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INTERBALL 1 / ALPHA 3 COLD PLASMA MEASUREMENTS IN THE EVENING PLASMASPHERE: QUIET AND DISTURBED MAGNETIC CONDITIONS

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ABSTRACT

Cold plasma fluxes measured by the ALPHA 3 instrument on INTERBALL 1 from July to October 1999, when the spacecraft crossed the dusk side outer plasmasphere are analyzed. The INTERBALL 1 orbit crosses the same flux tube on both sides of the magnetic equator at nearly the same height and most of the time cold ion spectra were very much alike. After a period of moderate geomagnetic activity similar isolated patches of dense plasma were observed during crossings of the same L-shell in southern and northern hemispheres at geomagnetic latitudes of ± 20°. This suggests that filled magnetic flux tubes were located above almost empty tubes.

The interrelationships between cold plasma parameters at a given L-shell and geomagnetic activity, and the external solar wind flow, were analyzed. A tendency for enhanced cold H^+ ion temperatures inside the dusk plasmasphere in magnetically disturbed periods is found. The cold ion density in the dusk side plasmasphere increases with the solar wind dynamic pressure.

INTRODUCTION.

The Earth's plasmasphere has been studied for almost 40 years, but there are still many unresolved questions concerning its formation and plasma characteristics. Perhaps the greatest number of these questions refer to the dusk side – the most important region for the processes involved in the plasmaspheric reaction to geomagnetic activity variations. The dusk side bulge region was intensively studied by whistler observations, geosynchronous satellites and DE-1, ISEE 1 and other satellites (Lemaire et al., 1998). Carpenter et al. (1993) published a rather comprehensive review of plasmasphere dynamics in the dusk side region but the authors did not investigate plasma parameter variations during magnetic storms. Comfort (1996) considered the overall thermal structure of the plasmasphere. Information about the responses of cold plasma parameters in the plasmasphere to geomagnetic activity variations is very limited, especially in the dusk sector. It is usually proposed from early whistler work that the density in the outer plasmasphere can be depressed in the aftermath of magnetic disturbances (Carpenter, 1993). However at least sometimes during the development of magnetic storms the density can increase as observed by INTERBALL 2 in the day side plasmasphere (Bezrukikh et al., 2001). Preliminary analysis of INTERBALL 1/ALPHA 3 dusk side data points to the possibility of similar density variations during magnetic storm on 30 July (Kotova et al., 2000). In the present paper an attempt will be made to analyze statistically all the data obtained in 1999 by the INTERBALL 1/ALPHA 3 instrument in the dusk side plasmasphere in order to obtain correlations between cold plasma parameters, geomagnetic activity indices and solar wind flow parameters.

EXPERIMENTAL DATA ANALYSIS

Overview

The ALPHA 3 experiment for cold ion flux measurements including retarding plasma analyzer (RPA) and modulating plasma analyzer (MPA) is continuously functioning on INTERBALL 1. The description of the instrument can be found in the paper by Bezrukikh et al. (1998). Density and temperature of plasmaspheric cold ions, as well as a value of the spacecraft potential were estimated via fitting the first (proton) peak in measured energy spectrum by a spectrum calculated assuming Maxwellian velocity distribution of cold ions distorted due to non-zero potential of the spacecraft. Due to the highly eccentric spacecraft orbit as a rule the instrument provides data on plasmaspheric cold ions once per four days. Cold ion spectra were measured during 2 s once per ~ 2 minutes. The data collected from 19 orbits of INTERBALL 1 in July – October 1999 when the plasmasphere was crossed in the outer dusk sector (15 – 22 MLT) between L □ 3 and L □5 will be analyzed.

Ion energy spectra measured by RPA along 3 different orbits are plotted in Figure 1. The left panel shows the data obtained on 23 July in rather quiet conditions but after a prolonged disturbed period. Irregular structure of the outer dusk plasmasphere with patches of dense plasma separated by plasma trough regions is observed (cp. Carpenter et al., 1993). The spacecraft trajectory crossed the plane of geomagnetic equator almost vertically and thus the two patches of plasmaspheric plasma detected on 23 July are related to nearly the same magnetic flux tube with L between 3.8 – 4.2. On the lower L-shells down to L = 3.46 only small irregular fluxes of cold ions were recorded. These data show also that flux tube content is conserved during at least ~ 1 hour.

The middle and right panels of Figure 1 refer to magnetic storms. The middle panel presents the spectra measured on 30 July in the period of very high magnetic activity. The K_p index was equal to 5 in the preceding 6 hours and to 8- during the period of the measurements. The Dst index just began its changing toward positive values, and very high auroral activity is observed by AE index variations. The storm main phase occurred later, after the ALPHA 3 observations. The right panel presents the data obtained on 22 October very close to the storm main phase. K_p was equal to 7 in the previous 3-hour interval and it was 8- in the interval of observations, and Dst was close to its minimum value for this storm (provisional values are: -152 nT, -201 nT (http://swdcdb.kugi.kyoto-u.ac.jp/dstdir/). A rather well known feature of plasmasphere behavior should be mentioned. In disturbed conditions the sharp plasmapause is clearly seen. The high fluxes of cold ions on 30 July correspond to the highest densities observed in such L shells during the whole period of the July – October observations. It was already noted in the Introduction that such density variations might be related to the density enhancements during the development of magnetic storms recorded by INTERBALL 2 in the daytime sector (Bezrukikh et al., 2001). The data in right panel of Figure 1 look different. The fluxes are not so high, but close to the plasmapause (especially close to the exit from the plasmasphere) patches of rather dense plasma are seen on nearly the same L – shells again. These probably correspond to the formation of so-called plasmaspheric tails (Lemaire, 2000).

Figure 2 presents a summary of all the plasmapause crossings detected by INTERBALL 1/ALPHA 3 from 11 July to 22 October 1999. The projection of crossings to the plane of magnetic equator is given. The spacecraft

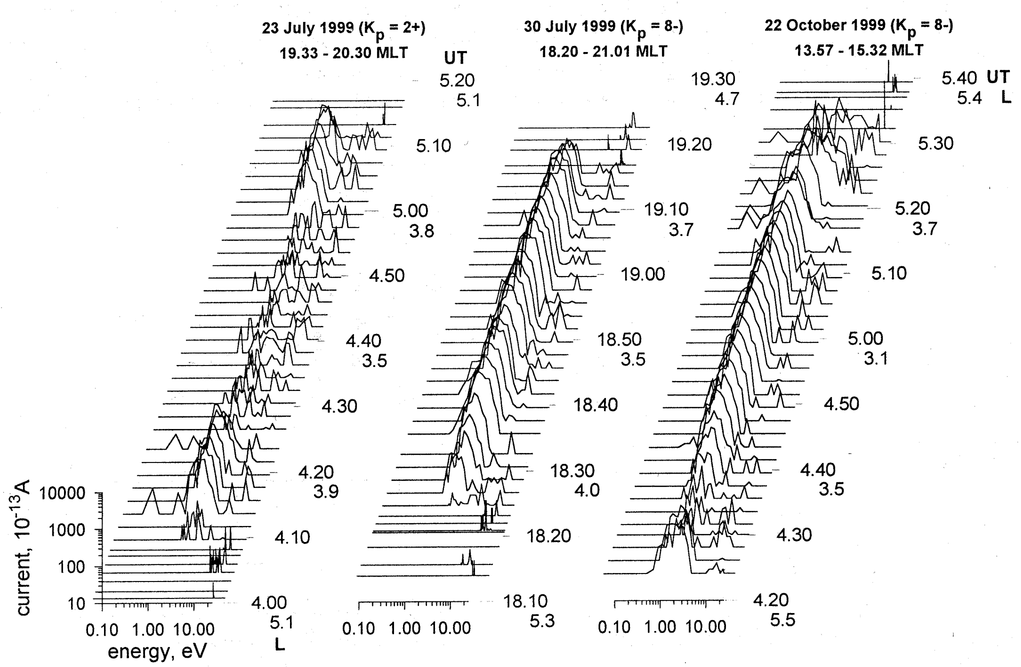

Fig.1 Cold ion energy spectra measured by ALPHA 3/RPA on 23 July, 30 July and 22 October 1999 in the Earth's plasmasphere.

trajectory crossed this plane almost vertically. The connected points refer to plasmapause crossings on the entrance into the plasmasphere and exit from it during the same pass. In 4 cases 'multiple' plasmapause crossings or patches of rather dense cold plasma were observed. All these latter cases are associated with rather quiet magnetic conditions but after a prolonged moderately disturbed period. Nine or more hours before the observation K_p was equal to 4 – 5. An example of such data was given in the left panel of Figure 1. This corresponds to the results reported earlier using other satellite data, e.g. DE-1, ISEE 1 (Carpenter et al., 1993; Horwitz et al., 1990). But the ALPHA 3 data differ from these earlier observations since the patches of plasmaspheric plasma were recorded twice on the same L – shell and at the same height. Such an L - shell was crossed at geomagnetic latitudes of ± 20° with MLT difference between two crossings of ≥ 30 minutes. The data in Figure 2 do not exhibit any asymmetry, i.e. any significant bulge effect. The average location of the plasmapause close to L = 4.1 together with the absence of any asymmetry suggests that we mostly observe the boundary of the main plasmasphere using the terms introduced by Carpenter et al. (1993).

The distribution of plasmapause positions L_{pp} versus maximum K_p value ($K_{p,max}$) recorded during the 12 hours preceding the plasmapause observation (3-hour interval including the observation was taken into account if the crossing occurred during the last 2 hours of K_p determination) is shown in Figure 3. It is seen that isolated patches of cold plasma (marked by triangles) were observed when $K_{p,max}$ ranged from 3 to 5+, and for low and high values of $K_{p,max}$ more or less featureless profiles were observed. One extreme case should be mentioned. On 3 October 1999 the plasmasphere was observed very briefly by INTERBALL 1/ALPHA 3 only in the innermost crossed L-shells. The plasmapause was detected at L ≈ 3.2 (~ 16 MLT) on the entrance to the plasmasphere and exit from it, and the magnetic conditions were quiet during more than 2 days, maximum K_p = 4- was recorded 21 hours before the observation.

The tendency for the reduction of plasmasphere size in the dusk sector with increasing of K_p is clearly seen (Figure 3) though correlation is not very good. The curve fitting the points of plasmapause crossings in the dusk sector ($L_{pp} = 4.6 - 0.12K_{p,max}$) is less steep than the dependencies obtained earlier for the time interval 00 – 15 MLT (e.g., Carpenter and Anderson, 1992) or the dependencies deduced for LEIT (low energy ion transition) on the basis of DE 1/RIMS data (Horwitz et al., 1990).

Density and temperature of cold H^+ ions.

Figure 4a, b presents densities and temperatures of cold H^+ ions in the plasmasphere reduced from the spectra measurements along the orbits, as functions of L – shells. Despite the large scatter of the points, the density fitting curve $N \sim L^{-4}$ well corresponds to the one proposed for a collisionless plasma (Gold, 1959). The same dependence for the density profile was obtained, for example, with GEOS 1 data (Farrugia et al., 1988). The temperature fitting curve though not very impressive due to a huge scatter of the data, was superimposed on the DE-1 data given in Fig.3 in Comfort (1996). The curve falls almost into the central part of the mean H^+ temperature profile of DE-1 for

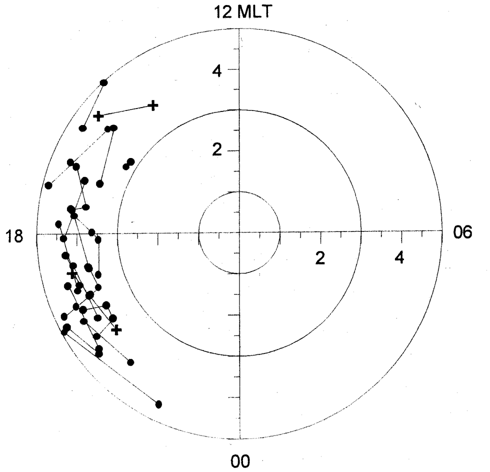

Fig. 2 Plasmapause positions as observed by INTERBALL 1 in July – October 1999 mapped to the plane of magnetic equator. Crosses represent 2 cases of magnetic storms.

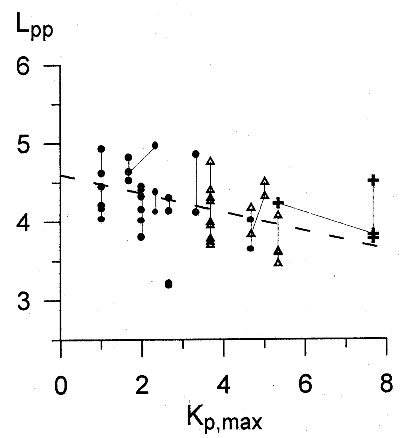

Fig.3 Plasmapause positions versus maximum K_p value during the preceding 12 hours. Crosses refer to magnetic storms, and triangles mark the cases, when isolated patches of dense plasma were observed.

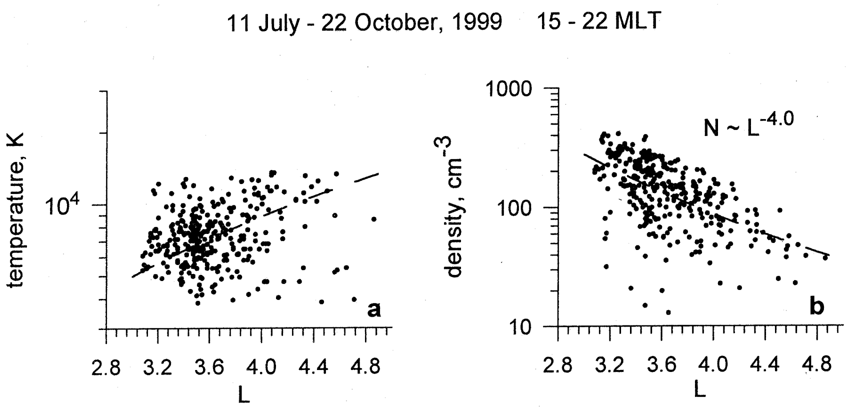

Fig. 4. Density and temperature variations as functions of L-shells.

~ 18 – 22 MLT sector.

It seems reasonable to look for some dependence of cold ion parameters in the dusk plasmasphere along constant L – shell on geomagnetic activity. INTERBALL 1 crossed the outer plasmasphere: in October 1999 it approached L = 3.1 and in July - only L = 3.5. For the analysis we tried to choose data in the innermost observed part of the plasmasphere, and we took L □ 3.4 as a reference level (of course it was close to 3.5 in the first orbits) and we avoided taking points very close to the plasmapause in the region of steep density gradient. Thus, we selected only 15 passes through the plasmasphere and consequently we have 15 points in the range L = 3.4 ± 0.1. In two orbits (23 July, 14 September) the ALPHA 3 instrument observed only patches of plasmaspheric plasma in the outer L-shells. On the contrary on 3 October the plasmasphere was encountered only in the inner shells (L < 3.2). And on 11 August rather small noisy fluxes were observed, probably simultaneously with more energetic electrons. These latter data have not been reduced yet.

The attempt to find any meaningful dependence of plasmasphere density variations on magnetic activity indices failed, but a tendency is seen for temperature to increase with the sum of K_p indices over 24 hours preceding the observation (Figure 5).

Then we examined the correlation of the plasmasphere parameters with those of the external solar wind, as the solar wind interaction with the terrestrial magnetosphere drives many processes in near Earth space. And, indeed, it appears that the cold plasma density in the dusk plasmasphere increases with the solar wind dynamic pressure. Figure 6 shows plots of plasmasphere density versus solar wind dynamic pressure. One-hour averaged solar wind parameters were taken from NSSDC OMNIWeb (http://nssdc.gsfc.nasa.gov/omniweb/ow.html). The solar wind parameters were chosen for the actual hour if the plasmasphere density measurement did not fall within the first 15 minutes of the hour, in this latter case the solar wind characteristics of the previous hour were taken. We calculate proton dynamic pressure as a proxy of the solar wind dynamic pressure. During the nearly 3.5 month time interval the solar wind dynamic pressure varied by almost 2 orders of magnitude and this permits to make reasonable analysis.

In figure 6a the cold ion density is plotted versus 'simultaneous' solar wind dynamic pressure. Correlation coefficient R = 0.68. In figure 6b the solar wind dynamic pressure was taken 6 hours before respective plasmasphere measurement. The correlation of plasmasphere density with dynamic pressure is still obvious but the correlation coefficient is worse (R = 0.47). And finally, taking the solar wind parameters 12 hours prior to the plasmasphere observation the dependence of cold ion density on solar wind dynamic pressure is lost. It is difficult to state confidently that really the correlation between simultaneous quantities is the best, because average solar wind parameters can keep constant for a long time, but the best correlation is obviously between quantities with a time shift less than 12 hours. Correlation of the ion density in the plasmasphere on the solar wind dynamic pressure result from the correlation of plasmaspheric density with solar wind density. No dependence of plasmaspheric density on solar wind velocity was found.

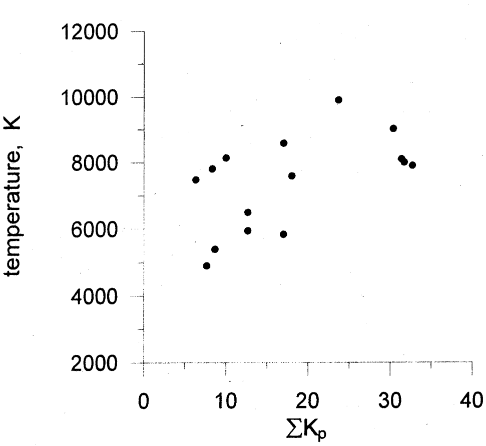

Fig. 5. Temperature of the H^+ cold ions in the plasmasphere as a function of the sum of K_p over 24 hours preceding the observation.

CONCLUDING REMARKS

Observations of cold plasma fluxes on 19 passes of INTERBALL 1 through the dusk side outer plasmasphere in July – October 1999 were analyzed. As a whole the data acquired by the ALPHA 3 instrument are in agreement with the results obtained earlier in the dusk side plasmasphere. A sharp

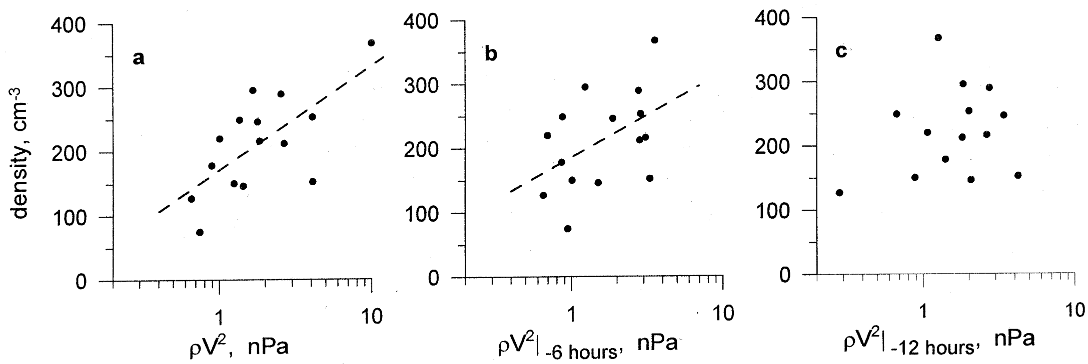

Fig.6 Cold ion density in the plasmasphere at L = 3.4 ± 0.1 versus solar wind dynamic pressure. a – the average solar wind parameters are taken for the hour of plasmasphere observation; b – the solar wind parameters are taken 6 hours prior to the plasmaspheric measurements; c - the solar wind parameters are taken 12 hours prior to the plasmaspheric measurements.

plasmasphere boundary is observed in disturbed magnetic conditions. Irregular cold ion spectra with patches of dense plasma occur during periods of low magnetic activity after a long moderately disturbed period. More or less smooth transitions from the plasmasphere to the trough region occur in quiet conditions.

The INTERBALL 1 trajectory crosses the same flux tube twice at nearly the same height and most of the time cold ion spectra were very much alike on both sides of the magnetic equator. After a period of moderate geomagnetic activity similar isolated patches of dense plasma were observed during the crossings of the same L-shell in southern and northern hemispheres. This suggests that filled flux tubes were located above the almost empty tubes and the content of the tubes is conserved for at least an hour. It might indicate the formation of plasmaspheric tails (Lemaire et al., 1998 and references therein).

The interrelationships between cold plasma parameters on a given L-shell and geomagnetic activity, and solar wind parameters, were analyzed. There is a tendency for the cold H^+ ion temperature to increase inside the dusk plasmasphere during magnetically disturbed periods. No correlation was found between the plasmasphere density variations and geomagnetic activity.

The cold ion density in the dusk side plasmasphere increases with the solar wind dynamic pressure. This dependence points to the important role of the solar wind flow in forming internal regions of the Earth's magnetosphere. The solar wind influences on the pattern of convection inside the magnetosphere, and convection plays an important role in forming the dusk plasmasphere. The observed dependence should be taken into account when constructing theoretical models of the plasmasphere and should find a straightforward explanation. It is the purpose of our future work to collect more points and to check this dependence for other time sectors.

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