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Satellite Studies of Magnetospheric Substorms on August 15, 1968

3. Some Features of Magnetospheric Convection

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A combination of Ogo 4 and 5 data and ground data for August 13–15, 1968, has revealed new details of unsteady magnetospheric convection and the gradual erosion of the plasmasphere during a weak magnetic storm. Evidence of erosion was detected by Ogo 5 in the form of complex density structure near the duskside plasmapause and by Ogo 4 as a persistent diminution in plasmapause L value near 0500 magnetic local time (MLT). Evidence of unsteady convection includes (1) Ogo 5 observations of the irregular duskside density profile, (2) Ogo 4 and Byrd ground whistler observations of an apparent rotation of the plasmasphere bulge during quieting, and (3) Ogo 4 observations near 0500 MLT of fluctuations of plasmapause L value around the slowly decreasing average value. It is inferred that most of the variations in plasmapause L value observed near 0500 MLT were the result of rotation under the satellite of spatial patterns imposed by convection activity in the midnight and dusk sectors. A pronounced decrease in plasmapause L value from $L \sim 3.4$ to $L \sim 2.5$ followed within a few hours the major substorms of early August 15. From the size of this decrease, and from previous whistler research on cross-L plasma drifts, it is inferred that westward electric fields of the order of 0.5 mv/m were present in the midnight sector during the substorms of interest.

The August 13–15, 1968, period provides a case study of magnetospheric convection during a weak magnetic storm. Convection is studied through its apparent effects on the size, the shape, and the plasma density profile of the plasmasphere. The plasmapause is observed within a roughly constant local time plane, and thus previous storm period descriptions based on data from whistler receivers rotating with the earth are extended [*Carpenter*, 1966; *Carpenter et al.*, 1971].

Figure 1 presents a simple descriptive picture of the sources of experimental data, with emphasis on the rendezvous situation of August 15, 1968. The equatorial satellite Ogo 5 made two plasmapause crossings on August 15 and provided detailed information on thermal plasma density along its orbit (the orbit is shown in coordinates of L versus magnetic local time, MLT). The Byrd, Antarctica, whistler station ($L \sim 7$, MLT $\sim$ UT $-$ 6 hours) provided additional information on magnetospheric plasma density near the inbound orbit of Ogo 5. An arc extending from ~0100 to ~0700 MLT shows the local time increase at the Byrd ground receiver as Ogo 5 moved from $L \sim 8$ inbound to $L \sim 8$ outbound. Ogo 4, in polar orbit at 400–900 km, provided day-to-day tracking of the plasmapause radius (VLF method) in the ~0500–1700 MLT plane. Radial arrows near the arc for Byrd Station show the magnetic local time of plasmapause crossing for several Ogo 4 orbits preceding and following the Ogo 5 perigee pass.

The rendezvous situation indicated in Figure 1 provided an opportunity to compare Ogo 4 and 5 measurements of the plasmapause as well as to compare plasma density data from Ogo 5 with information from the ground whistler station.

Experimental Methods

In the Ogo 4 VLF broad-band data the plasmapause is identified either by a rapid

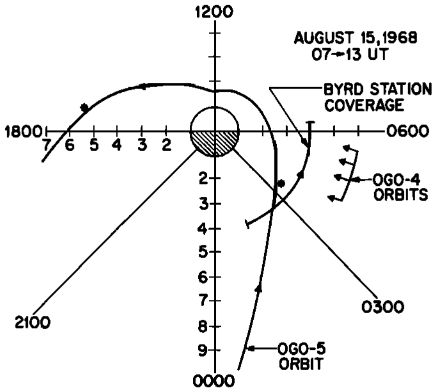

Fig. 1. Satellite and ground station position information during the August 15, 1968, rendezvous of Ogo 4 and 5 and Byrd Station, Antarctica. The Ogo 5 orbit is shown in coordinates of L versus magnetic local time. Radial arrows indicate the magnetic local times of several plasmapause crossings by Ogo 4 (polar orbit) during the Ogo 5 perigee pass. The increase in magnetic local time at Byrd Station during the Ogo 5 motion from $L = 8$ inbound to $L = 8$ outbound is shown by an arc of a circle.

change in the occurrence rate and spectra of whistlers propagating to the satellite from the conjugate hemisphere or by an onset or sudden variation in certain VLF noise forms [*Carpenter et al.*, 1968; *Taylor et al.*, 1969]. Frequently both effects are observed. The Ogo 5 data consist of direct ion spectrometer measurements of ambient H^+ and He^+ densities from a low-latitude highly eccentric orbit with perigee at 9093 km and apogee at about 23 R_E. On the August 15 pass shown in Figure 1 the plasmapause was detected at $-19°$ magnetic latitude inbound at 0312 LT and $+27°$ magnetic latitude outbound at 1728 LT. Only H^+ density measurements will be discussed here, since H^+ is the major ionic constituent of the outer plasmasphere. The details of the Ogo 5 instrument have been discussed elsewhere [*Harris and Sharp*, 1969]. The method of estimating magnetospheric electron density from ground whistler data has been described in a number of references [e.g., *Angerami and Carpenter*, 1966; *Angerami*, 1966; *Carpenter and Smith*, 1964].

Experimental Results

General trends in plasmapause position, August 13–15, 1968. On August 13 a weak magnetic storm began following 3 days of relatively quiet magnetic conditions. In Figure 2 the bottom panel shows the initial *Kp* increase and the following period of moderate, relatively steady agitation with *Kp* near 4. In the upper panels of Figure 2, Ogo 4 plasmapause crossing data are plotted in coordinates of L versus UT, with separate identification of results from the 1700 (upper panel) and 0500 MLT sectors. The L scale is linear in $1/L^2$ to facilitate recognition of effects due to convection electric fields (see later discussion). Dashed lines connecting pairs of symbols indicate the L range within which the plasmapause is estimated to lie. A single symbol indicates the plasmapause position to be in the direction of the arrow and within $\Delta L \sim 0.3$. The various symbols represent real time telemetry at Winkfield, England (WNK), Rosman, North Carolina (ROS), Fairbanks, Alaska (SKA), and Byrd, Antarctica (BY). The Ogo 5 plasmapause crossings on August 15 are indicated by asterisks (also in Figure 1).

In the ~0500 MLT sector the plasmapause radius shows a steady decrease on which relatively large fluctuations are superimposed. The average L value of the plasmapause changes

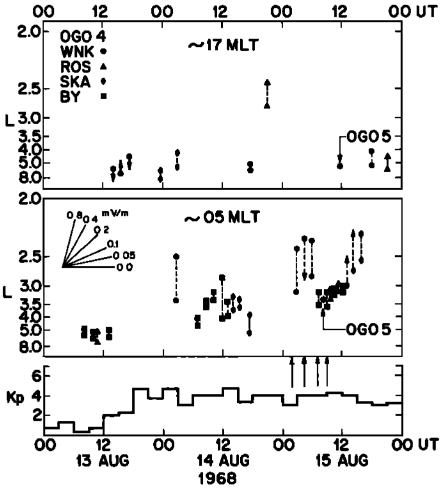

Fig. 2. Ogo 4 plasmapause crossing data in coordinates of L versus UT for August 13–15, 1968, showing the changes in plasmapause position as viewed in an approximately fixed local time plane (~0500–1700 MLT). The upper and middle panels separately identify the ~1700 and ~0500 MLT data. Asterisks mark the Ogo 5 plasmapause crossings on August 15. See the text for additional details.

from about 5.5 on August 13 to approximately 3.5 on August 14 and then to about 2.9 on August 15.

The 1700 LT data are relatively few and do not exhibit a systematic reduction in plasmapause radius. A relatively low L value of ~2.6 was recorded on August 14 near 2100 UT. This is believed to be a quieting effect in which the duskside plasmasphere bulge begins to drift in the direction of the earth's rotation [*Carpenter*, 1970], temporarily exposing the satellite to smaller dayside plasmapause radii. Byrd whistlers near 0000 UT on August 15 also showed evidence of such a drift.

Plasma density profiles. Figure 3 presents plots of magnetospheric plasma density versus L. The open circles in Figure 3*a* show Byrd ground whistler estimates of equatorial electron density on August 13 at 0820 UT (~0220 MLT), prior to the storm onset. Densities characteristic of the quiet time plasmasphere extend to $L \sim 5.4$, the approximate plasmapause location as identified from Ogo 4 (see 0500 MLT panel of Figure 2).

The solid circle in Figure 3*a* shows a data point from Byrd whistlers recorded on August 15 several hours prior to the nightside plasmapause crossing by Ogo 5. At the time (~0400 UT), Ogo 5 was inbound at 12.5 R_E in the magnetotail and Byrd was near the 2200 MLT meridian. The datum shows that plasmasphere density levels extended locally to at least $L = 4$. (The pronounced asymmetry of the plasmasphere at the time (~0400 UT) is evidenced by a comparison of this value of $L > 4$ for ~2200 MLT with simultaneous Ogo 4 detection of the plasmapause at $L \sim 2.7$ near the 0500 MLT meridian (Figure 2).)

Figure 3*a* shows in detail the nightside inbound plasma density profile obtained from Ogo 5 along the orbit illustrated in Figure 1. The plasmapause position and its steep density profile are in excellent agreement with previous Ogo 5 measurements near midnight during comparably disturbed periods [*Chappell et al.*, 1970*a*] and also with previous ground-based whistler measurements [*Angerami and Carpenter*, 1966; *Carpenter*, 1967]. In Figure 3*a* an open square shows an equatorial electron density estimate from Byrd ground whistlers recorded within 10 min of the plasmapause crossing by Ogo 5 and probably less than 1 hour in local time from the Ogo 5 orbit. There is good agreement, considering the uncertainty of less than 50% in estimating ion concentration from Ogo 5 ion current in this part of the plasmasphere, the separation of the measurements in time and space, and the fact that the Ogo 5 measurements represent positions slightly off the equator (about 19°) near $L = 3.3$ inbound.

Figure 3*b* shows the Ogo 5 outbound profile on August 15 in what was apparently the plasmasphere bulge region (see the orbit in Figure 1). The plasmapause appears to be at about $L = 5.3$, although there is a deep localized depression at about $L = 4.4$ and also relatively large fluctuations in density both between $L = 4.4$ and 5.3 and in the lower-density region beyond the apparent plasmapause position. Fluctuations of this kind have been reported previously [*Chappell et al.*, 1970*b*; *Taylor et al.*, 1970] as being characteristic of periods of enhanced but fluctuating magnetic activity.

DISCUSSION AND CONCLUDING REMARKS

The generally decreasing trend in plasmapause radius observed near 0500 MLT (Figure 2) probably resulted from erosion of the outer plasmasphere in the late afternoon–dusk sector [*Chappell et al.*, 1970*b*; *Taylor et al.*, 1970; *Carpenter*, 1970]. Owing to the unsteady substorm-related nature of the convection and the relatively slow plasma drift velocities characteristic of the dusk sector [*Carpenter*, 1970], much of the plasma 'removed' from the plasmasphere near dusk probably remained nearby for extended periods, appearing as irregular outlying structure in the Ogo 5 profile of Figure 3*b* [see *Chappell et al.*, 1970*b*].

It may be useful to have a measure of the rate of plasmasphere erosion. A possible measure is an 'equivalent' east-west convection electric field E_w, determined by considering the observed slow decrease in plasmapause radius as an equivalent, albeit fictitious, cross-L drift. Estimates of this equivalent field may be obtained from the diagram at the upper left of the 0500 MLT panel in Figure 2. The L scale in Figure 2 is linear in $1/L^2$; for a dipole geomagnetic field the slope of any line in the figure is proportional to the inferred E_w by a factor that is independent of L. According to the

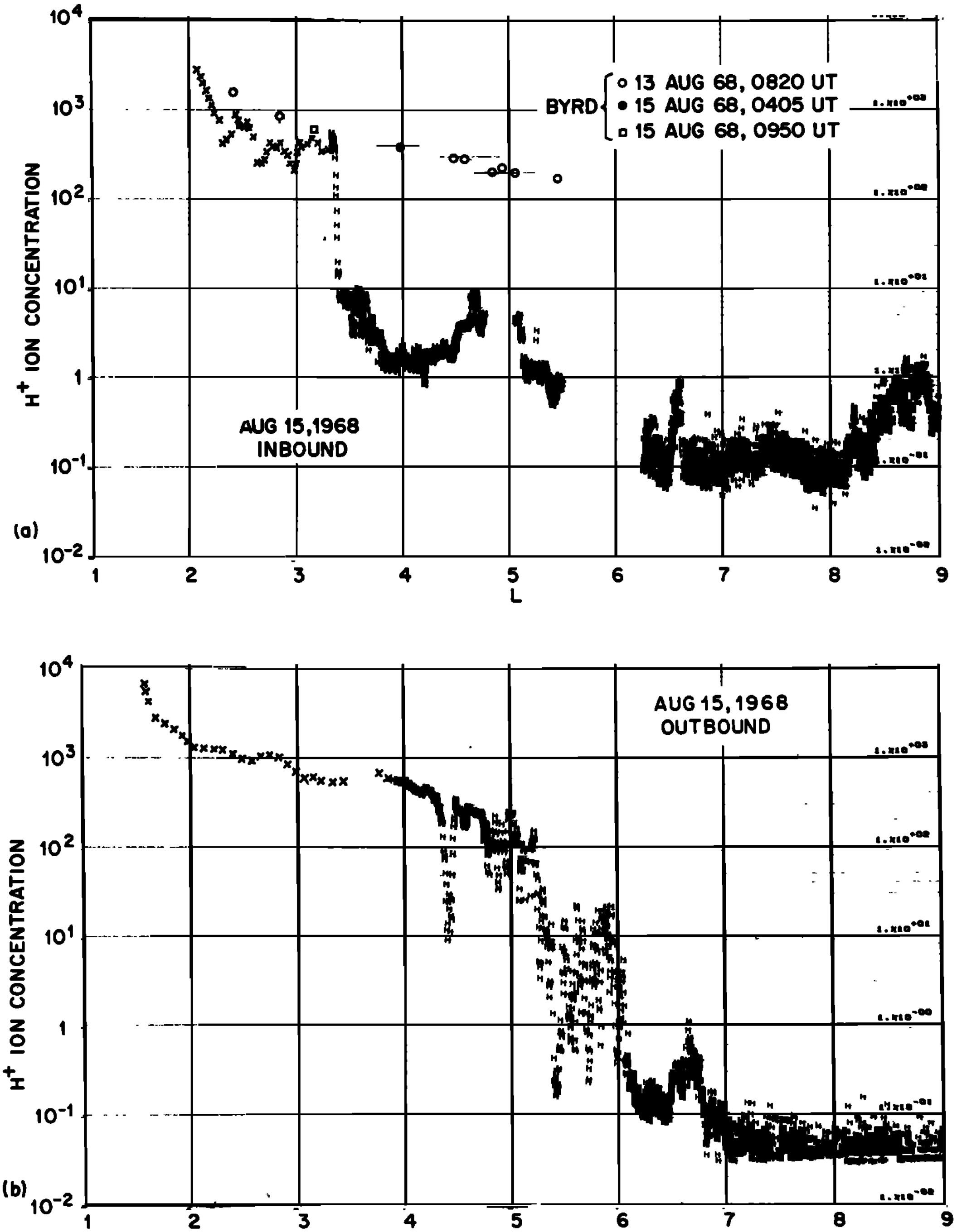

Fig. 3. (*a*) Nightside profile of magnetospheric plasma density versus L observed from Ogo 5 inbound on August 15, 1968. Also included are Byrd whistler data on equatorial electron density from three intervals in the August 13–15, 1968, period. (*b*) Duskside profile of magnetospheric plasma density versus L observed from Ogo 5 outbound on August 15, 1968.

diagram, a several-day equivalent E_w for August 13–15 is about 0.05 mv/m.

The fluctuations in plasmapause radius with periods of several hours (0500 MLT panel in Figure 2) are believed due to the combined effects of unsteady substorm-associated convection and a ±1-hour MLT wobble in the Ogo 4 plasmapause crossings. Arrows along the Kp scale at the lower right in Figure 2 indicate the onsets of the expansion phases of a series of substorms [see *McPherron,* 1973]. Previous whistler research [*Carpenter and Stone,* 1967; *Carpenter et al.,* 1972] has shown that, during weak to moderate magnetic storms, enhanced substorm-associated cross-L inward drifts near the plasmapause occur preferentially in the 2300–0200 MLT sector and may on occasion occur in a wider region extending to local dawn. *Carpenter et al.* [1972] found that the corresponding westward electric fields near the plasmapause are of the order of 0.5 mv/m and that the plasmapause exhibits nightside changes in radius that are consistent with the displacements of the nearby plasma. On August 15 at about 0400 UT there was a substantial tilt of the plasmapause to lower L between the ~2200 and ~0400 MLT meridians (reported above). Further, in the 0500 MLT panel of Figure 2 there is a steady decrease in the plasmapause L value between about 0900 and 1200 UT on August 15 and a more rapid decrease after 1200 UT. The extent of this decrease, from $L \sim 3.4$ to $L \sim 2.5$, is consistent with plasmapause displacements during known ~0.5-mv/m convection events [*Carpenter et al.,* 1972]. The detection of the decrease several hours after the expansion phases of the substorms of interest probably reflects the time required for the rotating plasmasphere to carry the effects imposed on it near midnight to the 0500 MLT sector.

The abrupt increase in plasmapause radius indicated near 0600 UT on August 15 is partly attributed to a corresponding change in the MLT of Ogo 4 plasmapause crossing from ~0600 to ~0400 hours (this is an extreme example of the ±1-hour MLT wobble mentioned above). Some part of the increase in observed plasmapause L value may be due to a period of quieting near 0000 UT on August 15. As was noted above, the duskside bulge region of larger plasmapause radius appeared to drift toward the nightside in this period. Its presence on the nightside during the subsequent series of convection events may have contributed additional detail to the fluctuations observed from Ogo 4 near 0600 UT.

The shape of the plasmasphere appears to be a sensitive and very complex integral measure of magnetospheric convection activity. Suitably planned multisatellite and satellite-ground experiments could probably extract much of the information 'stored' in this system during disturbed periods.

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