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Observations of Large-Scale Plasma Convection in the Magnetosphere with Respect to the Geomagnetic Activity Level

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Abstract—The data of the ionospheric observations (the daily *f* plots) at the Yakutsk meridional chain of ionosondes (Yakutsk–Zhigansk–Batagai–Tixie Bay) with sharp decreases (breaks) in the critical frequency of the regular ionospheric *F*2 layer (*foF*2) are considered. The data for 1968–1983 were analyzed, and the statistics of the *foF*2 break observations, which indicate that these breaks are mainly registered in equinoctial months and in afternoon and evening hours under moderately disturbed geomagnetic conditions, are presented. Calculations performed using the prognostic model of the high-latitude ionosphere indicate that the critical frequency break position coincides with the equatorial boundary of large-scale plasma convection in the dusk MLT sector.

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1. INTRODUCTION

Sharp decreases in the *F*2 critical frequencies (*foF*2), which are observed as frequency breaks in diurnal variations on vertical sounding (VS) *f* plots, can be represented as ionospheric signatures of the development of a narrow ionization trough caused by a change in the photochemical reaction rates and the ionospheric plasma westward removal in the region with rapid ion drifts (Filippov et al., 1989). In (Bryunelli, 1986; Besprozvannaya et al., 1986; Whalen, 1987), it was given a different explanation of the breaks in diurnal *foF*2 variations, which is associated with the impact of the polarization jet. On the ionograms recorded at times of frequency break, the reflections from the sporadic E_{sa} layer are not observed. This layer accompanies the development of PJ and is caused by the precipitation of electrons with an energy of several tens of keV. Below it will be shown that the localization of *foF*2 breaks spatially coincides with the large-scale convection equatorward boundary when a VS station falls in the zone of strong westward plasma convection (which takes place at a poleward electric field $E > 100$ mV m^{-1}). According to the measurements at EISCAT radiowave incoherent scattering stations (Willis et al., 1986; Collis and Hoggstrom, 1988), a wide band (5–10°) of a rapid westward drift (up to ~10 km s^{-1}) is observed in the postnoon sector. The electron density (*Ne*) also decreases in this wide band of strong convection. Based on the long-term incoherent scatter radar measurements at Millstone Hill, Foster and Burke (2002) introduced the subauroral polarization stream (SAPS) term in order to combine two types of subauroral electric field observations: the observations corresponding to the structure of the polarization jet/SAID (Galperin et al., 1973; Smiddy et al., 1977) and wide regions described in (Yeh et al., 1991) and (Burke et al., 1998; Rowland and Wygant, 1998; Foster and Vo, 2002). In all of the studies, it is noted that the ionospheric plasma drifts westward and the electron density (*Ne*) decreases in this wide band of strong convection; i.e., the band mainly covers the main ionospheric trough region (Anderson, 1991; Zheng, 2008). Thus, ionospheric VS stations register an *foF*2 break during the displacement of a steep *Ne* gradient, which is formed at the equatorward boundary of this zone of strong convection.

The goal of this work was to study the statistics of observed *foF*2 breaks and to compare the *foF*2 break position with the large-scale plasma convection equatorward boundary.

2. EXPERIMENTAL DATA AND DISCUSSION

To analyze the *foF*2 break spatial–time characteristics, we used the *f* plots from VS stations at the Yakutsk meridional chain of ionosondes for 1968–1969 (the complex expedition period) and 1973–1983. The coordinates of the stations used in this work are presented in the table.

† Deceased.

VS stations at the Yakutsk meridional chain of ionosondes

Station	Geographic coordinates		Invariant latitude, deg	L shell
	latitude, deg	longitude, deg		
Tixie Bay	71.6	129.0	65.1	5.60
Batagai	67.7	134.6	61.1	4.30
Zhigansk	66.8	123.4	60.4	4.06
Yakutsk	62.0	129.8	55.6	3.05

On the f plots, we determined breaks as sharp decreases in the $foF2$ frequency (by 2–4 MHz and more) for a short period (15–30 min). Figure 1 illustrates the registration of critical frequency breaks according to the data from the Yakutsk meridional chain of ionosondes. Figure 1 indicates that a frequency break shifts to low latitudes (from Tixie Bay to Yakutsk) with increasing geomagnetic disturbance.

Figure 2 illustrates a statistical analysis of ionospheric data performed based on the f plots from the Yakutsk chain of stations. We considered 647 cases when distinct $foF2$ breaks were registered. Figure 2a shows the distribution of the $foF2$ break occurrence frequency at all stations depending on the season. Figure 2a indicates that the break occurrence frequency has maximums in the seasonal variations in equinoctial months. Figure 2b shows the break occurrence frequency with respect to the local time. Figure 2 indicates that $foF2$ breaks are mainly observed in the postnoon–dusk sector with a maximum at 1700–1900 MLT. We note that the same seasonal and MLT distributions of the break occurrence frequency are observed when the break registration at individual stations is considered. The region of the maximal break probability with respect to the Kp level for different stations is shown in Fig. 2c, which indicates that the maximal number of the cases when breaks appeared was registered under moderately disturbed conditions ($Kp = 3$ and 4) at Tixie Bay and Zhigansk stations. The presented histograms also indicate that the region of the $foF2$ break maximal probability shifts to low latitudes with increasing disturbance levels.

Figure 3 presents the cases when $foF2$ breaks were registered at Tixie Bay, Batagai, Zhigansk, and Yakutsk stations under different Kp values in the invariant latitude–MLT coordinates. The solid line in Fig. 3 shows the position of the diffuse precipitation boundary (DPB) according to the empirical model from (Galperin et al., 1977), where DPB is associated with the poleward wall of the main ionospheric trough in the dusk–midnight sector. The position of the large-scale convection equatorward boundary according to the (Heppner and Maynard, 1987) model is marked by a dashed line. Figure 3 indicates that breaks are mostly localized at the Tixie Bay latitude at 1700–2030 MLT at $Kp = 2$ and 3. The convection equatorward boundary according to the (Heppner and Maynard, 1987) model passes below the Tixie Bay latitude, and DPB is located higher than this latitude by 3°–5°. The region where the $foF2$ break probability is maximal shifts to low latitudes with increasing geomagnetic activity (at $Kp = 4$ and 5) and is correspondingly localized at the Batagai, Zhigansk, and Yakutsk latitudes. At the same time, the large-scale convection equatorward boundary passes approximately at the latitudes of these stations. At that time, DPB is located poleward of these stations. Note that the number of the measurements performed at Tixie Bay and Yakutsk is much larger than such a number at Batagai and Zhigansk.

The average latitudes of the SAPS velocity peak according to (Foster and Vo, 2002) are shown by thick lines in Fig. 3 (at $Kp = 4$ and 5) for comparison. Figure 3 indicates that the stream peaks are located between the model DPB values and the convection equatorward boundary according to (Heppner and Maynard, 1987), i.e., in the main ionospheric trough region. Note that the peaks are not the equatorward boundary of the westward drift band.

The numerical experiment was performed for the spring equinox under the conditions of moderate solar activity at $Kp = 3$–5 based on the prognostic model (Chernyshev and Zabolotskii, 1994).

The prognostic model takes into account the photochemical processes and mass transfer due to vertical diffusion, thermospheric wind, and electric fields of the magnetospheric origin. A model epignosis is quite reliable for the $F2$ layer during the summer and equinoctial periods at maximal and moderate solar activity levels. The results of the electron density (Ne) calculation are returned at a latitude interval of 2° from 42° to 90° N and at an interval of 30° for all longitudes.

For calculations, we specified a band of the polarization jet (a narrow westward drift jet) or an additional external electric field with a strength of 200 mV m^{-1} at the large-scale convection boundary. The width of the 2° band was observed for 8 h (from 1400 to 2200 MLT). The large-scale convection boundary was specified at geographic latitudes of 74° and 70°. The latitudinal Ne profiles were compared at 120° longitude (approximately the longitude of the Yakutsk chain of VS stations).

Figure 4 presents the latitudinal sections of the Ne distribution for 1600, 1800, 2000, and 2200 MLT at different values of the Kp index. Figure 4 indicates that the Ne distribution before the instant when the electric field was switched on (the line with open circles) varied smoothly without steep gradients, which corresponds to the average conditions of the applied model under equinoctial conditions.

When an additional electric field (200 mV m^{-1}) was switched on, a steep gradient and deepening in the lat-

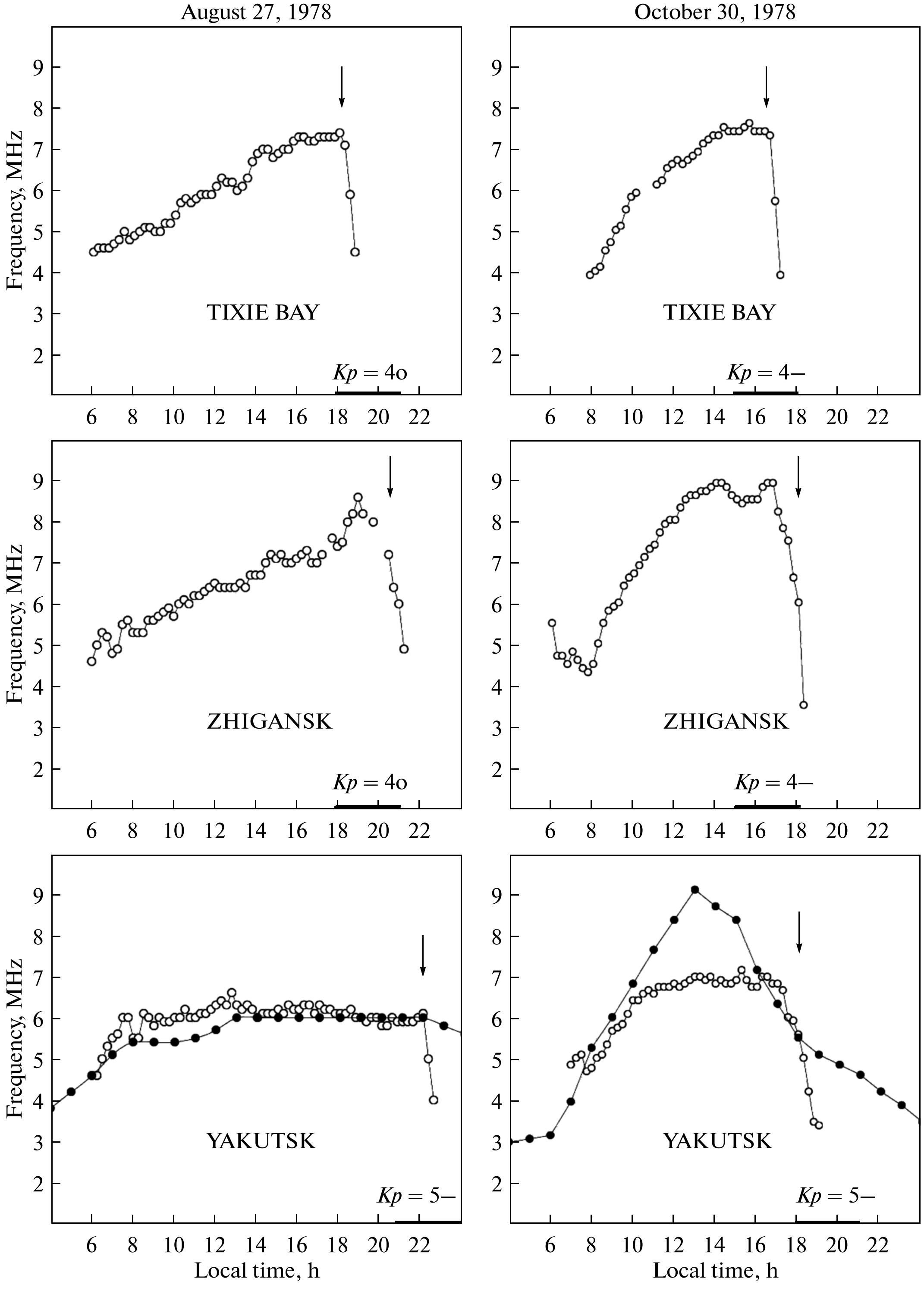

Fig. 1. Breaks of critical frequencies *foF*2 according to the measurement at the meridional chain of ionospheric stations (Tixie Bay–Zhigansk–Yakutsk) for August 27 and October 30, 1978 (marked by arrows). The median hourly *foF*2 values for the current month at Yakutsk are marked by a solid line with dots for comparison.

itudinal *Ne* variations (a line with filled circles), which were caused by an increase of the westward drift velocities and of the velocities of the main photochemical reactions, appear at the trough equatorward boundary. An increase in the *Kp* index results in a larger difference between the switched on and off external electric

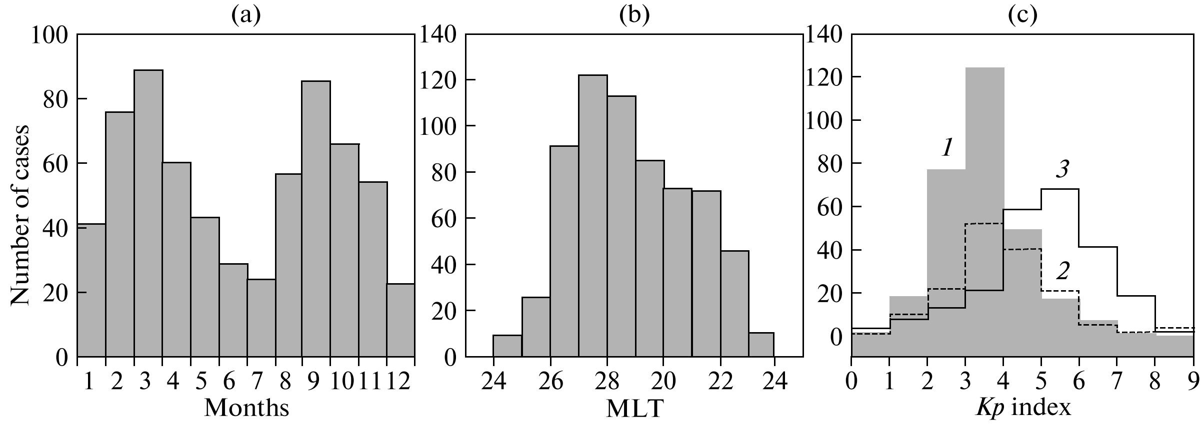

Fig. 2. The *foF*2 break distributions depending on the season and MLT, and the observation of frequency breaks depending on the station localization and the geomagnetic activity index (*Kp*): Tixie Bay (*1*), Batagai and Zhigansk (*2*), and Yakutsk (*3*).

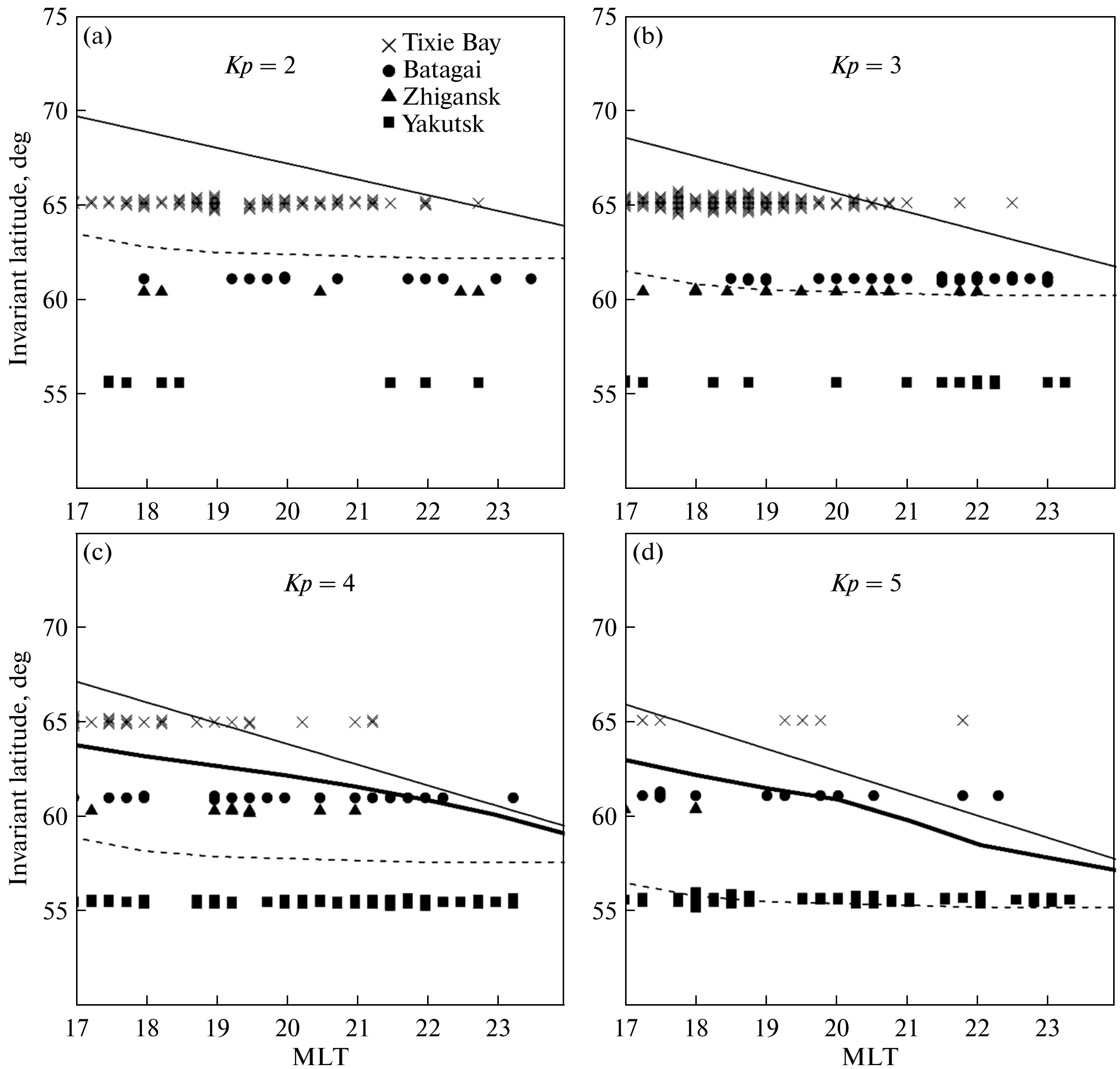

Fig. 3. The *foF*2 break registration at Tixie Bay (crosses), Batagai (filled circles), Zhigansk (filled triangles), and Yakutsk (filled squares) depending on MLT at different *Kp* values. The positions of DPB and the large-scale convection equatorward boundary are shown by thin solid and dashed lines, respectively. The thick solid line shows the average latitude of the SAPS velocity peak at *Kp* = 4 and 5.

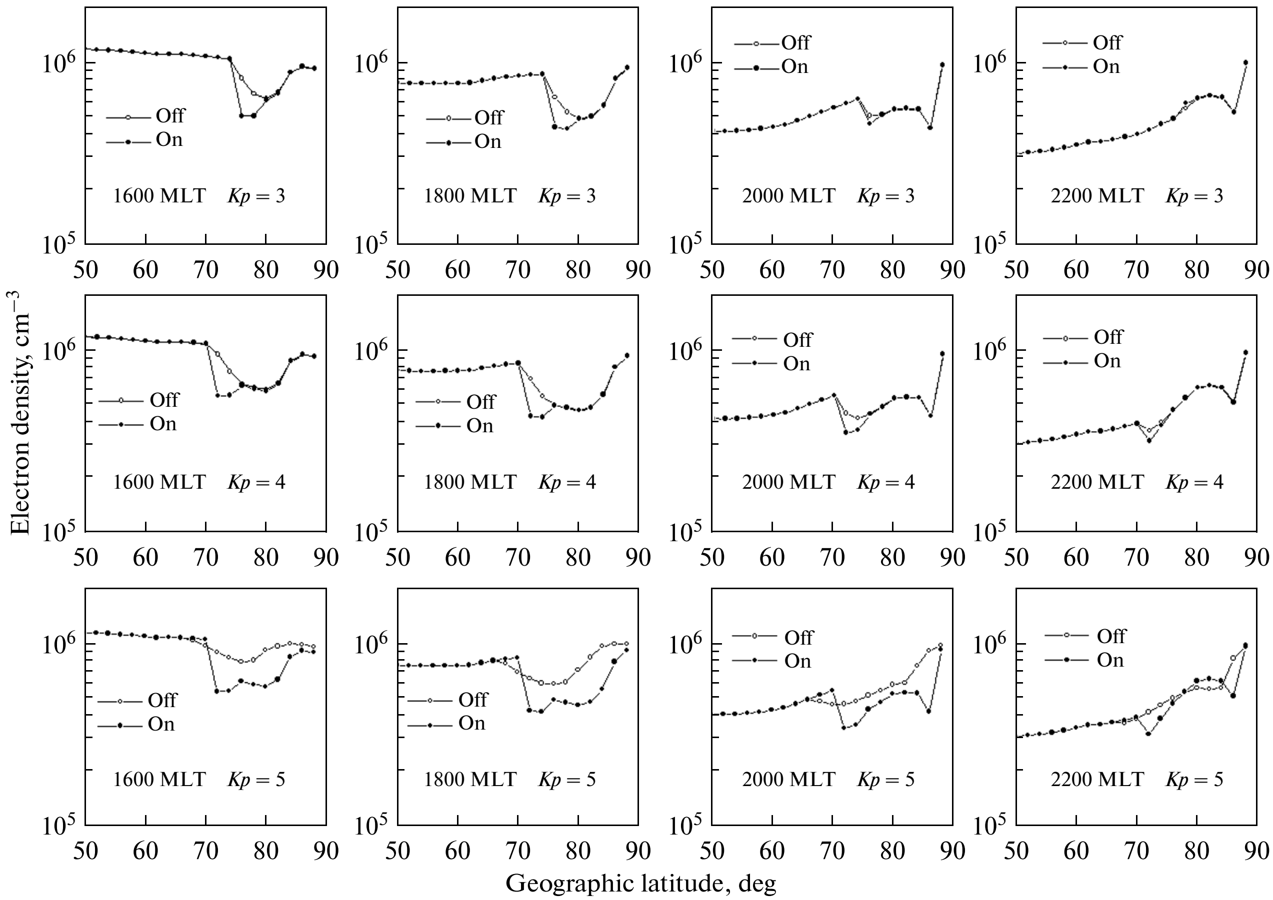

Fig. 4. The *Ne* latitudinal profiles at 1600, 1800, 2000, and 2200 MLT calculated using the prognostic model in accordance with the specified external parameters.

field. The results were confirmed by calculations performed using the model of a high-latitude ionosphere with regard to the thermal regime (Stepanov et al., 2011; Golikov et al., 2012) and the model of the magnetospheric convection electric field (Tashchilin and Romanova, 2014).

3. CONCLUSIONS

Based on the ionospheric data from the Yakutsk chain of ionosondes, we revealed that the critical frequencies are broken mostly in the equinoctial months. The break occurrence frequency has a maximum at 1700–1900 MLT and during periods of moderately disturbed geomagnetic activity (*Kp* = 3–4). The break registration probability shifts to lower latitudes as activity increases.

Comparison of the break registration cases with the model positions of DPB in the dusk sector and the convection equatorward boundary according to (Heppner and Maynard, 1987) shows that breaks are always observed equatorward of DPB. At the same time, the large-scale convection boundary according to the (Heppner and Maynard, 1987) model coincides with the localization of break maximums registered at the Yakutsk chain of stations. Thus, using ground ionospheric data, we can control the position of the large-scale convection equatorward boundary by registering *foF*2 breaks at the Yakutsk meridional chain of ionosondes.

Our calculations performed with the prognostic model show that steep electron density gradients appear at the equatorial convection boundary when a strong northward electric field up to 200 mV m^{-1} with a width of 2°, a length of 8 h, is switched on at this boundary. The electron density considerably decreases as compared to such a density under undisturbed conditions. Such a character of the *Ne* behavior is explained by an increase in the ionospheric plasma westward drift velocities and in the rates of the main photochemical reactions at ionospheric altitudes. When such a boundary crosses a zenith of observation station, the critical frequencies abruptly decrease at ionospheric altitudes, which are identified by us as critical frequency breaks on *f* plots.

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