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Brief Reports

Position of the Plasmapause during a Stormtime Increase in Trapped Energetic ($E > 280$ kev) Electrons

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This is a report on the position of the plasmapause relative to the region of appearance of enhanced fluxes of energetic ($E > 280$ kev) electrons during the magnetic storm of June 15, 1965. The plasmapause was measured near the prime geomagnetic meridian by whistler techniques; the trapped energetic electrons were detected by the satellite 1963-38C in polar orbit at 1100 km altitude. As the stormtime reduction in plasmasphere radius occurred, the electron fluxes increased in a region that was apparently exterior to the diminishing plasmasphere. The plasmapause position appears to have been adjacent to the region of inflation of the magnetosphere reported by Cahill from Explorer 26 magnetometer data. This relationship is similar to that deduced from the Ogo 3 measurements of Frank (ring current particles) and Taylor and his colleagues (thermal ion density).

It is well known that the radius of the plasmapause is reduced during periods of increasing planetary magnetic disturbance [*Carpenter*, 1966, 1967; *Taylor et al.*, 1965; *Chappell et al.*, 1970*a*]. For example, whistler observations during the active-sun years of 1958–1959 include several examples of plasmapause radii between 2 and 3 R_E [*Corcuff and Delaroche*, 1964; *Carpenter*, 1963]. Data from the August 16–19, 1959, magnetic storm indicate a minimum plasmapause radius of 2 R_E or less [*Carpenter*, 1962].

Williams et al. [1968] found that electrons with energy greater than several hundred kev are injected or energized deep within the magnetosphere during magnetic storms. These authors suggested that the energetic electrons initially appear exterior to the plasmapause. This note presents data on the plasmapause position and on the distribution of trapped energetic electrons ($E > 280$ kev) during the early phases of the June 15, 1965, magnetic storm. As the stormtime reduction in plasmasphere radius occurs, the electron flux increases in a region that is apparently exterior to the diminishing plasmasphere, in agreement with the suggestion of *Williams et al.* [1968].

Sources of Data

The whistler data on plasmapause radius were obtained from recordings at Eights, Antarctica, at $L \sim 4$ near the prime geomagnetic meridian. The energetic electron data, previously published by *Williams et al.* [1968], were obtained from the low-altitude (~1100 km) polar-orbiting satellite 1963-38C. (The satellite is magnetically aligned and the detectors oriented to look normal to the alignment axis.) The results of the comparison are summarized in Figure 1, which includes plots of the *AE* index, *Dst*, and *Kp* for the 3-day period June 15–17, 1965. Arrows and triangles represent whistler information on plasmapause equatorial radius, while observations of energetic particles are shown by isointensity flux contours. In the case of the whistler data, an arrow means that the estimated plasmapause position is in the direction of the arrowhead with an uncertainty of about 0.5 R_E. A filled triangle means that the position is in the direction of the apex and with uncertainty of about 0.2 R_E. In the case of the trapped energetic electron data a set of open circles aligned vertically indicates where counts of 10, 100, or 1000/sec were observed on an individual satellite pass. The position of the peak intensity for the pass is indicated by a

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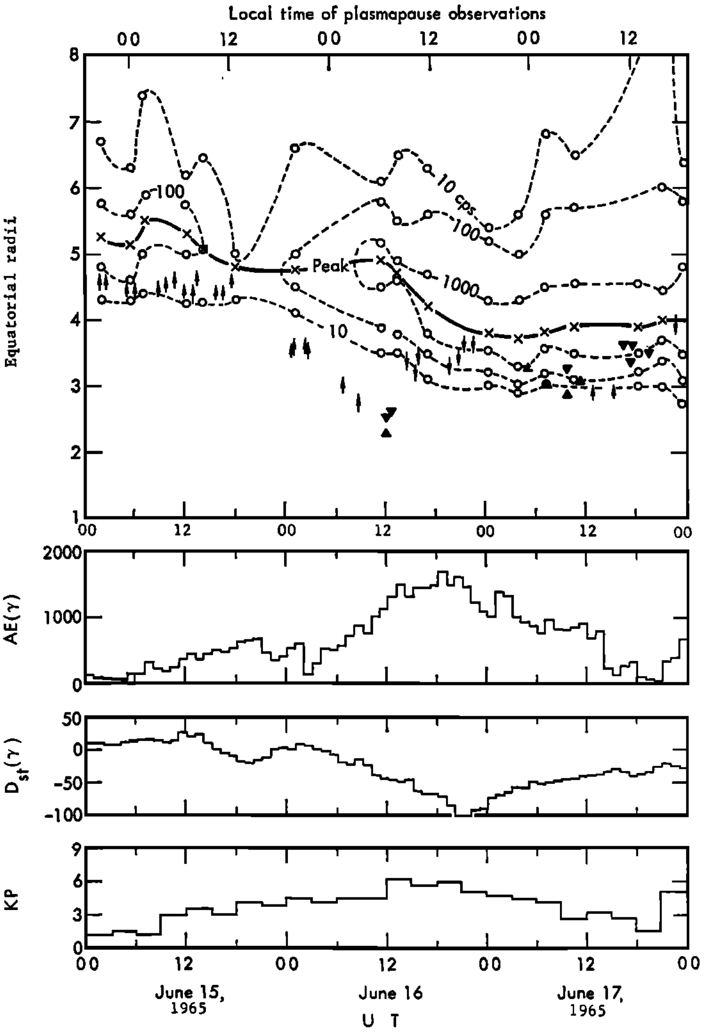

Fig. 1. Above: comparison of the plasmapause position (arrows and triangles) and observations of trapped energetic electrons with $E > 280$ kev (dashed flux contours) for June 15–17, 1965. There is a buildup or 'injection' of energetic electrons in a region apparently exterior to the diminishing plasmasphere. Equatorial radius is plotted versus universal time (bottom) and local time of the plasmapause observations (top). The plasmapause position was estimated from whistlers recorded at Eights, Antarctica ($L \sim 4$) near the prime geomagnetic meridian. The trapped electron data is from satellite 1963-38C in polar orbit at ~1100 km. See text for further details. Below: Plots of the hourly auroral electrojet index, D_{st}, and K_p.

cross. Dashed curves connect the circles to form crude iso-intensity flux contours, while the variation of the position of the peak with time is indicated by a solid curve.

The whistler data are essentially measurements of minimum B along field-aligned paths. (For a review of the whistler method, see *Angerami* [1966], *Angerami and Carpenter* [1966], or *Carpenter and Smith* [1964].) In the case of Figure 1, the values of minimum B were converted to equatorial radius by means of a dipole field model. Because of the shrinkage of the plasmasphere into a region of relatively large B during the storm main phase, estimated maximum corrections for ring current effects involve reducing dipole estimates by roughly 0.1 R_E. (The estimated corrections are based on Cahill's magnetometer observations from

Explorer 26 during the June 1965 storm [*Cahill*, 1970].)

The particle data are plotted in terms of L calculated for the ~1100-km altitude of the satellite in the main Jensen and Cain field [*Williams et al.*, 1968]. During the storm main phase, distension of the tubes of force was such that the corresponding equatorial L values should be somewhat larger than those indicated in the figure [*Williams et al.*, 1968]. As noted, there is an opposite effect in the whistler data; hence in terms of equatorial radius the plasmapause and curve of peak intensity should be displaced a few tenths of an earth radius further apart than is presently shown for late June 16 and early June 17.

A complication in the comparison of Figure 1 is that the whistler observations represent the thermal plasma as observed near the prime geomagnetic meridian, while the satellite data, involving high particle energies, represent an essentially worldwide picture (the satellite orbit was near the dawn-dusk meridian). The restriction of the whistler observations can be partially overcome through statistical information on plasmapause behavior during substorms and through results of a number of simultaneous plasmapause measurements that have been made at widely spaced longitudes. Some remarks on extrapolation of the whistler data to other longitudes will be made below.

PLASMAPAUSE-ENERGETIC ELECTRON COMPARISON DURING JUNE 15–17, 1965

Figure 1 shows an increase in *AE* activity to several hundred gammas following ~1200 UT on June 15. This increase is accompanied by an initial drop in *Dst* and a surge in *Kp*. As this activity develops the Eights meridian is moving into the morning sector (see upper, LT scale), and no immediate effect on the plasmapause radius is seen. This is consistent with the known tendency for the dayside to be shielded from large perturbing substorm electric field [*Mozer and Serlin*, 1969; *Carpenter*, 1970]. As the whistler observations move into the afternoon sector, substorm activity continues and there is a period of several hours during which measurable whistlers were not detected. When measurements could again be made near local dusk, at about 0000 UT on June 16, the estimated plasmapause radius was lower than before, although details remain uncertain because of an absence of clear whistler traces propagating outside the plasmapause. Pronounced reduction in apparent plasmapause position continues near and after midnight local time on the 16th as the *AE* index surges toward a very high maximum and the *Dst* level drops rapidly. By local dawn on June 16 the plasmapause position is well defined near 2.4 R_E (filled triangles). This reduction was achieved near the time of maximum substorm activity, and is consistent with the type of nightside main-phase behavior observed during several less severe magnetic storms in 1963, when the plasmapause radius near dawn was reduced to about 3 R_E [*Carpenter*, 1966].

Following the minimum in plasmapause radius there is an outward trend on the local dayside of the 16th, apparently to about 3 R_E. Details are not clear, but the information now comes from the outer, low-density region and thus provides information on the outer, rather than inner, limit of the plasmapause position. The minimum in *Dst* occurs at roughly 0000 UT on the 17th, and by the end of the 17th the more rapid part of the recovery of *Dst* is completed.

On June 17, *AE* activity is high but shows a pronounced quieting trend. Across local nightside on the 16–17th the plasmapause again shows an inward trend, less dramatic than on the 15–16th. (Some details of this inward trend are described by *Carpenter et al.* [1969*b*].)

The iso-intensity contours in Figure 1 show that fluxes of electrons with $E > 280$ kev began to build up rapidly between 4 and 5 R_E following 0000 UT on the 16th. The region of apparent injection is relatively broad, extending from 3.5 to about 5 R_E. In this region the fluxes reach half their maximum value in about half a day, while fluxes at higher and particularly at lower L values require longer, thus giving the impression of an injection near $L = 4.5$ and subsequent diffusion to higher and lower magnetic shells. Figure 1 indicates that the bulk of the 'injection' event takes place in the region beyond the plasmapause, insofar as the latter is defined from the Eights meridian. The figure also indicates some overlap of the plasmasphere and energetic electrons on June 17 following a period of rapid inward diffusion of the electrons late on the 16th.

Following June 17 the energetic electrons continued to diffuse to lower and higher L

shells in the manner reported by *Williams et al.* [1968]. The comparison of Figure 1 is terminated at the end of June 17 owing to complexities in describing the plasmapause position during the latter recovery phase of a storm. The recovery process is often complex, involving an interplay between continued substorm agitation and the slow filling of tubes of ionization outside the main-phase position of the plasmapause [*Park,* 1970]. During quieting, the conditions for the establishment of the plasmapause may exist at high L values before a steep gradient in the thermal plasma is readily detectable there, and while the thermal plasma at lower L shells retains an imprint of the stormtime plasmapause [see *Chappell et al.,* 1970*b*; *Carpenter,* 1970].

DISCUSSION

It is possible to make a crude estimate of the worldwide behavior of the plasmapause by use of statistics on stormtime behavior near the Eights meridan in 1963 and 1965 [see *Carpenter and Stone,* 1968; *Carpenter,* 1970]. From the intensity and long duration of substorm activity on June 15–16, it is inferred that the entire plasmasphere was significantly reduced in size during the early phase of the storm. When substorm activity increased sharply at about 1200 UT on June 15, Eights was near local dawn and beginning to move across the dayside. Because of the above-mentioned shielding of the dayside against substorm convection effects, it is conjectured that Eights required longer than stations to the east to reach a region of pronounced convection activity and hence to experience a reduction in locally observed plasmapause radius. Regions well to the west of Eights would have been near the midnight sector at ~1200 UT on the 15th and would thereafter have experienced pronounced inward displacements, probably to within 4 R_E. Thus the plasmapause data for meridians other than that of Eights would be expected to resemble the data of Figure 1, but be shifted to the left by varying amounts. It is probable that by 0000 UT on the 16th the plasmapause radius was everywhere less than about 4 R_E.

Direct evidence of the worldwide shrinkage of the plasmasphere was provided on June 17 at ~1000 UT by simultaneous measurements from Ogo 1 and from Eights [*Carpenter et al.,* 1969*a*]. Taylor's ion mass spectrometer on Ogo 1 showed a plasmapause crossing at $L \sim 3.5$ near 1300 LT, while the simultaneous Eights whistler data (Figure 1) indicate a radius of ~3 R_E at ~0500 LT. This is good agreement when expected variations with longitude and local time are taken into account.

From the results summarized in Figure 1 and from the foregoing discussion, it is tentatively concluded that the 'injection' event took place outside the plasmasphere, in agreement with the earlier suggestion of *Williams et al.* [1968]. Energetic electrons later appeared within the outer plasmasphere, following what was apparently a period of rapid cross-L diffusion.

From Explorer 26 magnetometer data *Cahill* [1970] has shown that the asymmetric, main phase of the June storm involved magnetospheric inflation concentrated in the L range ~2.7–3.7 R_E. This L range flanks and possibly somewhat overlaps the plasmapause as observed from Eights on the 16th of June. Assuming a worldwide reduction in plasmapause radius roughly comparable to that observed from Eights, this close spatial relation of ring current and plasmapause appears similar to that reported by *Frank* [1967] and *Taylor et al.* [1968] from observations during the July 9, 1966, storm.

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REFERENCES

Angerami, J. J., A whistler study of the distribution of thermal electrons in the magnetosphere, *Radiosci. Lab. Rep. SEL-66-017,* Stanford Electronics Labs., Stanford University, Calif., May 1966.

Angerami, J. J., and D. L. Carpenter, Whistler studies of the plasmapause in the magnetosphere, 2, Equatorial density and total tube electron content near the knee in magnetospheric ionization, *J. Geophys. Res., 71,* 711, 1966.

Cahill, L. J., Jr., Magnetosphere inflation during four magnetic storms in 1965, *J. Geophys. Res., 75,* 3778, 1970.

Carpenter, D. L., New experimental evidence of the effect of magnetic storms on the magnetosphere, *J. Geophys. Res., 67,* 135, 1962.

Carpenter, D. L., Whistler evidence of a 'knee' in the magnetospheric ionization density profile, *J. Geophys. Res., 68,* 1675, 1963.

Carpenter, D. L., Whistler studies of the plasmapause in the magnetosphere, 1, Temporal variations in the position of the knee and some evidence on plasma motions near the knee, *J. Geophys. Res., 71,* 693, 1966.

Carpenter, D. L., Relations between the dawn minimum in the equatorial radius of the plasmapause and *Dst, Kp,* and local *K* at Byrd Station, *J. Geophys. Res., 72,* 2969, 1967.

Carpenter, D. L., Whistler evidence of the dynamic behavior of the duskside bulge in the plasmasphere, *J. Geophys. Res., 75,* 3837, 1970.

Carpenter, D. L., and R. L. Smith, Whistler measurements of electron density in the magnetosphere, *Rev. Geophys., 2,* 415, 1964.

Carpenter, D. L., and K. Stone, Recent whistler research on hydromagnetic motions in the plasmasphere, paper presented at International Symposium on the Physics of the Magnetosphere, National Academy of Sciences, Washington, D. C., Sept. 1968.

Carpenter, D. L., C. G. Park, H. A. Taylor, Jr., and H. C. Brinton, Multiexperiment detection of the plasmapause from Eogo satellites and Antarctic ground stations, *J. Geophys. Res., 74,* 1837, 1969*a*.

Carpenter, D. L., K. Stone, and S. Lasch, A case of artificial triggering of VLF magnetospheric noise during the drift of a whistler duct across magnetic shells, *J. Geophys. Res., 74,* 1848, 1969*b*.

Chappell, C. R., K. K. Harris, and G. W. Sharp, A study of the influence of magnetic activity on the location of the plasmapause as measured by Ogo 5, *J. Geophys. Res., 75,* 50, 1970*a*.

Chappell, C. R., K. K. Harris, and G. W. Sharp, The morphology of the bulge region of the plasmasphere, *J. Geophys. Res., 75,* 3848, 1970*b*.

Corcuff, Y., and M. Delaroche, Augmentation du gradient d'ionisation dans la proche magnétosphere en périodes de forte activité magnétique, *Comptes Rendus, 258,* 650, 1964.

Frank, L. A., On the extraterrestrial ring current during geomagnetic storms, *J. Geophys. Res., 72,* 3753, 1967.

Mozer, F. S., and R. Serlin, Magnetospheric electric field measurements with balloons, *J. Geophys. Res., 74,* 4739, 1969.

Park, C. G., Whistler observations of the interchange of ionization between the ionosphere and the protonosphere, *J. Geophys. Res., 75,* 4249, 1970.

Taylor, H. A., Jr., H. C. Brinton, and C. R. Smith, Positive ion composition in the magnetoionosphere obtained from the Ogo A satellite, *J. Geophys. Res., 70,* 5769, 1965.

Taylor, H. A., Jr., H. C. Brinton, and M. W. Pharo, III, Contraction of the plasmasphere during geomagnetically disturbed periods, *J. Geophys. Res., 73,* 961, 1968.

Williams, D. J., J. F. Arens, and L. J. Lanzerotti, Observations of trapped electrons at low and high altitudes, *J. Geophys. Res., 73,* 5673, 1968.

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