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NIGHTSIDE PLASMAPAUSE POSITIONS OBSERVED BY DE-1 AS A FUNCTION OF GEOMAGNETIC INDICES: COMPARISON WITH WHISTLER OBSERVATIONS AND MODEL CALCULATIONS

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ABSTRACT

We have analysed 28 plasmapause crossings made by the DE1 satellite in the night local time sector (from January to March 1982). Different signatures obtained by the Retarding Ion Mass Spectrometer instrument (RIMS) have been used for this analysis. The observed plasmapause positions (Lpp) have been organized as a function of geomagnetic indices. They are compared with the empirical relationship deduced by Carpenter and Parks (1973) from whistler observations. Moreover, the dependence of Lpp versus K_p has been inferred from model calculation using K_p dependent electric and magnetic fields derived from McIlwain's (1974) E3H electric field model and M2 magnetic field model respectively. Stationary models, as well as time dependent ones, have been used to determine the positions of the plasmapause. The results of the model calculations are compared to the observations.

INTRODUCTION

The size of the plasmasphere is known to be related to the geomagnetic activity, the higher the activity, the smaller the plasmasphere. This behavior has been observed both in the equatorial plasmapause positions measured from the ground by the whistler technique/1/, as in measurements made in situ /2,3/. The general interpretation is based on the fact that the plasma escaping from the ionosphere is corotating with the earth at low L values, whereas it is carried along the general sunward convection at larger L values. The magnetic activity, which varies like the convection electric field, governs the size of the region dominated by corotation, the plasmasphere. Measurements of large scale electric field (or plasma drifts) in situ /4/, or from the ground/5/, confirm this view.

The relationship between the plasmapause L value, Lpp, and the activity measured for instance by K_p indices is particularly clear in the night sector of the magnetosphere, for two main reasons :

(1) the plasmapause movements resulting from a variation of the activity are taking place without delay in the night sector. Actually, we think that the plasmapause density gradient forms itself at this local time/6/. In the afternoon sector, conversely, an increase of activity results in an increase of density (due to plasma elements flowing sunward) prior to the arrival of empty flux tubes convected from the nightside magnetosphere/7/. Consequently the K_p versus Lpp relationship is complicated by the details in the time versus activity variation.

(2) the plasmapause signatures measured by different techniques may be related to slightly different physical boundaries which lie very close to each other in the night sector, but less so in the day sector/8/.

In this paper, we examine the Lpp(K_p) relationship in the night sector in two steps (1) we use a recent data set of in situ Lpp measurements (plasmapause signatures in the RIMS instrument on board the DE1 satellite) in order to analyze the quantitative relation between Lpp and different magnetic indices, and to compare it to preceding evaluations ; (2) we present model calculations of Lpp positions which are dependent on the K_p index either from a stationary view point (with time independent electric and magnetic fields) or in a dynamical state (the fields follow the actual K_p variations with time). We compare the observed Lpp values with the model predictions and examine the relations between the K_p and Lpp dynamics.

THE OBSERVED PLASMAPAUSE AND RELATED GEOMAGNETIC ACTIVITY

Out of 34 DE1 orbits studied from January to March 1982 (at magnetic local times from 23 to 3 hours) we have extracted 28 plasmapause signatures useful for our study (data acquisition covering the plasmapause field line, high enough above the ionosphere, far enough from the equatorial trapped warm ion population, absence of large confusing plasma irregularities). The plasmapause location, Lpp, is derived from the RIMS instrument observations. These observations show the transition between a population typical of the plasmasphere (cold isotropic light ions of high density : 50 cm^{-3} or higher) and a plasma regime prevailing in the trough region (warm field aligned ions of low density : 10 cm^{-3} or lower). This transition, the LEIT/8/ often coïncides with the plasmapause density gradient, visible in the wave data set when the natural upper hybrid frequency signature is present and well defined (Figure 1).

Contrary to the wave instrument, the thermal particle analyzers give always an indication on the plasma density value. However, this indication may be in error in the outer plasmasphere region, as cold populations of low density are not measured because of the presence of a positive satellite potential/9/. Being aware of this difficulty, our guideline, in examining the RIMS spectrograms, was to guess the position of the plasmapause density gradient. We have assumed that it was close to the outermost boundary of cold protons measured with a non negligible count rate in any of the RIMS heads. Cold protons are indicated either by a rammed part in the angular distribution provided by the spinning head, or by a cold peak in the energy distribution provided by the spin-axis oriented heads. It has been assumed that a warm double field aligned distribution is always located beyond the plasmapause, which gave an upper Lpp value in case of unclear features. All obvious sharp density gradients seen inside those boundaries are assumed to be vestigial plasmapauses, as described in the literature in the case of multiple density "knees".

In order to sort out the measured Lpp values versus activity, we have first considered the maximum value of the K_p index in the preceding 12 hours, as Carpenter and Park (1973) for their predictor of plasmapause L value in the post midnight sector. The linear fit obtained :

$$Lpp = 6.55 - 0.68\ K_p$$

is good, with a global correlation coefficient r = - 0.846, of the same order for postmidnight or premidnight observations (Figure 2). The relation given by Carpenter and Park :

$$Lpp = 5.7 - 0.47\ K_p$$

fits also fairly well the data (r = 0.843). In addition, the figure shows Lpp values calculated in a stationary situation by the model described below. Here again, the agreement between predictions and observations is satisfying.

Other estimators of geomagnetic activity have been compared to our data set. The K_m index gives a similar Lpp (index) relationship. The Dst index, which has been compared with success with plasmapause estimations/10/ gives not a particularly good fit in our case (r = 0.67). Both the maximum Dst in the previous 12 hours and in the previous 2 hours have been tested. The best correlation appears in choosing the K_p index at the time of the measurement, for $K_p > 1$ (r = -0.92), as shown in Figure 3. The predicted Lpp value is then :

$$Lpp = 6.2 - 0.66\ K_p$$

For low K_p values, $K_p < 1$, the measured Lpp is more variable. In this case, the history of geomagnetic activity has to be considered.

MODEL CALCULATIONS

Simple forms of the magnetospheric electric field, such as the uniform dawn-dusk field, have been useful to model the equatorial convection. The empirical K_p versus Lpp relations obtained experimentaly may be used then to adjust those fields in a K_p dependent way/11,12/. This has been done under the assumption that the electric field is stable over a long period, and that the plasmapause density gradient corresponds to the last closed equipotential (LCE) of the model. In the real life situation, the E-field varies constantly and the instantaneous LCE at a given time differs from the position of convecting density gradients formed at a previous time/13/. Consequently, the observed Lpp (the input) can at best give a first order approximation (the output) of the real E-field map.

The model that we have constructed is an attempt to view the plasmapause formation and dynamics in a different way. We start from realistic E- and B- field maps, based on observations. The plasmapause position (the output) is deduced from drift calculations of plasma irregularities in the equatorial plane. E- and B- field maps are K_p varying and the plasmapause may be located in "real time" during its formation mechanism. Vestigial plasmapauses are also calculated. This model may be tested and validated through the comparison

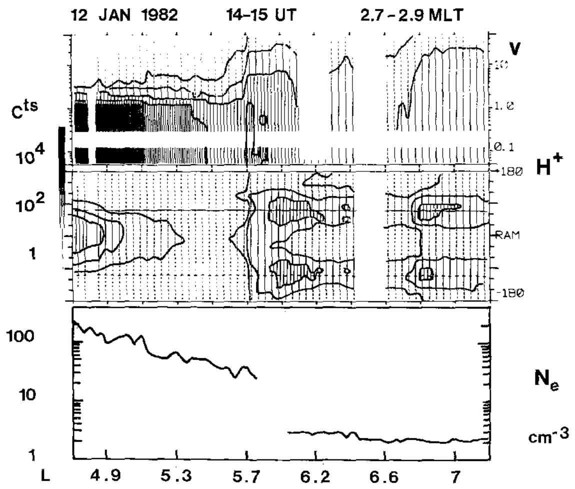

Fig.1. - Plasmapause signature in H^+ data (energy-time and spin angle-time spectrograms) as compared to the electron density gradient.

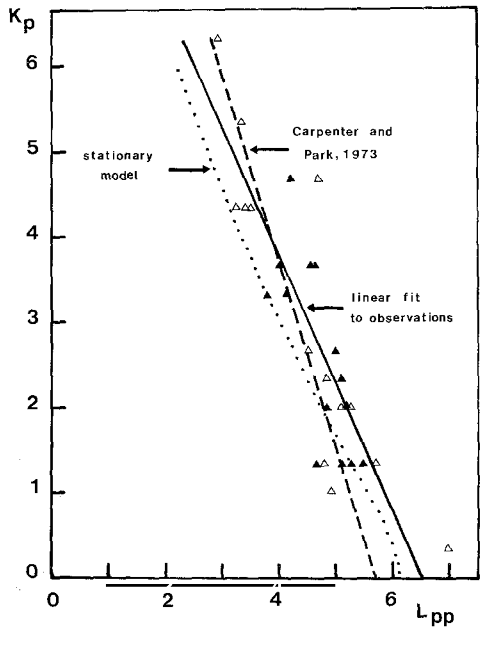

Fig.2. - Pre-(Δ) and post-(Δ) midnight plasmapause positions versus maximum K_p in previous 12 hours, as compared to predictions (model and previous observations).

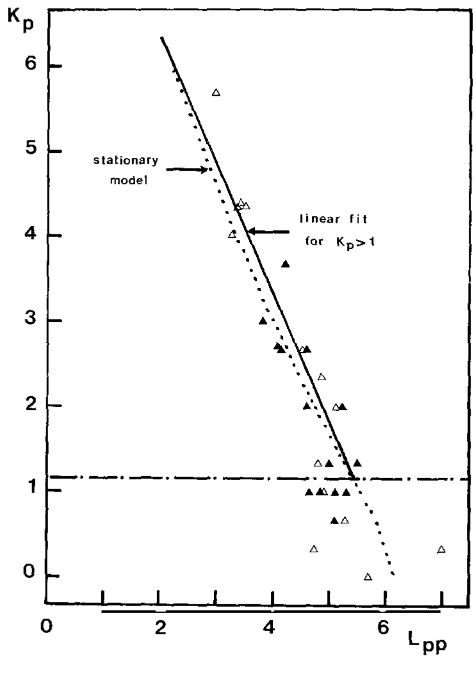

Fig. 3. - Plasmapause positions as in figure 2, versus instantaneous K_p

of calculated and experimental Lpp values.

The magnetic field model used, M-LD is an analog of McIlwain's model M2/14/but different values are used for the constants. Some of them depend linearly on the value of the geomagnetic index K_p. For $K_p = 0$, the values of B at 6.6 R_E fit those deduced from the M2 model, but for higher K_p, the magnetic field intensity in the nightside region has been reduced in order to match observations (e.g. at 6.6 R_E , B = 85 nT for $K_p = 0$, but B = 60 nT for $K_p = 4$).

The electric field model used is based on McIlwain's E3H electric field model/15/. The E3H field has been derived from ATS 5 particle flux measurements for periods of time when the K_p index ranged between 1 and 2. When K_p is outside this range, a scale factor, f, is used to modify all the parameters of the model, in order to better approximate the actual field configuration. It has been shown/16/ that the deformation of the plasmasphere in the case of substorm activity depends in fact on the local time. In order to take this feature into account, the f factor that we have used is expressed in terms of a modified K_p index :

$$K'_p = a\, K_p \;,$$

where a is local time dependent (with a = 0.7 at noon, a = 1.3 at midnight). Moreover, the electric field potential (except the corotation term) is multiplied by a term q, which goes to zero with K_p :

$$q = 1 - \frac{1}{1+0.25K_p2}$$

in order to better fit plasma drift observations under very quiet conditions.

The method used to locate the plasmapause position is explained in /16/ and /17/. It is based upon the theory where the plasmapause density gradient is created at the asymptotic trajectory of plasma irregularities/6/. Density holes are released regularly at seven earth radii and 18 MLT, and followed in their convection motion. After a few hours, they approach the asymptotic trajectory close enough to be considered to be the plasmapause position. We have first calculated such positions in the [1-2] MLT sector when the K_p index has been kept constant for several hours. This produces the Lpp values of the stationary model, shown in Figures 2 and 3.

The same method has been followed under dynamical conditions, when the E- and B- field maps are time varying. The Lpp versus K_p variation obtained (closed to the observed one) corresponds to a linear correlation coefficient r = - 0.95 for $K_p > 1$. In order to calculate the position of a vestigial plasmapause (seen when K_p decreases after an increase to high values), plasma holes which travel radially outward at MLT later than 3 hours have their densities increased up to the background density. In this way, the interchange motion (which forms the plasmapause gradient in the night sector) is suppressed. When those elements are seen again in the night sector, they follow the path of the "old" plasmapause, inward of the instantaneous one (Fig. 4). Such double plasmapauses are in agreement with the position of double boundaries observed in the spectrograms as shown in the figure for one example.

We have compared our set of experimental Lpp values to the corresponding values calculated in the dynamical model. The linear cross correlation coefficient between both data sets (r = 0.875) is of the same order that what is obtained when comparing experimental values with stationary model calculations (r = 0.865). However, in a case to case basis, the dynamical model is, at least qualitatively, closer to the real plasmapause deformations versus time than the stationary one.

Figure 5 shows on the same plot, K_p versus time variations and the three Lpp values (experiment, stationary model, dynamical model). Every time K_p changes the stationary Lpp automatically varies in the opposite direction, but not always the dynamical Lpp, nor the experimental one. Those cases are noted from 1 to 8 in Figure 5. Except in case 3, all these instances correspond to increasing experimental Lpp values whereas K_p increases (or stays constant). They are taken at the end of a recovery phase : K_p has decreased before increasing, an effect which is seen with some delay in the plasmapause movement. In all instances (except case 8), the dynamical model follows the real variations closer than the stationary one, showing in most cases (1,2,4,7), a correct sense of variation. In case 3, both models follow an apparent decrease of activity (increasing Lpp), but the experimental Lpp decreased. The examination of K_m indices, as well as Dst variations, shows that the activity was increasing at the time of the second measurement. We think, morever, that the two measurements of case 3 are taken too far apart (13 hours) to be valuably compared.

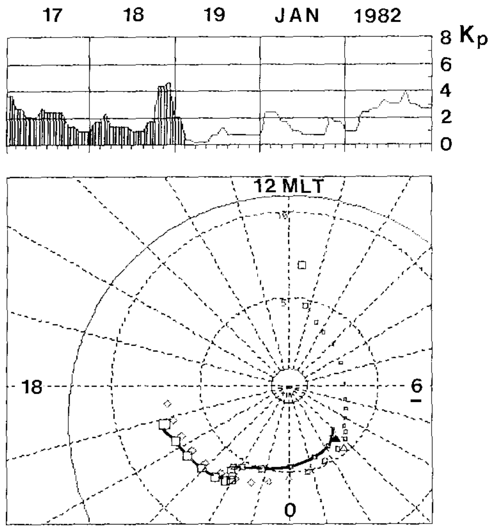

Fig. 4. - Equatorial positions of plasma elements on Jan. 19, 1982, 3:30 UT. They have been released every 30 minutes since Jan. 17, 0 UT, at 7 R_E and 18 MLT. The elements seen on the nightside after one full rotation around the earth are joined by a full line. Observations of vestigial (▲) and real time (Δ) plasmapauses are compared to the model.

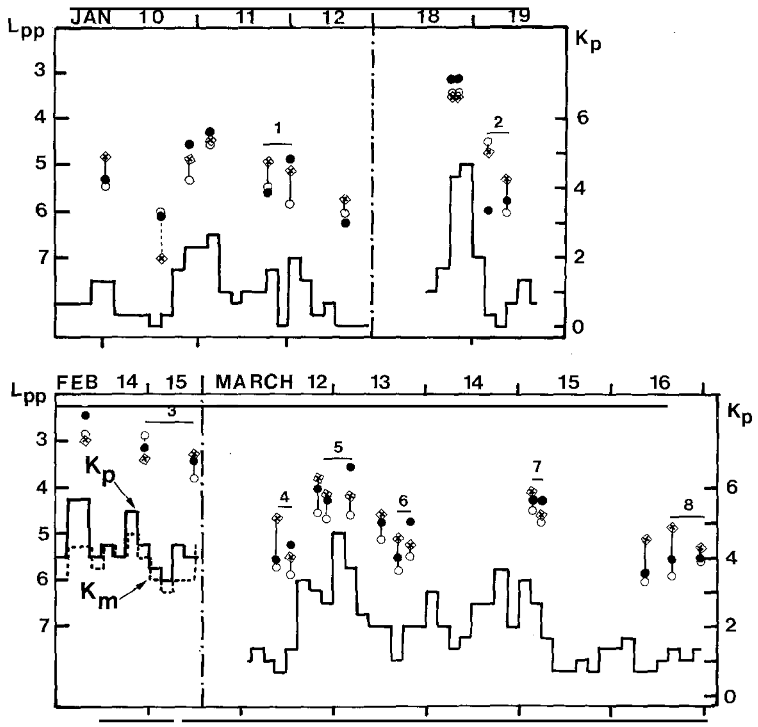

Fig. 5. - K_p variations for four periods of 1982 as compared to L_{pp} variations measured (squares) or obtained by the stationary model (full circles) and the dynamical model (open circles).

CONCLUSION

The plasmapause signatures derived from the RIMS instrument in the [23-03] MLT sector of the magnetosphere give an empirical relation between the level of magnetic activity and the plasmapause geocentric distance which is comparable to that previously obtained. Comparisons of observations with model calculations show a good fit, which validates our model of plasmapause formation, used together with realistic E- and B- field maps. Moreover, they show that the K_p variations in the few preceding hours have to be taken into account in the case of a quieting of activity followed by an increase of K_p.

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