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Whistler Evidence of the Dynamic Behavior of the Duskside Bulge in the Plasmasphere

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Approximately 180 days of whistler data for 1963 and 1965 from Eights and Byrd, Antarctica, were reviewed for information on the bulge in the plasmasphere, the region of large plasmapause radius that is frequently found in the 18–21 LT sector. Previous findings on the essential permanance of the bulge and the abruptness of its westward end (involving an increase in plasmapause radius of 0.5–2.5 R_E within 15–20 degrees longitude) were verified. The position in local time of the westward end of the bulge depends on the preceding history of substorm activity as evidenced in the auroral electrojet (*AE*) index. The bulge position was observed in the afternoon during particularly high levels of substorm activity, near 18 LT during more or less steady activity, and near 19–20 LT during periods preceded by 6–8 hours of quieting. The bulge is evidently released during periods of deep prolonged quieting and moves in the direction of the earth's rotation. The observations are interpreted in terms of sunward surges of the bulge plasma during substorms, followed by increased influence of the earth's corotation field during quieting. Several types of whistler evidence indicate shielding of the dayside plasmasphere from substorm convection fields. The plasmapause is not generally coincident with an equipotential of the combined magnetospheric flow, but it may approach an equipotential during relatively steady planetary conditions. Under such conditions the duskside radius of the plasmapause may provide a crude time-averaged measure of the stagnation distance and hence the intensity of the convection electric field in the dusk sector. Values of convection E_{YSM} within the duskside plasmasphere, inferred from the stagnation distance and from motions of the bulge, are ~1–4 mv/m during substorms, about 0.4–0.6 mv/m between substorms (but during moderate magnetic storms), and of order 0.1 mv/m during prolonged quiet periods. These values are larger by a factor of 3–4 than values of E_{YSM} inferred from tracking cross-*L* drifts of whistler ducts in the plasmasphere near midnight.

INTRODUCTION

A persistent feature of the plasmasphere is a bulge or region of larger radius in the dusk sector. Figure 1, reproduced from an earlier whistler study [*Carpenter*, 1966], shows the average equatorial radius of the plasmapause versus local time during periods of moderate steady geomagnetic agitation ($Kp = 2$–4). There is a significant increase in radius near 18 LT, followed in time by several hours of larger radii and then a period of decreasing radii on the nightside. The whistler description, based on measurements near the prime geomagnetic meridian (at Eights and Byrd, Antarctica) has been supported and significantly extended by satellite observations at many longitudes, including those by *Brinton et al.* [1968], *Taylor et al.* [1970], and *Chappell et al.* [1970], made with ion mass spectrometers of OGO satellites, by *Binsack* [1967], made with a Faraday cup on IMP 2, and by *Bezrukikh* [1968], by using ion traps on Electron 2 and 4. The satellite reports show plasmapause crossings in the dusk sector that are, on the average, at larger *L* values than crossings at other local times.

The observed asymmetry of the plasmasphere is similar topologically to features of magnetospheric convection patterns predicted by *Axford and Hines* [1961] that included sunward flow of plasma within the remote nightside magnetosphere (see *Axford* [1969] for related references). Recently, a number of authors have treated the bulge in terms of an interaction between plasma flowing toward the sun from the magnetotail and the flow associated with the rotation of the earth [e.g. *Nishida*, 1966; *Brice*, 1967; *Dungey*, 1967]. On the assumption that the outer limit of the bulge includes a stagnation point in the combined flow, the plasmapause radius in the dusk sector has been considered as a possible measure of the intensity of the convection electric field [c.f. *Vasyliunas*,

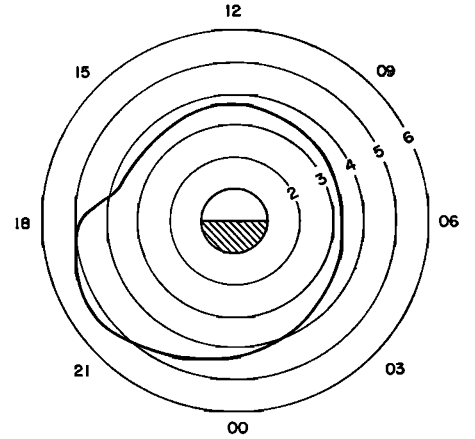

Fig. 1. Equatorial cross section of the magnetosphere, showing the estimated average diurnal variation of the plasmapause radius for conditions of moderate and steady planetary magnetic activity ($Kp = 2$–4). Reproduced from *Carpenter* [1966], and based on whistler data recorded at Eights and Byrd, Antarctica, June–August 1963.

1968]. A complication in this scheme stems from the fact that, although steady state treatments of the flow patterns are most convenient, the sunward flow may in fact be highly irregular. The concept of an unsteady flow from the magnetotail has recently been discussed by *Axford* [1969], and such a picture seems to be supported by the work reported here.

The present work represents part of a survey of antarctic whistler data on convective motions in the plasmasphere. Data representing roughly 90 days in June–August 1963 and 90 days in June–August 1965 were examined. Several surprisingly repeatable and previously unreported features of the bulge were noted, and much additional documentation was obtained on previously known features. The results are extensive and not easily described on a detailed basis; hence, only a limited report is offered at this time.

The whistler method of detecting the bulge. The whistler experiment is outlined in Figure 2, which shows (at the left) part of an equatorial section of the magnetosphere. The approximate instantaneous viewing area of the Eights, Antarctica, ground station at three successive times t_1, t_2, and t_3 is shown by a wedge-shaped region extending from 2.5 to 6 R_E and over ±15° around the longitude of the station. (The fraction of the viewing area occupied at any time by active whistler ducts varies in a complicated way with magnetic activity, local time, lightning source activity, and season.)

At the right of Figure 2 are sketched equatorial electron density profiles deduced from multipath whistlers recorded at times t_1, t_2, and t_3 (for a description of the whistler method of measuring magnetospheric electron density, see *Angerami* [1966] or *Carpenter and Smith* [1964]). In midafternoon at t_1, the electron density profile exhibits a knee at an equatorial distance R_A. At time t_2, the viewing area embraces both the sunward edge or shoulder of the plasma bulge and nearby features of the plasma trough. Because the equatorial intercepts of whistler paths are distributed over a range of longitudes, the inferred electron density profile is now double-valued, with a knee, as before, at R_A, but also with a high-density extension beyond R_A to some point R_B, where a knee may either be evident or where propagation showing high densities may simply terminate. The difference $R_B - R_A$ is usually in the range 0.5–2.5 R_E. The length of time during which overlapping or double profiles are observed varies from minutes to several hours, with most cases in the range 20–60 min.

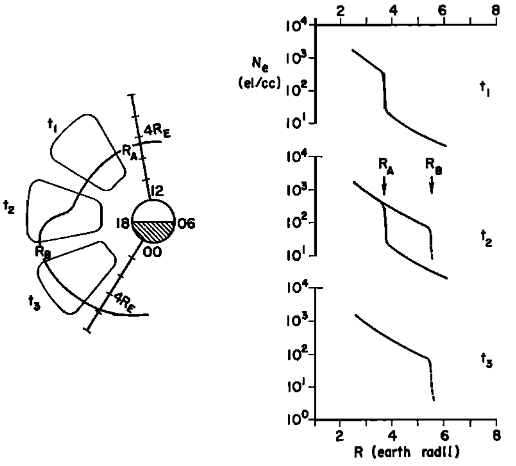

Fig. 2. Outline of the whistler method of detecting the bulge. At left, an equatorial section of the magnetosphere showing the approximate viewing area of the Eights ground station at times t_1, t_2, and t_3. At right, idealized equatorial electron density profiles representing observations at times t_1, t_2, and t_3. The dashes on the profile near R_B indicate a region where details are not yet well known.

At time t_3, the viewing area is well into the plasma bulge region. High plasma densities are seen well beyond R_A, although the knee profile itself may not be well defined because of low levels of ducted whistler activity in the low-density region.

RESULTS

Correlation of bulge encounter time with the AE *index.* The principal new result concerns the local time at which a ground station detects the westward limit of the bulge (beginning of the t_2 regime of Figure 2). This time varies in highly repeatable fashion with the pattern of preceding magnetospheric substorm activity. On days of relatively steady or increasing activity, the initial detection tends to lie between 14 and 19 LT, as illustrated in Figures 3*a* and *b*. Within the range 14–19 LT, the encounter frequently occurs at the approximate time of a large surge of substorm activity. The higher the average level of activity, the more likely the observation of an early encounter (Figure 3*a*).

If the ground station reaches the dusk meridian following several hours of quieting, the initial detection of the bulge tends to be after 19 LT, often in the 19–21 LT period (Figure 3*c*). In at least eight observations that followed quiet periods of 10 hours or more, the leading edge of the bulge was either not detected until midnight or later, or it was not clearly observed at all, with the t_1 condition of Figure 2 persisting across much of the nightside (Figure 3*d*).

The apparent correlation of the position of the bulge with the details of substorm activity is illustrated in Figure 4, which shows six examples of *AE* index activity (hourly values) versus UT (top) and LT at the observing whistler station (bottom). In each case, time coverage is from 18 hours preceding to 12 hours following 18 LT (vertical arrows and a thin vertical line indicate the position of 18 LT). Pairs of horizontal arrows indicate the time of initial detection by identifying the interval during which the t_2 phase of Figure 2 occurred.

The top panels show encounters near 18 LT, the middle panels show detection 1 or 2 hours later, and the bottom panels show cases of no encounter at all during the period indicated (case of Figure 3*d*). The substorm activity shows a corresponding variation, which is relatively steady in the top panels, shows quieting extending back to 10–12 LT in the middle panels, and shows still longer quieting, extending back to 07–08 LT, in the bottom panels.

Figures 5 and 6 show additional examples of bulge encounters, again with reference to 18 LT at the ground station. Cases 5*a* through *e* (left side) show early encounters, near 14–16 LT, whereas 5*f* through *j* illustrate detection near 18 LT. In the early cases (5*a* through *e*) the *AE* index exhibits a variety of patterns prior to the bulge observation, including persistent high activity (5*a*, *b*, *e*) and large surging increases from a relatively low level (5*c*, *d*). In cases 5*f* through *j*, the *AE* patterns are broadly similar to those at the left, but tend to reach lower average levels near 15 LT (20 UT).

Figure 6 shows additional examples of bulge observations after 18 LT and also cases of no observed bulge effect. In several cases similar to those in the middle panels of Figure 4 (i.e. 6*a*, *b*, *c*, and *d*), a quieting trend begins around 12 LT, and the bulge is detected around 19–21 LT.

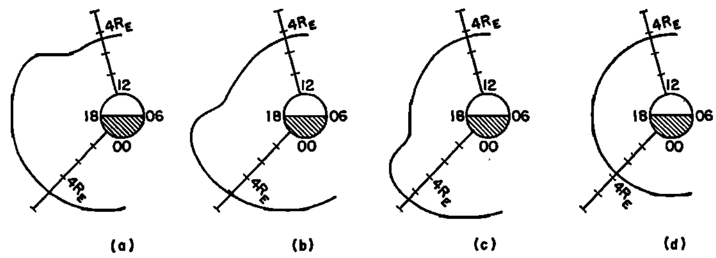

Fig. 3. Equatorial sections of the magnetosphere illustrating a range of bulge positions around the 18 LT meridian, *a*, *b*, *c*, and the condition of no observed bulge, *d*. The curves of plasmapause radius in *a*, *b*, and *c* are intended to represent snapshots taken at the time of bulge detection by the ground station. Case 3*d* represents a snapshot taken at about 23 LT at the ground station.

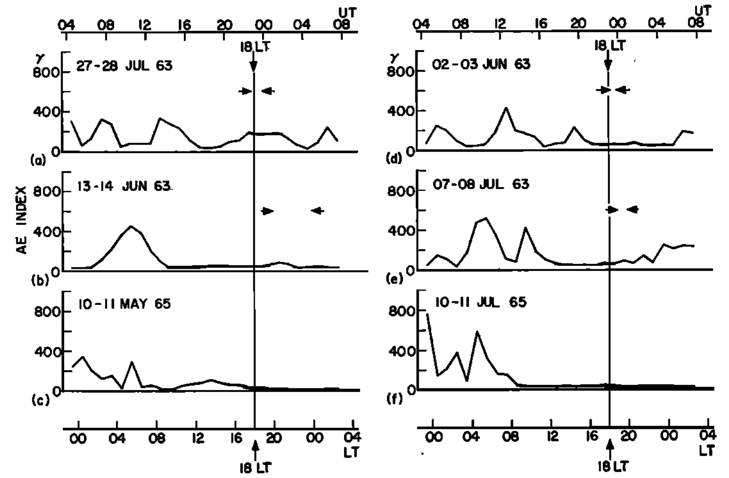

Fig. 4. Examples of auroral electrojet (*AE*) signatures identified with various observed positions of the westward end of the bulge. A thin vertical line identifies 18 LT at the observing whistler station, and pairs of horizontal arrows indicate the period within which the bulge was encountered (t_2 phase of Figure 2). From top to bottom the panels show successively later encounters and progressively increasing quieting effects (bottom panels show no bulge encounter). Hourly *AE* indices were taken from *Echols et al.* [1968] for 1963, and from *Davis and Wong* [1969] for 1964. The National Space Science Data Center at Goddard Space Flight Center kindly provided the indices for 1965.

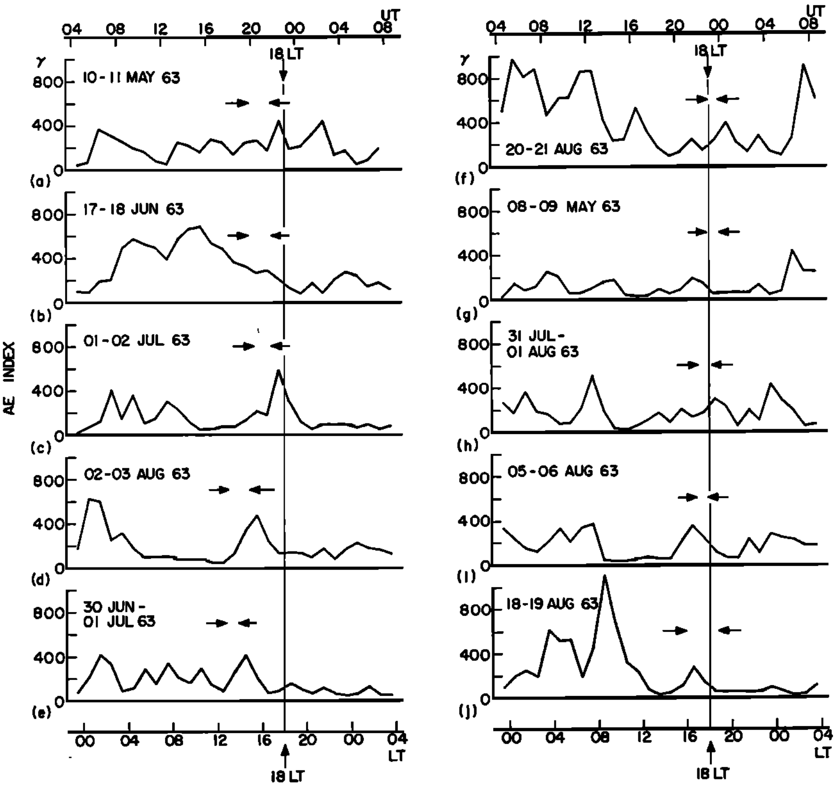

Fig. 5. Additional examples of *AE* signatures associated with initial detection of the bulge near 14-16 LT (left) and near 18 LT (right).

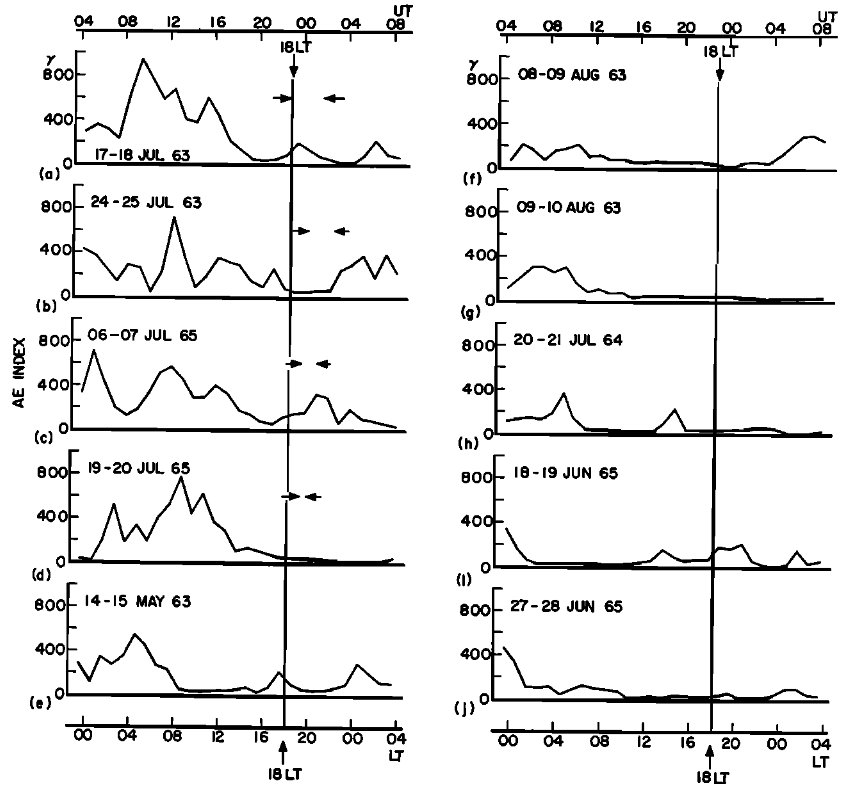

Fig. 6. Additional examples of *AE* signatures associated with encounters of the bulge near 19–21 LT (*a, b, c, d*) and with cases of no observed bulge (*e, f, g, h, i, j*).

In other cases similar to those in the bottom panels in Figure 4 (i.e. 6*e, f, g, h, i,* and *j*) the quieting begins relatively early, near 06–08 LT, and no bulge effect is detected.

A simple statistical view of the correlation between bulge encounter time and the *AE* index is presented in Figure 7, where the time scale is limited to the 8 hours preceding 19 LT at the group station. The upper panel (7*a*) shows the median hourly *AE* index for: (1) 24 cases in which initial detection (beginning of the t_a phase) preceded 19 LT; (2) 16 cases in which the encounter followed 19 LT. The before 19 LT ground exhibits a relatively high average level and a broad surging increase in the 15–18 LT period. The median *AE* index for the after 19 LT cases remains near 50 γ, thus reflecting the patterns of persistent quieting shown in Figure 6 and in Figure 4, middle and bottom panels.

Figure 7*b* provides additional information on the before 19 LT group of 7*a* through separate identification of 9 early cases occurring near 14–16 LT and 7 cases occurring at approximately 18 LT. Both curves show a distinctive surging effect, with peak levels near the time of encounter for the associated group of observations. The generally higher level of activity associated with the early group is reflected in the high values of its median *AE* index near 15–16 LT.

Asymmetry of the bulge. The present study confirms earlier identification of a rapid spatial increase in plasmapause radius at the westward or sunward end of the bulge [*Carpenter*, 1966]. Through comparisons of data from Byrd and Eights, roughly 1 hour apart in magnetic time, the longitudinal viewing range of the Eights receiver is estimated to be ±15° around the meridian of the station (cf. Figure 2). The whistler paths active at a given time, however, may occupy only some fraction of the longitudinal range that the receiver is capable of seeing. Because the observed duration of the t_a regime of Figure 2 is typically in the range 20–

60 min, we infer that the bulk of the increase in plasmapause radius takes place in a range of order 15°–20°.

Details of the plasmapause on the eastward or nightside of the bulge are not well known. On days of moderate steady magnetic activity, plasma in the outer part of the bulge is frequently observed to drift slowly inward for several hours after 21 LT [*Carpenter*, 1966]. This motion is often followed by enhanced substorm-associated inward displacements as the plasma reaches the midnight sector [*Carpenter and Stone*, 1967].

Permanence of the bulge. Although highly variable in matters of detail, the bulge appears to be an essentially permanent feature of the plasmasphere. Well-defined observations have been made in every year since 1959. There is no evident change in the gross effect with season; clear examples were seen at Eights from early May through late September. Of 180 days of Eights data examined, roughly half showed the bulge clearly. The remainder were not contradictory but were simply poorly defined, due, for example, to shift of the activity describing the plasmapause to latitudes on the poleward edge of the Eights viewing area.

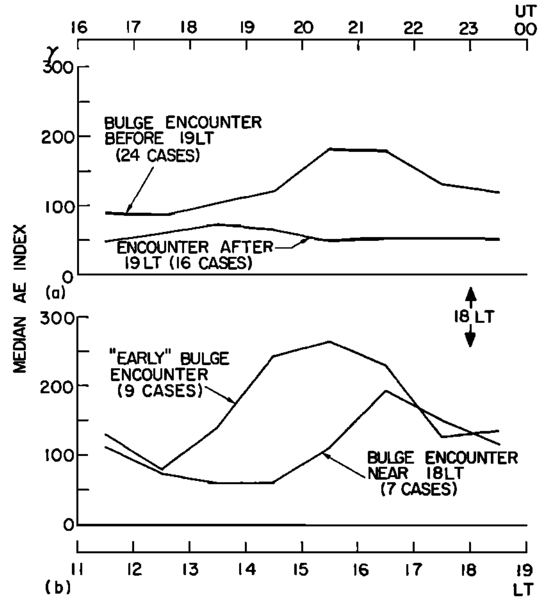

Fig. 7. Crude statistical view of the correlation between bulge encounter time and the *AE* index. The upper panel shows the median hourly *AE* index versus UT and LT for bulge encounters preceding and following 19 LT. The lower panel shows the median *AE* index behavior for encounters near 14–16 LT and for encounters near 18 LT.

Discussion

Interpretation of shifts in bulge position. The eastward shift in bulge position during quieting probably involves a corresponding decrease in the intensity of magnetospheric convection activity, and hence an extension of the region dominated by the earth's corotation field. (Drift of the bulge past the midnight meridian was first identified from two stations spaced roughly 1 hour apart in magnetic local time. The leading station, Eights, overtook the bulge near 19–20 LT, but the following station, Byrd, continued to observe the t_1 regime of Figure 2 until near midnight, after which time the data were not clear.)

The shift of the bulge encounter from a later to an earlier time (as, say, from case 3*b* to *a*, or *c* to *b*) may involve: (1) westward drifts of the bulge plasma, (2) filling of previously low-density tubes of ionization, (3) drifts that erode the plasmasphere to carve out a bulge at a new position. Results from previous whistler studies [cf. *Angerami and Carpenter*, 1966; *Carpenter*, 1966] suggest that accretion of plasma through diffusion into low-density tubes of ionization is a relatively slow process that probably affects the details of the bulge region but cannot produce significant positional variations in less than several hours. Erosion of plasma is also an unlikely explanation, because most of the observations reported here represent periods of relatively small day-to-day change in plasmasphere magnetic flux content (see later remarks on the erosion process).

Westward plasma drifts are probably of major importance in the displacement of the bulge to earlier local times. The possibility that such drifts occur near dusk is suggested by observations in the midnight sector of inward cross-*L* drifts with amplitudes of up to 1 R_E/hour (near 4 R_E) during substorms [*Carpenter and Stone*, 1967, 1968]. Hence, the plasma near the westward end of the bulge is interpreted as moving forward and backward in the solar direction as substorms develop and subside, but exhibiting an approximately zero *average* velocity referred to sun-earth coordinates (except during significant changes in worldwide magnetic activity).

Remarks on certain details of plasma flow velocity in the bulge. Whistler ducts have not been *observed* to drift outward into the bulge as the t_2 stage of Figure 2 develops [*Carpenter*, 1966], nor have significant inward drifts been observed within the bulge at time t_2. Low-amplitude $\lesssim 0.1\text{-}R_E/\text{hr}$ cross L motions, however, are difficult to identify near dusk. (The azimuthal motion of the associated whistler ducts is apparently small with respect to the corotation velocity of the whistler receiver's viewing area; thus, a given duct can typically remain in view and be tracked for cross-L motion during about 2 hours at most.)

The actual flow patterns near dusk may range from a condition of separate circulation within the bulge, not enclosing the dipole (see *Axford and Hines* [1961]), to circulation that is part of the main roughly corotating flow, with the pattern during a particular substorm depending upon the intensity of the perturbing convection and the initial conditions of the plasma distribution. Whistler data suggest that the bulge may at times be separated topologically from the plasmasphere, in that the radial density profile beyond R_A of Figure 2 is frequently not smoothly joined to the profile inside R_A. In some cases, there may be a roughly $\approx 2:1$ reduction or trough in electron density near R_A that extends well into the t_3 period. The approximate region of this effect is indicated in Figure 8*a* by shading.

The apparent shielding of the dayside from perturbing substorm electric fields. Several forms of evidence suggest that the dayside plasmasphere is shielded from perturbing substorm convection effects. In the present research large substorm fields are found near dusk, but exceptionally high disturbance levels are apparently required for the bulge to move significantly earlier than the 1800 LT meridian (cf. Figure 7*b*). The abrupt geometry of the westward end of the bulge may in some sense indicate a shielding effect [*Axford*, 1969].

A shielding effect on substorm plasma drifts also occurs in the dawn sector, where cross-L inward drifts are found after 06 LT only during very large disturbances, and then virtually never after about 08–09 LT [*Carpenter and Stone*, 1968]. In a descriptive sense, the plasmapause radius at a given longitude is clamped at some time near dawn and then varies only slowly until midafternoon or later.

The strongest whistler evidence of shielding comes from a comparison of plasma drift activity near midnight and near noon. Large transient sunward cross-L drifts of plasma have been repeatedly observed near midnight [*Carpenter and Stone*, 1967, 1968; *Carpenter et al.*, 1969], while there is no counterpart of this behavior in the noon sector. In the recent survey of whistler data from 180 days in 1963 and 1965,

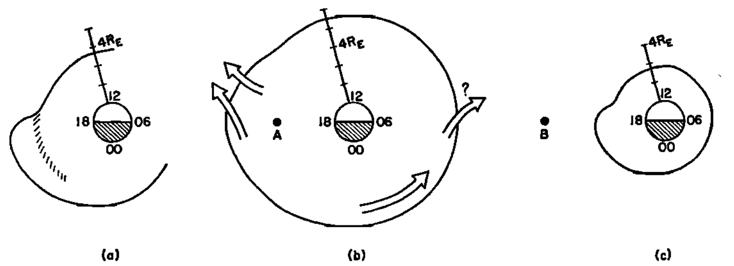

Fig. 8. Equatorial sections of the magnetosphere illustrating several features of magnetospheric convection. At left (*a*), shading identifies a region where a local reduction or trough in electron density is sometimes observed. In the center (*b*), arrows indicate possible convection activity in the outer part of a large plasmasphere preceding or during the erosion phase of a magnetic storm. At such times the innermost stagnation point of the combined flow may reach an average position well inside the plasmapause, say at point *A*. An outward component of flow near dawn and dusk suggests the (at least) partial shielding of the dayside from perturbing convection electric fields. At right (*c*) is a small plasmasphere, reduced in magnetic flux content by the erosion process indicated in (*b*). During quieting, the innermost stagnation point of the flow may move out to an average position at point *B*, thus allowing the bulge to be released and to move in the direction of the earth's rotation.

none exhibited significant cross-L drift activity in the plasmasphere near local noon. Evidence of an essentially corotation field on the dayside near $L = 7$ was found in recent long-duration balloon measurements of electric fields made by *Mozer and Serlin* [1969].

Heppner [1969] has called attention to the high ionospheric conductivity of the dayside ionosphere and the apparent absence of large perturbing ionospheric currents, which would be expected if correspondingly large electric fields penetrated the dayside magnetosphere near the plasmapause. (It is possible that an enhanced steady component of convection does produce relatively important effects in the dayside. This is evidenced by cross-L inward drifts of plasma in the afternoon sector during quieting, suggestive of a recovery from a sunward distension of the dayside plasmasphere during disturbed periods. Examples of this effect will be described in a future paper.)

The duskside plasmapause radius and the stagnation distance. Under what conditions does the duskside position of the plasmapause provide a measure of the distance to a stagnation point in the combined magnetospheric flow? The problem associated with a sharp increase in magnetic activity is illustrated in Figure 8*b*, which shows a large quiettime plasmasphere during an intense substorm convection event. As dense plasma surges in the sunward direction, the corresponding stagnation distance moves well inside the maximum plasmapause radius (say to A in Figure 8*b*). Reduction of the plasmapause radius to the vicinity of A and hence to a new quasi-equilibrium may occur only on a time scale of order 10 hours, or the time required for significant amounts of plasma in the outer plasmasphere to be stripped away (arrows in Figure 8*b*. An outward trend near dawn and dusk is shown to account for dayside shielding effects). If the substorm is isolated in time, the loss of plasma may not be large, and the principal observed effects may be distortions of the plasmasphere shape, including compressions near midnight, expansion before dawn [*Carpenter and Stone*, 1968], and the westward shifts near dusk reported here. If the disturbance is continuous for a period of order 10 hours, then very pronounced erosion may occur, and the average plasmapause radius may decrease from a value of 4–6 to 2.5–4 R_E in roughly 10 hours. Such pronounced erosion has apparently been observed by *Freeman* [1968] from a low-energy particle analyzer on ATS 1. The detector involved is insensitive to the thermal plasma densities characteristic of the region outside the plasma pause, but it can detect directed flow of relatively high-density plasma characteristic of the plasmasphere. Sunward flows have been observed on a number of isolated occasions, each in the late afternoon sector and during the early phase of a relatively large magnetic storm. Much additional evidence of duskside erosion effects deduced from satellite observations of thermal ions was recently reported by *Taylor et al.* [1970] and by *Chappell et al.* [1970].

The problem of relating the plasmapause radius to the stagnation distance during periods of quieting likewise depends on the suddenness and persistence of the change in magnetic activity. During very gradual quieting a kind of quasi-equilibrium may exist throughout. During sudden, persistent quieting the stagnation distance may move and remain well beyond the maximum radius of the plasmasphere (say to B in Figure 8*c*). The bulge is then released and may begin to approximately corotate with the earth. The development of a detectable plasmapause profile at a new, larger plasmapause radius near dusk becomes a question of the time and other conditions required for filling tubes of ionization whose plasma content was previously low. *Park* [1970] has shown experimentally that this time is long, of the order of several days. *Chappell et al.* [1970] show density profiles indicating various stages of the slow filling process.

The plasmapause as an equipotential of the flow. The question of the plasmapause as an equipotential of the combined flow is closely related to the question of the plasmapause radius as a measure of the stagnation distance. In general, the plasmapause is not an equipotential, although it may under some conditions approach such a form. Departures from an equipotential result in part from response-recovery time factors which, as discussed above, tend to delay the plasmapause in reaching a particular equilibrium configuration. Another major and related influence is the highly nonuniform distribution of convection electric fields, particularly those of substorms. This nonuniformity, already mentioned as involving dayside shielding and nightside localization of effects, results in complex modification of the plasmapause radius and apparently in production of density irregularities within the plasmasphere [*Park and Carpenter*, 1970]. The approximate rotation of the plasmasphere with the earth causes the indentations produced by a series of substorms to appear as longitudinal irregularities in the plasmapause radius, even when the electric field is relatively uniform such as between substorms and at most times on the dayside of the earth. In times of relatively steady agitation the plasmapause may approach an equipotential relatively closely, with localized departures of perhaps only a few tenths of an earth radius. Future attempts to develop a scheme of worldwide plasmapause monitoring may do much to clarify this picture.

Estimates of convection electric field strength in the dusk magnetosphere. If a bulge is observed near dusk, then by inference the convection is relatively steady and an average value of the associated component of electric field $E_{Y_{SM}}$ may be estimated (the solar-magnetospheric Y direction is normal to the plane containing the earth-sun (X) direction and the dipole (Z) axis). Because the outermost part of the bulge may be in a somewhat turbulent state from repeated detachment or loss during substorms and injection or accretion during quieting [cf. *Chappell et al.*, 1970; *Taylor et al.*, 1970], the time-averaged stagnation distance may be taken to be somewhere between R_A and R_B of Figure 2. During the prolonged recovery phase of moderate magnetic storms, R_A is typically near 3.5 R_E, and R_B is near 5 R_E, so that 4.5 R_E is a convenient estimate of the stagnation distance. At this distance the corotation field and hence the time-averaged $E_{Y_{SM}}$ are roughly 1 mv/m. Similar inferences concerning $E_{Y_{SM}}$ have been made by several authors [e.g. *Nishida*, 1966; *Brice*, 1967; *Vasyliunas*, 1968].

The reported azimuthal fluctuations of the bulge around its average position provide the basis for crude estimates of fluctuations in the convection electric field. An estimate of $E_{Y_{SM}}$ between substorms may be made from the average length of quiet time required for the bulge to drift or slip from a disturbed-time position near the 17–18 LT meridians to some point of observation in the pre-midnight sector. Figure 6*a-d* shows cases in which quieting begins near noon at the ground station and the bulge is overtaken roughly 7–8 hours later near 20 LT. Assuming from Figure 5*f*-5*j* that the leading edge of the bulge stands near 17–18 LT as the quieting begins, it is inferred that the bulge drifts through $\sim 2\frac{1}{2}$ hours in local time in 7–8 hours, or at roughly $\frac{1}{3}$ the angular velocity of the earth. From this it is estimated that the value of $E_{Y_{SM}}$ between substorms is $\sim$0.4–0.6 mv/m (at about 4.5 R_E).

The field magnitude during substorms is estimated to be between $\sim$1 and 4 mv/m. This is based on assuming an average value of $\sim$1 mv/m, a between-substorm level of $\sim$0.4–0.6 mv/m, a typical substorm duration of 1–2 hours, and a quiettime interval of order 2–4 hours.

During prolonged quiet periods the plasmapause radius increases to 6 R_E or more [cf. *Binsack*, 1967; *Taylor et al.*, 1970; *Chappell et al.*, 1970]. Whistler data studied by the author show that the quiettime plasmasphere sometimes extends to distances of order 10 R_E in the afternoon sector, that is, to regions where equatorial geomagnetic field strength is $\sim 60\ \gamma$ [cf. *Carpenter*, 1963]. Assuming a plasmapause radius of 10–12 R_E near dusk during prolonged quieting (5–10 days), an estimate of the average value of convective $E_{Y_{SM}}$ at such times is $\sim$0.1 mv/m. (The assumption that convection and thus counter streaming persists on the dusk side during quieting is based on the fact that the plasmapause electron density profile at say $L = 6$–7 deduced from whistlers and from direct probes frequently exhibits a steepness much like that exhibited at $L = 3$–4 during higher levels of disturbance activity (see *Chappell et al.* [1970], *Taylor et al.* [1970]).

The surging increases in duskside convection activity inferred in this research occur at about the time of substorm-associated increases in cross-L drifts within the plasmasphere near midnight [*Carpenter and Stone*, 1967, 1968]. However, the two patterns of activity may not be related in a simple way. Other whistler studies indicate a fundamental difference in details of substorm-associated cross-L drifts between the sectors preceding and following $\sim$23 LT. For example, the tendency for fast inward cross-L drifts to set in abruptly near the beginning of large substorm bay activity occurs only after $\sim$23 LT at the observing whistler station, and usually in the $\sim$00–02 LT sector (see *Park and Carpenter* [1970]). (Other phenomena exhibit a similar statistical variation with respect to ~23 LT. See, as examples, the review by *Winckler* [1970] of particle observations on ATS 1, a report on barium cloud observations by *Haerendel and Lust* [1970], and a summary of high-latitude magnetic perturbations by *Heppner* [1969].) Also, the values of convection $E_{Y_{SM}}$ estimated for the bulge region are a factor of 3 or 4 higher than those previously inferred for $E_{Y_{SM}}$ in the midnight plasmasphere. In the latter case, peak perturbing fields of ~0.5–2 mv/m are repeatedly found during substorms [*Carpenter and Stone*, 1967, 1968; *Carpenter et al.*, 1969], and fields between substorms are ~0.05–0.1 mv/m. These values, determined from the tracking of whistler ducts, are presented in Table 1 for comparison with values from the dusk sector. The differences between the two sectors could be the result of several factors, and should probably not be emphasized until more is known of the overall substorm development on the nightside.

Table 1 indicates that during the quieting between substorms, the convection fields $E_{Y_{SM}}$ at dusk (and probably at midnight) are roughly a factor of 4 stronger than in very quiet times. Thus during disturbed periods the more or less steady component of convection is enhanced, an important effect that tends to be overshadowed by the large substorm events.

CONCLUSIONS

The bulge or region of larger plasmasphere radius is usually located within ±45° of the dusk meridian. It surges irregularly forward and backward in the solar direction in synchronism with substorm activity, and is released during periods of deep prolonged quieting, moving in the direction of the earth's rotation. The behavior of the bulge strongly indicates the existence of a high-latitude convection system such as that proposed by *Axford and Hines* [1961] and also discussed by a number of other authors (see *Axford* [1969]). The dayside plasmasphere is evidently shielded from perturbing substorm convection fields as predicted by *Heppner* [1969]. The plasmapause is not in general coincident with an equipotential of the combined magnetospheric flow, but may approach an equipotential during relatively steady planetary conditions. Under such conditions the duskside radius of the plasmapause may provide a crude time-averaged measure of the stagnation distance and hence of the average intensity of the convection electric field. The electric field is evidently unsteady, with large substorm-associated increases riding upon an increased general level of activity during disturbed periods. The convection activity near dusk exhibits variations broadly similar to cross-L convection deduced from the tracking of whistler ducts within the plasmasphere near midnight, but the inferred electric field component $E_{Y_{SM}}$ is apparently larger near dusk than near midnight, possibly by a factor of 3 to 4.

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TABLE 1. Estimated Values of the Y_{SM} Component of Magnetospheric Electric Field within the Plasmasphere

	Moderate Magnetic Storm Period			Conditions of Prolonged Quiet, mv/m
	Peak Values during Substorms, mv/m	Typical Values between Substorms, mv/m	Average Level, mv/m	
Dusk*	1–4	~0.4–0.6	~1	~0.1
Midnight†	0.5–2	0.05–0.1	~0.2–0.3	≤0.1

* Based on statistics of the position of the plasma bulge.

† Based on tracking of whistler paths.

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