Some features in observations of mid-latitude auroras and emission perturbations in the upper atmosphere during magnetic storms over Eastern Siberia

A.V. Mikhalev

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

Received August 8, 2001

Using data of observations over the airglow in the upper atmosphere over Eastern Siberia (52°N, 104°E), the properties of mid-latitude auroras and emission perturbations in the upper atmosphere during magnetic storms in the periods of the high solar activity in 1989–1993 and 1997–2000 are analyzed. It is suggested that Eastern Siberia is a favorable region for monitoring and investigation of mid-latitude auroras under conditions of geomagnetic perturbations.

Introduction

During geomagnetic storms in mid-latitudes, some perturbations are observed in the emission of the upper atmosphere. Especially powerful geomagnetic perturbations manifest themselves as mid-latitude and low-latitude auroras (MLA).

For some forms of the aurora polaris, the probability of observation depends on the time of a day, universal time (UT), and the location of an observation station (see, for example, Refs. 1 and 2). The existence of similar dependences for MLA was confirmed experimentally only in a few works.

Thus, in Ref. 3 it was noted that during strong magnetic disturbances and in near-midnight hours the intensity of emission of atomic oxygen [OI] at 630 nm increases sharply up to 350 Rayleigh (R), and this increase was assumingly related with the movement of the aurora oval to the equator. In Ref. 4, the maxima were observed in the night behavior of [OI] emission at 630 nm; these maxima had the amplitude up to 100 R at 23–03 LT and were mostly observed in the periods of geomagnetic storms.

Of particular interest are perturbations of emission at 630 nm that are observed at strong magnetic storms. These perturbations manifest themselves as a significant increase in the emission intensity at 630 nm and appearance of irregular variations or additional emissions in nightglow of the mid-latitude atmosphere that are uncharacteristic of quiet geomagnetic situation.

This paper presents results of tentative analysis of the observed mid-latitude auroras and emission perturbations in the upper atmosphere during strong geomagnetic storms in the periods of high solar activity (1989–1993 and 1997–2000). The observations were conducted at the Geophysical Observatory (52°N, 104°E) of the Institute of Solar-Terrestrial Physics SB RAS.

Observation technique and instrumentation

In 1989–1993, the optical radiation of the upper atmosphere was measured with separation of emission of atomic oxygen [OI] at 557.7 and 630 nm using zenith photometers with tilting interference filters ($\Delta\lambda_{1/2} \sim 1–2$ nm). In 1997–1999, in addition to measurements at 557.7 and 630 nm, the emission in the near-infrared (720–830 nm) and ultraviolet (360–410 nm) spectral regions was being recorded. The spectral regions of 360–410 and 720–830 nm were separated with the absorption filters. The angular fields of view of the photometer channels were 4–5°. The absolute calibration of measuring systems was carried out in certain periods against reference stars and then controlled with the use of reference light sources. The photometer software allowed the data of photometric channels to be recorded with the averaging over about 12 s; at appearance of signals exceeding a preset threshold, the time resolution being ~ 8 ms.

Observations and discussion

For the period of observations, optical manifestations of three strong geomagnetic storms were recorded on the following dates: March 24–25 of 1991 (the maximum indices of geomagnetic activity K_p and D_{st} being, respectively 9_- and −298 nT), February 2–5 of 1992 (8_- and −170 nT), and April 6–7 of 2001 (9_- and −321 nT).

Figure 1 depicts the behavior of 630-nm emission on the three nights for the above geomagnetic storms. The behavior of the nightglow at 630 nm in Fig. 1 has similar features for the three magnetic storms considered here. The remarkable growth of the emission at 630 nm starts in the second part of the night and in hours before dawn. A short-term maximum is observed in the nightglow behavior in hours before dawn.

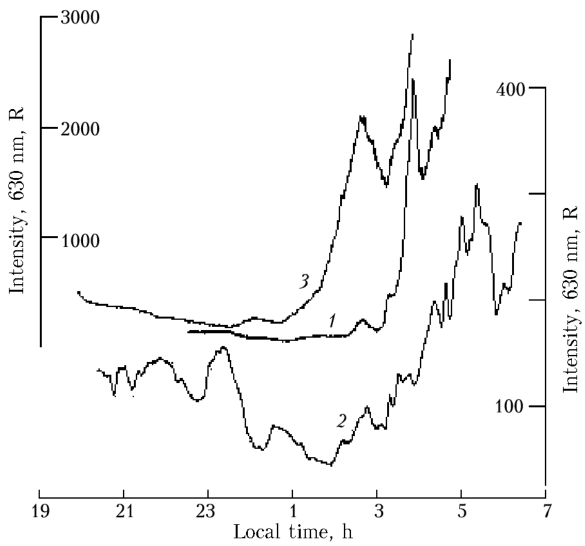

Fig. 1. Night behavior of emission of atomic oxygen [OI] at 630 nm during strong magnetic storms on March 24–25 of 1991 (curve *1*, left intensity scale), February 3–4 of 1992 (curve *2*, right intensity scale), and April 6–7 of 2000 (curve *3*, left intensity scale).

Many papers use the D_{st}-index, as a geomagnetic index being in the closest relation to the intensity of emission at 630 nm under geomagnetic disturbances, in combination with other indices of solar and geomagnetic activity.[5–7]

We have analyzed the mean diurnal distributions of the hourly values of the D_{st} index similar to analysis made in Ref. 8 for all days of the period of 1957–1997. The difference was that we took only disturbed days with D_{st}-index, respectively, ≤ -50, -100, -200, and -300 nT. Analysis was performed for the period since January of 1957 until April of 2000. For this period (15826 days), the number of days, for which at least one value of the D_{st} index during a day was less than -50, -100, -200, and -300 nT, was, respectively, 2620, 468, 72, and 20.

Figure 2 depicts the diurnal (obtained by averaging the hourly values) distributions of the D_{st} index for geomagnetically disturbed days with the D_{st} index ≤ -50 and -200 nT for the period since January of 1957 till April of 2000. The diurnal distributions with the D_{st} index ≤ -100 and -300 nT are qualitatively similar. In Ref. 8, two minima were observed in the diurnal distributions of the D_{st} index in the equinox periods that fall on 0–6 and 18–24 UT. Similar minima are marked in Fig. 2. One of the main causes for appearance of the longitude and UT dependence in the auroras is the lack of coincidence between the geomagnetic and geographical poles and, correspondingly, the change of the position of the Earth's geomagnetic field with respect to the interplanetary field during a day.

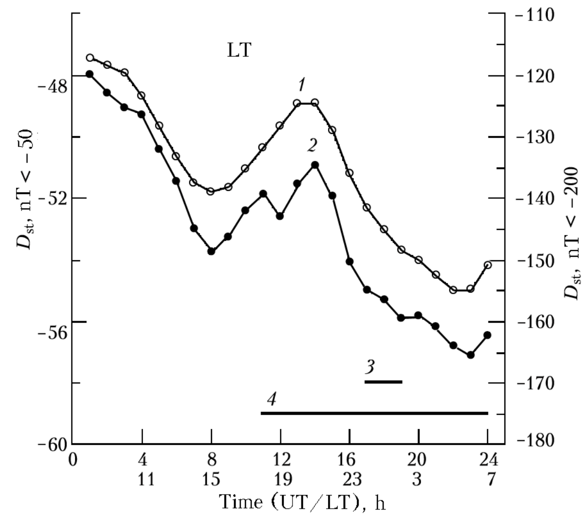

Fig. 2. Diurnal behavior of the D_{st} index of geomagnetic field variations: geomagnetically disturbed days with the index less than-50 (curve *1*) and -200 nT (curve *2*). Straight lines *3* and *4* show the night hours for the Geophysical Observatory of ISTP SB RAS for the summer and winter solstices.

It follows from Fig. 2 that in the considered longitude zone the time intervals suitable for night optical measurements in the winter and fall-spring periods coincide with the minimum values of the D_{st} index (maximum levels of geomagnetic disturbances) on the mean diurnal dependences of the D_{st} index in the UT coordinates. The minimum and extreme values of the D_{st} index fall, respectively, on the second part of night and the hour before dawn by the local time (LT).

For the considered magnetic storms, the remarkable growth of the emission intensity at 630 nm and its maximum values correspond to one of the minima in the mean diurnal distribution of the D_{st} index and fall on 18–23 UT. This fact can be interpreted within the framework of the discussed mechanisms of perturbation of the 630-nm emission during geomagnetic storms. The increase in the concentration of excited oxygen atoms O(1D) in the mid-latitudes during geomagnetic storms is connected with heating of the ionospheric *F*-region, increase of the electron temperature, and overheating flows from the plasmasphere,[6,9] where the energy exchange occurs between the thermal plasma and the growing ring current, which, in its turn, determines the value of the D_{st} index.

In some other papers,[10,11] the perturbations of the mid-latitude emissions are attributed to injected ions of the ring current generated during the main phase of a storm at geomagnetic shells $L \sim 2$–6. It is assumed that this current involves mostly H^+, O^+, and He^+ ions with the energy of tens of kiloelectronvolts, which are lost in the processes of recharging with atoms of the upper atmosphere. In these processes, neutral H, O, and He are generated, which have the same energy, but cannot be controlled by the magnetic field. Being injected into the thermosphere, these particles lead to formation of excited particles and their following emission.

Thus, experimental optical observations of the behavior of 630-nm emission during three magnetic storms, the obtained mean diurnal behavior of the D_{st} index for the geomagnetically disturbed conditions of 1957–2000, and the mechanisms of excitation of 630-nm emission during geomagnetic storms allow us to suppose that the statistical probability to observe the phases of enhancement of 630-nm emission in the periods of geomagnetic storms for the observatory of the ISTP SB RAS and Eastern Siberia is high in the second part of night and in hours before dawn.

The existence of pronounced UT dependence of the D_{st} index of geomagnetic field and the discussed relation of the intensity of 630-nm emission to the ring current (D_{st}) must lead to the appearance of the longitude dependence of the probability of MLA observation due to different night periods of universal time for different longitudinal zones. The night period in the UT coordinates in Eastern Siberia falls on the interval of the minimum values of the D_{st} indices (maximum geomagnetic disturbances) in the diurnal distribution of the D_{st} indices for disturbed days. This allows us to express the opinion that Eastern Siberia can be classified as a region favorable for monitoring and study of mid-latitude auroras at geomagnetic disturbances. This longitude dependence of the probability of MLA observation should likely be taken into account when estimating the probability of visual MLA observations in the past centuries.

As to the appearance of the local maximum in 630-nm emission observed in the hours before dawn during the considered magnetic storms, we can note the following. The insufficient statistics of optical observations during strong magnetic storms still does not allow us to reveal how regular is this feature and what are its causes. Now we can only assume that the appearance of the local maximum in 630-nm emission may be caused by the both total enhancement of the emission at 630 nm and by the movement of the spatially localized disturbance along the zenith direction.[12]

Here it is worth mentioning similar time dynamics of the effect of pre-twilight enhancement of the emission at 630 nm in the mid-latitudes, which is observed in winter months and assumingly [13] connected with the conjugate ionosphere and magnetosphere. Emission at 630 nm in the period of pre-twilight enhancement first grows fast, almost doubling with respect to its midnight value. Then the growth decelerates and often a minimum is observed as the intensity decreases by ~ 25–30% (Ref. 14), roughly before the onset of local astronomic twilight, and then the second fast growth connected with local twilight begins.

In observations reported in Ref. 15 devoted to the study of the spatial dynamics of subauroral (SAR) stable arcs in the subauroral ionosphere in the considered longitude region, SAR arcs observed at moderate magnetic activity moved in the equatorial direction as the magnetic activity increased.

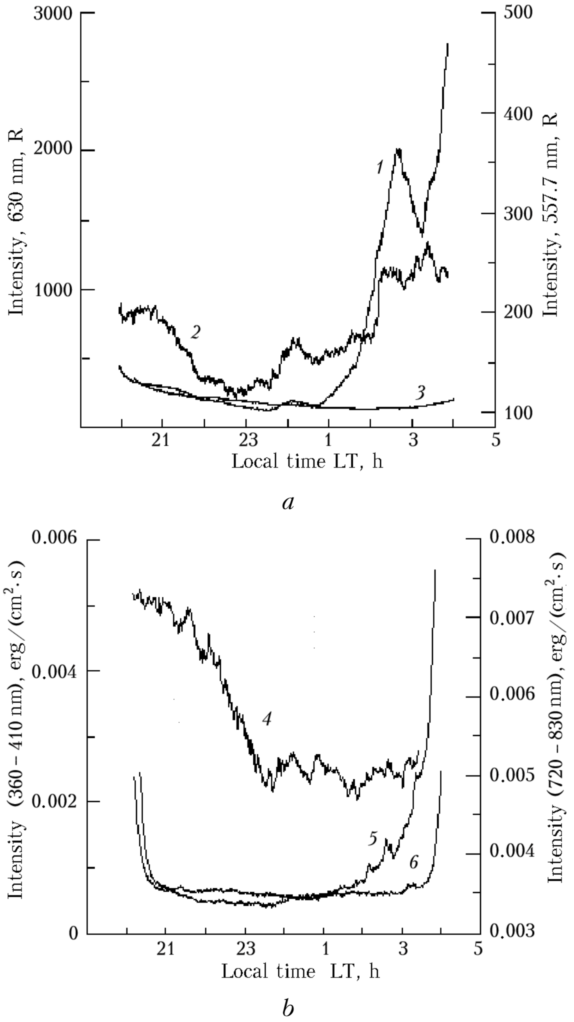

Fig. 3. Nightglow behavior on April 5–6 of 2000.

It is interesting to consider the behavior of other emission lines and bands during the analyzed magnetic storms. Figure 3 shows the behavior of emission of the upper atmosphere during the strong magnetic storm of April 6 of 2000 as measured by a zenith photometer. As was already noted, the main peculiarity in the airglow behavior in the upper atmosphere during strong magnetic storms is remarkable enhancement of emission at 630 nm (Fig. 3*a*, curve *1*). In the behavior of emission at 557.7 nm (Fig. 3*a*, curve *2*), we can notice a perturbation near 0 LT that coincides with the corresponding perturbation of emission at 630 nm, as well as sharp enhancement of the intensity (≥ 35%) coinciding with the first phase of the maximal growth in the intensity of 630-nm emission. For emission in the spectral region of 360–410 nm (Fig. 3*b*, curve *5*), starting from 0 LT we can observe the monotonic increase of the intensity, which is untypical for quiet geomagnetic conditions, with superposition of irregular short-period perturbations. Emission in the spectral region of 720–830 nm (Fig. 3*b*, curve *4*) in the time interval since 21 to 23 LT before the beginning of geomagnetic disturbance (~ 23 LT) was subject to the monotonic decrease of the intensity, which stopped after 23 LT. For comparison, Fig. 3 shows the behavior of emission at 630 nm (Fig. 3*a*, curve *3*) and emission in the spectral region of 360–410 nm (Fig. 3*b*, curve *6*) in the previous quiet night of April 5–6 of 2000.

In Ref. 16, it was proposed to classify mid-latitude and low-latitude auroras according to the type of exciting particles and their energies, main emissions, locations, etc. Mid-latitude and low-latitude auroras with the dominant emission of [OI] at 630 nm are assumingly located in the plasmapause, whose projection in the night F-region corresponds to the boundary of the main ionospheric dip. Thus, the airglow parameters measured by us are affected by the location and dynamics of the main ionospheric dip, plasmapause, and particle injection zone (auroral oval). As estimated by different authors,[17,18] the boundary of the plasmapause in most disturbed periods can achieve the limiting values $L \sim 1.7–2.5$ (for the Irkutsk latitude $L \sim 2$). According to the NOAA data, the boundary of the auroral oval in the second half of the night on April 6–7 of 2000 (at the level of 0.1 erg/(cm$^2 \cdot$ s)) reached the latitude ~ 56–58° in the considered longitude sector.

Thus, there is some reason to assume that elements of the subauroral ionosphere will be observed at the Irkutsk latitude during strong magnetic storms. The conclusion is also supported by the spectral peculiarities of optical observations in the regions of 360–410 and 557.7 nm. The increase of the signal in the spectral region of 360–410 nm after 0 LT on April 6 of 2000 can be interpreted as manifestation of N_2^+ emission at the wavelength of 391.4 nm that is usually observed in polar auroras as a result of electron injections and ionization of molecular nitrogen. Perturbation of the emission at 557.7 nm also can be attributed to particle injection. Similar perturbations of the emission at 557.7 nm were observed during the storm of March 24 of 1991, and they coincided in time with development of the sporadic E_s layer of auroral type r.

Analysis of observed perturbations of airglow in the upper atmosphere at the Irkutsk latitude during strong magnetic storms suggests that these perturbations may be caused both by the change in thermodynamic characteristics of the atmosphere (heating of the upper atmosphere and the related enhancement of the emission at 630 nm) and by particle injections (perturbation of emission at 557.7 nm and N_2^+ emission).

Conclusions

The analysis of the optical observations of strong magnetic storms in Eastern Siberia has allowed us to establish the high probability to observe the phases of enhancement of emission at 630 nm in the period of magnetic storms in the second part of a night. For such events, a short-term maximum is observed on the curves of nightglow at 630 nm in the hours before dawn. Spectral features of perturbations of the observed emissions and the analysis of geophysical data point to manifestation of elements of the subauroral ionosphere at the latitudes of Irkutsk in the periods of strong magnetic storms.

Acknowledgments

This work was partly supported by the Russian Foundation for Basic Research (Grant in Support of Leading Scientific Schools of the Russian Federation No. 00–15–98509).

References

1. Omholt, *The Optical Aurora* (Springer-Verlag, New York, 1971).
2. J.H. Meek and G.G. Shepherd, J. Geomagn. and Geoelec. **35**, No. 4, 87–102 (1983).
3. R. Torr Marsha, Ann. Geophys. **27**, No. 2, 201–204 (1971).
4. K. Misawa, I. Takeuchi, Y. Kato, and I. Aoyoma, J. Atmos. and Terr. Phys. **46**, No. 1, 39–46 (1984).
5. Yu.L. Truttse, in: *Auroras and Night Sky Glow* (Nauka, Moscow, 1973), Issue 20, pp. 5–22.
6. M.M. Gogoshev, Space Res. Bulg., No. 1, 83–94 (1978).
7. H.K. Rassoul, R.P. Rohrbaugh, and B.A. Tinsley, J. Geophys. Res. A **97**, No. 4, 4041–4052 (1992).
8. E.W. Cliver, Y. Kamide, and A.G. Ling, J. Geophys. Res. A **105**, No. 2, 2413–2424 (2000).
9. S.I. Akasofu, V Mire Nauki, No. 7, 34–42 (1989).
10. M. Ishimoto, M.R. Torr, P.G. Richards, and D.G. Torr, J. Geophys. Res. A **91**, No. 5, 5793–5802 (1986).
11. L.M. Fishkova and N.M. Matsvaladze, Geomagnetizm i Aeron. **25**, No. 3, 509–511 (1985).
12. E.L. Afraimovich, Ya.F. Ashkaliev, V.M. Aushev, A.B. Beletsky, L.A. Leonovich, O.S. Lesyuta, A.V. Mikhalev, V.V. Vodyannikov, and A.F. Yakovets, LANL e-print archive (2001): http://www.lanl.gov/abs/physics/0104070.
13. D. Barbier, Ann. Geophys. **15**, No. 2, 179–217 (1959).
14. L.M. Fishkova, *Night Emission of Midlatitude Upper Earth's Atmosphere* (Metsniereba, Tbilisi, 1983), 271 pp.
15. V.N. Alekseev and I.B. Ievenko, Geomagn. i Aeron. **31**, No. 5, 938– 940 (1991).
16. H.K. Rassoul, R.P. Rohrbaugh, B.A. Tinsley, and D.W. Slater, J. Geophys. Res. A **98**, No. 5, 7695–7709 (1993).
17. O.V. Khorosheva, Geomagnetizm i Aeron. **27**, No. 5, 804–811 (1987).
18. Yu.I. Gal'perin, L.D. Sivtseva, V.M. Filippov, and V.L. Khalinov, *Subauroral Upper Ionosphere* (Novosibirsk, 1990), 192 pp.