Latitudinal profiles of solar protons in the Earth’s magnetosphere

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Abstract. Dynamics of the latitudinal profiles penetrating into magnetosphere solar protons is studied using particle spectrometers data on board of the low latitude satellite CORONAS-F with orbit inclination ~83°. Formations of several different types of the profiles during magnetic storms are considered.

1. Introduction
Low energy (<100 MeV) solar protons penetrate into the Earth’s magnetosphere through the magnetotail with the depthness depending of the particle energy and the magnetic disturbance. Investigations of the penetration boundary both experimental and theoretic have long history (see for example [1-5]).

In the present work dynamics of the latitudinal profiles, dependence on particle energy and magnetic activity were studied instead of single point penetration boundary. Several particle spectrometers were installed onboard the low latitude satellite CORONAS-F [6] with orbit inclination ~83°. Data obtained by these detectors used in the presented article.

2. Types of latitudinal profiles

2.1. Definitions.
Example of the latitudinal profiles of three energy ranges: 1-5, 14-26 and 50-90 MeV with typical energy shift are presented on Fig. 1a. McIlwain L-index for a low magnetic activity is used here as a equivalent of corrected geomagnetic latitudes. Point of transition from polar cap to lower proton flux is shown as “A”, ‘PB’ presents a commonly used position of penetration boundary, and “F” indicates the latitude where solar proton counts meets with counter’s background galactic cosmic rate.

2.2. Night sector.
In the magnetotail and outer night-time quasitrapping region protons have isotropic distribution, and precipitation flux registered by satellite is equal to the interplanetary one. Larmor radius of the proton $\rho$ there is larger than magnetic field line curvature radius $R_c$. When the ratio $\varepsilon = \rho / R_c$, named parameter of adiabasity, reaches critical level, (between 0.1 and 0.6, [7,8]) some particles became trapped and precipitating flux began to decrease. Thus nighttime profiles formation depends on a local magnetosphere structure. Night-time field line stretching during magnetic storm shifts profiles...
Proton penetration mode is stochastic – some protons precipitates earlier, some later. Because of that a relation to the results of trajectory calculation must be regarded by care.

At the end of the main phase of a strong magnetic storms stretching became so intense that particles of all energies from 1 to 50 MeV freely penetrate down to the dipole field lines where all became stopped independent of energy. Figure 1b shows an example of such profiles.

2.3. Day time sector
Figures 2a and b present examples of comparison of day and night profiles. There is theoretical possibility for penetration on the day sector through casp region, but strong magnetic field gradient at the transition region does not allow for low energy protons to penetrate deep to close field lines. More reliably for them to arrive at the day side by the magnetic drift.

During magnetic storms our L-coordinate does not reflect drift trajectory. It must be calculated based on conservation of the second adiabatic invariants. In a paper [8] such trajectories were found for a model of disturbed magnetosphere and it was shown that protons from some night high latitude region of isotropy will arrive to the dayside well trapped, with decreased level of the precipitating flux. As a result, day profiles are more prolonged and precipitation boundaries are located at the higher latitudes.

Increased proton energy leads to the penetration closer to the Earth. Difference between magnitude and magnetic field line configuration became smaller, and smaller became difference between day and night profiles.

3. Magnetic storms
During the main phase of the magnetic storms all profiles, day and night, became shifted to the lower latitudes with a steeper intensity decrease. Latitudinal shift is very individual at different magnetic storms. We will point out only at one peculiarity at the end of the main phase of a strong magnetic storm. As one can see on figure 1b, all night time profiles coincide for the whole registered energy range from 1 to 50-100 MeV. Proposed in [9] explanation based on a distortion of regular magnetic field decrease with latitudes. Particles of all energies freely penetrate outer tail-like field lines, lingering together at the steep dipole magnetic field lines.
4. Solar wind pressure

Fast increase of a solar wind pressure with arrival of enhanced flux may cause latitudinal shift of a proton profiles before the beginning of the storm main phase. Such effect of magnetosphere distortion was found by Meng [10] by active aurora dynamics and later such shift was mentioned in October 2003 storm case study [11].
extends magnetic field lines. Importance of the solar wind pressure for the night penetration boundary position was found previously by [12].

5. Conclusion

- Solar protons penetrate to the night side with isotropic pitch-angle distribution until particle larmor radius is larger than magnetic field line curvature. Closer to the Earth precipitating flux started to decrease because of partial trapping and only small fraction of particles reach background boundary.
- To the day side protons comes by the magnetic drift with a trajectory, which conserved second adiabatic invariant. As a result of magnetic field asymmetry, protons from isotropic night side position may arrive to the dayside trapping region with decreased precipitation flux. As a result, dayside profile are more prolonged and their mechanism of formation is different because depends of the whole magnetic field configuration.
- With the increase of the proton energy and toward the end of storm main phase protons penetrate closer to the Earth, profile became steeper and difference between day and night profiles became smaller. At the end of the main phase of a strong magnetic storms profiles coincides for all energy range because of the specific magnetic field configuration.
- Essential earthward shit of the nighttime proton profiles may be observed before the beginning of the main phase caused by the rise of the solar wind pressure.

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