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MAGNETOTAIL STRETCHING UNDER DIFFERENT SOLAR WIND CONDITIONS

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Abstract. We investigate how the latitudinal location of proton precipitation boundary called b2i (which is a proxy for the boundary of isotropic precipitation) relates to the type of solar wind stream. It is known that the isotropy boundary latitude is an indicator of the magnetosphere magnetic field stretching. We found that the strongest stretching is observed during the streams containing so-called "magnetic clouds" with southward magnetic field. This agrees with increased intensity of geomagnetic disturbances during such solar wind streams. Also, this explains why substroms during magnetic clouds occur at lower latitudes and have larger longitudinal dimension in comparison with substorms taking place during other solar wind streams.

Introduction

It has been demonstrated (e.g., Sergeev et al., 1993; Newell et al., 1998) that the latitude of the isotropy boundary (IB) of energetic protons (equatorward boundary of isotropic proton fluxes at the ionosphere level corresponding to the boundary between regions of chaotic and adiabatic motion of particles in the magnetotail) correlates with elevation of the magnetic field at geostationary orbit in the nightside equatorial magnetosphere. The lower the isotropy boundary latitude at midnight, the smaller the magnetic field elevation angle. Smaller elevation of the magnetic field lines means their stronger deviation from the dipole configuration, that is, stronger tailward stretching of the magnetic field in the near-Earth magnetosphere. Newell et al. (1998) also showed that decrease of the midnight IB latitude is accompanied by the decrease of the vertical component (Bz) of magnetic filed near the equatorial plane of magnetosphere. The longitudinal extent of the reduced Bz increases significantly and occupies the whole night sector when the IB latitude shifts down up to ~60º (from 18 up to 06 MLT, see, Fig. 5 in paper by Newell et al., 1998). Evidently, this signals that when the IB latitude is low, the cross–tail current is intensified and close to the Earth not only in the midnight, but also in the evening and morning sectors. Interaction of the magnetosphere with the solar wind determines the shape of magnetosphere and brings influence on the configuration of the magnetospheric magnetic field (and, correspondingly, on the IB latitude). In some ways, the dependence of the IB latitude on solar wind parameters has been studied by Lvova et al. (2005) and Yahnina et al. (2005). The strongest influence on the magnetotail stretching has been found for solar wind electric field and Bz component of the interplanetary magnetic field. Also, the latitude of IB varies in the course of the solar activity cycle. During solar activity minimum (maximal) the IB latitude is maximal (minimal), that is, during solar activity maximum (minimum) the tailward stretching of the magnetic field lines is larger (smaller). During solar activity maximum the majority of geoeffective solar activity consists of coronal mass ejections related (as shown by Burlaga et al., 1982) to the magnetic clouds, and during solar minimum the coronal holes prevail generating recurrent fast solar wind streams. Thus, it is reasonable to investigate how the different solar wind streams affect the magnetotail stretching.

Data selection and treatment

For this study we used the IB proxy derived from the low-orbiting DMSP satellite particle measurements, namely, the latitude of the maximal flux of protons with energy E>3 keV. This latitude called b2i (Newell et al., 1996) nicely, like the IB derived from >30 keV proton measurements onboard NOAA satellites (Sergeev et al., 1993), correlate with the elevation angle of the magnetic field in the near-Earth magnetotail (see, Newell et al., 1998). The b2i values along with other precipitation boundaries are routinely determined from the DMSP particle data by the Auroral Particles and Imagery Group at JHU/APL. The database containing b2i values since 1984 till present time can be found at the website of this group. The list of magnetic cloud events observed by the Wind spacecraft for 1995-2007 was retrieved from the web page of the WIND Magnetic Field Instrument team (http://wind.nasa.gov/mfi_instrument/mfi/team_science.html). The information on the recurrent high speed solar wind streams was taken from the High Speed Streams Catalog (1996-2007) by O. Maris and G. Maris published at http://www.spacescience.ro/new1/HSS_Catalogue.html. We selected several high-speed recurrent streams for 1996 and 2001. These two years represent, respectively, minimum and maximum of the solar activity. To increase the statistics of the IB measurements during magnetic clouds, the well-defined events were selected for intervals 1995-1997 and 2000-2002 (centered at 1996 and 2001). All the events were re-examined using the 5-min resolution OMNI database. As result, the intervals of southward and northward magnetic field within the magnetic clouds where selected as well as intervals within recurrent streams with the stream velocity greater than 400 km/s. In addition, the intervals of enhanced plasma density at fronts of the magnetic clouds and fast recurrent streams called, respectively, as "Sheath" and CIR (corotating interaction regions) were determined.

The isotropy boundary latitudes were averaged for every subset of the events (magnetic clouds with southward Bz, fast recurrent streams, Sheath, CIR) separately for minimum and maximum of the solar activity.

Results and discussion

The number of selected events for the four subsets is presented in Tables 1 and 2. Entries on these Tables are, also, averaged parameters of the considered solar wind streams. The MLT variation of the isotropy boundary latitude is plotted in Figure 1. Plots for 1996 and 2001 are shown on the left and right, respectively. The line 1 is the averaged

Table 1. Mean solar wind parameters for 1996 and some selected solar wind stream intervals

	Number of events	Bz mean (nT)	N mean (cm^{-3})	V mean (km/s)	P mean (nPa)
(1) Whole year		-0.16	7.89	425	2.4
(2) RS	13	-0.34	3.56	565	2.3
(3) CIR	10	-0.71	12.61	417	4.3
(4) Sheath	10	-2.39	20.44	407	6.5
(5) MC (Bz<0)	5	-7.11	8.46	403	2.5

Table 2. Mean solar wind parameters for 2001 and some selected solar wind stream intervals

	Number of events	Bz mean (nT)	N mean (cm^{-3})	V mean (km/s)	P mean (nPa)
(1) Whole year		-0.37	6.10	422	2.2
(2) RS	9	0.27	3.11	566	1.7
(3) CIR	13	0.83	14.53	403	4.3
(4) Sheath	13	0.78	22.49	479	10.1
(5) MC (Bz<0)	6	-8.70	4.68	452	1.9

IB for whole years 1996 and 2001 independently on the type of the solar wind stream. The line 2 represents recurrent streams influence on the magnetospheric state (configuration). Lines 3-5 are the averaged IB latitudes as function of MLT for CIR, Sheath, and southward Bz part of magnetic clouds. The Figure clearly demonstrates that every kind of considered solar wind fluxes produces a distortion of magnetotail from an average state. The strongest magnetotail stretching is observed during magnetic clouds with Bz < 0. Indeed, southward Bz strongly affects the IB latitude (Yahnina et al., 2005). The weakest magnetic field distortion is found for high-speed recurrent streams. Evidently, this distortion relates to large values of V, while Bz is variable, and averaged Bz is about zero (see Tables 1 and 2).

The enhanced magnetotail stretching during both CIR and Sheath events relates, probably, to increased density (and dynamic pressure). The stronger effect of Sheath is, likely, due to the higher (in comparison with considered CIRs) plasma density. (Note that mean values presented in Tables differ from those obtained by Yermolaev et al. (2009), who used much larger statistics, but did not separate minimum and maximum of solar activity and did not divide magnetic clouds into intervals with negative and positive Bz).

As mentioned, the line 5 in Figure 1 represents only that part of the magnetic clouds, which contains southward Bz. The latitude of the isotropy boundary corresponding to the magnetic clouds (or their parts) with northward Bz is higher than the line 1 (not shown).

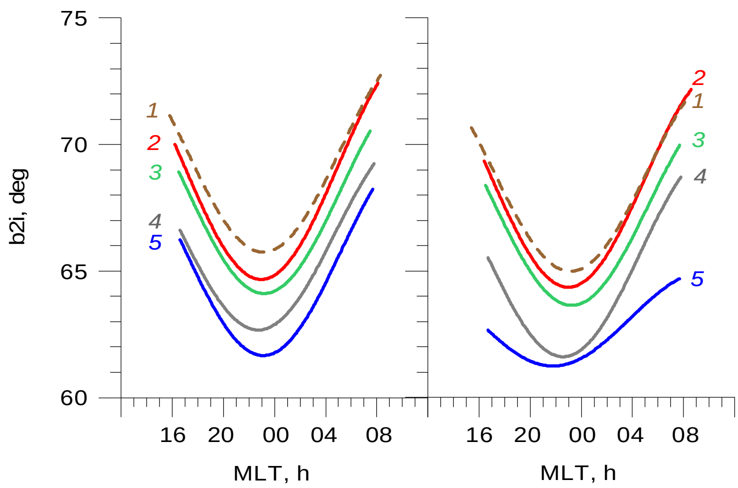

Figure 1. Latitude of the proton isotropy boundary as function of MLT for different solar wind conditions.

It is worth to note that the IB latitude averaged through the year is lower for 2001 than for 1996 (see, also, Yahnina et al., 2005). It holds for every type of the streams as well. The reason is not clear yet. It is possible that it is a consequence of the limited statistics used in this study.

Let us discuss the differences of the isotropy boundary location related to different solar wind streams in the context of substorms.

Sergeev et al. (1983) (see, also, Yahnin (2008)) on the basis of comparison of the auroral onset with the electron isotropy boundary argued that substorms start in the magnetotail at stretched field lines (namely, in the region where the value of the magnetic field is only few nT). Decrease of the isotropic boundary latitude means stronger stretching of the field lines. In turn, this means that the region of weak magnetic field approaches the Earth. Besides, as mentioned in Introduction, the low-latitude IB location relates to longitudinal expansion of region of the weak magnetic field (Newell et al., 1998). Thus, one can expect that during magnetic clouds the region where substorms start is closer to the Earth, and the substorms is to develop in a wider longitudinal region than during other solar wind structures.

Indeed, Henderson (2004) and Henderson et al. (2006) found that during magnetic clouds the substorm activity (stretching, dipolarization, particle injections, NENL formation, etc.) occurs and is sustained at locations extremely close to the Earth. Henderson (2004) and Pulkkinen et al. (2006) noted the wide azimuthal range of dispersionless injection activity during magnetic clouds, and Despirak et al. (2009) stressed that the ratio of the longitudinal dimension of the auroral bulge to its latitudinal expansion is larger during magnetic clouds than other types of the solar wind streams.

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