficiently large number of spectral lines and bands of atomic and molecular atmospheric constituents, and most intense lines and bands lie in the blue and UV spectral regions.

Analysis of spectra of the nighttime sky, polar lights, and airglow under various excitation conditions and at different pressure allows revealing possible atmospheric constituents responsible for the recorded emission. Table 1 lists the atmospheric constituents, which can emit optical radiation at different mechanisms of excitation in the spectral regions we used in our observations.

Table 1

Spectral region	Atmospheric constituent	Line or band
360–480 nm	N_2^+	391.4, 427.8 nm (1NG)
	N_2	357.7 nm (2PG)
	OI	369.2, 394.7 nm
	O_2	360–400 nm (A^3E_u–X^3E_g)
555–557.7 nm	OI	557.7 nm
	OH	OH*(7–1)
	NO_2^*	cw spectrum
628–630 nm	OI	630 nm
	OH	OH*(9–3)
	N_2	601.3, 632 nm (1PG)
	NO_2^*	cw spectrum
720–830 nm	OH	OH*(8–3, 4–0, 9–4, 5–1, 6–2)
	OI	725, 774, 799 nm
	N_2	750, 763, 775 nm (1PG)
	NO_2^*	cw spectrum
	O_2	768 nm (atmospheric, 1-1)

According to data from Refs. 2 and 6, the main peculiarities in the 24-hour distribution of the OF observation probability (see Fig. 4) are high probability of OF occurrence in the first half of a night and the presence of a slight peak nearby midnight (16–17 UT). It should be noted that the data from Ref. 2 were obtained from measurements of the integral radiation, whereas the data from Ref. 6 from measurements in the region of atomic oxygen lines at 557.7 and 630 nm. In addition to the above-mentioned peculiarities, the results obtained in 1997–1999, exhibit a pre-dawn peak. The pre-dawn peak may be caused both by a great number of flares in the blue and UV spectral regions and by the automatic computer selection (in contrast to Refs. 2 and 6) of the flare events. Comparing curves *2* and *3* in Fig. 4, we can reveal one more peculiarity. The evening peak comes not immediately after the evening twilight and beginning of nighttime, but one to two hours later. This is true for both the high-latitude data (curve *3*) and the mid-latitude data (curve *2*), for which nighttime optical observations began at different time because of different duration of nighttime.

In Refs. 11 and 12, attempts were undertaken to interpret optical flares by optical manifestation of microbursts of electron flows, which, according to the satellite data,[10] extend over the whole globe and occur at all latitudes and longitudes, inside and outside the plasmosphere. The phenomenon of optical flares seems to be a sort of pulsed glow having a millisecond-duration. Gorbachev et al.[8] interpreted the experimental results of the OF observations[1] by gamma-ray bursts in the Earth's atmosphere. It should be emphasized that the problem of observation of optical manifestations of gamma-ray bursts in the atmosphere has sufficiently long history (see, for example, Ref. 3) and, in our opinion, this question is still open.

We have compared the moments of OF occurrence recorded in 1998, including the above-described OF of March 1, 1998, with the data from the BATSE experimental catalog of the Compton Gamma Ray Observatory.[13] This catalog contains the data of observations of gamma-ray bursts. For the considered period, 993 optical flares were recorded with a photometer, and 194 gamma-ray bursts according to Ref. 13. After excluding the daytime gamma-ray bursts and the days when optical observations of OFs were not conducted, we obtained 21 events of gamma-ray burst observation, the time of which coincides with the periods of night optical observations of OFs. Among these gamma-ray bursts, no one coincides in time with an optical flare within the measurement error. For four gamma ray bursts the difference in time of observation was within 22–58 s, and in three events gamma-ray bursts were ahead of optical flares, and in one event an optical flare preceded a gamma-ray burst. For other bursts and flares the observation time differed from several minutes to several tens of minutes and even more. We also failed to find a partner in the BATSE catalog[13] for the above-described optical flare of March 1, 1998.

It should be emphasized here that power estimates of the optical manifestation of gamma-ray bursts in the Earth's atmosphere, which were presented, for example, in Ref. 8, gives lower values of light fluxes than those we observed during optical flares. Thus, the light flux density in the blue spectral region for an intense gamma-ray burst with the gamma-ray power density of $5\cdot10^{-8}$ J/m^2 was estimated as 10^{-9} J/m^2 (Ref. 8), whereas the characteristic density of optical radiation fluxes in optical flares we have measured in this spectral region is 10^{-7} J/m^2 and higher.

Thus, the problem on the nature and sources of the observed optical flares with the characteristics described above, as well as the problem of detecting optical flares caused by gamma-ray bursts, calls for further investigations. In this case, detailed studies of the OF radiation spectra would be the most valuable source of information.

References

1. Yu.A. Nadubovich, Geomagnetism i Aeronomiya **10**, No. 5, 926–929 (1970).

2. L.P. Kuzakova, Geomagnetism i Aeronomiya **12**, No. 3, 560–561 (1972).

3. W.N. Charman and J.V. Jelley, J. Phys. A: Gen. Phys. **5**, No. 5, 773–780 (1972).

4. L.P. Korobtsova, in: *Inhomogeneities in the Ionosphere* (YaA SB AS USSR, Yakutsk, 1981), pp. 96–102.

5. J. LaBelle, Geophys. Res. Lett. **15**, No. 3, 279–282 (1988).

6. S.Yu. Ermilov and A.V. Mikhalev, in: *Researches into Geomagnetism, Aeronomy and Solar Physics* (Nauka, Moscow, 1989), Issue 84, pp. 119–125.

7. O.A. Gress, T.I. Gress, L.V. Pan'kov, et al., in: *Astrophysics and Physics of Microcosm* (Irkutsk State University Publishing House, Irkutsk, 1998), pp. 115–120.

8. L.P. Gorbachev, N.N. Vzorov, L.V. Levakhina, et al., Kosm. Issled. **32**, No. 6, 172–183 (1994).

9. http: // elf.gi.alaska.edu/

10. W.L. Jmhof, H.D. Voss, J. Mobilia, M. Walf, U.S. Jnan, and D.L. Carpenter, J. Geophys. Res. **A 94**, No. 8, 10 079–10 093 (1989).

11. A.V. Mikhalev, "*Population of Neutral Oxygen Spectral Levels* [OI] ^1S ^1D *at microbursts of electron beams,*" Preprint No. 17 (SibIZMIR SB AS USSR, Irkutsk, 1990), 14 pp.

12. S.Yu. Ermilov and A.V. Mikhalev, J. Atmos. Terr. Phys. **53**, Nos. 11/12, 1157–1160 (1991).

13. http://www.batse.msfc.nasa.gov/