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Abstract

IMP 5 magnetic field measurements at geomagnetic latitudes up to 75° and at distances beyond 6 R_E reveal the permanent existence of a broad depressed field region centered on the polar or dayside cusp. Field strengths at 7 R_E on cusp field lines which connect to the earth are typically only 50-70% that of an undistorted dipole field. The transition region between the magnetosheath and the point where the fields are clearly of dipolar origin is characterized by large amplitude fluctuations and the lack of a clear magnetopause boundary. Magnetic field perturbations are observed in the cusp region with magnitudes up to 45γ and in directions which are approximately perpendicular to the average field. These perturbations are suggestive of field aligned currents and their magnitudes are consistent with the low altitude measurements obtained on low altitude polar orbiting spacecraft.

Introduction

Early suggestions that solar wind particles may enter the magnetosphere at high latitudes in the sunward hemisphere (Plaetnev, et al., 1965; Piddington, 1965; Ershkovich, 1967; Spreiter and Summers, 1967; Willis, 1969) have recently been confirmed by measurements on the spacecraft ISIS-I (Heikkila and Winningham, 1970), IMP 5 (Frank, 1970a) and Injun 5 (Frank and Ackerson, 1971). On these spacecraft, a magnetosheath-like plasma is observed near the moon meridian plane on high latitude geomagnetic field lines which intersect the earth at auroral oval latitudes near 78°. The IMP 5 measurements reveal the continual presence of this plasma in the region beyond $4\ R_E$ and the Injun 5 and ISIS-I measurements confirm its extension to lower altitudes. During one large magnetic storm OGO-5 detected similar type plasma at magnetic latitudes as low as 43° (Russell et al., 1970)

Theoretical predictions of high latitude particle entry have generally suggested that such plasma would intrude at approximately 9 R and 70° latitude in a region of weak magnetic field surrounding a "neutral point". This location separates a low latitude region where field lines close on the day side of the earth from a high latitude region where field lines turn back over the polar cap and extend into the magnetic tail. Consideration of the existence of an interplanetary magnetic field leads to the additional possibility that geomagnetic field lines may connect to magnetosheath field lines which in turn lead into the interplanetary medium.

Such interconnection would involve field lines of the outer magnetosphere, which are those passing near the high latitude weak field region. The location of the actual neutral point may change appreciably in response to changes in interplanetary field orientation (e.g. Forbes and Speiser, 1971) but this is primarily a topological difference and the high latitude weak field region will still exist.

Few high apogee spacecraft have had sufficiently high inclinations to sample the outer magnetosphere at high magnetic latitudes. The OGO-1 spacecraft reaches 58° geomagnetic latitude and Heppner et al. (1967) reported that the quantity Δ B (observed field strength minus unperturbed reference field strength using internal sources only) decreased as the spacecraft moved to higher latitudes and in fact became negative in a region poleward of approximately 40° geomagnetic latitude. The IMP 3 spacecraft achieved adequately high latitudes late in its lifetime and in fact sampled field lines which turn back over the pole (Fairfield, 1968) but the 40γ saturation level of the magnetometer instrumentation prevented an adequate study of magnetosphere fields in this region.

The first good opportunity to make high latitude-high altitude measurements began with IMP 5 which was launched on June 21, 1969 into an eccentric polar orbit (inclination 86.8°) with initial apogee at a geocentric distance of 28.7 R_E approximately 15° east of the noon meridian plane. Although this spacecraft achieved only moderately high ecliptic latitudes beyond 6 R_E, the maximum tilt of the dipole at the time of the June launch meant that geomagnetic latitudes up to

75° were sampled at these larger distances. It is the purpose of this paper to make the initial report of these high latitude magnetic field measurements which correspond to the plasma observations reported by Frank (1970).

Instrument

The IMP 5 magnetometer experiment consisted of a dual range triaxial fluxgate magnetometer with one sensor parallel and two sensors perpendicular to the spacecraft spin axis. The sensor was mounted at the end of a six foot boom to minimize the effects of spacecraft magnetic fields. Prelaunch testing indicated that any spacecraft field at the sensor position was below the 0.25γ detectability threshold level of the test facility. The sensors were switched automatically between the two ranges of $\pm 40\gamma$ and $\pm 200\gamma$, depending on the strength of the measured field. The analog outputs were digitized onboard with an 8 bit A-D converter yielding a digitization uncertainty of $\pm 0.20\gamma$ and $\pm 1.0\gamma$ in the low and high ranges respectively.

The spacecraft spin period was 2.18 seconds at launch. This spacecraft spin was utilized in making an inflight determination of the zero levels on the sensors perpendicular to the spin axis. Every 3.9 days the sensor set automatically "flipped" 90° about a radial axis, reversing the relative position of two sensors parallel and perpendicular to the spin axis and allowing a determination of the zero level of the third sensor. Zero level determinations were made every 50 minutes throughout the flight and they were updated in the processing program on an orbit to orbit basis. The zero levels varied slowly throughout the first year of operation by amounts which were less than 0.7γ and 1.2γ in the low and high ranges respectively. Their accuracy is estimated as $\pm 0.2\gamma$. The bandpass of the instrument was 0-4 Hz in the low range and 0-7 Hz in the high range with a fall off of 20 db/decade beyond the cutoff frequency. Vector field measurements were made every 2.557 seconds with the three individual sensors being sampled at 80 millisecond intervals. The data plotted in this paper are the eight point averages over one telemetry sequence of duration 20.455 seconds.

Results

The spatial regions traversed by IMP 5 can be deduced from Figure 1 which is a graphical display of the noon meridian field configuration. The line segments plotted at various geomagnetic latitudes and radial distances represent data averaged over half earth radii intervals (typically 10-20 minutes) for various passes of the spacecraft. Each line segment is plotted at the angle the field vector makes with the horizontal. In effect each line segment is tangent to the field vector in the local plane of the field line and distortions out of a meridian plane are suppressed. These data are from orbits 2-14 and 17 which were those orbits lying within 30° of the solar magnetic noon meridian plane. (In solar magnetic coordinates the Z axis is aligned with the dipole axis and the X axis is in the plane formed by the earth sun line and the Z axis. The Y axis completes the right handed orthogonal system).

Only data which were confidently felt to be within the distorted geomagnetic field were included in Figure 1. Since the data are presented in a dipole coordinate system, the geomagnetic latitude of the sun (the approximate incident direction of the solar wind) changes as the time of day and season vary. For the data shown, solar latitude varied from 5° to 35° as is illustrated by the histogram distribution in Figure 1. The dashed line represents the theoretical magnetosphere boundary of Olson (1969) for a 20° aspect angle of the solar wind flow with respect to the geomagnetic equator. The generally dipolar nature of the field is apparent when the line segments are compared with the solid dipole lines which have been labeled with their earth intersection latitudes. Dayside compression effects are apparent at large distances and lower latitudes.

A summary of the field strength measurements on the 14 solar meridian orbits is displayed in Figure 2. Squares represent positive ΔB's (compressional effects) and circles represent negative ΔB's (field depressions). The location of the symbol indicates the location of the measurement (geomagnetic latitude and radial distance) and the area of the symbol is proportional to the magnitude. Compressional effects predominate at low latitudes but field depressions are observed above at least 40° latitude as discussed by Heppner et al. (1967) and Sugiura et al. (1970). The circles near 6 R_E in the southern hemisphere confirm the presence of a quiet day ring current (Mead and Cahill, 1967; Sugiura et al. 1970) and apparently merge into the field depression region at high latitudes. The northern hemisphere data lies almost entirely in the field depression region and is largest at the highest latitudes and at the times when the polar cusp is observed.

Figure 3 summarizes the directional changes in the field as indicated by ΔI where ΔI is defined as the measured inclination (the angle field makes with the horizontal to the earth's surface) minus the inclination of the internal sources only reference field. The format of the presentation is the same as Figure 2, only now with squares and circles representing positive and negative ΔI changes respectively. Due to the definition of I, compressional effects are represented by positive ΔI in the southern hemisphere and negative ΔI in the northern hemisphere. Although compressional effects are dominant in the outer magnetosphere, some ΔI values of the opposite sign are seen at the lower altitudes. These opposite signs which occur at low latitudes are probably related to inflation of the magnetosphere by ring currents while those at higher latitudes may be related to the fact that some of these high latitude field lines may be turning back over the pole.

Figure 4 represents the data from an inbound pass through the northern hemisphere magnetosphere. The quantities plotted are magnitude B, ΔB, inclination I and declination D (the angle the horizontal component of the field makes with the geomagnetic north direction). Twenty second average fields are plotted and the quantity δ is the pathagorean mean of the standard deviations associated with the three average vector components at each point. One smooth trace for I and D represents the values predicted from the dipolar reference field while the other smooth trace represents that obtained from the Mead-Williams model (Williams and Mead, 1965) which is included despite the fact that it is really appropriate only for the solar wind incident normally on the dipole. The internal reference field D is the trace nearer zero and the corresponding I trace is the least variable of the two on Figure 4 and subsequent figures.

The latitudes traversed by the spacecraft on orbit 5 are at relatively low latitudes for an inbound pass of IMP 5. The magnetopause is located at 00:45 ± 4.5 according to the plasma instrument of Frank (private communication). This boundary is designated by a vertical dashed line as are the boundaries supplied by Frank on subsequent figures. In all cases the open block straddling the vertical line designates the uncertainty of the determination which in most cases is related to the sampling period of the plasma instrument. In this figure the line is near the time when the field angles change and the level of fluctuations abruptly changes from the disturbed conditions of the magnetosheath to the quiet level characteristic of the magnetosphere.

The reduced magnitude of the inclination angle in the magnetosphere relative to a dipole field is consistent with dayside compression. The depressed magnitude of the field is characteristic of latitudes greater than approximately 40° near the noon meridian (Heppner et al., 1967, Sugiura et al., 1970). The declination is small and is consistent with that expected in the Mead-Williams model. This pass is characteristic of many passes through this latitude region and except for the depressed magnetosphere field strength it would be characteristic of lower latitude passes (Mead and Cahill, 1967). Frank does not observe the polar cusp on this orbit until 3:37 ($\approx 3.9\ R_E$) when the magnetometer is saturated by the strong fields.

Figure 5 illustrates data from the inbound high latitude pass of orbit 4 with the data in the same format as Figure 4. At the boundary between the magnetosheath and the polar cap the 20 second average field strength reaches a minimum of 5.3γ at 16:22 before increasing to 51.3γ four minutes later. The minimum field strength sampled within the low 20 second average was 3.2γ which suggests a possible close approach to a magnetic field neutral point. The inclination angle is close to that of a dipole at low altitudes but exhibits a decrease between 8 and 9 R_E which is characteristic of field lines which are compressed. The abnormally large field depression and fluctuations which are observed between 17:00 and 17:30 are not characteristic of lower latitudes but are apparently associated with the observation of the magnetosheath-like plasma of the polar cusp which Frank (1970) specifies as occurring between 16:47 and 17:41. The fact that the fluctuations occur within 8.5 R_E and at the inclination expected for a distorted dipole field strongly suggests that the spacecraft is sampling field lines with at least one end intersecting the polar cap.

The large values of declination after 17:00 indicate distortion of the field out of a meridian plane. The large values for D after 17:00 correspond to field components of the order of 10γ perpendicular to a meridian plane. The direction of D is consistent with the distortion expected in the dawn hemisphere even though the spacecraft is located slightly toward the dusk side of the earth sun line. This orbit is an exception and usually a geomagnetic longitude of nearly 0° separates those orbits which have perturbation as expected in the dawn and dusk hemispheres. This divergence of the field lines away from the noon meridian plane is a common feature at high latitudes and is consistent with the reduced magnetic flux density of the weak field region.

The absolute values of low fields in this cusp region are 54γ at 17:03 (46% of dipole field strength) 54γ at 17:08 (44% dipole values) and 73γ at 17:13 (55% dipole). The field lines adjacent to the cusp on either side of it are identified by Frank as polar cap field lines by their absence of trapped particles. Although the field inclination observed after the cusp termination at 17:41 shows a slight enhancement such as one might expect for field lines turning back towards the tail, the polar cap field lines before the first observations of the cusp have decreased inclination such as one might expect for field lines closing in front of the earth. Probably the locally measured field direction is not a sensitive indicator of the eventual path of field lines. The alternate possibility that there are field lines closing on the day side which have no trapped particles on them seems less likely. The large fluctuations in B on July 4 are occurring despite a low Kp value of 0+.

Another high latitude quiet day inbound pass is presented in Figure 6. The entire region from the bow shock crossing at 11.6 R_E to instrument saturation at 5.8 R_E is included. On this orbit Frank identifies a gradual transition from magnetosheath to cusp type plasma at 12:23 ±5 minutes at a time when no significant changes in the magnetic field are occurring. The cusp terminates at 13:52 ±2.5 min which means that the cusp is centered on the region of maximum B depression. The angle changes at 11:37 and 12:13 appear to correspond to changes seen at Explorer 35 in the interplanetary medium and hence they can be explained by convection of interplanetary field into the magnetosheath (Fairfield, 1967; Behannon and Fairfield, 1969) and are probably unrelated to close proximity to the magnetosphere. The angle changes between 12:45 and 13:15 are related to the transition between fields that are clearly within the magnetosheath and those that are clearly within the magnetosphere.

It is difficult to identify any narrow region as the magnetopause during this interval because of the extreme variability of the field in direction and magnitude. Power spectra computed for the interval 12:40-13:10 revealed the presence of more power than in any of 70 magnetosheath spectra computed by Fairfield and Ness (1970) at lower latitudes. This was particularly true for frequencies less than .05 Hz and for the total field magnitude spectra which was larger than the components perpendicular to the average field direction. Some low 20 second average field magnitudes that occurred during this interval were 14.1γ at 13:10 and 25.0γ at 13:16 which are 10% and 17% of the reference field values respectively. Values half this large were not uncommon within individual 20 second intervals nor were changes of 30γ in 10 seconds. A field minimum of 68γ (37% dipole field strength) was observed at 13:28 at a time where the field almost certainly must have connected to the earth. Note that the ΔB scale on this orbit had to be changed from that in other figures in order to accommodate values as small as -128γ at 13:10.

Again distortion of the field out of the meridian plane is indicated by the large value of D, although it should be realized that the field is nearly perpendicular to the horizontal (I near 90°) so a small component of the field is controlling the declination. A value of D of 90° indicates the horizontal field component is perpendicular to a meridian plane and a value of 180° indicates the horizontal component points back toward the sun in a meridian plane, as would a field line which was turning back over the pole. Values near 180° are attained at the highest latitudes near the region designated polar cap on the basis of particle measurements.

The high latitude data from orbit 7 are presented in Figure 7. The innermost crossing of the magnetopause probably occurs near 18:20 and the magnetosphere field directions are typical of that region. Inclination angles less than the dipole values correspond to field lines with increased curvature such as they would exhibit if they were closing in the daylight hemisphere. The large declination angle represents a bending of the field line away from the noon meridian in the direction generally seen in the dawn hemisphere. These large positive declinations correspond to field components perpendicular to the meridian plane of 40γ near 19:00 and 50γ near 20:15. The new feature in Figure 7 is the negative perturbation in the declination centered on 19:59 which is included in the region identified by Frank as the polar cusp. The maximum deviation at this time corresponds to a perturbation vector with approximate magnitude of 45γ and components -25γ, -35γ, and +10γ in the solar magnetic X, Y and Z directions respectively. The vector at the time of maximum perturbation differs by approximately 20° from the before and after vectors at 19:53 and 20:08 and these latter vectors differ by 5° themselves.

Since the total field magnitude change is less than 4γ the perturbation vector must be approximately perpendicular to the total field which in turn implies the existence of a field aligned current. Since the perturbation is confined to a relatively narrow region it is suggestive of two parallel sheet currents. The generally dusk to dawn direction of the perturbation vector requires an upward current on equatorward field lines and an earthward current on higher latitude field lines. This is in agreement with the results of Frank who consistently observes two sheets of downward directed electrons and protons with the electrons making up the equatorward sheet and the protons the higher latitude sheet. Declination changes similar to Figure 7 have been seen on other orbits near the noon meridian and similar though smaller changes can even be observed in Figures 5 and 6. Perturbations of the opposite sign have been seen less frequently. The direct comparision of field and plasma data will be pursued in a future study as will an investigation of the latitudinal and longitudinal extent of such events.

The observation of effects identified as due to field aligned currents at these latitudes is in agreement with the observations of Zmuda et al. (1966, 1967, 1970) and their interpretation by Cummings and Dessler (1967). Zmuda et al. measure transverse field perturbations on a low altitude polar orbiting spacecraft in the region of the auroral oval. The direction of the IMP 5 perturbation shown in Figure 7 and the interpretation in terms of sheet currents are similar to the one low altitude observation near the same local time which was analyzed in detail by Armstrong and Zmuda (1970). Sheet currents were also invoked to explain rocket observations at 2000 local time (Cloutier et al.) but here the relative north-south positions of the in going and outcoming currents were reversed from the dayside cases.

Although the perturbation vectors 1100 km above the earth's surface are in the range 30-900γ (Zmuda et al., 1970) whereas the outer magnetosphere perturbations are generally less than 45γ, this difference can be explained by the longitudinal divergence of the sheet of current. The field between two parallel sheet currents is proportional to the currents and is uniform and independent of position between the sheets. In the magnetosphere, however, the geomagnetic field diverges in the east-west or longitudinal direction yielding reduced sheet current intensity at the higher altitudes.

The total current, J, per unit length of longitude flowing into <u>and</u> out of the ionosphere in parallel sheets may be calculated as $J = \int \vec{j} \cdot d\vec{S}$ where $d\vec{S}$ is a rectangular area element oriented perpendicular to the field aligned sheets and containing one of them. Since $\vec{j} = \nabla x \vec{B}$ we obtain $J = \int \vec{B} \cdot d\vec{l}$ where the integration is around the area element. The only contribution to the integral is between the current sheets in the direction parallel to them. If two elements are considered, one at 1100 km and one in the outer magnetosphere, both of which contain the same field lines and consequently the same field aligned currents, $J = B_{L'}L' = B_L L$, where L' refers to low altitudes and the L to the outer magnetosphere. We see that the high latitude perturbation field B_L is smaller than the perturbation at 1100 km. by the ratio 1/L which is determined by the longitudinal divergence of field lines. For a dipole field line which intersects the earth at 75° latitude this ratio is 1/15 if L is calculated at 7 R_E. Thus the current and field perturbation observed in the outer magnetosphere should be reduced by this factor which brings the high and low altitude measurements into good agreement. Distortions from a dipole field will tend to increase L but this effect is undoubtedly less than a factor of 2, at least at distances within 7 R_E.

The outer magnetosphere observations appear to differ from the low altitude observations in their estimation of the latitudinal extent of the current region. Although IMP 5 is moving predominantly along lines of force rather than cutting across them, it is possible to use a dipole approximation to project the outer boundaries of the current region down toward the ionosphere and obtain a low altitude latitudinal width. If 19:58 and 20:06 are taken as the limits of the sheet current in Figure 7 a low altitude width of 8 km is obtained which is in agreement with the equivalent figure of 10-30 km cited by Frank as the typical width for the particle sheets. Heikkila and Winningham (1970) and Zmuda et al. (1966, 1967, 1970) on low altitude spacecraft find that the particle precipitation region and the field fluctuation region have widths which are typically several degrees of latitude (several hundred kilometers). For the example studied in detail by Armstrong and Zmuda they found the sheet currents to be separated by 218 km.

Summary and Conclusions

The configuration of the noon meridian magnetosphere magnetic field is in approximate agreement with previous measurements and the prediction of theory. Inside of approximately 6 R_E near the equator the field strength is generally depressed relative to a dipole, confirming the continual presence of a ring current. The field strength is enhanced in the outer magnetosphere near the equatorial plane but the enhancement decreases away from the equatorial plane. The enhancement becomes negative at approximately 40° geomagnetic latitude and a broad high latitude depressed field region is centered on the position of the polar cusp. Maximum field depressions in the cusp region are typically 50-70% of dipole field strength at 7 R_E and lower at greater altitudes near the point of transition between magnetosphere and magnetosheath fields. Bending of field lines away from the noon meridian plane is observed and is consistent with the necessity that less field lines pass through the weak field region. The generally depressed field in the high latitude region can probably be explained by currents on the magnetopause and the additional depressions by the presence of magnetospheric plasma but both of these suppositions must await further work.

Directional distortions of the dipole field are a maximum away from the geomagnetic equator in the outer dayside magnetosphere. Field line curvature is greatly enhanced at latitudes below and near the cusp region as the compressed fields close through the equatorial plane. At high latitudes the field lines are slightly bent towards the night hemisphere as if turning back over the polar cap. High latitude field lines diverge from the noon meridian plane and have vector components as much as 50γ perpendicular to a meridian plane. This effect reduces the amount of flux in the high latitude magnetosphere and accounts for the depressed fields which are observed. The magnetic field measurements confirm that the magnetosheath-like plasma observed by Frank on the same spacecraft is indeed seen in the magnetosphere in the sense that the magnetic field lines on which the plasma resides almost certainly have one end intersecting the earth.

The important question of interconnection between the geomagnetic field and the magnetosphere field remains difficult to answer definitely in spite of measurements in the appropriate region. In the outer cusp region between the magnetosheath and the clearly dipole field lines of the magnetosphere, the outstanding characteristic of the field is its high level of fluctuations. Still, the lack of a well-defined magnetopause in this region argues for reconnection since this in itself is a statement about the apparent equivalence of magnetosphere and magnetosheath fields. With fluctuating fields and the lack of a magnetopause surface it is impossible to perform the conventional analyses determining field components perpendicular to a surface.

Perturbations with magnitudes up to 45γ in a region of field of nominal 200γ strength are seen in the region of the polar cusp. Since the perturbations often tend to be perpendicular to a meridian plane and they tend to have a minimal effect on the total field strength, they must be approximately perpendicular to the total field and they can best be explained by field aligned currents of a filamentary or sheet-like nature. Sheets of precipitating protons and electrons measured by Frank are apparently consistent with the field observations but direct comparisons have not yet been made. The field perturbations are consistent with the low altitude perturbation measured by Zmuda except for the fact that the high altitude perturbations appear to be restricted to a narrower region of latitude. The theory of the current sheets has been discussed by Böstrom (1964) and extended by Taylor and Perkins (1970).

The fact that field aligned currents are so frequently observed even during magnetically quiet times suggest that they are related to a region of localized polar cap geomagnetic fluctuations (Mayaud, 1956; Lebeau, 1965) which are distinct (Fairfield, 1963; Feldstein and Zaitzev, 1968) from the usual pattern of disturbance observed during geomagnetic substorms.

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References

Armstrong, J. C. and A. J. Zmuda, Field-Aligned Current at 1100 km in the Auroral Region Measured by Satellites, J. Geophys. Res., 75, 7122-7127, 1970.

Behannon, Kenneth W. and Donald H. Fairfield, Spatial Variations of the Magnetosheath Magnetic Field, Planet. Space Sci., 17. 1803-1816, 1969.

Böstrom, Rolf, A Model of the Auroral Electrojets, J. Geophys. Res., 69, 4983-4999, 1964.

Cloutier, P. A., H. R. Anderson, R. J. Park, R. R. Vandrak, R. J. Spiger and B. R. Sandel, Detection of Geomagnetically Aligned Currents Associated with an Auroral Arc, J. Geophys. Res., 75, 2595-2600, 1970.

Cummings, W. D. and A. J. Dessler, Field Aligned Currents in the Magnetosphere, J. Geophys. Res., 72, 1007-1013, 1967.

Ershkovich, A. I., V. D. Pletnev and G. A. Skuridin, Injection of Solar Wind Particles into the Magnetosphere in the Neighborhood of a Neutral Point, J. Atmos. Terr. Phys., 29, 367-376, 1967.

Fairfield, Donald H., Ionosphere Current Patterns in High Latitudes, J. Geophys. Res., 3589-3602, 1963.

Fairfield, D. H., The Ordered Magnetic Field of the Magnetosheath, J. Geophys. Res, 72, 5865-5877, 1967.

Fairfield, D. H., Average Magnetic Field Configuration of the Outer Magnetosphere, J. Geophys. Res., 73, 7329-7338, 1968.

Fairfield, Donald H. and Norman F. Ness, Magnetic Field Fluctuations in the Earth's Magnetosheath, J. Geophys. Res., 75, 6050-6060, 1970.

Feldstein, Y. I., and A. N. Zaitzeve, Quiet and Disturbed Solar Daily Variations of Magnetic field at High Latitudes During the IGY, Tellus, 20, 338-366, 1968.

Forbes, T. G., T. W. Speiser, Mathematical Models of the Open Magnetosphere: Application to Dayside Auroras, U. Of Colorado Department of Astro-Geophysics preprint, January 1971.

Frank, L. A. and K. L. Ackerson, Observation of Charge Particle Precipitation into the Auroral Zone, J. Geophys. Res., 76, 3612-2643, 1971.

Frank, L. A., Plasma in the Earth's Polar Magnetosphere, Department of Physics, U. of Iowa preprint, November 1970.

Heikkila, W. J. and J. D. Winningham, Penetration of Magnetosheath Plasma to Low Altitudes through the Dayside Magnetospheric Cusps, J. Geophys. Res., 76, 883-891, 1971.

Heppner, J. P., M. Sugiura, T. L. Skillman, B. G. Ledley, and M. Campbell, OGO-A Magnetic Field Observations, J. Geophys. Res., 72, 5417-5471, 1967.

Lebeau, A., Sur l'activite Magnetique diurne dans les colottes polaires, Annls, Geophys. 21, 167, 1965.

Mayaud, P. N., Activite Magnetique Dans Les Regions Polares, Ann. Geophys. 12, 84-101, 1956.

Mead, Gilbert D. and Laurence J. Cahill, Jr., Explorer XII Measurements of the Distortion of the Geomagnetic Field by the Solar Wind, J. Geophys. Phys. 72, 2737-2748, 1967.

Olson, W. P., The Shape of the Tilted Magnetopause, J. Geophys. Res., 74, 5642-5651, 1969.

Piddington, J. H., The Magnetosphere and Its Environs, Planet. Space Sci., 13, 363, 1965.

Pletnev, V. D., G. A. Skuridin, V. P. Shalimov, and J. N. Schuachunov, Dynamics of the Geomagnetic Trap and Origin of the Earth's Radiation Belts, Geomagnetizm i Aeronomiya, 5, 485-498, 1965.

Russell, Christopher T., Charles R. Chappell, Michael D. Montgomery, Marcia Neugebauer, and Fredrick L. Scarf, OGO-5 Observations of the Polar Cusp on November 1, 1968, preprint March 1971.

Spreiter, J. R. and A. L. Summers, On Conditions Near the Neutral Points on the Magnetosphere Boundary, Planet. Space Sci., 15, 787-798, 1967.

Sugiura, M., T. L. Skillman, B. G. Ledley and J. P. Heppner, Magnetic Field Observations in High Beta Regions of the Magnetosphere, in Particles and Fields in the Magnetosphere edited by B. M. McCormac, D. Reidel Pub. Co., Dordrecht, Holland, 1970.

Taylor, Harold H., and Francis W. Perkins, Auroral Phenomena Driven by the Magnetospheric Plasma, J. Geophys. Res., 76, 272-277, 1971.

Williams, Donald J. and Gilbert D. Mead, Nightside Magnetosphere Configuration as Obtained from Trapped Electrons at 1100 Kilometers, J. Geophys. Res., 70, 3017-3029, 1965.

Willis, D. M., The Influx of Charged Particles at the Magnetic Cusps on the Boundary of the Magnetosphere, Planet. Space Sci., 17, 339-348, 1969.

Zmuda, A. J., F. T. Heuring and J. H. Martin, Dayside Magnetic Disturbances at 1100 Kilometers in the Auroral Oval, J. Geophys. Res., 72, 1115-1117, 1967.

Zmuda, A. J., J. H. Martin and F. T. Heuring, Transverse Magnetic Disturbances at 1100 km in the Auroral Region, J. Geophys. Res., 71, 5033-5045, 1966.

Zmuda, A. J., J. C. Armstrong and F. T. Heuring, Characteristics of Transverse Magnetic Disturbances Observed at 1100 Kilometers in the Auroral Oval, J. Geophys. Res., 75, 4757-4762, 1970.

Figure Captions

Figure 1 Measured field line directions near the noon meridian plane displayed in a geomagnetic coordinate system. The bars representing the tangents to the measured field vectors are averages over half earth radii intervals. Undistorted dipole field lines are labeled with their earth intersection latitude. The histogram represents the incident directions of the solar wind during the measurements.

Figure 2 Spatial distribution of ΔB near the noon meridian. The area of the circles is proportional to the depression of the measured field relative to a dipole and the area of squares is proportional to the compression of the field. Circles at low latitudes and low altitudes confirm the presence of a ring current whereas those at high latitudes are associated with the polar cusp.

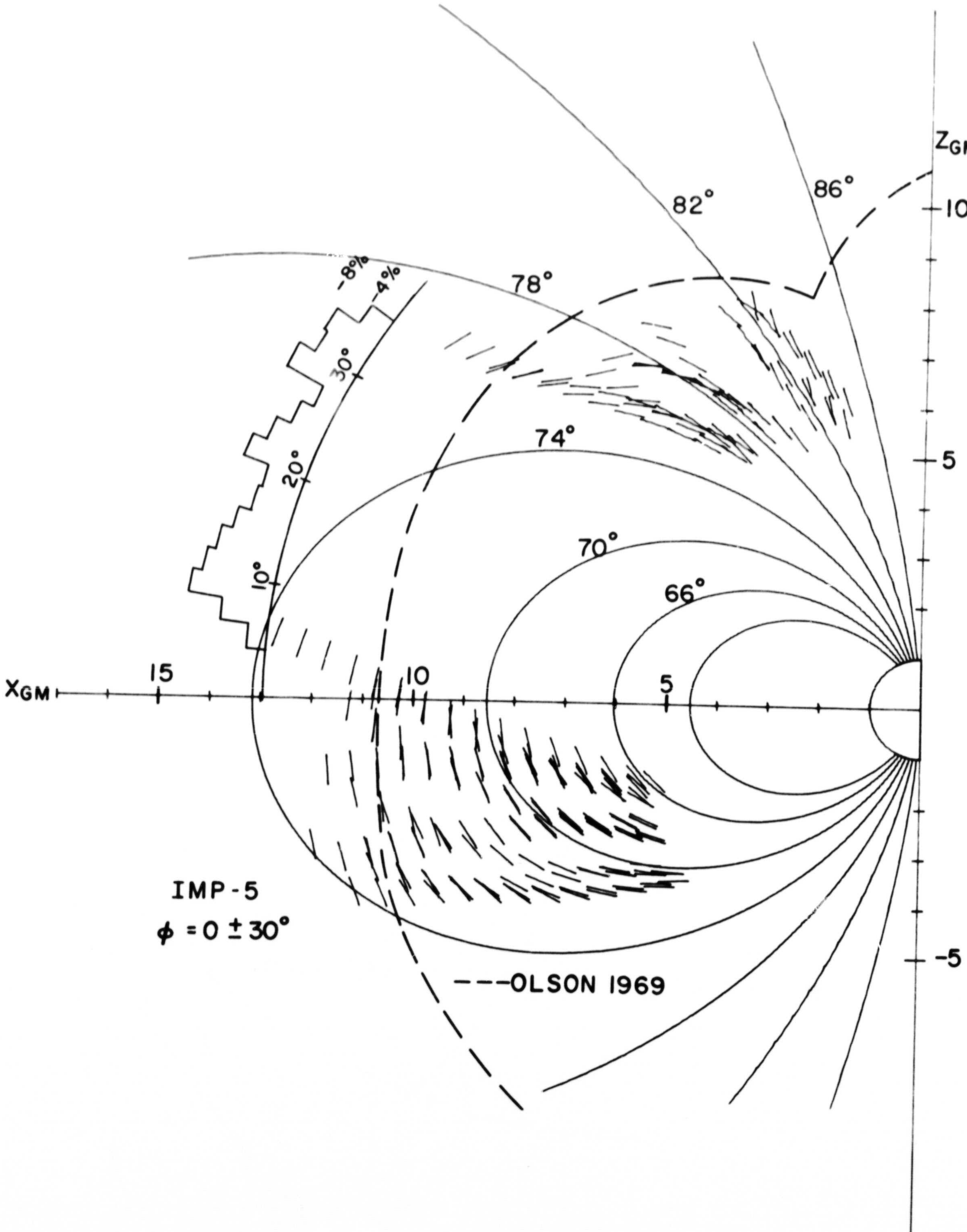
Figure 3 Spatial distribution of I near the noon meridian plane in the same format as Figure 2. Because of the definition of I, squares in the southern hemisphere indicate the equivalent distortion of circles in the northern hemisphere.

Figure 4 Field magnitude B, field magnitude difference ΔB, inclination I, declination D and standard deviation δ for an inbound pass at relatively low IMP 5 latitudes. The agreement of the measured I and D values with the smooth trace of the Mead-Williams model is better than the agreement with the smooth trace representing an undistorted dipole. The vertical line representing the magnetopause as determined by Frank is near the region where the field direction changes and the magnetosheath fluctuations terminate.

Figure 5 High latitude inbound pass of IMP 5 with data in the same format as Figure 4. The depressed field region is centered on the polar cusp as defined by Frank.

Figure 6 High latitude inbound pass where IMP 5 passed directly from the magnetosheath into the polar cusp region. Minimum B values were again centered on the cusp region. Magnetic field spectra using the detailed data obtained between 1240 and 1310 contain more power than any of 70 IMP 4 spectra from lower latitudes.

Figure 7 Inbound pass of IMP 5 where the polar cusp was encountered at lower altitudes. The perturbation vector producing the declination change near 2000 was of approximately 45γ magnitude and perpendicular to a meridian plane.



Z_{GM}
10
5
-5
86°
82°
78°
74°
70°
66°
-8%
-4%
30°
20°
10°
X_{GM}
15
10
5
IMP-5
$\phi = 0 \pm 30°$
---OLSON 1969

Figure 1

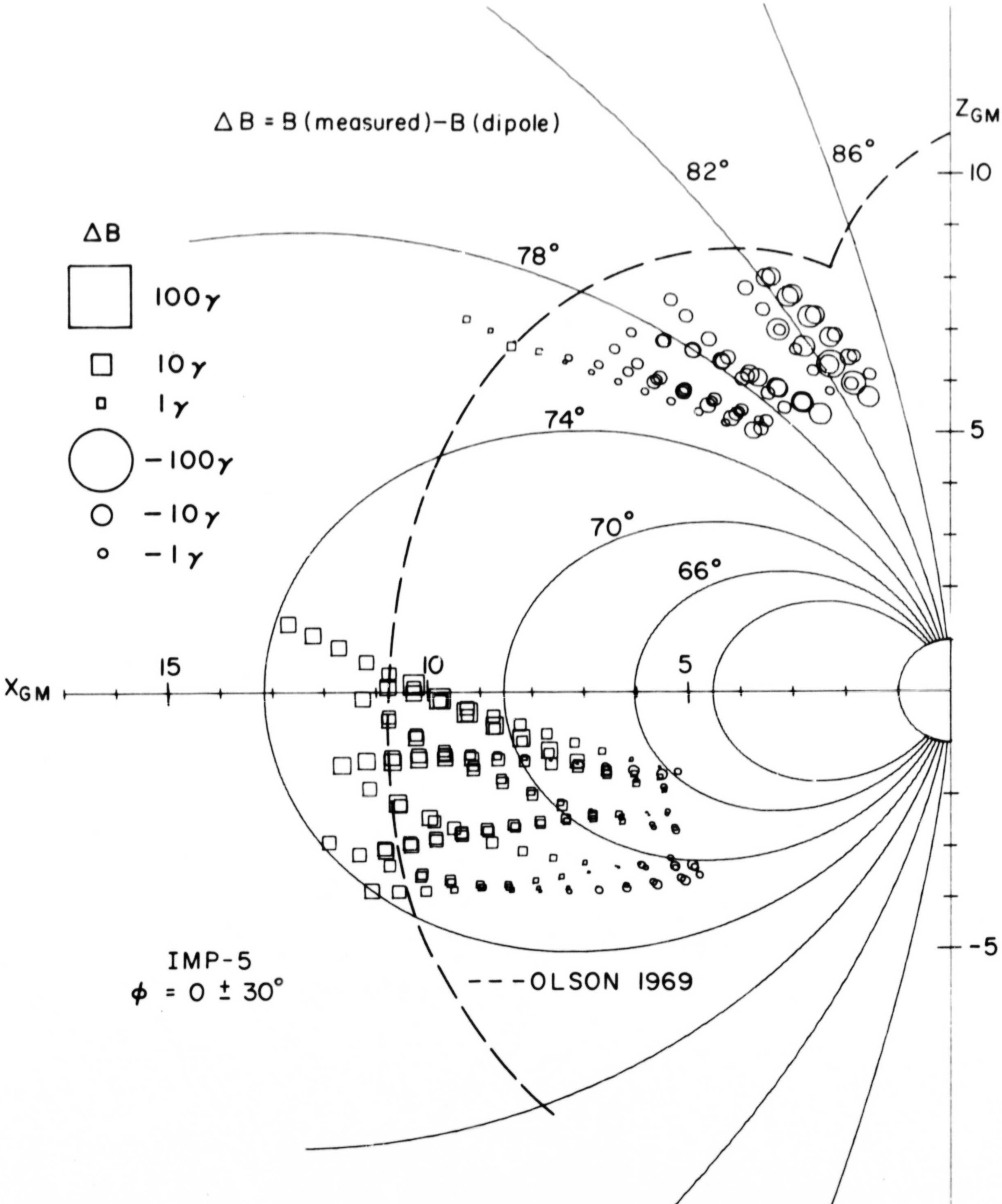

ΔB = B (measured) − B (dipole)
ΔB
100 γ
10 γ
1 γ
−100 γ
−10 γ
−1 γ
Z_{GM}
X_{GM}
86°
82°
78°
74°
70°
66°
10
5
−5
15
IMP-5
φ = 0 ± 30°
OLSON 1969

Figure 2

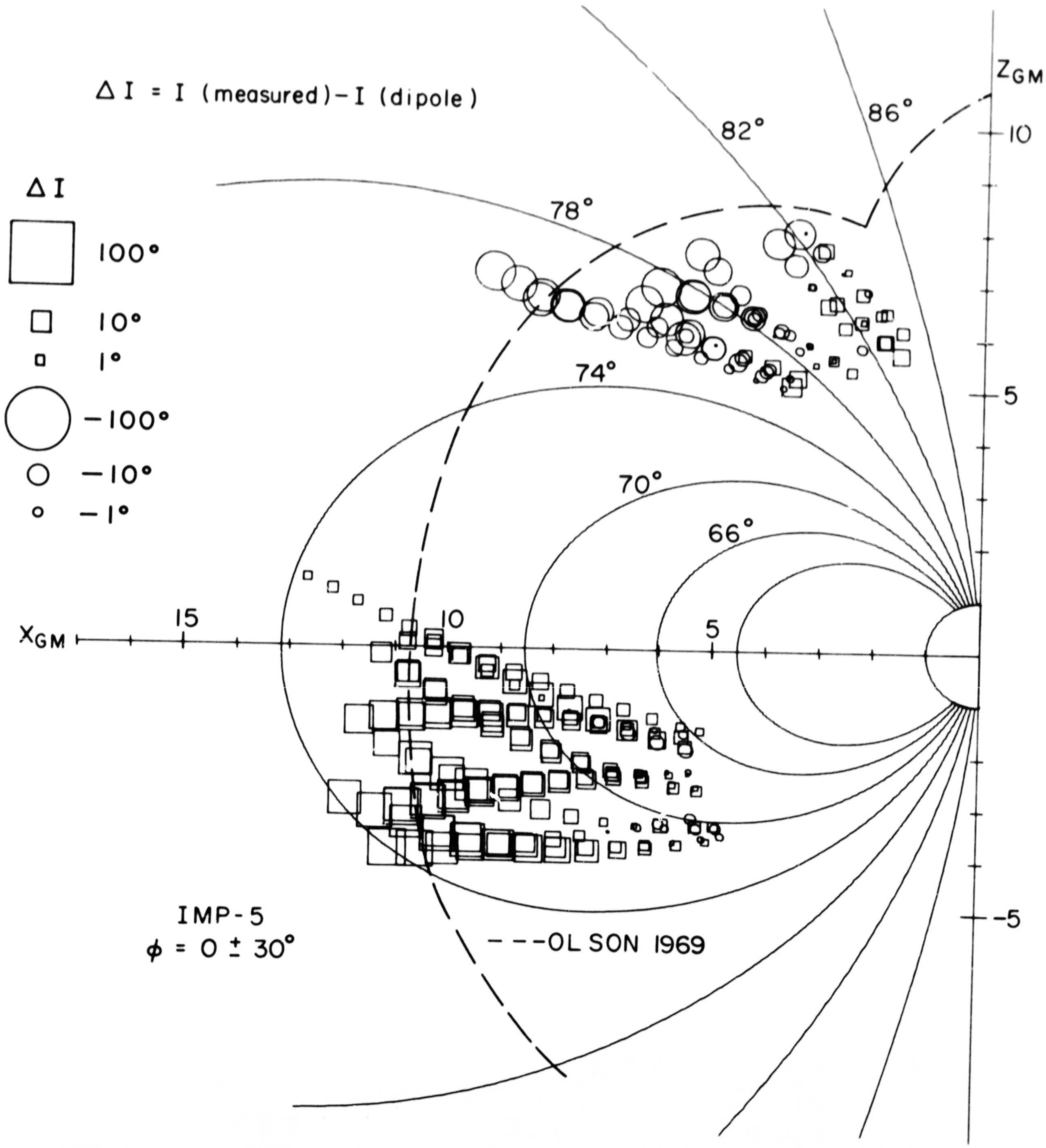

ΔI = I (measured) − I (dipole)
ΔI
100°
10°
1°
−100°
−10°
−1°
Z_{GM}
10
5
−5
86°
82°
78°
74°
70°
66°
X_{GM}
15
10
5
IMP-5
$\phi = 0 \pm 30°$
---OLSON 1969

Figure 3

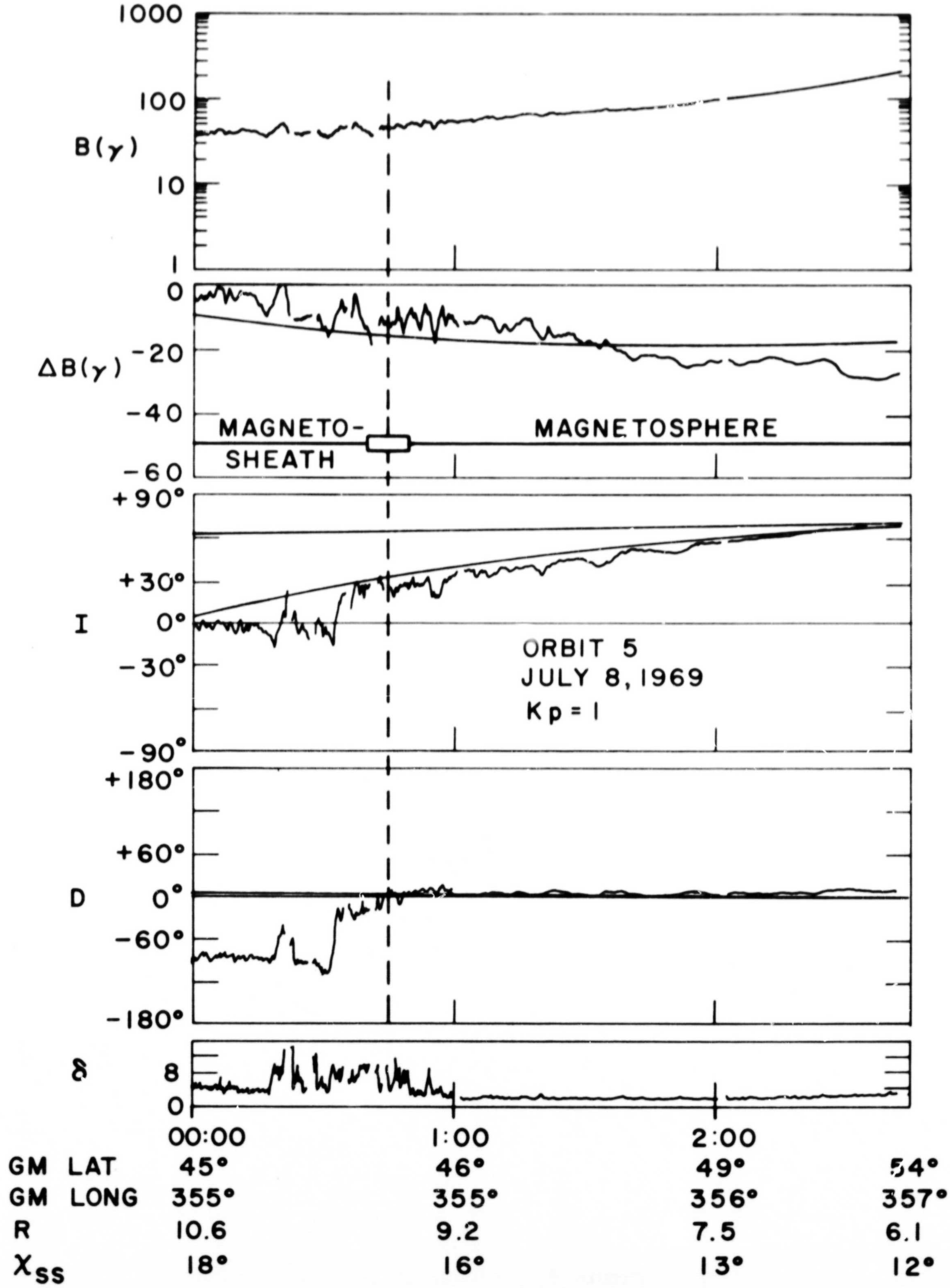

1000
100
B(γ)
10
1
0
ΔB(γ) -20
-40
-60
MAGNETO-
SHEATH
MAGNETOSPHERE
+90°
+30°
I
0°
-30°
-90°
ORBIT 5
JULY 8, 1969
Kp = 1
+180°
+60°
D
0°
-60°
-180°
δ
8
0
00:00
1:00
2:00
GM LAT 45° 46° 49° 54°
GM LONG 355° 355° 356° 357°
R 10.6 9.2 7.5 6.1
X_SS 18° 16° 13° 12°

Figure 4

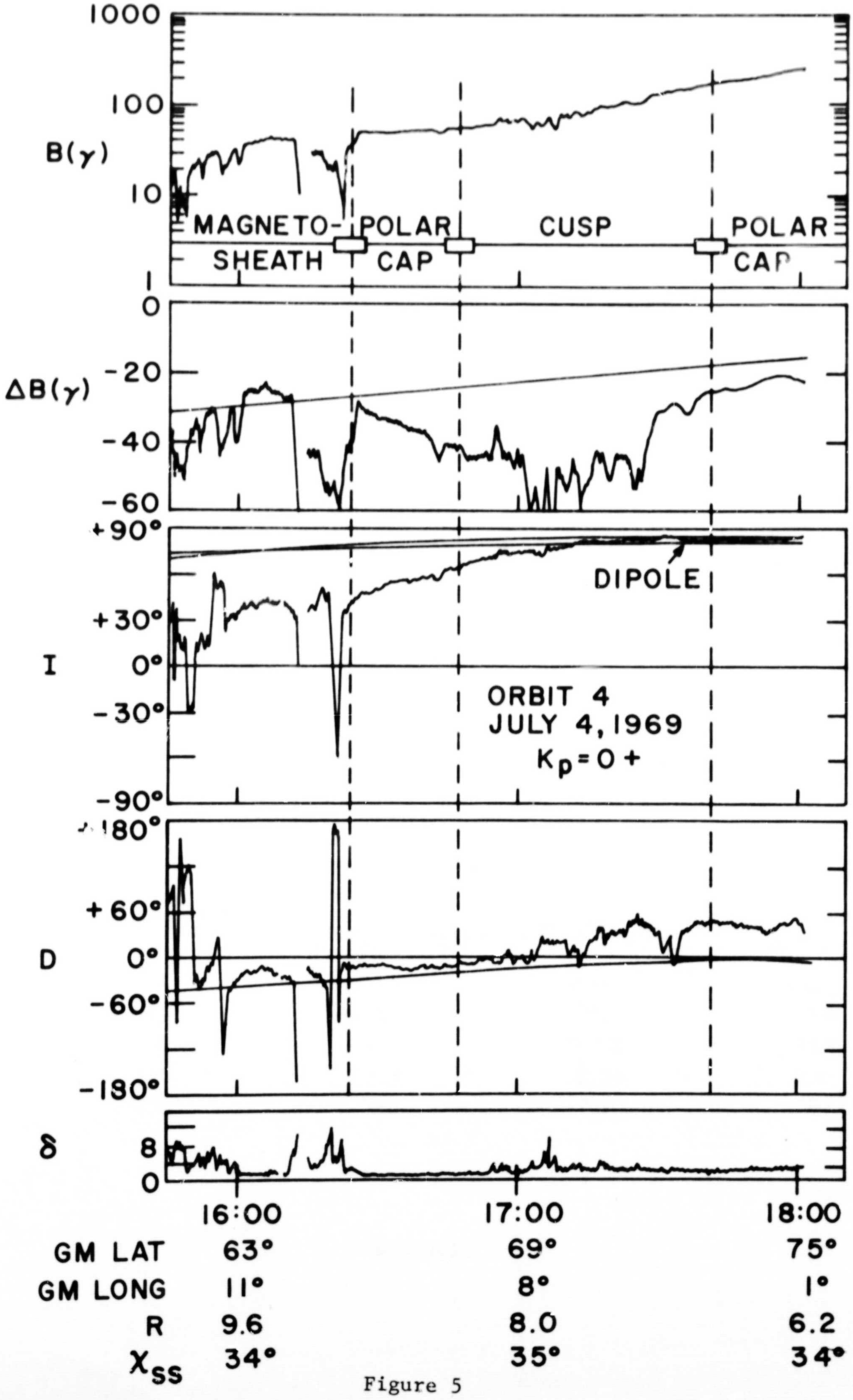

1000
100
B(γ)
10
1
MAGNETO-
SHEATH
POLAR
CAP
CUSP
POLAR
CAP
0
-20
ΔB(γ)
-40
-60
+90°
DIPOLE
+30°
I
0°
-30°
ORBIT 4
JULY 4, 1969
Kp = 0 +
-90°
180°
+60°
D
0°
-60°
-180°
δ
8
0
16:00
17:00
18:00
GM LAT 63° 69° 75°
GM LONG 11° 8° 1°
R 9.6 8.0 6.2
χss 34° 35° 34°

Figure 5

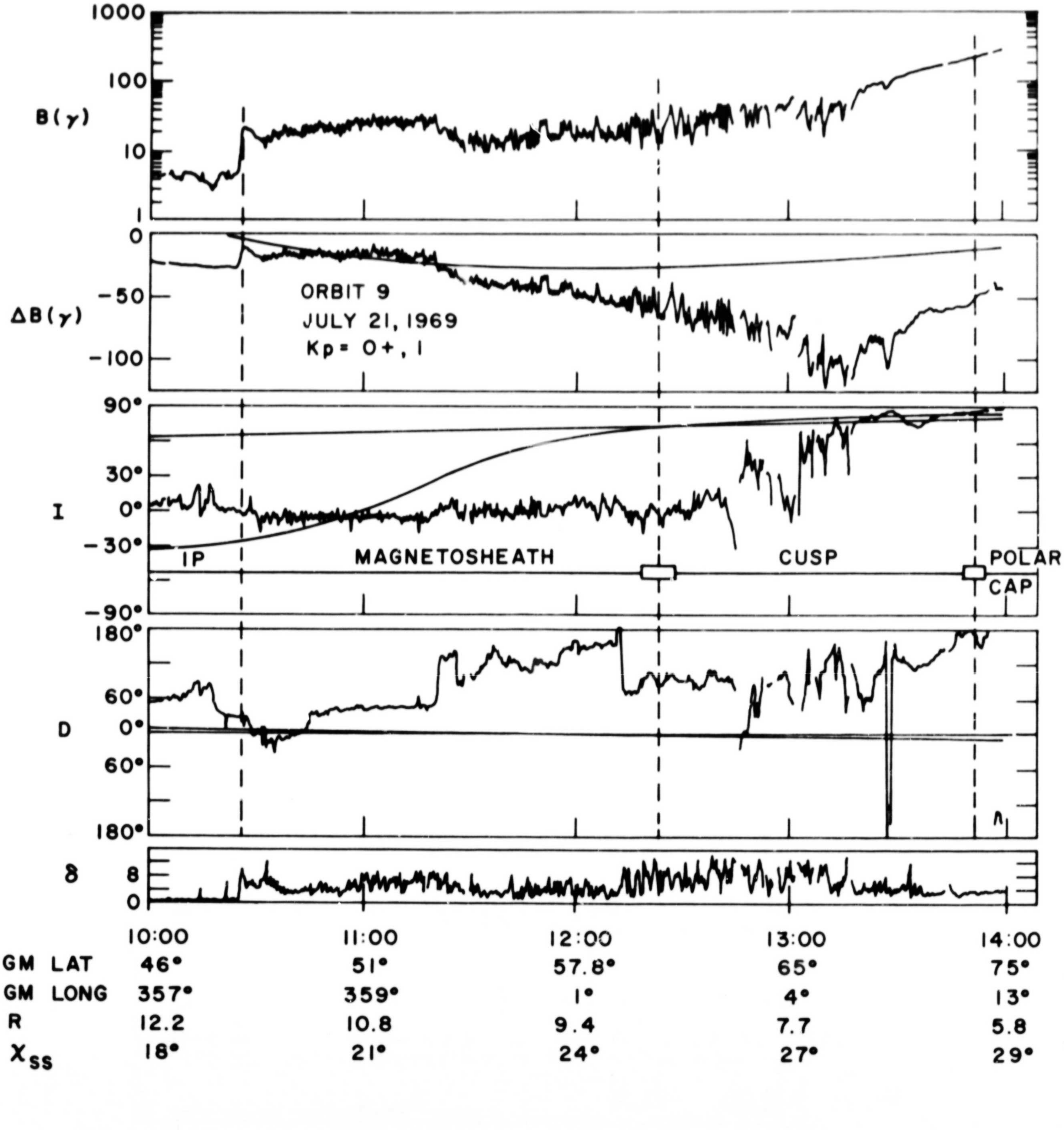

1000
100
10
1
B(γ)
0
-50
-100
ΔB(γ)
ORBIT 9
JULY 21, 1969
Kp= 0+, 1
90°
30°
0°
-30°
-90°
I
IP
MAGNETOSHEATH
CUSP
POLAR
CAP
180°
60°
0°
60°
180°
D
δ
8
0
10:00
11:00
12:00
13:00
14:00
GM LAT 46° 51° 57.8° 65° 75°
GM LONG 357° 359° 1° 4° 13°
R 12.2 10.8 9.4 7.7 5.8
χss 18° 21° 24° 27° 29°

Figure 6

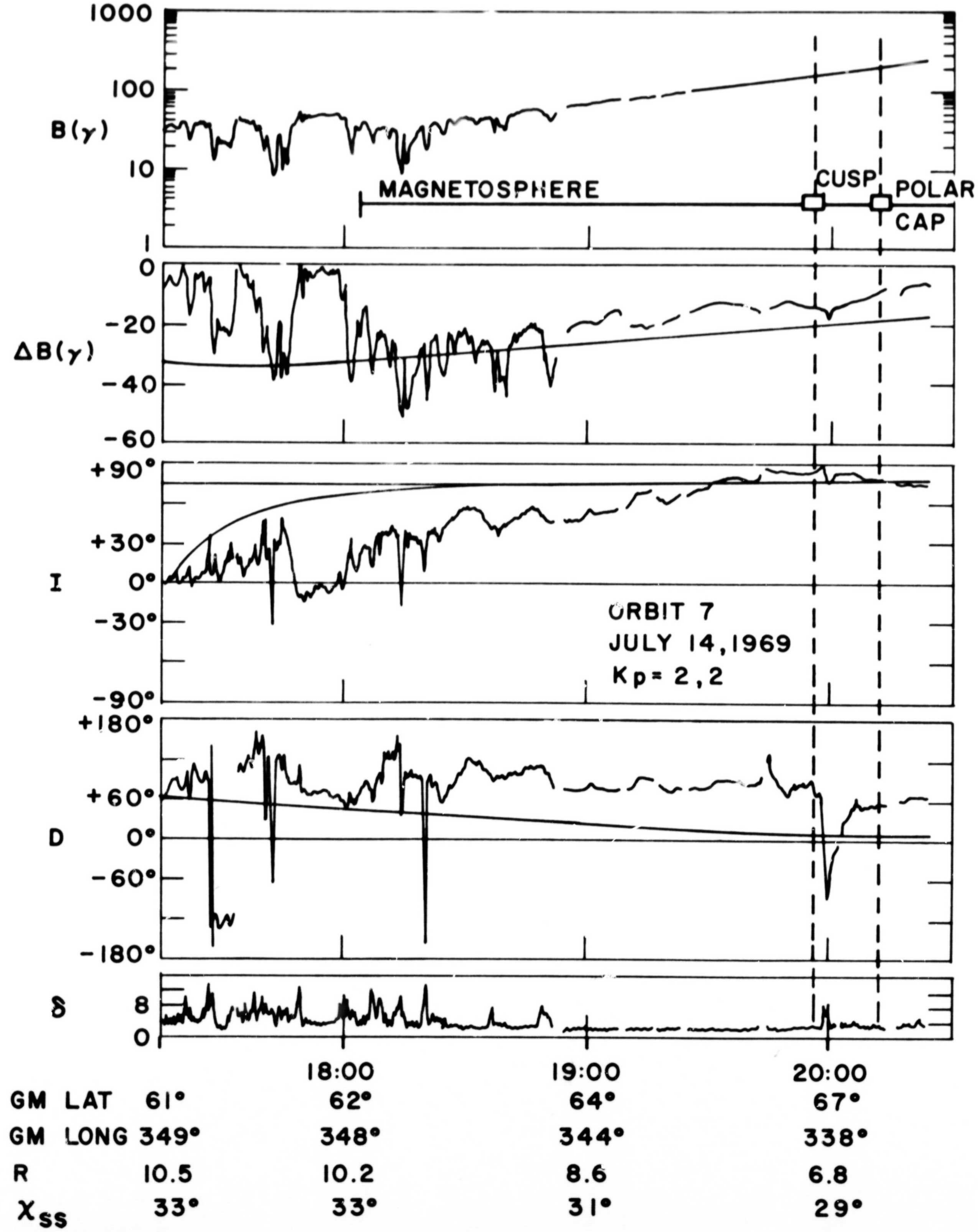

1000
100
B(γ)
10
1
MAGNETOSPHERE
CUSP
POLAR
CAP
0
-20
ΔB(γ)
-40
-60
+90°
+30°
I
0°
-30°
-90°
ORBIT 7
JULY 14, 1969
Kp= 2, 2
+180°
+60°
D
0°
-60°
-180°
δ
8
0
18:00
19:00
20:00
GM LAT 61° 62° 64° 67°
GM LONG 349° 348° 344° 338°
R 10.5 10.2 8.6 6.8
X_{SS} 33° 33° 31° 29°

Figure 7