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Simultaneous ground-based observations of 630 nm emission and space measurements of electron temperature in SAR arc area

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Abstract. Results of photometric measurements of latitudinal profiles for 630 nm emission intensity and measurements of electron temperature by satellite Interkosmos 24 during intersection of the stable auroral red (SAR) arc area at altitudes of 500–1000 km near the Yakutsk meridian are presented. It is shown that meridional profiles of the emission and T_e coincides in latitude and are similar in their forms. The obtained distributions of maximum brightness in the SAR arcs with the corresponding values of T_e maximums and Dst index show the linear relation between these parameters. It is shown that the increase in background intensity of 630 nm emission near the SAR arcs may be caused by increased background electron temperature.

Introduction

Midlatitude stable auroral red (SAR) arcs have attracted the attention of researcher since their discovery by *Barbier* [1958]. Comparison of ground-based observations with the first space measurements showed that in the area of the SAR arcs, electron temperature T_e increases at the altitudes of the ionospheric F region [*Roble et al.,* 1971]. *Glass et al.* [1970] and *Hoch and Smith* [1971] revealed spatial coincidence of the SAR arcs with the projection of the plasmapause at ionospheric altitudes. These results in a first approximation confirmed a hypothesis about formation of the SAR arcs due to interaction of the ring current with the cold plasma during the magnetic storm recovery phase [*Cole,* 1965; *Cornwall et al.,* 1971]. Further space studies revealed association of the electron temperature maximums typical for the SAR arcs in the F region of the ionosphere with the ion density gradient and maximum of their temperature in the outer plasmasphere [*Horwitz,* 1986]. It gives the reason to relate the SAR arc and a hot region of the outer plasmasphere, the presence of which was discovered by *Bezrukikh and Gringauz* [1976].

Since 1987 regular photometric observations of a diffuse auroral emission and SAR arcs have been carried out at the meridian of Yakutsk [*Alekseyev et al.,* 1989; *Alekseyev and Iyevenko,* 1991, *Iyevenko,* 1993]. In 1989 such observations were performed during the passes of satellite Interkosmos 24 near the meridian. As a result, we obtained satellite data on the latitudinal profiles of electron temperatures at altitudes of 500–1000 km for seven cases when the ground-based observations of the SAR arcs occurred. In this paper we analyze observational data and, contrary to other similar studies, we carry out a comparison of meridional profiles of 630 nm emission with latitudinal distribution of T_e in the area of the SAR arcs.

Experimental Data

Optical ground-based data were obtained from station Maymaga (63°N, 129°E geographic and 56.5°N, 200°E geomagnetic coordinates) located about 100 km northward from Yakutsk. Observations of the SAR arcs were carried out with a two-channel scanning photometer with the field of view angle 3°, which recorded distribution of luminescence at wavelengths of 630.0 and 557.7 nm [*Alekseyev and Iyevenko,* 1991] along the geographic meridian. Main parameters of the photometer were presented by *Iyevenko* [1993]. Using the 630 nm emission scanograms, we projectioned the meridional distribution of intensity in the area of the SAR arcs at

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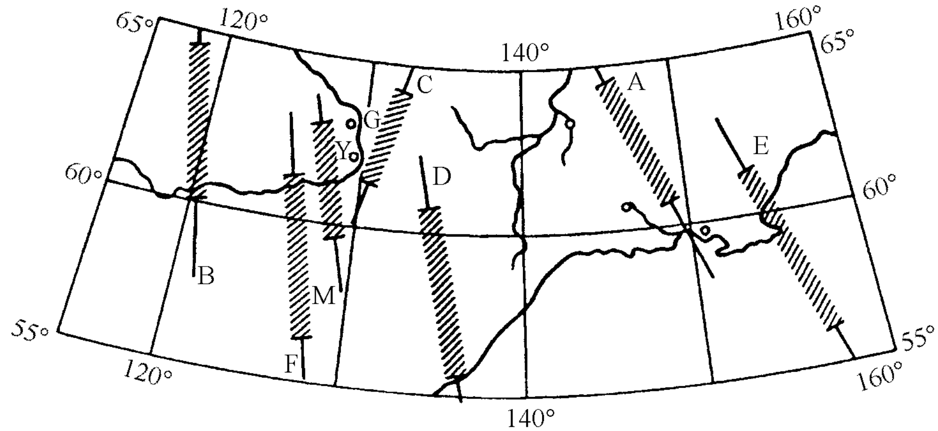

Figure 1. Paths of analyzed Interkosmos 24 passes in geographical coordinate system (A–G). Hatched areas show the segments with increased electron temperature. Yakutsk and Maymaga are measured by letters Y and M, respectively.

the Earth's surface under the assumption that the altitude of the arc intensity maximum was about 450 km. The arc surface brightness in the maximum was defined as an increase of red a line intensity ΔI above its background level in the night sky emission. For the analysis, we estimated the summarized intensity of 630 nm emission in the area of arc intensity maximum ($\Delta I + \Delta I_\mathrm{b}$), where ΔI_b is the increase in background intensity of the red line above its level at scanograms for the low level of geomagnetic activity.

Recorded by the instrument KM-6 onboard Interkosmos 24, maxima of electron temperature were projected from the satellite altitude to the average altitude of the SAR arcs (about 450 km). This was performed by a shift of T_e maximums in latitude along the geomagnetic field lines with inclination of 15°S in the area covered by the optical observatory. Figure 1 shows trajectories of the analyzed satellite passes in the geographic coordinate system with marked segments of the peak-form increases in electron temperature. It is seen that four passes occurred close to the meridian of optical observations (129°E); the remaining three passes were far from the meridian by 10–25°in longitude.

Comparison of Ground-based and Satellite Data

Figure 2 shows peaks of T_e recorded by the satellite and shifted in latitude by projection along the geomagnetic field lines to altitude of 450 km. It also presents meridional profiles of a red line of atomic oxygen in the area of SAR arcs. We consider every case of simultaneous measurements with a brief description of geophysical conditions from ground-based observations. Optical observations on November 28, December 2, and December 4 coincided with the period of prolonged variations in the *Dst* index up to 50–100 nT (from November 26 to December 6). In this period, a set of weak and moderate magnetic storms occurred, their main and recovery phases overlapped.

On November 28, the red arc was observed from 1530 to 2200 UT (sunrise beginning) near the zenith of Maymaga. During this period the scanning photometer recorded the diffuse auroral zone characteristics in 557.7 and 630.0 nm emission northward from the station. The satellite crossed the latitudinal area of SAR arc observation at an altitude of about 750 km in the morning hours of MLT (local geomagnetic midnight is at 1540 UT) at 2019 and 2215 UT near 148 and 120 meridians, respectively (passes A and B in Figures 1 and 2). From Figure 2, it is seen that the luminescence and temperature profiles in both cases coincide spatially and are similar in their forms. They are asymmetric: the polar edge is steeper than the equatorial edge. Maximums of luminescence and temperature also coincide well. During these satellite passes, the arc was measured near and in the zenith of the station, this gave a reason to consider the obtained profiles of the surface intensity close to a real latitudinal distribution of the volume emission intensity at 630 nm. Intervals of pass time are characterized by an average level of planetary magnetic activity and low variations in *Dst*, the corresponding values of which are presented in Table 1. Besides, Table 1 presents values of maximum and background electron temperatures, increases of 630 nm emission intensity in the arc above its background level on scanograms (ΔI), and summarized intensity of the red line with account of background amplification ($\Delta I + \Delta_\mathrm{b}$).

The following two comparisons of satellite and gro-

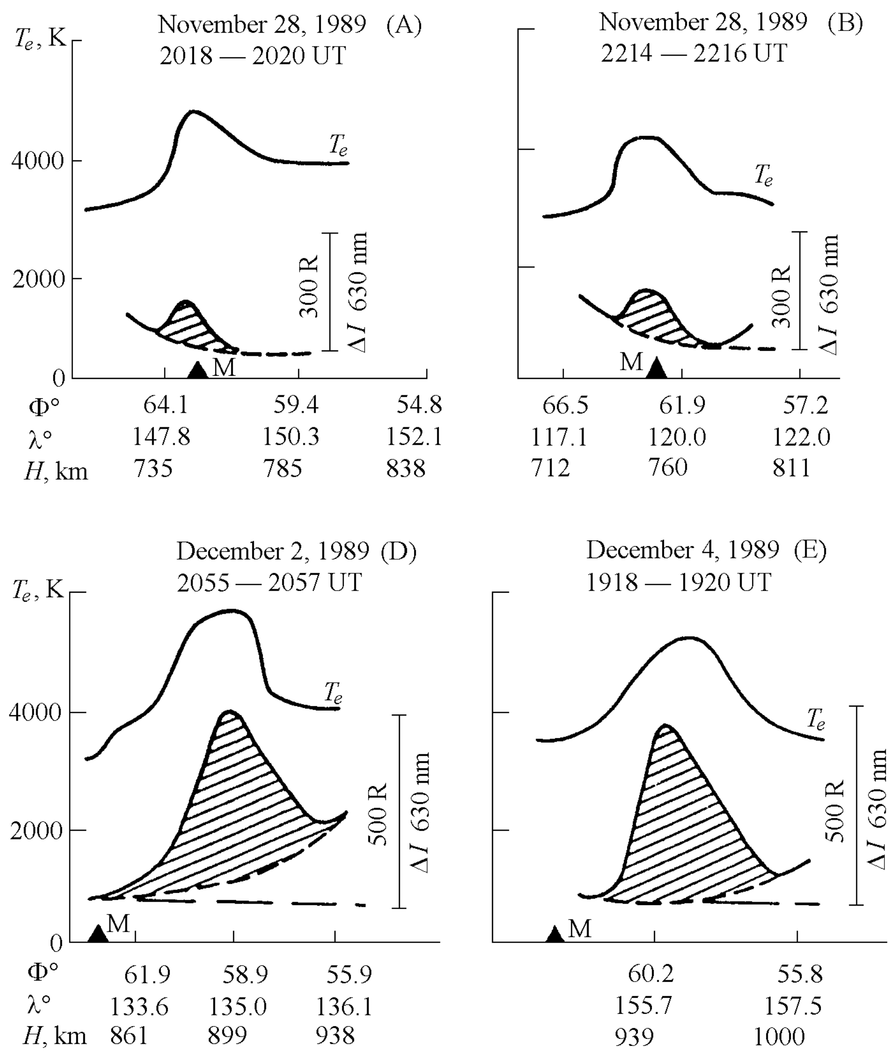

Figure 2. Latitudinal profiles of T_e for the orbits A–G and 630.0 nm emission intensity in the SAR arc. M, zenith of Maymaga.

und-based observations are made from data of December 2, when the stable red arc was observed during the night with equatorial motion from the station zenith to $\Phi \approx 59°$. Arc intensity (ΔI) was up to 650 Rayleigh. The satellite crossed the area of the SAR arcs near the meridian of optical observations (passes C and D in Figure 1) in early evening and morning sectors of MLT (at 1103 and 2056 UT). Diffuse auroral zone at the north was recorded by the scanning photometer only during the first intersection of the SAR arc area by the satellite. Altitudes of the satellite were ~ 510 and ~ 900 km, correspondingly. During the first pass, the latitudinal profile of surface arc intensity was obtained in the zenith of Maymaga, as on November 28. However, in this case, from satellite data, we obtained only values of background and maximum electron temperatures in the SAR arc area, which are presented in Table 1. The latitudinal profile of electron temperature in Figure 2, recorded by the satellite on December 2 during its pass in the morning sector, is sufficiently close in form to the arc luminescence profile despite that its maximum is located equatorward from the station by about 4°. From the data presented in Table 1, it is seen that there were significant *Dst* variations during satellite passes on December 2. Higher electron temperature responds to a higher intensity of the arc. The level of planetary magnetic activity was average and low (see values of *Dst* and *Kp* in Table 1).

On December 4, the red arc with intensity up to 500 Rayleigh was observed from 1100 UT in the station zenith with further equatorial motion until the morning twilight period. The satellite crosses the area of the observed SAR arc in the early morning sector of MLT at the altitude of about 1000 km twice: at 1919 UT

Table 1. Values of parameters in the area of the SAR arcs obtained from simultaneous ground-based and satellite observations

Number	Date	Time, UT	H, km	T_e, K, max	T_e, K, background	ΔI, Rayleigh	$\Delta I + \Delta I_b$, Rayleigh	Dst, nT nT	Kp
1	Nov. 28, 1989	2019	750	4800	3500	120	290	–16	3_+
2	Nov. 28, 1989	2215	760	4500	3500	120	400	–8	3_+
3	Dec. 2, 1989	1102	510	4600	2700	250	440	–66	3
4	Dec. 2, 1989	2056	900	5450	3000	430	750	–40	2_+
5	Dec. 4, 1989	1919	1000	5500	3600	440	750	–43	4_+
6	Dec. 4, 1989	2114	1000	5250	3400	430	790	–52	4_+
7	Dec. 26, 1989	1844	1760	4950	2800	130	190	–24	5

along 155 meridian and at 2114 UT near the meridian of Yakutsk (passes E and F in Figure 1). During the satellite passes, the arc was located equatorward from Maymaga by 4–5°. In this period, poleward from the station, the scanning photometer recorded diffuse auroral luminescence in green and red lines of atomic oxygen, enhanced due to activity in the auroral zone. Figure 2 presents the obtained latitudinal distributions of electron temperature and luminescence for the first pass of the satellite (pass E). It is seen that the latitudinal profile of T_e is similar in form to a meridional profile of the surface intensity of 630 nm emission in the arc which, as on December 2 (pass D); was at a significant distance from the zenith of the observatory. Results of the electron temperature measurements for the second intersection by the satellite of the latitudinal area of the same SAR arc approximately 2 hours later are presented in Table 1. Table 1 shows that during satellite passes on December 4, the of Dst index was -43 and -52 nT, and the level of planetary magnetic activity was above average ($Kp = 4_+$). Low changes of 630 nm emission intensity in the arc between two passes correspond to low changes in T_e.

The last comparison of the ground-based data with simultaneous satellite measurements is made for the closest pass to the Yakutsk meridian December 26 in the postmidnight sector of MLT (pass G in Figure 1). The satellite passed the area of the SAR arc at the altitude of 1760 km at 1844 UT, which was observed near the station zenith (at latitude of about 62°). Figure 2 does not present the corresponding latitudinal distributions but in this case, the meridional profile of intensity in the arc was identical in form to the latitudinal profile of T_e, analogously to observations on November 28. They have the same asymmetry and coincide spatially with regard to the latitudinal shift of T_e peak at its projection to an altitude of 450 km. Table 1 presents the main measured parameters of this pass. One can note the correspondence of low arc intensity to low Dst variations despite the high level of planetary magnetic activity ($Kp = 5$).

Analysis and Generalization of the Complex Observation Results

Describing satellite and ground-based data, we have performed a comparative analysis of latitudinal coincidence in the profiles of electron temperature and luminescence, as well as their similarity in form. For three passes of the satellite on November 28 and December 26, when the SAR arc was observed near the station zenith, we can discuss the correspondence of the latitudinal distribution of T_e at the ionospheric F region altitudes to the latitudinal distribution of the volume 630 nm emission intensity in the arc. So, we can make a conclusion about the existence of a functional relationship (perhaps, linear) between electron temperature and the intensity of red line of the atomic oxygen in the arc.

It is necessary to consider in more detail the parameters presented in Table 1 to reveal a possible association between them despite the limited data set. Table 1 contains background and maximum values of electron temperature and luminescence intensity. It is easy to see that increases in background intensity of a red line relative to the quiet level of night sky (ΔI_b) is comparable with its additional amplification (ΔI) in the maximum of arc luminescence. An increase in background intensity of 630 nm emission in the equatorial half of the sky may be due to the precipitation of low energy particles from the plasmasphere, which is sharply amplified during substorms [*Iyevenko,* 1993; *Iyevenko et al.,* 1987]. However, during the analyzed time intervals with satellite passes except for two cases on December 4, we did not observe amplification of auroral and magnetic activity. It is possible that the increase in red line intensity is caused by electron precipitation as well as with the background electron temperature near T_e peaks. As it is seen from Table 1, background electron temperature in the majority of cases is higher than 3000 K.

Figure 3 presents distributions of red line intensities ΔI and $(\Delta I + \Delta I_b)$ as functions of electron tempera-

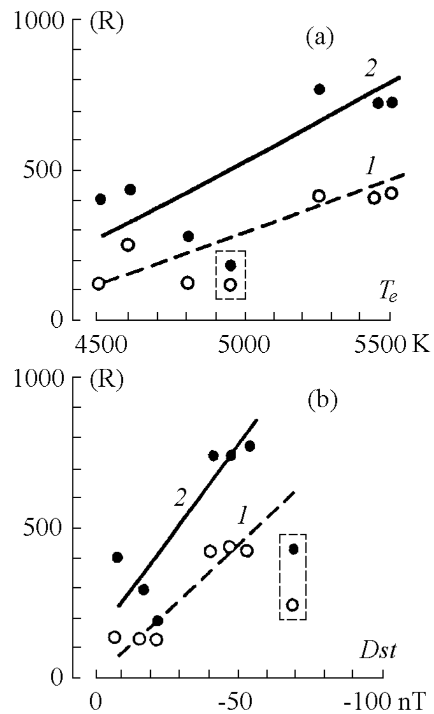

Figure 3. Distributions of intensities (in Rayleigh) of 630.0 nm emission in the SAR arc luminescence maximum as a function of maximums of (a) T_e and (b) Dst: of increases in the arc intensity ΔI above the background level (1); summarized intensity ($\Delta I + \Delta I_b$) accounted for the background 630.0 nm emission amplification in the night sky (2).

ture of the corresponding T_e peak and Dst index. The number of measurements is insufficient to make an unambiguous conclusion about the existence of correlation in these distributions. In this case, it is possible to judge only that both intensities rise (in Figure 3 they are denoted as 1 and 2) with an increase of T_e in the peak (Figure 3a) and Dst index (Figure 3b). This tendency is expressed in a presence of two clouds of points in distributions with a jump of intensity for increase of T_e up to 5200–5500 K and Dst variations up to 40–50 nT. In this case we have a reason to remove from Figure 3a the points (marked by a dashed line) with temperatures measured on December 26 at an altitude of 1760 km, because all remaining measurements were carried out in the interval of altitudes from 510 to 1000 km. Dashed lines denote abnormal deflections in Figure 2b.

The obtained linear relationship between 630 nm emission intensity in the arc with T_e is quantitatively in agreement with results obtained by *Roble et al.* [1971]. An increase in the summarized intensity of the red line in the SAR arc area with the increase of T_e and Dst points out indirectly the relationship between background intensity increase (ΔI_b) and these parameters. Therefore we suppose that the increase of background 630 nm emission in the night sky airglow is also related to the background electron temperature and possibly to a global heating of the outer plasmasphere [*Horwitz et al.,* 1986]. An increase of this emission in the SAR arc with typical T_e peak in the ionospheric F region reflects the amplification of the heating process in the area of sharp gradient of the cold plasma density in the outer plasmasphere [*Horwitz et al.,* 1986].

Conclusions

We have performed a comparison of meridional profiles of surface 630 nm emission luminance with latitudinal distribution of T_e at altitudes of 500–1000 km in the area of the SAR arcs obtained from ground-based and satellite observations. Comparison is carried out for seven passes of Interkosmos 24 near the meridian of Yakutsk. As a result, we conclude the following:

1. Profiles of luminescence and electron temperature coincide in latitude and are similar in form. Good similarity of the profiles in the cases of SAR arcs observation near the station zenith points probably to the existence of a linear relationship between electron temperature and volume intensity of 630 nm emission in the arc.

2. Analysis of distributions of maximum luminance values in the SAR arc with the corresponding values of T_e and Dst maximums reveals the linear relationship between these parameters. The maximum intensity of a red line in the arc increases from 120–200 up to 400–450 Rayleigh (from 300–400 until 700–800 Rayleigh with account of background intensity increase) for this increase of T_e from 4500 until 5500 K and index Dst from -10 until -50 nT. We assume that amplification of background 630 nm emission intensity above the quiet level in the period of SAR arc observation is due to both precipitation of low-energy particles from the plasmasphere and an increase of background electron temperature.

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