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Ion Drift in the Earth's Inner Plasmasphere during Magnetospheric Disturbances and Proton Temperature Dynamics

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Abstract—Based on the thermal plasma measurements in the Earth's inner plasmasphere on the INTERBALL-2 and MAGION-5 satellites it has been indicated that the plasmaspheric ion temperature as a rule decreases during the main phase of magnetic storms; in this case the plasma density increases or remains at the level typical of undisturbed conditions. The physical mechanism by which the ion drift during a magnetic storm results in a temperature decrease is described. It is shown that the third adiabatic invariant also remains in processes with a characteristic time shorter than the period of charged particle drift around the Earth for cold equatorial plasma. The constructed model of the drift shell displacement from the Earth caused by a decrease in the magnetic field in the inner magnetosphere during the development of a magnetic storm satisfactorily describes the decrease in the proton temperature near the equatorial plane.

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1. INTRODUCTION

The plasma characteristics in the Earth's plasmasphere and the structure and dynamics of the plasmasphere boundary (plasmapause) are extremely sensitive to geomagnetic disturbances in the magnetosphere. The dependence of the plasmapause position on geomagnetic activity and the processes of plasmasphere depletion and refilling have been studied in detail theoretically and experimentally [Lemaire and Gringauz, 1998; Kotova, 2007]. The data of recent experiments on the CLUSTER and IMAGE spacecraft substantially widened the concepts on the variations in the plasma density distribution in the plasmasphere and revealed a number of new specific features in the structure of the plasmasphere and plasmapause [Darrouzet et al., 2009].

Nevertheless, the variations in the plasma parameters in the inner plasmasphere during magnetospheric storms are still insufficiently well studied. It is customary to consider that the density in the inner, not empty, part of the plasmasphere decreases during a storm [Carpenter and Park, 1973; Spasojevic and Sandel, 2010]; however, nobody knows whether this always takes place and the set of physical processes responsible for a change in the plasma density in the inner plasmasphere is described, correspondingly, incompletely. In contrast to the plasma density, its temperature can be measured only during direct experiments; therefore, the set of data on plasma temperature in the plasmasphere is more limited.

The dynamics of the dawn and dusk plasmaspheric sectors have been studied in more detail based on the data of an RIMS mass spectrometer with retarding potential, which operated on the DE-1 satellite. According to the data of this experiment, the ion temperature is almost independent of the geomagnetic activity level on the plasmaspheric dawn side at $L < 3.0$. On the evening side at $2 < L < 3$, the average temperatures typical of the periods with low and moderate magnetic activities are close to one another, but the temperature is slightly lower during high activity. The temperature of ions in the outer plasmasphere in contrast rises with increasing magnetic activity [Comfort, 1996].

The thermal proton density and temperature distributions in the Earth's plasmasphere were also obtained based on the cold plasma measurements on the INTERBALL-2 spacecraft (1996) and on its subsatellite MAGION-5 (1999–2000). In these measurements, it was found that the temperature in the inner plasmasphere decreased during the main phase of small and moderate magnetic storms and often increased to values exceeding the level observed during the magnetically quiet period before a storm during the recovery phase [Kotova et al., 2007, 2008].

The aim of this work is to thoroughly analyze the effect of a temperature decrease in the inner plasmasphere and to specify the physical mechanism by which the ion drift during a magnetic storm, which results in a temperature drop, is described. For this purpose, we will present examples of the experimental data indi-

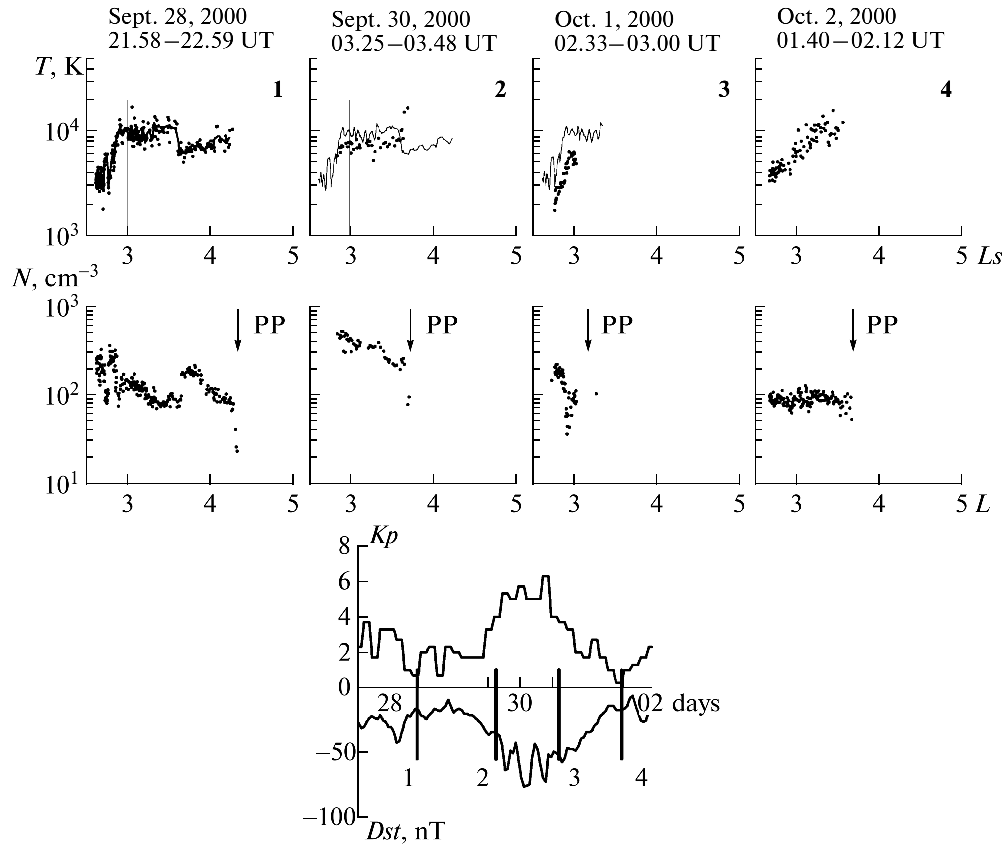

Fig. 1. Thermal proton density and temperature measured on MAGION-5 when it crossed the Earth's nightside plasmasphere (1.2–1.9 MLT) near the geomagnetic equator during a small magnetic storm. Dots show the measured density and temperature values. A thin solid line on temperature plots 1–3 shows the moving average temperature value for September 28, 2000. Arrows on the density plots mark the plasmapause position (PP). Changes in the *Kp* and *Dst* indices in the considered time interval are shown on the bottom (http://swdcdb.kugi.kyoto-u.ac.jp/). Lines show the corresponding measurement times.

cating that the proton temperature decreases during the magnetic storm main phase in the second section. In the third section, we will consider the physical mechanism resulting in a plasma temperature drop in the inner plasmasphere when the magnetic field decreases; in the fourth section, the achieved theoretical results are compared with the MAGION-5 measurements during 12 magnetic storms and with the INTERBALL-2 observations during two magnetic storms.

2. EXPERIMENTAL OBSERVATIONS

The Alfa-3 complex of devices, including a PL-19 modulation analyzer, was used to measure thermal plasma on the INTERBALL-2 spacecraft. The energy spectra in the 0–25 eV range were measured during 2 s, once in 15 s, or at 280 s, depending on the telemetric mode [Bezrukikh et al., 1998]. A short period of the satellite near-polar orbit (6 h) is especially convenient for analyzing the effect of magnetic activity on the dynamics of the plasmaspheric characteristics.

The thermal plasma energy spectra on the MAGION-5 subsatellite of the INTERBALL-2 satellite were measured using a PL-48 analyzer with retarding potential for 0.4 s every 8 s. Unfortunately, these measurements started after the termination of the main spacecraft operation and were performed mainly only in the descending orbit leg once a day [Kotova et al., 2008].

Similar data on thermal plasma, which were obtained using a PL-48 device on the INTERBALL-1 spacecraft, were previously compared to the RIMS mass spectrometer with retarding potential that operated on the DE-1 spacecraft [Kotova et al., 2002]. The good agreement between the data confirms that thermal plasma was reliably measured on the INTERBALL project spacecraft.

Figure 1 illustrates the proton density and temperature distributions depending on parameter L, measured successively once a day on September 28–October 2, 2000, when the MAGION-5 satellite entered into the nighttime plasmasphere during the development of a small magnetic storm. The plasmapause

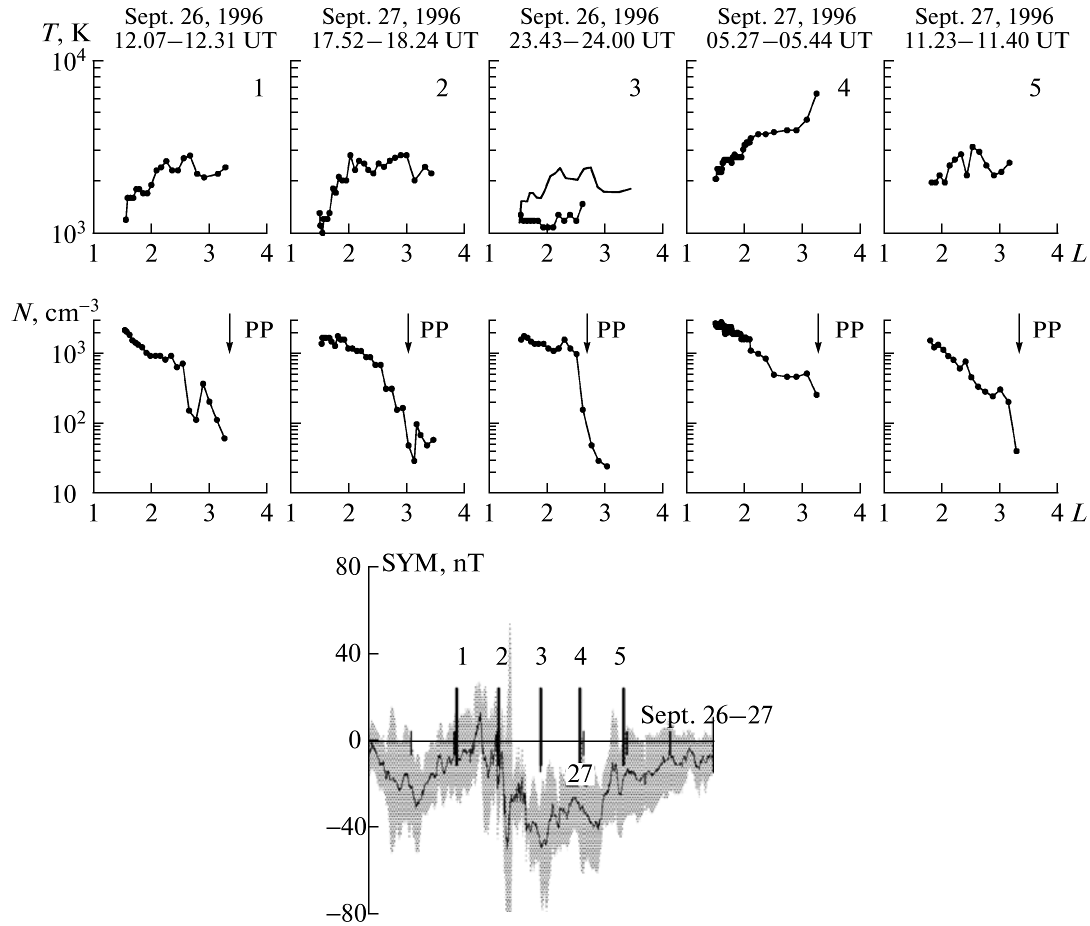

Fig. 2. The density (below) and temperature (above) of thermal protons measured on the INTERBALL-2 satellite on September 26–27, 1996, when the satellite successively passed through the nightside plasmasphere (23.5–1.5 MLT) at a geomagnetic latitude of 15°–30° during the development of a small magnetic storm. The numbers on the plots on the top correspond to the times marked on the bottom plot that shows the variations in the *SYMH* index (http://swdcdb.kugi.kyoto-u.ac.jp/). The *SYMH* ± *ASYH*/2 region is shaded. Arrows on the density plots show the plasmapause position (PP). A thin solid line on temperature plot 3 is the temperature profile calculated in a proton drift approximation in the equatorial plane based on initial profile 1 (T_{in}) at $B_{dst} = -80$ nT.

approaches the Earth to L ~3.1 with increasing *Kp* and decreasing *Dst* values during the development of a disturbance. It is interesting that the density at $L < 2.8$ in the inner plasmasphere increases (rather than decreases) during the storm initial phase and decreases only later with the development of a disturbance, which does not correspond to popular concepts [Spasojevic and Sandel, 2010]. The temperature in the inner plasmasphere near the *Dst* variation minimum decreases.

Figure 2 illustrates the proton density and temperature distributions obtained on INTERBALL-2 during successive (in ~6 h) satellite passes through the plasmasphere when a small magnetic storm developed on September 26–27, 1996. The first two crossings of the plasmasphere occurred during the storm's main phase when the *SYMH* index value was minimal. The *SYMH* index is similar to the *Dst* index but only with a time resolution in the minute rather than hourly range; it characterizes the magnetic field disturbance component symmetric along longitude. However, the *ASYH* index describes the difference between the maximal and minimal deviations of the magnetic field disturbance from the average *SYMH* disturbance. During pass 3 (see Fig. 2) an extremely low ion temperature was observed deep in the plasmasphere; however, the concentration at $L \approx 2$ remained almost unchanged as compared to such a concentration measured during the previous passes. In 6 h during the next pass, pass 4, the ion temperature in the nighttime plasmasphere during the recovery phase was even higher than the values registered previously under quiet conditions and the temperature typical of quiet conditions was registered only during the next pass. The measurements during these passes were performed at a geomagnetic latitude of 15°–30°

3. MODEL OF ION DRIFT IN THE INNER PLASMASPHERE DURING A MAGNETIC STORM

We consider a simple model of the magnetic field disturbance in the geomagnetic equator plane near the Earth when the symmetric ring current increased during the magnetic storm.

Let **E** be an additional vortex electric field that appears due to a change in the magnetic field $\partial \mathbf{B}/\partial t$:

$$\mathrm{curl}\,\mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}. \qquad (1)$$

In the equatorial plane, both this field (**E**) and the magnetic field (**B**) have one component in the cylindrical coordinate system (r, φ, z), where the z axis is directed along the dipole axis:

$$\begin{aligned} \mathbf{E} &= (0, E_\varphi(r, t), 0), \\ \mathbf{B} &= (0, 0, B_z(r, t)), \end{aligned} \qquad (2)$$

where $B_z(r, t) = B_e(r_e/r)^3 + B_{dst}(t)$, B_e is the stationary field on the Earth's surface at the equator, B_{dst} is an additional magnetic field related to the storm, and r_e is the Earth's radius. Having substituted (2) in (1), we obtain:

$$\begin{gathered} \frac{1}{r}\frac{\partial(rE_\varphi)}{\partial r} = -\frac{1}{c}\frac{\partial B_z(r, t)}{\partial t} = -\frac{1}{c}\frac{dB_{dst}(t)}{dt}, \\ \partial(rE_\varphi) = -\frac{1}{c}\frac{dB_{dst}(t)}{dt}r\partial r, \\ E_\varphi(r, t) = -\frac{r}{2c}\frac{dB_{dst}(t)}{dt}. \end{gathered} \qquad (3)$$

With regard to (3), the drift radial velocity is

$$V_{dr} = c\frac{E_\varphi(r, t)}{B_z(r, t)} = -\frac{r}{2B_z(r, t)}\frac{dB_{dst}(t)}{dt}. \qquad (4)$$

At this velocity, a proton will drift over a distance of

$$dr = V_{dr}dt = c\frac{E_\varphi(r, t)}{B_z(r, t)} = -\frac{r}{2B_z(r, t)}dB_{dst} \qquad (5)$$

during time dt. Thus, we obtained the differential equation:

$$\frac{dr}{dB_{dst}} = -\frac{r}{2(B_e(r_e/r)^3 + B_{dst})}. \qquad (6)$$

Having integrated (6), we can obtain the radius of a new proton drift shell depending on B_{dst}: $r = r(B_{dst})$. It is simpler to perform integration for an inverse function $B_{dst} = B_{dst}(r)$ since Eq. (6) for this function is transformed into the linear equation:

$$\frac{dB_{dst}}{dr} + \frac{2}{r}B_{dst} = -\frac{2B_e r_e^3}{r^4}. \qquad (7)$$

The solution to this equation multiplied by πr^2 is:

$$\pi r^2 B_{dst} - \frac{2\pi B_e r_e^3}{r} = \pi r_{in}^2 B_{dst}^{in} - \frac{2\pi B_e r_e^3}{r_{in}}, \qquad (8)$$

where r_{in} is the proton drift shell radius before its drift at $B_{dst} = B_{dst}^{in}$. Since the flux of the dipole magnetic field component through the drift shell is

$$\Phi_d(r) = \int_0^r \frac{B_e r_e^3}{r^3}2\pi r dr = -\int_r^\infty \frac{B_e r_e^3}{r^3}2\pi r dr = -\frac{2\pi B_e r_e^3}{r_{in}}, \qquad (9)$$

solution (8) can be written as:

$$\Phi_d(r) + \pi r^2 B_{dst} = \Phi_d(r_{in}) + \pi r_{in}^2 B_{dst}^{in}, \qquad (10)$$

i.e., in the form of conservation of the total magnetic field flux through the drift shell (the third adiabatic invariant).

Since a proton should not perform a complete rotation around the Earth as Eq. (7) was derived, (8) and (10) can also be used for faster processes. These formulas can apparently be used when the following formula should be satisfied during the cyclotron period τ_c

$$\frac{\partial B}{\partial t}\tau_c \ll B. \qquad (11)$$

A direct dependence of the radius of the shell to which a proton that started from r_{in} will drift on B_{dst} can be obtained by solving Eq. (8), which is cubic with respect to $r = r(B_{dst})$. An approximate solution of this equation at $r - r_{in} \ll r_{in}$ is:

$$r \approx r_{in} + \frac{r_{in}}{2}\frac{B_{dst}^{in} - B_{dst}}{B_e r_e^3/(r_{in}^3 + B_{dst})}. \qquad (12)$$

Since $B_{dst} < 0$ in the inner plasmasphere too $B_e r_e^3/r_{in}^3 > |B_{dst}|$, $r > r_{in}$, and protons drift from the Earth.

However, to solve the inverse problem and find r_{in}, i.e., the distance from the Earth's center from which a proton that drifted to $r = r(B_{dst})$ started, it is sufficient to solve the same equation (8) linear relative to r_{in} at $B_{dst}^{in} \approx 0$, i.e., for an always valid condition $|B_{dst}^{in}| \ll 2B_e r_e^3/r_{in}^3$. In this case

$$\frac{r_{in}}{r_e} = \frac{r/r_e}{1 - \frac{B_{dst}}{2B_e}\left(\frac{r}{r_e}\right)^3}. \qquad (13)$$

Figure 3 presents the dependence of $L_{in} = r_{in}/r_e$ on $L = r/r_e$ (13) for different magnetic field disturbances B_{dst} ($L = r/r_e$ is the McIlwain parameter, i.e., the distance to the field line at the geomagnetic equator in the Earth radii). The proton drift becomes pronounced at $L > \sim 2.2$.

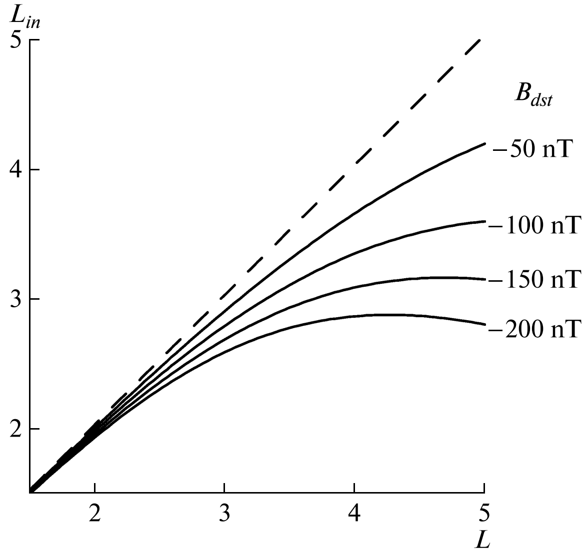

Fig. 3. Dependence of the proton starting position on its final observed position at different values of a magnetic field disturbance caused by the ring current.

We now consider how the proton temperature will change during the drift. From the condition of conservation of the first adiabatic invariant T/B = const, it evidently follows that the temperature also decreases when the magnetic field decreases ($B_{dst} < 0$):

$$\frac{T_{in}}{B_{in}} = \frac{T_r}{B_z(r,t)} \quad \text{or} \quad T_r = \frac{T_{in}}{B_{in}}B_z(r,t) \tag{14}$$
$$= T_{in}\frac{B_{in}(r_{in}/r)^3 + B_{dst}}{B_{in}} = T_{in}\left(\left(\frac{r_{in}}{r}\right)^3 + \frac{B_{dst}}{B_e}\left(\frac{r}{r_e}\right)^3\left(\frac{r_{in}}{r}\right)^3\right),$$

where B_{in} and T_{in} are the magnetic field and proton temperature before a disturbance at distance r_{in} from the Earth's center. Thus, a change in the proton temperature at shell r can be estimated as:

$$\frac{T_r}{T_{in}} = \frac{1 + \dfrac{B_{dst}r^3}{B_e r_e^3}}{\left(1 - \dfrac{B_{dst}r^3}{2B_e r_e^3}\right)^3}. \tag{15}$$

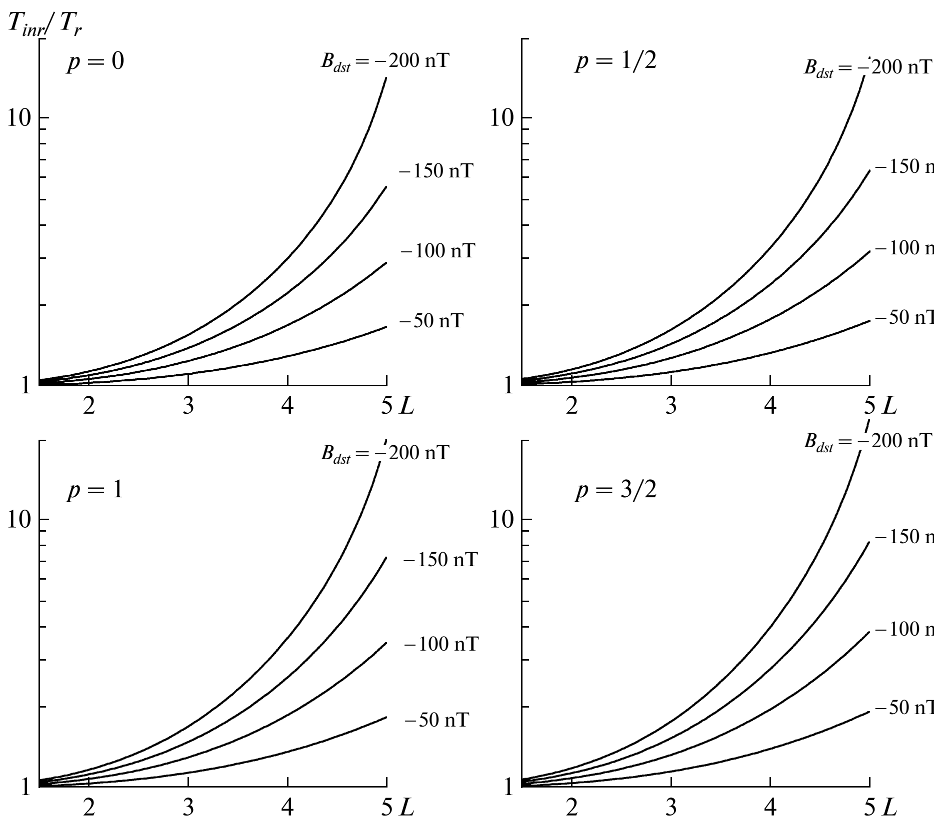

Fig. 4. The ratio of the initial (corresponding to quiet geomagnetic conditions) temperature of protons located at distance r from the Earth's center in the equatorial plane to the proton temperature at the same distance after the action of a magnetic disturbance (B_{dst}) with different values: the relationship inverse to (17). Different panels correspond to different powers p of the initial temperature profile.

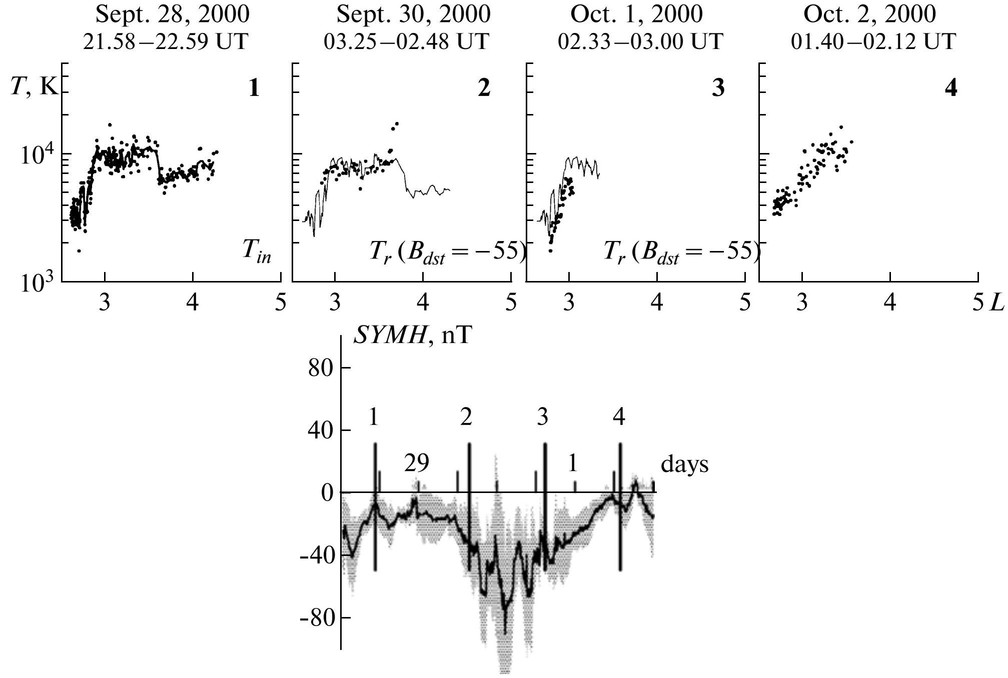

Fig. 5. The same as in Fig. 1 but thin solid lines on temperature plots 2 and 3 are the temperature profiles calculated in a proton drift approximation in the equatorial plane based on initial profile 1 (T_{in}) at $B_{dst} = -55$ nT. The *SYMH* index variations are shown on the bottom. The *SYMH* ± *ASYH*/2 region is shaded.

For a temperature profile in the plasmasphere before a storm with temperatures of T_{in} and T_{inr} at distances of r_{in} and r:

$$T_{in} = T_{inr}\left(\frac{r_{in}}{r}\right)^P. \tag{16}$$

With regard to (16), the change in the proton temperature at shell r will be:

$$\frac{T_r}{T_{inr}} = \frac{1 + \dfrac{B_{dst}r^3}{B_e r_e^3}}{\left(1 - \dfrac{B_{dst}r^3}{2B_e r_e^3}\right)^{3+p}}. \tag{17}$$

The linearization of this expression at $p = 0$ results in the known estimates [Roederer, 1970] of the change in T at slow variations in B_{dst}:

$$T_r = T_{inr} + \frac{5}{2}\frac{B_{dst}r^3}{B_e r_e^3}T_{inr}. \tag{18}$$

The initial expression (17) certainly has a wider domain of applicability than (18).

Expression (17) indicates that the temperature decreases more strongly during a storm the steeper the temperature profile under quiet conditions is before a storm. Figure 4 shows the possible proton temperature variations during a magnetic storm: a dependence inverse to (17) for different values of a field disturbance (B_{dst}) and different powers p. It is evident that, e.g., at $L = 3$ the proton temperature can drop twice at $B_{dst} = -200$ nT. Since the temperature profile in the inner plasmasphere can be much steeper under undisturbed conditions than is shown in Fig. 4 ($p > 1.5$), the proton temperature can also substantially decrease during small magnetic storms.

4. DISCUSSION. COMPARISON OF THEORETICAL AND EXPERIMENTAL TEMPERATURE VALUES

Figure 5 shows the same successive proton temperature distributions during the development of a small magnetic storm that are presented in Fig. 1, but temperature profiles that are recalculated based on the initial temperature distribution $T_{in}(L)$ in panel 1 are presented here by thin lines in panels 2 and 3. For the $L = r/r_e$ shell, for which we plan to calculate the temperature using formula (14), we determined the initial shell $L_{in} = r_{in}/r_e$ from which the protons observed at L started. Then, using the proton temperature measured at the L_{in} shell before a magnetic storm, we calculated the temperature T_r at L shell using formula (15).

In these calculations the B_{dst} value was determined based on 1 minute values of the *SYMH* and *ASYH* indices. During a magnetic storm, the magnetic field disturbance in the inner magnetosphere is mainly related

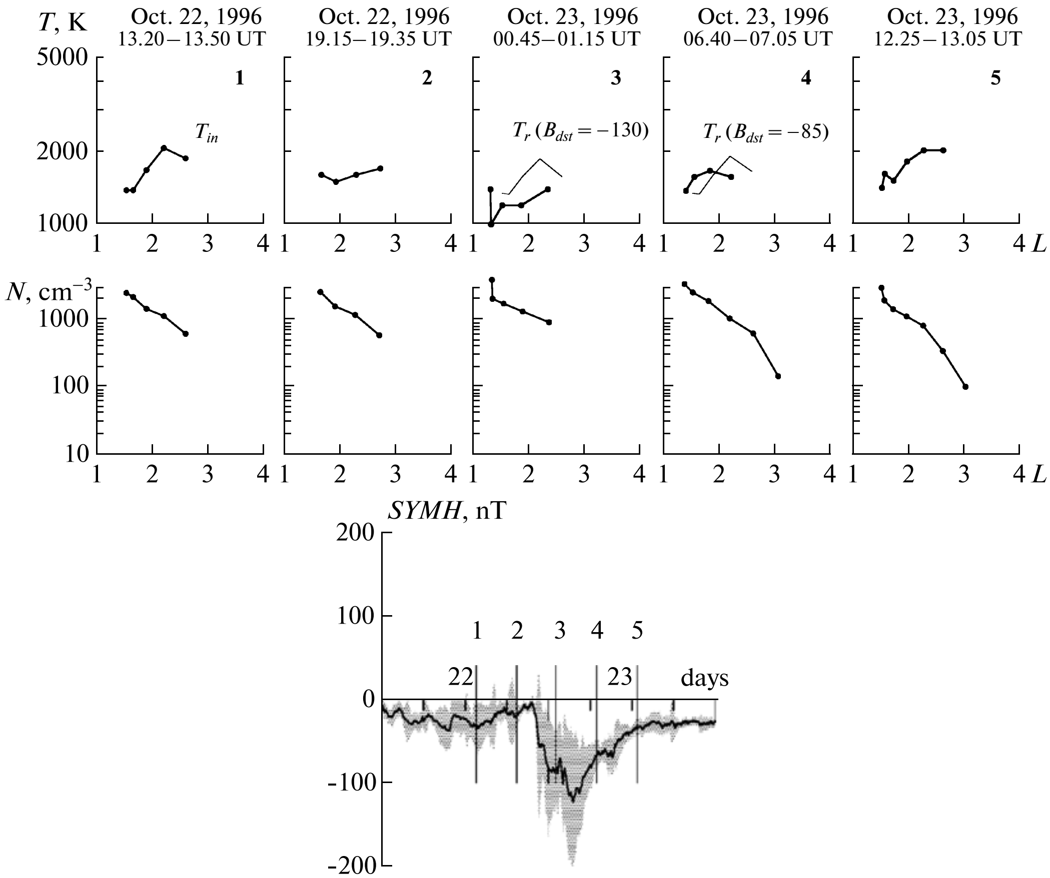

Fig. 6. The same as in Fig. 2 for October 22–23 at 20.1–22.5 MLT. The geomagnetic latitude varies from –20° to +20°. Thin lines on temperature plots 3 and 4 are the temperature profiles calculated in a proton drift approximation in the equatorial plane based on initial profile 1 (T_{in}) at B_{dst} = –130 and –85 nT, respectively.

to the near-Earth ring current. The injection of the comparatively hot plasma of the plasma sheet during the storm main phase creates a partial ring current on the nightside, whose maximum intensity gradually shifts westward [Brandt, 2002]. Since the ring current intensity during a magnetic storm is usually higher in the evening and nighttime local time hours, we can anticipate that the additional proton drift from the Earth is more intense in the evening and nighttime hours. We used the $B_{dst} = SYMH - ASYH/2$ value, the magnitude of which is larger than *Dst* (*SYMH*), in order to estimate the magnetic field disturbance above the Earth nightside and the $B_{dst} = SYMH + ASYH/2$ value for the dayside.

We used the B_{dst} = –55 nT value in the calculations for panels 2 and 3 in Fig. 5. It is clear that the proton temperatures measured during a small magnetic storm in the period close to the *Dst* index minimum are in rather good agreement with the temperatures calculated in the approximation of the proton drift in the equatorial plane based on the initial temperatures measured before a magnetic storm. Note that the MAGION-5 measurements during the considered passes were actually performed near the geomagnetic equator plane.

Figure 6 presents the distributions of the proton density and temperature measured on INTERBALL-2 on October 22–23, 1996 near the geomagnetic equator in the late dusk sector. The thin lines in panels 3 and 4 show the temperature profiles that were recalculated based on the initial temperature profile (T_{in}) in panel 1 at $B_{dst} = SYMH - ASYH/2$ = –130 or –85 nT, respectively. The measured and calculated profiles are in very good agreement.

In contrast to the considered two examples of measurements near the equatorial plane of the Earth's plasmasphere, Fig. 2 (see above) presents the INTERBALL-2 data obtained at higher latitudes. The thin solid line on the temperature plot of panel 3 in Fig. 2 shows the temperature profile calculated in a proton drift approximation in the equatorial plane based on the initial profile 1 (T_{in}) at B_{dst} = –80 nT. Such a considerable additional variable magnetic field results in a pronounced temperature drop relative to the initial temperature, although it does not lead to agreement between the experimental and theoretical temperature

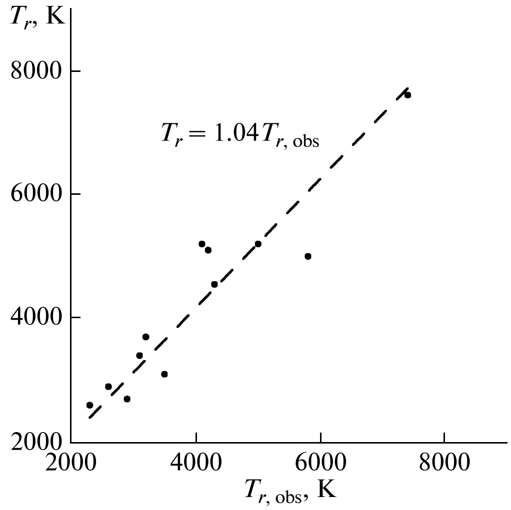

Fig. 7. A comparison of the temperature in the plasmasphere, observed during geomagnetic storms on the MAGION-5 satellite near the geomagnetic equator, with the temperature calculated based on the values measured before the storm. A dotted line is the $T_r = 1.04T_{r,\,\mathrm{obs}}$ dependence.

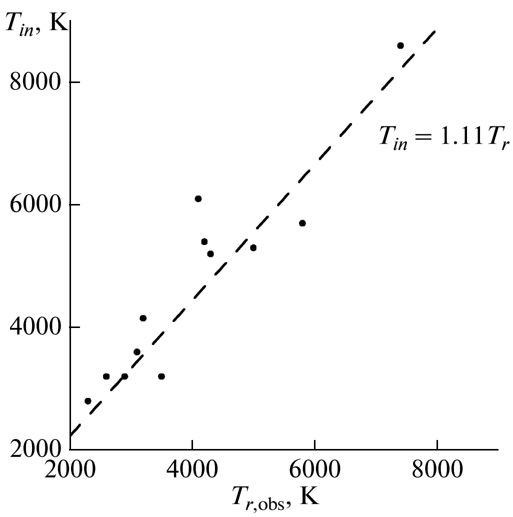

Fig. 8. A comparison of the initial proton temperature at the initial L shell before a magnetic storm with the final temperature at the final shell during a storm. A dotted line is the $T_r = 1.11T_{r,\,\mathrm{obs}}$ dependence.

profiles corresponding to the period near the *Dst* minimal value. The discrepancy is possibly related to the fact that the INTERBALL-2 measurements during these passes through the plasmasphere were performed at geomagnetic latitudes substantially higher than equatorial ones and also can be related to any additional mechanism by which plasma cools operates here.

An insignificant (~10%) decrease in the dayside plasmasphere temperature at increased magnetic activity was reported in Bezrukikh et al. [2003, 2006] based on the INTERBALL-2 data.

Twelve cases of crossing the plasmasphere during geomagnetic storms, when the data on the proton temperature were available were found for MAGION-5. Information about these crossings is presented in the table. One L shell, which was located as deeply as possible in the plasmasphere, was selected for each of these satellite passes in order to perform an analysis and calculations using formulas (14) and (15). The used L values varied in the range 2.65–3.25. In this case the geomagnetic latitude (λ_{geom}) varied from $-2°$ to $+9°$, i.e., was near the magnetic equator, and the local time was arbitrary.

Figure 7 presents the proton temperature observed near the *Dst* minimum during magnetic storms ($T_{r,\,\mathrm{obs}}$) calculated at the same L shells based on the temperatures registered before a storm. Figure 7 indicates that the calculated and measured temperatures are in very good agreement ($T_r = 1.04T_{r,\,\mathrm{obs}}$) with a determination coefficient of $R^2 = 0.987$. Meanwhile, an insignificant increase in the calculated temperature (T_r) over the observed one ($T_{r,\,\mathrm{obs}}$) can indicate that an additional mechanism by which plasma cools operated and was less pronounced at equatorial latitudes than at higher ones (see Fig. 2).

The dependence of the temperature measured under quiet geomagnetic conditions (T_{in}) on the temperature that was observed during a magnetic storm ($T_{r,\,\mathrm{obs}}$) is shown in Fig. 8 for the same 12 passes of the MAGION-5 satellite through the plasmasphere. The T_{in} value was determined for the starting L_{in} shell that was preliminarily calculated using (14). For the selected 12 crossings of the plasmasphere, the average values are $\langle L\rangle = 2.835$ and $\langle B_{dst}\rangle = -56$ nT. According to (15), the approximating dependence should be as follows: $T_{in}(T_r) = 1.11T_r$. This dependence is shown by the dotted line in Fig. 8. Clearly, the dependence rather adequately approximates the available data (the determination coefficient is $R^2 = 0.984$), which is also an argument for the mechanism by which ions cool in the inner magnetosphere during a storm related to the ion drift from the Earth when the magnetic field decreases in this region.

We now consider the plasma density dynamics in the inner magnetosphere during magnetic storms. In all considered passes of the INTERBALL-2 and MAGION-5 satellites through the plasmasphere during magnetic storms, the density in the inner magnetosphere did not decrease during the storm main phase: it remained unchanged or increased. This does not agree with the very popular concept that the plasma density decreases in the inner, not empty, region of the plasmasphere during a storm [Carpenter and Park, 1973; Spasojevic and Sandel, 2010]. The plasma density in the inner magnetosphere during the passes considered in the present paper decreased only

The cases of crossing the plasmasphere during geomagnetic storms

Date/time before storm	Date/time after storm (UT)	L	MLT	λ_{geom}	SYMH (nT)	ASYH (nT)	B_{dst} (nT)	T_{inr} (K)	$T_{r,\,obs}$ (K)	T_r (K)	L_{in}	T_{in} (K)
Oct. 5, 1999/0900	Oct. 13, 1999/0802	2.65	8.99	0.15°	–41	59	–41	3500	2300	2600	2.62	2800
Nov. 6, 1999/0459	Nov. 14, 1999/0400	2.80	6.50	2.3°	–73	32	–73	5550	4300	4550	2.73	5200
Sept. 3, 2000/0335	Sept. 5, 2000/0149	2.80	3.90	2.8°	–31	17	–31	4500	3100	3400	2.77	3600
Sept. 24, 2000/0310	Sept. 26, 2000/0127	2.70	2.00	2.6°	–45	46	–68	3700	3500	3100	2.64	3200
Sept. 28, 2000/2230	Sept. 30, 2000/0344	3.00	1.80	9.1°	–37	36	–55	9500	7400	7600	2.94	8600
Sept. 28, 2000/2250	Oct. 1, 2000/02:57	2.80	1.70	3.1°	–39	30	–54	3700	2600	2900	2.75	3200
Nov. 9, 2000/2150	Nov. 10, 2000/2103	2.80	22.00	4.0°	–65	10	–70	3500	2900	2700	2.73	3200
Nov. 26, 2000/1901	Nov. 29, 2000/2218	2.77	20.50	1.5°	–72	18	–72	6200	5800	5000	2.71	5700
Mar. 4, 2001/1055	Mar. 5, 2001/1004	2.70	12.00	–2.0°	–42	41	–21	5700	5000	5200	2.68	5300
Mar. 18, 2001/1020	Mar. 20, 2001/0850	2.75	10.50	0.8°	–139	84	–97	6400	4100	5200	2.66	6100
Mar. 22, 2001/1250	Mar. 28, 2001/0738	3.00	10.00	8.5°	–37	22	–26	5900	4200	5100	2.97	5400
Mar. 30, 2001/0545	Mar. 31, 2001/0455	3.25	9.3	8.5°	–64	88	–64	5700	3200	3700	3.14	4150

during the recovery phase when the *Dst* minimum was crossed. According to the data of these satellites, the plasma density decreased during a storm's main phase only during very strong magnetic storms accompanied by prolonged auroral activity [Kotova et al., 2008]. Takasaki et al. [2006] also observed an increase in the density in the inner plasmasphere at $L = 1.4$ based on the ground data during the main phase of the strong magnetic storm of October 31, 2003. The authors assumed that a density increase in the plasmasphere could be caused by fluxes of heavy O^+ ions from the ionosphere into the plasmasphere.

5. CONCLUSIONS

The INTERBALL-2 and MAGION-5 satellite measurements indicate that the ion temperature in the plasmasphere as a rule decreases during a magnetic storm's main phase; in this case the plasma density increases or remains at the previous level typical of undisturbed conditions.

The model of a drift shell displacement from the Earth caused by a decrease in the magnetic field in the inner plasmasphere during the development of a magnetic storm satisfactorily described the decease in the proton temperature near the equatorial plane.

Other mechanisms, which explain the larger decrease in the plasmasphere temperature at higher latitudes, should be used for this purpose.

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