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DAYTIME ELECTRON DENSITY AT IONOSPHERIC F1-LAYER HEIGHTS DURING GEOMAGNETIC STORMS (IRKUTSK)

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Abstract. We have examined variations in electron density N_e at ionospheric F1-layer heights during geomagnetic storms at the Irkutsk ionospheric station (52° N, 104° E). We have selected geomagnetic storms of varying intensity as well as quiet days for each event for the winter and summer seasons of 2003. We have analyzed the electron density in the daytime during geomagnetic storms at 150–190 km heights. Different effects of geomagnetic storms on N_e in different seasons at these heights were found. There is a slight change in the electron density during summer geomagnetic storms. On the other hand, there is an interesting effect in winter indicating the summer-winter asymmetry of the N_e response to the geomagnetic storms at these heights in 2003: in winter there is a significant influence of disturbances on N_e at a height of 190 km and a smaller effect at lower heights.

Keywords: electron density, winter-summer asymmetry of the electron density N_e response to geomagnetic storms.

INTRODUCTION

Geomagnetic disturbances cause various changes in the complex atmosphere–ionosphere system, affecting electric fields, temperature, wind, gas composition, and all ionospheric parameters. There are quite a few publications on the impact of geomagnetic storms on the ionosphere, in particular at F1-layer heights [Buresova, Lastovicka, 2001; Buresova et al., 2002; Kushnarenko et al., 2013, 2018; Mikhailov, Schlegel, 2003]. There is, however, no sufficiently clear understanding of some mechanisms that explain the ionization reaction during geomagnetic storms at these heights. We analyze the daytime electron density at the 150–190 km heights. This height range is part of the lower ionosphere, where under certain conditions the F1 layer is formed. Hereinafter, the term "F1-layer heights" will be used instead of the term "F1 layer" since the F1 layer does not exist as a separate layer in winter under undisturbed conditions at midlatitudes. Nonetheless, according to some observations [Polekh et al., 2019], the F1 layer develops even in winter during sufficiently strong geomagnetic storms.

In terms of the ultraviolet radiation penetrating into all ionospheric regions, taking into account their gas composition and various structural features, we can expect a different reaction of each region to storm-induced disturbances. The aim of this study, in continuation of previous works [Kushnarenko et al., 2013, 2018], is to expand knowledge on the response of the ionospheric F1-region to geomagnetic disturbances. The analysis is based on data on storms for two seasons (winter and summer) in the year of increased geomagnetic activity (2003) [Panasyuk et al., 2004]. A similar study detecting different responses of the electron density N_e to the impact of geomagnetic storms in summer and winter seasons has been carried out by Buresova et al. [2002] for several European mid-latitude observatories.

DATA IN USE

For the analysis, we took the period of 2003 containing many disturbed days in summer (May–August) and in winter (January–February and November–December). We used N_e values obtained from Irkutsk digisond (52° N, 104° E) measurements. The study was limited to daylight hours and the 150–190 km height range. Tables 1, 2 list the geomagnetic events analyzed in this work and their associated geomagnetic indices A_p and *Dst* [http://wdc.kugi.kyoto-u.ac.jp]. Quiet days with A_p<10 have been selected for comparison with each storm [http://ckp-rf.ru/ckp/3056].

Since strong geomagnetic storms occur near the equinoxes approximately five times more often than near the winter or summer solstices [Buresova et al., 2002], the number of summer and winter events in the analysis is smaller and they have lower intensities compared to spring and fall storms.

ELECTRON DENSITY DURING SUMMER DISTURBANCES

Unlike winter events, geomagnetic disturbances in summer of 2003 are classified as weak and moderate in terms of their impact; therefore, we also include them in the analysis. There are also some strong storms. Daytime N_e variations during all days of maximum development of the disturbances are quite similar. There is no noticeable effect of summer geomagnetic storms on the electron density at the F1-layer heights even during

Table 1

Geomagnetic storms under study (summer 2003)

Quiet days	Day of storm commencement	A_p, *Dst* indices	Time of storm maximum (UT)
May 17	May 29	A_p=108, *Dst*=–133	May 30 at 02:00
May 17	May 31	A_p=20, *Dst*=–46	May 31 at 05:00
June 05	June 01	A_p=22, *Dst*=–40	June 02 at 04:00
June 05	June 02	A_p=38, *Dst*=–91	June 02 at 09:00
June 05	June 03	A_p=29, *Dst*=–38	June 03 at 01:00
June 20	July 11	A_p=52, *Dst*=–55	July 11 at 11:00
July 09	July 12	A_p=52, *Dst*=–105	July 12 at 06:00
July 09	July 16	A_p=48, *Dst*=–70	July 16 at 14:00
July 09	August 08	A_p=33, *Dst*=–40	August 08 at 09:00
August 05	August 12	A_p=39, *Dst*=–20	August 12 at 09:00
August 05	August 18	A_p=108, *Dst*=–119	August 18 at 09:00
August 05	August 21	A_p=39, *Dst*=–62	August 21 at 24:00

Table 2

Geomagnetic storms under study (winter 2003)

Quiet days	Day of storm commencement	A_p, *Dst* indices	Time of storm maximum (UT)
January 14–16	January 20	A_p=39, *Dst*=–33	January 20 at 05:00
January 14–16	January 25	A_p=28, *Dst*=–46	January 25 at 24:00
January 14–16	January 30	A_p=48, *Dst*=–66	January 30 at 01:00
February 24	February 02	A_p=52, *Dst*=–59	February 02 at 16:00
February 24	February 04	A_p=31, *Dst*=–54	February 04 at 10:00
February 25	February 27	A_p=30, *Dst*=–60	February 27 at 21:00
November 27	November 11	A_p=61, *Dst*=–50	November 11 at 14:00
November 27	November 13	A_p=52, *Dst*=–36	November 14 at 07:00
November 27	November 20	A_p=150, *Dst*=–156	November 21 at 07:00
December 17	December 05	A_p=39, *Dst*=–48	December 06 at 04:00
December 18	December 10	A_p=41, *Dst*=–50	December 10 at 12:00
December 19	December 21	A_p=24, *Dst*=–22	December 21 at 17:00

strong disturbances. For example, the strong storm on May 29 (A_p=108), the moderate storm on July 11 (A_p=52), and the weak storm on June 3 (A_p=29) almost do not differ in their effect on ionization at the 190 km height (see Figure 1, *a*, summer): on disturbed days, N_e varies, as on quiet days, from $2.5 \cdot 10^5$ to $3.5 \cdot 10^5$ cm^{-3}.

Note that during the strong storm on August 18 (A_p=108) N_e at 190 km significantly decreased from $3.6 \cdot 10^5$ to $2.5 \cdot 10^5$ cm^{-3}; it also went down at lower heights. This storm confirms the conclusion [Kushnarenko et al., 2018] about deeper penetration of the effects of strong geomagnetic disturbances to F1-layer heights at midlatitudes.

All the summer storms considered, except for two strong ones (on May 29 and August 18 with A_p=108), can be classified as weak and moderate with A_p varying from 20 to 60 (see Table 1). Summer disturbances have little or no effect on ionization at F1-layer heights. Figure 2, *a* shows N_e variations at three heights on quiet and disturbed summer days. Deviations of N_e from the quiet level are weak or non-existent. The effect of other analyzed summer storms on N_e is similar to the scheme described above.

The overall result for summer storms is that the response of N_e to moderate, strong, and weak summer storms in 2003 is rather weak or completely absent and depends little on the intensity of the storm. The exception is one strong storm on August 18 (A_p=108) with deeper penetration to the F1-layer heights.

ELECTRON DENSITY DURING WINTER DISTURBANCES

Winter disturbances can be conveniently classified into two groups: storms at the beginning (January–February) and at the end (November–December) of the year (see Table 2). The first period shows the presence of almost continuous moderate and rather strong geomagnetic disturbances. During this period, it is difficult to find quiet days for comparison.

In winter, the effect of geomagnetic disturbances on the electron density is significant at 190 km, noticeable at 170 km, and less pronounced at lower heights. The 190 km height is an indicator of the effect of geomagnetic storms on N_e. Here, N_e variations during disturbances are much in evidence. Figures 1, *b*, *c* illustrates

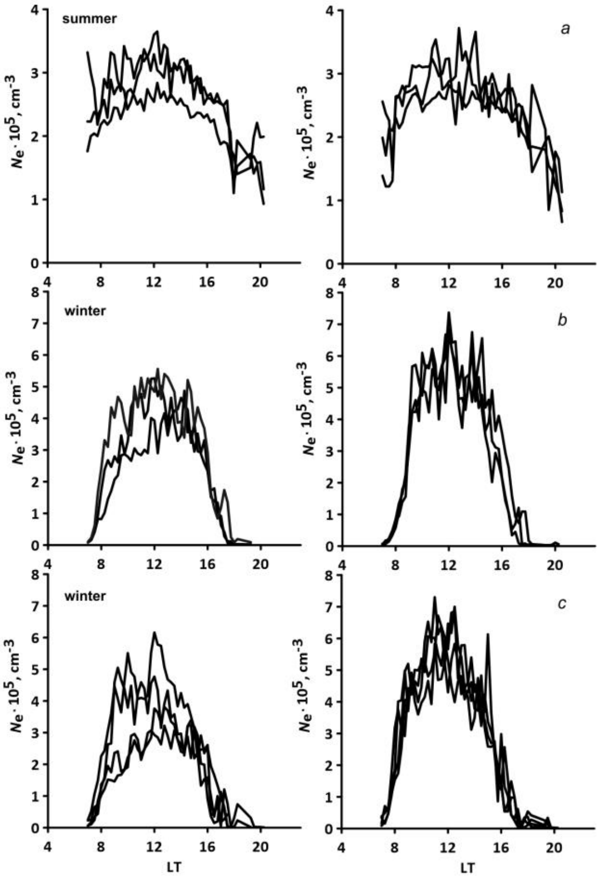

Figure 1. Daytime N_e variation at 190 km on disturbed (left panel) and quiet (right panel) days: summer storms (*a*); winter storms at the beginning of the year (*b*); winter storms at the end of the year (*c*)

the daily behavior of N_e at 190 km for several winter storms at the beginning and end of 2003, as compared with quiet days. At the beginning of the year, on quiet days in January, N_e varied from $4{\cdot}10^5$ to $7{\cdot}10^5$ cm^{-3}. During moderate disturbances on the days of their maximum development, N_e decreased at 190 km on average from $4{\cdot}10^5$ to $5.6{\cdot}10^5$ cm^{-3} for the February 02 and 04 storms and from $2{\cdot}10^5$ to $4.6{\cdot}10^5$ cm^{-3} for the January 30 and February 27 storms. At the end of the year (November–December), the N_e variations at 190 km are similar to those at the beginning of the year. There is a large spread of N_e values for storms with different intensities, and this separation does not depend on A_p.

A significant change in N_e at three heights on the disturbed day of November 11 is shown in Figure 2, *b* (left panel) in comparison with N_e on a quiet day (right panel): at 190 km around midday, N_e decreased to $(2{\div}3.2)10^5$ cm^{-3} from $(4{\div}6)10^5$ cm^{-3} on a quiet day. At lower heights, the influence of the disturbance is also pronounced: at 170 km N_e decreases from $3.5{\cdot}10^5$ to $2{\cdot}10^5$ cm^{-3}; at 150 km, from $1.9{\cdot}10^5$ to $1.5{\cdot}10^5$ cm^{-3}. The analysis of N_e variations during other storms has shown that effects of winter geomagnetic events at all heights differ in their strength, even with the same characteristics (A_p and *Dst*): they may be both more significant and weaker.

Thus, the effect of winter disturbances is that N_e decreases generally at 190 km and to a lesser extent at lower heights.

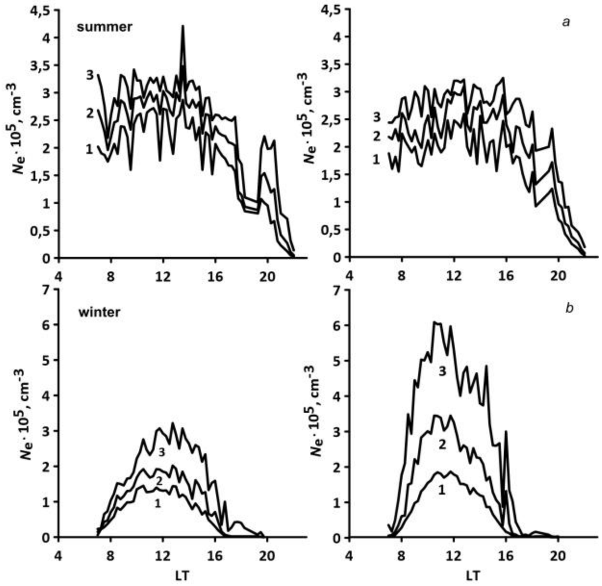

Figure 2. Daytime variations in N_e on disturbed (left panel) and quiet (right panel) days in summer (July 12, 2003 storm) (*a*) and in winter (November 11, 2003 storm) (*b*) at heights of 150 km (1), 170 km (2), and 190 km (3)

CONCLUSION

The reported results point to the summer–winter asymmetry in the N_e response to geomagnetic storms at F1-layer heights at the mid-latitude station Irkutsk in 2003.

- In summer, the effect of geomagnetic storms on N_e is insignificant at all the heights considered.
- The effect of winter storms manifests itself as a significant decrease in N_e at all the heights: the strongest at 190 km and to a lesser extent at lower heights.
- For all the disturbances considered, their effect on N_e at the F1-layer heights in all seasons is always negative, i.e. leads to a decrease in N_e.

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