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DIAMAGNETIZM OF PLASMA AND FORMATION OF LOCAL DECREASES OF THE MAGNETIC FIELDS NEAR THE EQUATORIAL PLANE

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Abstract. We analyze the distribution of the magnetic field at the equatorial plane and plasma pressure using data of the AMPTE/CCE satellite at the equatorial plane and select the formation of local minima of the magnetic field. The main feature of such minima is the decrease of the magnetic field along the satellite trajectory accompanied by the increase of the field. Selected decreases of the magnetic field have the forms of magnetic holes. More than hundred magnetic holes are selected at all local times. Comparatively stable character of magnetic field decreases leads to the suggestion about quasistable character of observed magnetic holes. The formation of local minima of the magnetic field near midnight is traditionally explained as the result of the magnetic field distortion by tail current near its near Earth boundary. However the formation of magnetic holes can be connected with the local increases of plasma pressure in the magnetic trap in the conditions of magnetostatic equilibrium due to the diamagnetism of plasma. Action of such mechanism becomes rather probable due to observations of magnetic holes in all MLT sectors. We select the event 06 June 1985 when the increase of plasma pressure (pressure hump) was observed simultaneously with the magnetic hole. The nonlinear modeling of the magnetic field distortion by the observed pressure hump shows that the magnetic hole observed 06 June 1985 is the result of the diamagnetic effect of hot magnetospheric plasma.

1. Introduction

Decreases of B_Z component of the magnetic field near the equatorial plane are frequently observed near midnight and ordinarily interpreted as the magnetic field stretching in the tailward direction (see, for example, *Petrukovich et al.* [1999]). *Saito et al.* [2010] show using data of multipoint observations via NASA's magnetospheric mission THEMIS that the decrease of B_Z can have the local character and is accompanied by B_Z increase with the increase of geocentric distance. Observed by *Saito et al.* [2010] local decreases of B_Z can be considered as magnetic holes and had the quasistationary nature for ~20 min before dipolarization onset. Magnetic configuration with magnetic hole can be unstable. Therefore the result of *Saito et al.* [2010] leads to the appearance of multiple papers on the balloon mode development near midnight. Such development is considered as one of the possible mechanisms of substorm expansion phase onset. Constantly existing high level of plasma sheet turbulence at geocentric distances >10R_E (see *Stepanova et al.* [2009, 2011] and references therein) complicates the observations of magnetic holes and humps. That is why the analysis of CLUSTER observations made by *Petrukovich et al.* [2013] between 8 and 18 R_E downtail selected only a few of events which exhibit clear quasistationary magnetic hump formation in the middle tail. However, quite time plasma distribution at geocentric distances <10R_E is comparatively stable in comparison with plasma sheet proper. That is why it may be rather interesting try to find magnetic holes and humps in this region which in accordance with *Antonova et al.* [2013, 1014a] is the high latitude part of the ring current. It is necessary to mention that *Antonova et al.* [2014b], *Vorobjev et al.* [2015] argue that most part of the auroral oval is mapped to the equatorial plane (more exactly to the surface of minimal values of the magnetic field at the magnetic field line) to the outer part of the ring current in contrast to the ordinary suggestion of its mapping to the plasma sheet proper.

Decrease of the magnetic field in the comparison with not disturbed magnetic field and the field increase at larger geocentric distances is the characteristic feature of the magnetic field distortion by the ring current [*Chapman and Akasofu*, 1968]. The increase of the magnetic field is formed at the outer boundary of the ring current simultaneously with the magnetic field decrease inside the ring current with the maximal distortion in the region of pressure maximum. Such feature corresponds to the observations of magnetic hole/hump structures by *Saito et al*. [2010]. Taking into account the results demonstrating the existence of ring current continuation till geocentric distances ~12R_E it may be very interesting to check the hypothesis about hole/hump structure formation by the ring current. The proof of such hypothesis requires simultaneous observations of magnetic field and plasma pressure.

Comparatively good results of plasma pressure observations at the equatorial plane were obtained due to realization of AMPTE project. AMPTE/CCE data were used for the obtaining of global picture of pressure distribution at the equatorial plane during quite conditions [*Lui and Hamilton*, 1992; *DeMichelis et al.*, 1999; *Lui et al.*, 2004] and magnetic storms. Such data continue to be interesting till now due to location of satellite orbit near to the equatorial plane till geocentric distances 8.8R_E and helium and O^+ measurements which provide comparatively high accuracy of pressure determination. Hole/hump structures of magnetic field were not analyzed using AMPTE/CCE observations.

In this paper we present the results of the analysis of the magnetic field measurements at the equatorial plane using data of AMPTE/CCE satellite. We select the quasistationary decreases of the magnetic field which can be considered as the magnetic holes and obtain their MLT distribution. We obtain AE and Dst dependence of the probability to observe such events. We produce the nonlinear modeling of the magnetic field distortion by plasma pressure hump observed 06 June 1985 near midnight and try to show that local increase of plasma pressure can be considered as the probable mechanism of hole/hump structure formation in the magnetic field.

2. Results of the analysis of AMPTE/CCE observations of magnetic holes

The AMPTE/CCE spacecraft had a near-equatorial elliptical orbit with an inclination of 4.8°, an apogee of 8.8R_E and perigee altitude of ~1000 km. The orbital period is 15.7 hour. We used for this study the results of AMPTE/CCE fluxgate magnetometer system. We also analyze the measurements of the ion population from ~1 keV to 300 keV from the charge-energy-mass spectrometer (CHEM), and ion fluxes above 300 keV from the medium energy particle analyzer (MEPA).

We try to select hole/hump quasistationary regions of B_z decrease accompanied by B_z increase. Fig. 1 sows such kind of event near to midnight, position of the hole/hump event at the equatorial plane and corresponding geomagnetic parameters (SYM-H, AE, PC). Solar wind parameters were not available for this event. Vertical line shows the moment of structure registration. It is possible to see the formation of hole/hump structure at geocentric distance form 4.7 till 5.4$R_{E.}$

The event 06 June 1985 can be identified as classical magnetic field decrease near midnight. However such kind of events can be observed not only near midnight. Fig. 2 show the results of hole/hump structure observed 10 December 1984 in the morning sector. This event demonstrates comparatively large azimuthal scale of hole/hump structure and its existence for more than five hours.

We analyze all time of AMPTE/CCE operation when data were available and selected 102 hole/hump events. Their positions at the equatorial plane are shown on Fig. 3.

It is possible to see analyzing Fig. 3 that hole/hump events are observed at all local times at geocentric distances larger than 5R_E till the AMPTE/CCE apogee. Such feature shows that the most natural explanation for the appearance of the observed hole/hump events is the diamagnetic effect of the ring current plasma. Ring current in such a case is located at distances smaller than the AMPTE/CCE apogee but mainly larger than 5R_E.

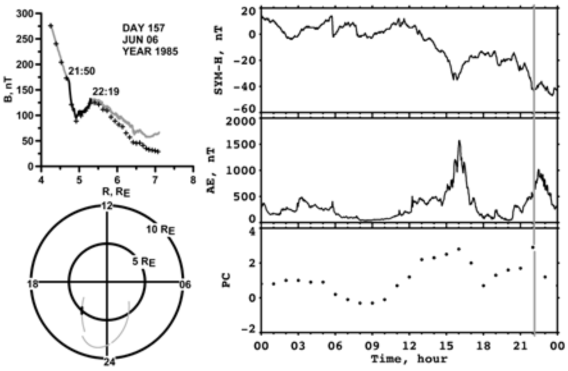

Figure 1. The event 06 June 1985 (near midnight)

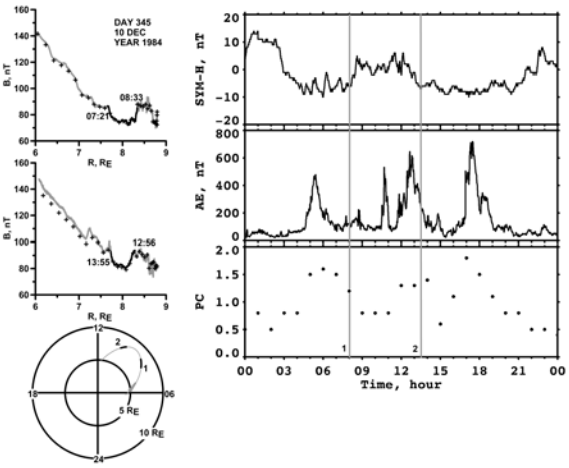

Figure 2. The event 10 December 1984 (morning sector)

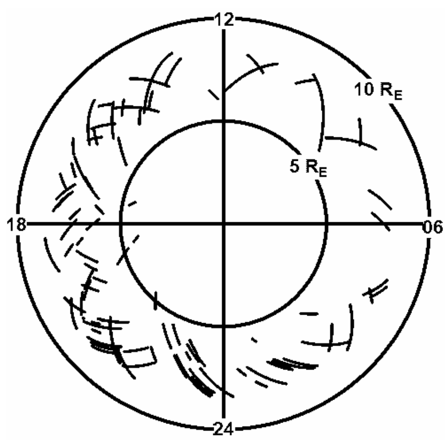

Figure 3. Position of selected hole/hump events at the equatorial plane

Fig. 4 and 5 show the numbers of observed events on Dst and AE. It is possible to see that the probabilities to observe analyzed phenomena practically do not depend on the geomagnetic activity.

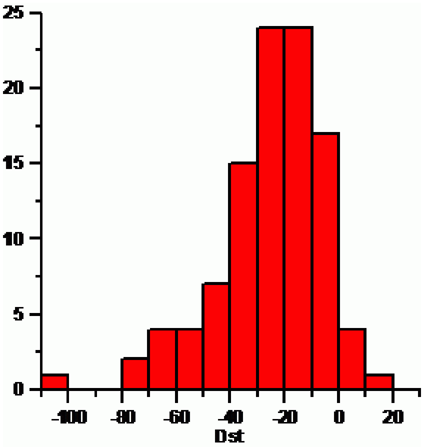

Figure 4. Dependence of the number of observed events on Dst

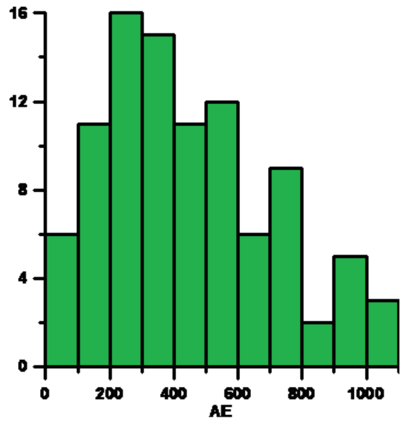

Figure 5. Dependence of the number of selected events on AE

3. Results of modeling of the event 06 June 1985

Trying to analyze the role of the diamagnetism of plasma for the creation of magnetic hole/hump events we produce the modeling of the magnetic field distortion by the observed plasma pressure distribution. The event 06 June 1985 was selected as the results of plasma observations for this event were available and comparatively good. Fig. 6 shows such results. Black and red lines on the upper part of the figure correspond to the observations of the module of the magnetic field *B* and *Bz* component of the magnetic field. Coincidence of *B* and *Bz* means the satellite position at the equatorial plane. Lower parts are the spectrograms of H^+ and O^+ ions obtained using CHEM device.

Clear pressure hump is observed for the analyzed event. Calculating the distortion of the magnetic field by the observed pressure hump we restore the undisturbed magnetic field distribution suggesting that it is produced by magnetospheric current systems excluding current system connected with pressure hump. We suggest the validity of the condition of magnetostatic equilibrium as the analyzed effect is observed during time interval which is much larger than the sound and Alfven travel times in the magnetosphere. We used the algorithm developed by *Vovchenko and Antonova* [2010, 2012] for calculation of the nonlinear magnetic field distortion. Fig. 7 shows the results of calculations (red line) and their comparison with the results of observations (black line).

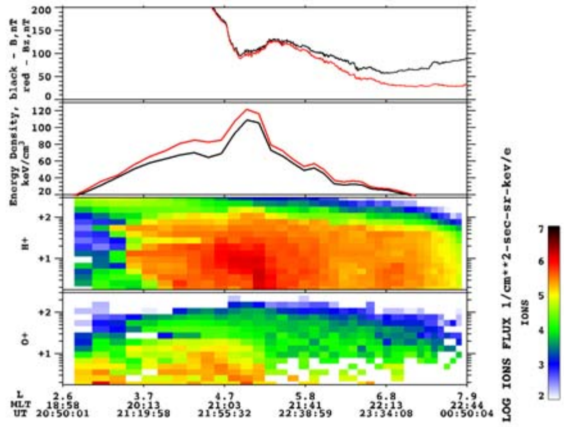

Figure 6. Results of the observations of the magnetic field variation, plasma pressure distribution and H+ and O+ particle fluxes for the event 06 June 1985

4. Conclusions and discussions

Hole/humps of the magnetic field in the magnetosphere of the Earth are clearly selected. Data of AMPTE/CCE observations at geocentric distances <8.8Re very near to the equatorial plane demonstrate the appearance of pressure holes in all MLT sectors. The probability to observe pressure holes does not depend on AE and Dst indexes of geomagnetic activity. Formation of observed pressure holes and humps can be connected with local increases of plasma pressure (due to diamagnetic effect). Such formation does not requires tail current distortion of the geomagnetic field and probably connected with ring current effect.

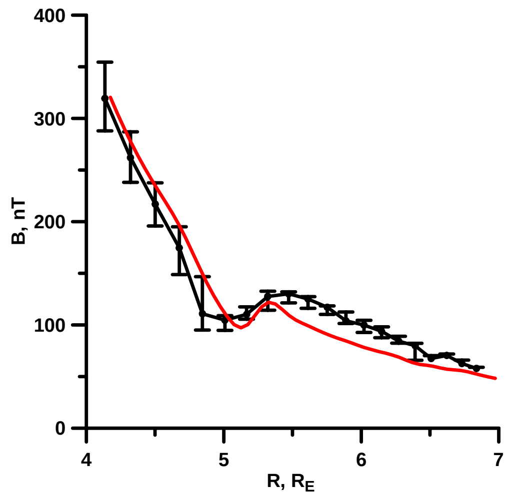

Figure 7. Comparison the results of modeling (red line) with the results of observations (black line)

Existence of local magnetic holes and humps is important not only for the clarification of the mechanism of substorm expansion phase onset. *Myagkova et al.* [2010] show that local increases of fluxes of energetic electrons can be quasistationary observed to the pole of the outer electron radiation belt and suggested that the observed increases can be connected with the formation of local magnetic traps. Particle trajectories at the equatorial plane in such traps do not surround the Earth. *Antonova et al.* [2011] show that not surrounding the Earth contours B_Z=const appear in Mead and Faierfield and different versions of Tsyganenko models. *Riazantseva et al*. [2012] demonstrate the location of quasistationary increases of energetic electrons at the latitudes of the auroral oval. *Vovchenko and Antonova* [2014] show that hole/hump effect appears in the process of the modeling of the dipole magnetic field distortion by azimuthally asummetric plasma pressure and explained the formation of local plasma traps at the latitudes of the auroral oval. All such results show the real perspectives of the analysis of quasiequilibrium plasma pressure configurations in the magnetosphere of the Earth. However such analysis is only on the first stages of its development.

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