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FINAL REPORT

"ANALYSIS OF ATS-5 DATA"

Contract NASw 2424

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Our principal activity under this contract has been in the area of cooperative studies of various events for which coordinated data from ATS-5 and other satellites or ground observations are available. One of these studies in cooperation with the University of Alberta has recently been completed and the resulting paper entitled "The Expansive Phase of Magnetospheric Substorms. II - The Response at Synchronous Altitude of Particles of Different Energy Ranges" is included as Appendix A. An invited paper on these results will be presented by Dr. Richard D. Sharp at the topical conference on "The Electro-dynamics of Substorms and Magnetic Storms" at Bryce Mountain, Virginia, 11-14 June 1974. Several other similar projects are in various stages of completion as will be described below. We hope to finish these projects under a follow-on program for which a proposal has been submitted (ATS-5 Data Analysis, A Proposal for a Follow-On to Contract NASw 2424, dated November 1973).

1. VELA Coordinations

The VELA 5A and VELA 6A satellites were located in the magnetotail during the substorm of 1 September 1970 which is discussed in Appendix A. A comparison of the energetic particle data from these satellites with the ATS-5 data is currently in progress. Dr. Edward W. Hones, Jr., of the Los Alamos Scientific Laboratory is cooperating in this study. Plasma sheet "thinning" began at VELA well in advance of the clearly defined onset of the substorm expansion phase, almost simultaneously with the observed "thinning" at ATS-5. Recovery of the particle fluxes occurred almost simultaneously at both VELA satellites, much later in the substorm event than it was observed at ATS-5. The significance of this apparent radial dependence of the recovery time of the plasma sheet is currently under study.

2. University of Alberta Coordinations

A further and more quantitative study of simultaneous ATS-5 and magnetometer data in cooperation with Prof. Gordon Rostoker has revealed a surprising relationship between the electron energy flux at ATS-5 and the strength of the westward electrojet modeled from the magnetometer chain data. In four substorm events, these two quantities exhibited a linear relationship over an extended time period and a large dynamic range. This relationship was observed for the electrojet amplitude at the projected latitude of the ATS-5 field line and did not hold for the electrojet maximum amplitude which varies in latitude over the course of the events. Some preliminary working drawings illustrating this relationship are included in Appendix B. It should be noted that the proportionality constant between the energy flux and the magnetic field perturbations is roughly the same for all four cases studied. This linear relationship is not expected on the basis of simple considerations of ionospheric conductivities and electric fields during substorms and may imply that the controlling factor in the amplitude of the electrojet is the Birkeland current in series with it which could be carried by, or be proportional to, the measured fluxes in the keV range.

3. Low-Latitude Substorm Signatures

Professor A. Nishida of the University of Tokyo is a specialist in interpreting substorm signatures from low-aatitude nightside magnetograms. We are working with him in an attempt to order a substantial body of ATS-5 observations with respect to the timing inferred from these magnetogram signatures. In an initial survey of 16 isolated events we have found thirteen cases where the onset of the low-latitude positive bay is detected in association with the plasma events at synchronous altitude. In Nishida's latest work[1] he has

[1] Nishida, A., and N. Nagayama, "Synoptic Survey for the Neutral Line in the Magnetotail during the Substorm Expansion Phase," J. Geophys. Res., 78, 3782, 1972.

shown that these signatures signify the onset of neutral line formation in the magnetotail. We are currently investigating the behavior of the plasma at ATS-5 on a time frame defined by this onset.

## 4. All-Sky Camera Coordinations

Dr. Steven B. Mende of the Lockheed Palo Alto Research Laboratory has acquired a substantial body of ground-based optical data, all-sky camera and photometer data, in coordination with the ATS-5 particle data. These optical data, although more restricted in their latitudinal extent than the magnetometer chain data, have the advantage that one can quantitatively estimate the particle precipitation rate from the intensity of the emissions, and thereby estimate the strength of pitch-angle scattering and the particle lifetimes in conjunction with the plasma data. We have begun a comparison, in cooperation with Dr. Mende, of two substorm events on 13 and 14 February 1970.

## 5. NASA Airborne Auroral Expedition

Professor G. G. Sivgee of the Geophysical Institute of the University of Alaska is currently analyzing data from the 1969 NASA Airborne Auroral Expedition in which the NASA CV-990 made optical observations near the foot of the ATS-5 field line. We are cooperating with him in analyzing some of the coordinated results. In one event, an estimate of the precipitation intensity of electrons from the optical data yields 1.9 ergs/cm$^2$-sec-sterad (assuming isotropy) while the ATS-5 data give the trapped electron flux at 14.0 ergs/cm$^2$-sec sterad. The electron lifetime inferred from the comparison bears out the puzzling trend reported by us earlier[2] for an increasing particle lifetime with increasing flux intensity. These earlier results were based on coordinated ATS-5 and polar satellite measurements.

[2] Sharp, R. D., D. L. Carr, R. G. Johnson, and E. G. Shelley, "Coordinated Auroral Electron Observations from a Synchronous and a Polar Satellite," J. Geophys. Res., 76, 7669, 1971.

6. September 1969 Events

Dr. Richard D. Sharp has been invited to participate in a seminar on selected substorms in September 1969 at the conference on "The Electrodynamics of Substorms and Magnetic Storms" at Bryce Mountain, Virginia, 11-14 June 1974. Dr. Sharp will present the ATS-5 results during the selected substorms for which multiply-coordinated data exist. The study of these events is being carried out in cooperation with R. L. McPherron (UCLA), G. Rostoker (Univ. of Alberta), and E. W. Hones, Jr. (LASL).

7. Plasma Properties

We have begun a statistical study of the plasma properties at ATS-5 under this contract. Unexpected difficulties with the rather noisy data tapes and an unexpectedly large number of requests from scientists wanting to collaborate with us on various projects have prevented us from finishing the project to this time. We have, however, completed the development of a new computer program applicable to this task which overcomes the difficulties associated with the noisy data tapes and provides for the automatic processing of the in-flight calibration sequence data in order to allow us to evaluate the effects of channel multiplier degradation on the experimental results.

# A P P E N D I X   A

## THE EXPANSIVE PHASE OF MAGNETOSPHERIC SUBSTORMS

## II. THE RESPONSE AT SYNCHRONOUS ALTITUDE OF PARTICLES OF DIFFERENT ENERGY RANGES

NOTE: Unfortunately, three figures (2, 3, and 7) and a few numbers in the text, all to be provided by the University of Alberta co-authors, had to be left out of this version of the paper since they were not available in time to make the deadline for this report. The final version of the paper as submitted to the Journal of Geophysical Research will be forwarded as soon as it is available.

The Expansive Phase of Magnetospheric Substorms

II The Response at Synchronous Altitude of Particles of Different Energy Ranges

by

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Abstract

Data from the Lockheed particle detectors on ATS-5 in synchronous orbit and from the meridian line of magnetometers operated by the University of Alberta are correlated for periods of well defined substorm activity. Specific substorm events are presented whose region of maximum perturbation can be accurately identified using current system modelling techniques. It is found that impulsive particle response at ATS-5 is correlated with changes in the auroral electrojet structure during the development of the substorm expansive phase. The response of the particle detectors appears to differ from event to event depending on the geometry of the disturbed region of the magnetosphere. It is concluded that the substorm disturbance typically begins at low latitude and propagates poleward in impulsive steps and that energetic electron enhancements are observed at ATS-5 when the poleward border of the electrojet intensifies in the latitude range of the ATS-5 field line.

This fact permits the mapping of field lines in the equatorial plane to the earth's surface at specific instants during the substorm expansion phase.

Introduction

With the increasing interest in the theoretical description of substorm mechanisms over the last few years, it has become necessary to attempt to define in great detail the morphology of the development of all aspects of the magnetospheric substorm. This has been done to some extent through ground based monitoring and through recordings of interplanetary and magnetospheric plasma and magnetic field parameters obtained by spacecraft instrumentation. The reader is referred to a review on polar magnetic substorms by Rostoker (1972) for the details of such studies and a comprehensive bibliography.

Unfortunately interpretation of the data obtained by spacecraft and ground based instrumentation has always been subject to some degree of ambiguity, particularly in the attempts to correlate the two suites of data. On the part of the satellite, it is extremely difficult to separate spatial and temporal variations recorded on a moving vehicle and multisatellite correlation studies are rare and also subject to considerable limitations. With regard to the ground based studies, there is a great problem in using the existing widely and irregularly spaced network of observatories to study what is essentially a spatially localized and temporally short lived perturbation.

Data taken on synchronous satellites have been very valuable in establishing the statistical behaviour of the energetic particle distribution during substorms. Since the field lines at synchronous orbit drop into the average auroral zone, the satellite often sees intense particle fluxes near the onset of substorm perturbations. In addition, it is known that the inner edge of the plasma sheet tends to move inwards in association with substorm activity (Vasyliunas, 1968) and the average location of the inner edge of the plasma sheet is such that it often sweeps over a satellite at synchronous orbit (Schield and Frank, 1970; Shelley et al., 1971).

Fluxes of very energetic electrons (E > 50 kev) associated with substorms have been studied by Parks and Winckler (1968), Arnoldy and Chan (1969), and Lezniak and Winckler (1971) among others using ATS-1 data. In particular Lezniak and Winckler noted a statistically significant difference in the behaviour of the energetic electron fluxes depending upon the position of the satellite with respect to local midnight. They concluded from their results that in the evening sector substorms are associated with inflation of the magnetosphere while in the morning sector they are accompanied by collapse. More recently Erickson and Winckler (1973) have shown that marked decreases in the energetic electron flux in the evening sector are associated with substorm expansive phases in the midnight sector.

Studies of the behaviour of energetic electrons and protons over a wide energy range have been carried out recently using ATS-5 data by DeForest and McIlwain (1971) and Shelley et al. (1971), and some of the results have been summarized by Sharp and Johnson (1972). In particular, DeForest and McIlwain have claimed on the basis of their data that they can use knowledge of the dispersion in the energy traces of their spectrograms to infer the time of injection of the particles into the trapping region. However, at the present time it is unknown as to whether the energetic particles exist prior to the substorm and are convected inward in association with the substorm expansion phase, or whether they are accelerated during that expansive phase. Only in the correlative study by Mende et al. (1972) has it been established that for the one event which was studied the increase in electron flux was a temporal and not spatial event.

In our paper we hope to look further at this question of the separation of spatial and temporal effects. To do so we shall use data from the meridian line of magnetometers operated by the University of Alberta. Data from this meridian line have been used to separate the spatial and temporal fluctuations of the auroral electrojet using techniques developed by Bonnevier et al. (1970) and Kisabeth (1972). In addition the geometry of perturbation current systems associated with electrojet development has been modelled (Rostoker and Kisabeth, 1973; Kisabeth and Rostoker, 1973) and these modelling techniques will be used to estimate the position of ATS-5 with respect to the intensified region of the westward electrojet.

Description of the Data Acquisition and Presentation

The Lockheed experiment has been described by Sharp et al. (1970). It includes six individual channel multiplier detectors which will be principally utilized in this work. Four electron detectors use 180$^{o}$ permanent magnet analyzers to define the differential energy windows listed in Table 1. Two proton detectors utilize thin foils to define proton thresholds at 5 and 15 keV. These detectors employ broom magnets to sweep out electrons with energies below about 500 keV. One should bear in mind that in constrast to the electron detectors the proton detectors are integral channels. The view angles of the detectors are oriented approximately parallel to the spacecraft spin axis and toward geographic north. Data

Table 1 Energy Ranges of Detectors

| Channel | Particle | Energy Range (keV) |
|---|---|---|
| CME-A | electrons | 0.65-1.9 |
| CME-B | electrons | 1.9-5.4 |
| CME-C | electrons | 5.9-17.8 |
| CME-D | electrons | 17.4-53 |
| CFP-A | protons | > 5 |
| CFP-B | protons | > 15 |

from the ATS-5 magnetometer are available through the courtesy of T. Skillman. These data have not been corrected for vehicle backgrounds and instrumental effects and are used here only as a qualitative guide. The foot of the ATS-5 field line drops into Central Canada near Lynn Lake, Saskatchewan (67.3$^{\circ}$N, 316.1$^{\circ}$E corrected geomagnetic), which is $\sim$ 15$^{\circ}$ to the east of the meridian line of magnetometers. Local midnight at the satellite is approximately 0700 UT.

The locations of the sites of the University of Alberta magnetometer line have appeared in several publications (see, for example, Kisabeth and Rostoker, 1971). The coordinates are listed in Table 2 along with the code names which appear in the presentation of the data in magnetogram format. A detailed description of the data acquisition appears in the first paper of this series (Kisabeth and Rostoker, 1974) and it will suffice to say here that the data sampling rate of the magnetometers gives a resolution of ±2 seconds which is comparable to that obtained for the ATS-5 data. The modelling techniques are found in Kisabeth (1972) and involve current flow along the auroral oval while taking into account the effects of earth induction. In the following section we will study the detailed development of three substorms, paying considerable attention to temporal and spatial variations of the current systems during the expansion phases.

Table 2

Corrected Geomagnetic Coordinates of Magnetometer Line Sites

| Site | Code Name | Invarient Latitude(°N) | Corrected Geomagnetic Longitude(°E) |
|---|---|---|---|
| Resolute Bay | RESO | 83.2 | 306.0 |
| Cambridge Bay | CAMB | 76.9 | 300.3 |
| Fort Reliance | RELI | 70.5 | 300.0 |
| Fort Smith | SMIT | 67.5 | 299.8 |
| Fort Chipewyan | FTCH | 66.5 | 301.3 |
| Fort McMurray | MCMU | 64.5 | 302.7 |
| Meanook | MENK | 62.2 | 301.2 |
| Leduc | LEDU | 60.9 | 301.5 |
| Calgary | CALG | 58.8 | 302.0 |
| Newport | NWPT | 55.9 | 299.5 |

## Analyses of the Substorm Events

(i) Day 244, 1970

This day has some typical features common to many substorms and also contains some unusual aspects to the response of the particles at synchronous orbit to the buildup of substorm conditions. In addition, the magnetograms exhibit a well-defined behavior in the polar cap, auroral zone, and middle-to-low latitudes which is interpretable in terms of the phase of substorm activity. The magnetograms from the station line are shown in Figure 3 of paper I; selected magnetograms from high-latitude, auroral zone, and low-latitude stations are shown in Figure 2 of paper I. In addition to these data and the ATS-5 data shown in Figure 1, the following information was available:

(i) Interplanetary field data (Figure 1 of paper I);

(ii) All-sky camera data at SMIT; and

(iii) Visual auroral observations at SMIT accurate to ± 10 seconds.

The interval of interest commences at ∿ 0530 UT before which the activity was rather weak at auroral zone latitudes and the interplanetary magnetic field had a northward component. At ∿ 0535 UT the IMF turned southward (the IMF was observed to turn southward at 0515 UT at Explorer 35; see paper I for extrapolation to earth) and stayed in that configuration for the duration of the interval of interest.

At ∿ 0530 a sharp substorm-type disturbance was noted in the Alert magnetogram (Figure 1 of paper I), and at auroral zone latitudes (see Figures 2b of paper I) an eastward electrojet was observed to grow in the evening sector and a westward jet in the morning sector. By 0600 UT there was clear eastward electrojet activity in the evening sector and westward electrojet activity in the morning sector (see Leirvogur in Figure 2b of paper I). During this time low-latitude observatories began to show depression in the H-component (see Huancayo in Figure 1 of paper I) and at the ATS-5 orbit all electron channels showed increasing fluxes until about 0625 UT. This type of increase has been interpreted by Shelley et al. (1971) as the signature of the inward convecting plasma sheet engulfing the satellite. On the ground no visual arcs were apparent at the station line, although one cannot rule out the possibility of diffuse subvisual auroral luminosity. Also at about 0600 UT the energetic proton fluxes began to decrease (see CFP-P in Figure 1) as a characteristic midnight sector signature in these particles began to develop (Sharp et al., 1970; Mende et al., 1972).

From $\sim$ 0620-0640 UT the electron fluxes decreased in all channels, starting at high energies and moving sequentially to lower energies. By 0648 UT electron fluxes were observed above detector background only in the lowest energy channel (CME-A). This sequence of events was quite unusual. Decreases in the more energetic particle fluxes in conjunction with substorms are a common occurrence at synchronous orbit (Lezniak and Winckler, 1970; Bogott and Mozer, 1972; Erickson and Winckler, 1973) and are generally interpreted as the result of earthward motions of the trapped particle populations with steep negative radial gradients (i.e., boundaries) to the fluxes; however, the electron fluxes in the energy range of the Lockheed spectrometer rarely reach such low levels as seen in Figure 1. A reasonable interpretation of this event is discussed later.

The Z component of the ATS magnetometer, $B_Z$ (the component along the spacecraft spin axis - approximately geographic north) was generally decreasing during this period, reaching a minimum at $\sim$ 0630 UT after which it was level until the onset of the major substorm. Examination of the other components of the spacecraft magnetometer (which are available only at much reduced temporal resolution) indicates that the change in the Z component was principally due to a rotation of the field into a more tail-like configuration rather than a magnitude change.

After 064? UT a quiet arc became visible at SMIT; the arc appeared to be approximately over FTCH (67.0°N) and was quite faint.

The above-mentioned sequence of events appears to have occurred during a time interval when there was no substorm activity in the average auroral zone. Such a period might be construed as the growth or development phase of the ensuing substorm expansive phase activity. On the other hand, there appears to be very high-latitude substorm-like activity going on at this time which is discussed in detail in paper I of this series. At Alert (see Figure 2 of paper I) we see evidence of a large amplitude magnetic perturbation near 0530 UT when the IMF turned southward and subsequent substorm-type activity until ∿ 0640 UT. It is interesting to note that the cessation of activity in the polar cap corresponded to the appearance of visual arc activity in the auroral zone.

The substorm which followed this buildup of activity was observed to onset in both the magnetic and auroral signatures at 0654:34 UT. The center of the current system was ∿ 64°N (invarient latitude) and it was initially no more than 3° in width. The diagrams showing the development of the expansive phase are shown in Figures 6-11 of paper I.

At ATS-5, no response to the substorm onset was observed until 0658:20. At that time the electron fluxes began to increase simultaneously in all energy channels and $B_Z$ increased by approximately 10 gamma. Examination of the other components of the magnetic field indicated that this change was also primarily a rotation, but this time to a more dipole-like configuration. Approximately one minute later there was a very rapid increase in proton flux. The fact that the electron flux increases began nearly simultaneously in all energy channels indicates that the particles originated in the near vicinity of the satellite rather than being injected or heated elsewhere and drifted to the satellite. It is noteworthy that there was a delay of about four minutes between the onset of the expansion phase in the auroral zone and the rapid changes in particle fluxes at ATS-5. This implies that the initial substorm onset did not occur on the field line passing through ATS-5. Since the principal effect in the ground observations was a poleward propagation of the expanding northern border of the electrojet, we infer that the radial outward motion of this disturbance was the cause of the sudden particle changes beginning at 0658:20 UT. We also note that after the initial onset at 0654:34 UT the peak disturbance of the electrojet was $\sim 100\gamma$ and it retained that magnitude until after 0657:37 UT. However, by 0658:34 UT, the disturbance had more than doubled indicating that at ∿ 0658 the current flow intensified sharply. In addition, there was a pronounced northward motion of the auroral arcs over the station line at this time. Finally, we note that the D-component response at the station line was negative, indicating that any surge activity was to the east of the line and closer to the satellite.

If one associates the sudden particle flux increase at ATS in the period after the onset of the expansion phase of the substorm with the poleward propagation of the northern border of the electrojet, one can infer some valuable information about the location on the ground of the field line passing through ATS. At the time of the initial development of the current system (∿ 0654 UT) there was no flux increase observed at ATS, implying that the northern border of the electrojet at about $65^{\circ}$ (invarient latitude) was equatorward of the ATS field line. This puts a limit on the tail-like distortion of the geomagnetic field at this time close to the onset of the substorm when such a distortion should be at a maximum. At the time of the rapid particle flux increase (0658:20 UT) the location of the northern border of the electrojet was at $66^{\circ} \pm 0.5^{\circ}$ (invarient latitude). We infer that this is the field line passing through ATS at this time. This is to be compared with the prediction of the internal field model (GSFC 12-66) which gives the invariant latitude of the ATS field line as $67.6^{\circ}$ and the model of Fairfield (1968) which gives a magnetic latitude of approximately $66^{\circ}$. Thus, at this point in substorm time, the geomagnetic field line at ATS was in good agreement with models of the average field.

Between 0701 and 0702 UT the electrojet intensified sharply, and until 0704 UT the poleward border expanded northward again. Between 0704 and 0705 UT, there was again a sharp intensification of the electrojet. The marked $+\Delta D$ near SMIT indicates the presence of a surge or loop (which was visible on the ASCA). The surge was short-lived and had vanished by 0706 UT. During this period between 0701 and 0706 UT the electron spectrum continued to harden and there were many rapid variations in the particle fluxes, but there was no clear one-to-one correspondence between the particle flux variations and the electrojet intensifications. These large rapid reversible variations in the particle fluxes are frequently observed to be superimposed on general flux increases and have previously been interpreted as adiabatic motions of existing particle populations rather than new injection and rapid loss of particles at the satellite (Shelley et al., 1971). The minimum lifetime for these trapped particles due to strong pitch-angle diffusion is long compared to the times of the observed fluctuations; thus, to produce the observed flux reduction rates by loss processes would require a mechanism much more efficient than pitch-angle diffusion. On the other hand, a possible mechanism for the adiabatic motions of the particles is a drift wave instability in this region of steep radial gradients in the particle fluxes (Hasegawa, 1970).

Although there was a lack of detailed correlation between the particle flux variations and the magnetic perturbations on the ground, there was general agreement between the time during which the electron flux observed at ATS increased and hardened and the time during which the electrojet intensified (based on the $\Delta H$ perturbation) near the ATS field line. This strongly indicates that ATS was inside the expansion phase sector approximately $15^\circ$ east of the western edge of the substorm-associated westward electrojet. The modelling in Kisabeth (1972) suggests this westward electrojet is $\sim 50^\circ$ in longitudinal extent, so that ATS is still $10^\circ$ west of the center of the electrojet. It is also interesting to note that it was just during this period of rapid electron energy flux increase and intensified electrojet activity that the equatorial magnetic field was rapidly rotating toward a more dipole-like configuration.

As has been indicated there was an energy dispersion in the dropout of the various electron channels in the period after 0625 UT with the more energetic electrons decreasing first. The order of this dispersion was reversed in the rapid recovery after 0658 UT. A possible interpretation of this sequence is suggested by the magnetic latitude dependence of the average energy of the plasma sheet electrons at 18 $R_E$ as reported by Hones (1968). These results indicate a softening of the spectrum with increasing latitude. The ATS satellite at 105°W longitude is approximately 11° above the geomagnetic equator. Thus, if the plasma sheet on this occasion had a limited latitudinal extent, gradually contracted equatorward beginning at 0625 UT, and thereafter rapidly expanded at 0658 UT, one might expect a signature similar to the one observed in the electron channels during this period. This is, of course, under the assumption that the plasma sheet electron spectrum on this occasion had a latitudinal dependence at 6.7 $R_E$ similar to that reported at 18 $R_E$.

Hones et al. (1973) report that a gradual thinning of the plasma sheet takes place for some tens of minutes before the expansive phase of at least some substorms. This gradual thinning is observed from $X_{SM} \approx -6\ R_E$ to at least $X_{SM} = -60 R_E$. They further report that the onset of the expansive phase of the substorm is accompanied by further thinning at distances beyond $X_{SM} \approx -15\ R_E$ but initiates rapid thickening at closer distances to the earth. The later thickening beyond $X_{SM} \approx -15\ R_E$ is associated with a rapid poleward shift of the principal current of the auroral electrojet. In Figure 1, we see what could be interpreted as "thinning" starting at about 0625 UT, 30 minutes before the onset of the expansive phase, and the corresponding "thickening" four minutes after this onset. The "thickening" was associated with the rapid northward expansion of the poleward border of the westward electrojet. We feel that the remarkable morphological correspondence between the ATS results and the results of Hones et al. (1973) provides support for the interpretation of the electron data outlined above.

This passage of ATS into the lobe of the tail is an unusual event relative to the body of data we have examined to this time. It implies a magnetic field configuration such that the plasma sheet is displaced southward with respect to the geomagnetic equator, which in turn is about 11° south of the ATS location on the geographic equator. Some support for this picture is provided by the data from Pioneer 6 (Lazarus et al., 1973) which indicate that the solar wind is flowing with a relatively strong north-to-south component near the time of interest. The one-hour average value of the flow component normal to the ecliptic plane is -68 km/sec for the period from 05 to 06 UT on September 1, 1970 (the closest available data). This is the 9th largest hourly value of the 296 values tabulated for the month of September.

For the duration of this substorm event after 0706 UT there were persistent quasi-periodic intensifications of the poleward border of the electrojet, as described in paper I. However, none of the ATS parameters respond significantly in conjunction with any one of these events. The electrons maintained approximately constant flux intensities which were significantly harder and more intense than those associated with pre-substorm conditions and the protons gradually returned to about their pre-substorm levels by 0745 UT. The fact that no further impulsive intensifications of energetic particle flux were noted after 0706 UT suggests that any further injections did not take place as close to the earth as the ATS-5 orbit.

One further fact is apparent from this event. That is, after the initial part of the expansive phase, there is every reason to believe that ATS-5 is on field lines which drop into the auroral electrojet. Now it is clear that for an hour (at least) after the onset of the event, the electrojet is very wide and very intense, so that there must be considerable precipitation of energetic particles to maintain it. The relative constancy of the fluxes measured by ATS-5 in this period indicate that the loss of electrons to maintain the level of ionospheric conductivity is small compared to the net flux available.

One can see if this is reasonable by estimating from the measured flux level at ATS, what time would be necessary to dump the entire contents of the flux tube into the ionosphere at a rate necessary to maintain say an IBC, Class I, aurora. Assuming isotropy, the omnidirectional electron energy flux at ATS ($\phi_{ATS}$) between 0700-0900 UT was of the order of 100 ergs/cm$^2$-sec. The precipitation rate into the ionosphere ($\phi_{ion}$) necessary to maintain a Class I aurora is 0.6 ergs/cm$^2$-sec (Dalgarno et al., 1965). The electron lifetime

$$T_L = \frac{\phi_{ATS}}{\phi_{ion}} \frac{\tau}{8} \frac{B_{ion}}{B_{ATS}}$$

where $\tau$ is the particle bounce period and B is the field magnitude at the appropriate location. For 10-keV electrons, $\tau$ is approximately four seconds, $B_{ion}/B_{ATS}$ is approximately 400 and $T_L \approx 9$ hours. This is approximately a factor of ten longer than the minimum lifetime due to strong pitch-angle diffusion (Kennel, 1969). So we see the flux at ATS is sufficient to maintain a considerable percipitation level for an extended period of time.

In summary, the period of interest for this substorm began at about 0530 UT with the sharp onset of magnetic activity at high latitudes in conjunction with the southward turning of the interplanetary magnetic field following a period of several hours during which the field was northward. A rapid thinning of the plasma sheet was initiated at $\sim$ 0625 UT, resulting in a marked drop in the fluxes of energetic electrons but no significant ground based magnetic signatures. The onset of the expansive phase of the major substorm occurred at about 0654 UT. The electrojet intensified and expanded northward in several impulsive events in the period between 0654 and 0709 UT. The poleward border remained unchanged for approximately the next hour while the entire electrojet was subject to localized irregular intensifications. Thereafter the northern border decayed while the southern border experienced marked fluctuations. At synchronous orbit, the ATS-5 particle observations showed the electron fluxes to be gradually increasing between 0530 and 0620 UT and then decaying until the substorm expansive phase onset. During this period the magnetic field at ATS was becoming more tail-like. We have interpreted this sequence of events as a motion of the plasma sheet over the satellite leaving the satellite temporarily above the high-latitude edge of the plasma sheet and therefore in the lobe of the tail. At about 0658 UT there was a very rapid intensification of both the electron and proton fluxes. The energetic (E > 6 keV) electron flux continued to increase significantly while the magnetic field of ATS became more dipole-like between 0658 and 0707 UT, the period of rapid growth of the electrojet. We have interpreted this as the outward propagation of a disturbance which is heating the electrons and thereby expanding or thickening the plasma sheet. After about 0707 UT the particle fluxes did not change dramatically during the remainder of the substorm, but the flux intensities were adequate to provide the precipitation necessary to maintain the electrojet without significantly diminishing the trapped population.

(ii) Day 195, 1970 (July 14)

This was a relatively active day with pronounced substorm activity in the intervals 0130-0500 UT and 0640-0900 UT. Only during the latter period were ATS-5 and the station line in the disturbed sector of the nightside magnetosphere so only that sequence of activity will be studied in detail. The station line magnetograms for this period are shown in Figure 2 and selected normal magnetograms from the North American sector are shown in Figure 3. The data from the ATS-5 particle detectors and magnetometer are shown in Figure 4. The first indication of the development of activity in the North American sector was at 0640 UT, when the growth of a weak westward electrojet was noted at Churchill associated with a substorm onset. The center of the electrojet was somewhat south of Churchill. There was a second weak intensification at $\sim$ 0700 UT, again slightly south of Churchill, but there was virtually no activity at the magnetometer line save for a weak eastward jet centered at $\sim 66^{\circ}$N.

At ATS there was a gradual but continuous increase in the soft electron fluxes. The increase initially appeared in CME-A and then in CME-B and CME-C in that order. There was no significant increase in the highest energy electron channel during this period.

The next significant event began at $\sim$ 0730 UT, and involved the sharp intensification of the westward electrojet noted at our station line. The center of the electrojet was at $67^{\circ}$N, and it was rather narrow with the equatorward border being at $\sim 65^{\circ}$N. The sharp $-\Delta D$ response indicates the current flow was tilted with respect to a line of constant geomagnetic latitude. The eastward electrojet remained relatively unchanged at this time and produces a $+\Delta H$ peak equatorward of the Harang discontinuity. The electrojet reached its peak intensity of $\sim 80\gamma$ near 0736 UT, by which time it had broadened to stretch from $66-71^{\circ}$N and its center had moved slightly poleward (see Figure 5a). During this event, there were no significant changes at ATS until $\sim$ 0735 UT. Between 0735 and 0736 UT the electron flux increased and hardened significantly (the CME-D electron flux increased by a factor of 6 - see Figure 4) and there was a slight increase in the proton flux. There was also a very slight decrease in $B_Z$ ($\sim 3\gamma$). The fact that the electron flux increase occurred nearly simultaneously in channels C and D indicates that the satellite was in or very near the source region. Inspection of the magnetometer chain data via latitude r profiles (see Figure 5b) indicates that there was an intensification of the northern border of the electrojet at $\sim$ 0736 UT.

Thus, while there was no change in the particle fluxes at ATS in association with the substorm onset at 0730 UT, there was a significant electron flux increase associated with the intensification of the poleward border of the electrojet and the magnetic perturbation in the equatorial region at $\sim$ 0736 UT. We can again interpret this event in terms of a disturbance propagating outward after the substorm onset and thus producing a poleward shift of the northern edge of the electrojet. However, the characteristics of this event at ATS are different from the others discussed here in at least two respects. First, the flux increase is quite smooth and there appears to be little, if any, effect in the low-energy electrons. Second, there was no significant reconfiguration of the magnetic field of ATS. Thus, it may be that ATS-5 was slightly to the east of the actual disturbance and the heated electrons rapidly drifted to the satellite. It should also be pointed out that this was not a large event in terms of the electrojet intensity even though it involved a substantial perturbation in the equatorial electron flux. After 0736 UT the event decayed up until 0748 UT, at which time the electrojet strengthened again slowly with its peak being over SMIT (68.1$^{o}$N). It is noticeable that the +ΔH regime over MCMU (65.0°N) intensified simultaneously with the -ΔH regime over SMIT. It is interesting to note that the satellite $B_Z$ field became depressed in association with a rotation of the field into a more tail-like configuration after 0752 UT. This is consistent with a substorm to the east of both the satellite and the station line. Also, there was a slight increase in the CFP-B protons at 0752 UT consistent with injection of these protons to the east of the satellite where substorm activity was in progress as seen at Churchill and Great Whale. Data from these two stations pinpoint the substorm onset at 0742 UT, and around this time quiet auroral arcs appeared over the station line at the latitude of SMIT. The arcs, which appeared initially in the east, gradually extended into the zenith by 0758 UT at which time the westward electrojet completely dominated the eastward electrojet to the south (see Figure 5c). After 0802 UT the strength of the current flow decayed gradually, and the arcs and ΔZ = 0 crossover of the latitude profile moved equatorward. By 0819 UT the arcs were quite weak and the electrojet was centered near ∼ 67.5°N (see Figure 5d). Over the period after the 0752 UT event up until 0819 UT, the fluxes of electrons and protons fell off slowly and the magnetic field at ATS remained nearly constant.

At 0819 UT, an event commenced during whose course the entire nightside magnetosphere was violently distorted. Expansion phase signatures were observed clearly to occur simultaneously from Huancayo (353.8$^{\circ}$E) to Honolulu (266.5$^{\circ}$E) at low latitudes, indicating that the disturbed region of the magnetosphere extended over at least 90$^{\circ}$ of longitude. We shall see that the macrostructure of this event was quite complex. We wish to point out at this time that no ground based signature of growth appeared to precede this major event, and all that was noted was weak, but well defined, expansive phase activity. However, the magnetic field in the ATS-5 sector remained in a tail-like configuration throughout the period from 0700 UT until the onset of this event.

First of all we note that a weak residual westward electrojet remained across the station line at 0818:40 UT, centered at $\sim$ 67.5$^{\circ}$N (see Figure 5d). The sizeable $-\Delta D$ and asymmetric character of $\Delta D$ indicate our station line to be near the western edge of the westward jet. From Figure 3, we see that this residual electrojet is observed to the south of both Churchill and Great Whale, but the lack of $\Delta D$ disturbance indicates they are well away from the ends of the current system. It also indicates this weak westward jet to be quite long.

When the disturbance in question exploded, the onset time was estimated as close to 0819:12 UT. At the station line, the initial two minutes featured the growth of a latitudinally localized ($67^{\circ} < \Phi < 69^{\circ}$) current element with some small $+\Delta D$ perturbation, whereas at Churchill all three components changed simultaneously. At Churchill the lack of $+\Delta D$ indicates no surge at that longitude; however, the quasi-periodic appearance of $\Delta Z$ indicates several impulsive bursts of activity in this sector, which can be seen better using the magnetometer line data.

By 0821:18 UT a significant $+\Delta D$ was in progress over the station line indicating the presence of a surge over SMIT (Figure 6a).

The surge grew until 0823:21 UT (see Figure 6b) after which it began to decay; however, at 0823:32 UT the auroral arcs brightened and a new surge formed over SMIT moving to the northwest. By 0825:24 UT (see Figure 6c) an intense $+\Delta D$ region developed between SMIT and RELI, and RELI was in a strong $-\Delta H$ ($\sim 600\gamma$) regime. The surge died by 0827:26 UT (see Figure 6d), only to be regenerated near RELI at $\sim$ 0828 UT and again at $\sim$ 0832 UT and $\sim$ 0839 UT. Each of these intensifications involved a $+\Delta D$ regime to the north of RELI.

The first effect observed in the particles was a marked decrease in the high-energy electrons (CME-C and CME-D) from 0815 to ∿ 0818 UT, prior to any apparent activity of either an auroral or magnetic nature in the station line sector. There was merely continued decay of the weak residual electrojet centered at ∿ $67^{\circ}$N. The arcs were very diffuse at that time but when they were brighter, near 0810 UT, they had been noted as moving equatorward. This decrease in the higher-energy electron fluxes can be interpreted as an adiabatic motion of the existing particle population resulting from enhanced inward convective flow during this phase of the substorm.

Between 0818 and 0819 UT, less than one minute prior to the onset of the substorm, the energetic electron fluxes began to increase slowly, returning to their prior levels at approximately the time of the substorm onset. Beginning at approximately the same time, the ATS $B_Z$ field component also began to increase very slowly; however, due to the rather poor resolution on the other magnetometer axes, it was not possible to distinguish between a field line rotation and an intensity change. In the period between 0820 and 0824 UT when the electrojet intensity was increasing at the latitude near the foot of the ATS-5 field line there was a general increase in the energetic electron fluxes. During this period there were also large oscillations in all the particle fluxes and the magnetic field increased from approximately 120$\gamma$ to 140$\gamma$ and rotated to a more dipole-like configuration. The slow flux increases prior to 0820 UT may well have resulted from adiabatic motions of the existing particle populations, but the more rapid increases, occurring after 0820 UT in conjunction with the field configuration change and the intensification and northward shifting of the electrojet, are again most consistent with the outward (poleward) propagation of a disturbance which is heating the plasma and enhancing the precipitating particle energy flux. We estimate from the ground magnetometer data that the northern border of the electrojet was at approximately 69$^\circ$ invarient latitude at this time. Again, we should point out that the rapid up and down fluctuations of the particle fluxes are most probably the result of adiabatic motions of the particle populations in the region of steep radial gradients. We also note that at least part of the net overall flux change that we observed could have been due to motions of the particle drift shells resulting from the increased magnetic field.

By 0824 UT all particle parameters had reached relatively stable values with a higher average energy than prior to the substorm intensification. In addition, the auroral activity over the station line had degenerated into milky diffuse activity over the entire night sky.

At 0824:20 UT, the auroral arcs brightened strongly to the southwest of SMIT, and the magnetic records (Figure 9c) show an intense electrojet developed to the north near RELI (71.5$^{o}$N). <u>It is important to note that there was not a significant response to this event at ATS.</u> In addition there were no significant effects observed at ATS in association with the intensifications of the electrojet which followed at $\sim$ 0828 UT, 0832 UT and 0839 UT. However, we note that the major intensifications of the electrojet after 0824 UT occurred at latitudes above 68$^{o}$ and we thus infer that any electron injections associated with these events took place outside (poleward) of the ATS-5 orbit. Nonetheless, ATS-5 was on field lines which penetrate the electrojet, and therefore must be on field lines on which electrons are being dumped. The omnidirectional energy flux of electrons at ATS in this period was of the order of 50 ergs/cm$^{2}$-sec (assuming isotropy). This is enough flux to maintain an IBC class II aurora for 25 minutes before depleting the flux tube. Therefore, even without fresh injections of particles there was enough flux at ATS to maintain sufficient conductivity for the electrojet for a considerable period. This lack of dramatic activity in the ATS particle detectors when the satellite is inferred to be on field lines penetrating the electrojet equatorward of the poleward border is typical of the events we have studied.

To summarize, we note that during the first event, at about 0730 UT, a narrow westward electrojet was centered at $\sim 67^{\circ}$N at the station line and there was evidence that ATS-5 was near the eastern end of the region of the disturbance. There were no changes in the particles or the magnetic field observed at ATS-5 at the time of the substorm onset ($\sim$ 0730 UT); however, there was a significant increase in the energetic electron fluxes at about 0736 UT in conjunction with an intensification of the northern border of the electrojet. In spite of the fact that ATS may have been slightly to the east of the main sector of activity, this event was interpretable in terms of the disturbance initiating inside the ATS orbit and propagating outward.

The second event of this day which we covered in detail occurred at about 0819 UT. This event was rather widespread in longitude and both the station line and ATS-5 were clearly in the sector of the main disturbance. There was no classic growth period preceding the event, but we did observe a significant decrease in the energetic electrons at the satellite beginning about four minutes prior to the onset of the substorm. There were several electrojet intensifications observed at the station line in the period between 0819 and 0839 UT. The energetic electron fluxes increased significantly in the period between 0819 and 0823 UT while the field became more dipole-like. There were several rapid fluctuations in all of the particle fluxes during this time, but there was not a clear one-to-one correlation between these fluctuations and time variations of the electrojet observed at the station line. It was, however, just during this period that the electrojet intensified in the latitude range corresponding to the ATS-5 field line. The later intensifications of the electrojet occurred at higher latitudes. Thus, again we can interpret this event as being initiated near or slightly inside the ATS-5 orbit and propagating outward enveloping the satellite in the period between 0820 and 0823 UT as it progressed outward.

(iii) <u>Day 183, 1970 (July 2)</u>

This was a moderately active day which included two very large substorms near 0630 UT and 1045 UT. We shall concentrate on the 0630 UT event, which had been described in some detail in Kisabeth and Rostoker (1971). The station line magnetograms are shown in Figure 7, and selected magnetograms from the North American sector are shown in Figure 8. The ATS-5 data are shown in Figure 9 . The first indication of activity was the beginning of a slow rotation of the magnetic field at ATS into a more tail-like configuration starting at about 0400 UT. At 0444 UT a substorm onset occurred in the Great Whale sector (the best estimate of the time is obtained from the low-latitude magnetograms). Churchill was near the western end of the substorm electrojet. A typical evening sector substorm signature was seen at ATS, viz., a gradual increase of the (A,B) proton flux at $\sim$ 0446 UT and an approximately simultaneous rotation of B to a more tail-like configuration. At 0504 UT there was an SSC noted at all low-latitude nightside stations; it was also seen at Explorer 35 between the earth and the sun at $\sim$ 0450 UT and involved an increase in $B_{TOT}$ from $\sim 8\gamma$ to $\sim 12\gamma$. At this time (within the limits of our measurements) the plasma sheet was pushed in past the satellite, as indicated in the (A,B,C) electrons. Note the typical energy dispersion that has been interpreted as the signature of the soft inner edge of the plasma sheet (Shelley et al., 1971). The satellite remained in this enhanced plasma region until the start of the main event.

At the magnetometer chain (choosing the baseline at 0545 UT) no activity was noticeable until ∿ 0623 UT, at which time a weak westward electrojet was observed to grow centered at ∿ 70$^{o}$N. This electrojet persisted until ∿ 0632 UT when the substorm broke out strongly in the region of the meridian line (Figure 10a). The electrojet intensified sharply at ∿ 0639 UT (Figure 10b); this was an intensification of the existing electrojet and not a northern border effect. Again at ∿ 0641 UT the electrojet experienced a very large intensification, almost doubling from ∿ 200γ to ∿ 390γ in 58 seconds (see Figure 10c and d). At this time the station line truly entered the substorm sector (+ΔH at Newport and a large +ΔD over MENK implied passage of a loop or surge indicating the western edge of the electrojet and passed over the station line). The electrojet continued to intensify steadily until ∿ 0648 UT, at which time the northern border of the electrojet intensified (see Figure 9 from Kisabeth and Rostoker (1971) for the pertinent latitude profiles) and the +ΔD perturbation indicated the development of a surge over SMIT. The electrojet northern border remained weakly active for the period 0650-0726 UT with peak magnitude staying between 600-700γ. After 0726 UT the electrojet decayed rapidly.

At ATS there were significant variations in the particle fluxes throughout the period discussed, but there was not a simple one-to-one correspondence between the events observed on the ground and the principal particle flux changes. The satellite magnetic field and energetic proton fluxes showed typical midnight sector substorm signatures, namely a slow decrease in flux and a rotation of the field toward a more tail-like configuration beginning between 0530 and 0600 UT (see Figure 9) followed by the beginning of the recovery of the proton fluxes and the magnetic field between 0634 and 0636 UT. In the period preceeding the substorm onset (prior to 0632 UT) there were slow variations in the electron fluxes, but there were no dramatic variations at the time of onset of the expansion phase apart from an apparent increase in turbulence. The turbulence increased during the period of growth of the electrojet noted between the latitudes and . The situation changed markedly at $\sim$ 0636 UT ($\sim$ 4 minutes after the onset of the expansion phase) at which time there was a sudden increase in proton fluxes. This time is significant in that there was no onset of pronounced growth of the ring current as inferred from the low- and middle-latitude observatories in western North America (see Figure 8). After the sharp increase in proton flux at $\sim$ 0636 UT, there were quasi-periodic modulations of both the proton and electron fluxes. As discussed previously, these large fast reversible flux changes are interpreted as adiabatic motions of existing particle populations with relatively large spatial gradients, perhaps as a result of drift waves.

There was a continued slow and irregular growth in the high energy electron fluxes and the strength of the auroral electrojet until about 0700 UT. It was at this time that the poleward border of the electrojet was finally confirmed as being north of $^{o}$N (see Figures 10e and f). There was a clear expansion phase signature in $B_Z$ at 0713:42 UT, at which time the electrojet intensified sharply at ∿ 67$^{o}$N and clear expansion phase signatures were noted at Victoria and Newport. There were no significant changes in the particle flux levels associated with this event. The substorm did not begin to decay at the station line until about 0726 UT. The particle fluxes changed only slowly and the electron spectrum remained hard until about 0840 UT. Again we see a situation where the electron fluxes at the equator are sufficiently intense (50-100 ergs/cm$^2$-sec, assuming isotropy) to maintain the precipitation necessary to sustain the ionospheric conductivity at a high level without themselves showing any substantial depletion.

To summarize this event, the equatorial magnetic field and proton fluxes measured at ATS displayed a typical premidnight substorm signature beginning approximately one hour prior to the substorm onset as determined from ground observations. There was not a clear signature in the particle fluxes in coincidence with the substorm onset; however, there was good agreement between the rapid recovery of the proton fluxes and $B_z$ increase at ATS and the onset of ring current growth observed at low latitudes about four minutes after the substorm onset was noted at the meridian line. On the basis of the electron fluxes, the ATS satellite had entered the plasma sheet about 90 minutes prior to the substorm. During the period of electrojet activity the electron spectrum continued to harden and there were quasi-periodic flux modulations in the higher energy electrons and protons. There was not a simple one-to-one correspondence between the flux modulations and electrojet activity. This event differs from the previous ones in that the poleward border stayed in the vicinity of $\sim 67$-$68^{\circ}$N for a large portion of the event (0632-0700 UT) before it moved further poleward. It is significant that during the period 0632-0700 UT the energetic electron fluxes increased in association with electrojet intensification, in the fashion observed in the previous cases where the poleward border of the electrojet was inferred to map into the ATS field line. It is also important to note that, after the poleward border moved north of $\sim 68^{\circ}$N, the energetic electron fluxes stabilized in the fashion noted for the previous events.

Conclusions

We have shown that there exists a close relationship between the fluctuations in the intensity of the auroral electrojet and changes in the fluxes of energetic particles at synchronous orbit, however this relationship depends strongly on the position of the foot of the satellite field line with respect to the substorm intensified auroral electrojet. We have shown that major injections or enhancements of energetic particle fluxes occurring in conjunction with substorm onset or intensifications of the poleward border are only seen when the satellite is on field lines which penetrate the poleward border of the substorm disturbed region. When the satellite is in a meridian plane that cuts the auroral electrojet (which was the case for all the events presented in this paper) delays between the appearance of energetic particle enhancements and the substorm onset are related to the radial displacement of the satellite with respect to the region in the equatorial plane into which the substorm disturbed region of the ionosphere is mapped. In particular, we note that for Day 244 the substorm was initiated earthward of the ATS orbit, and at the time of the onset no particle enhancements were observed at the satellite even though the electrojet had intensified in the longitudinal sector in which the satellite lay. Only when the electrojet expanded poleward in an impulsive jump (see paper I) did the particle fluxes enhance sharply and, as for the onset, the intensified electrojet lay in the longitudinal sector of the satellite. The lack of dispersion among the energetic electron channels also indicated that the particles were injected close to the satellite meridian plane. On the basis of these observations, together with corroborating evidence from the other events studied in this paper, we conclude that only when the foot of the satellite field line penetrates the region of the poleward border of the ionospheric electrojet, are impulsive particle injections observed at the satellite at the same time as the intensification of the poleward border is observed near the earth. This observation applies only to cases where the satellite meridian plane cuts the substorm intensified portion of the electrojet. It is clear that sudden enhancements of particle fluxes may be observed at synchronous orbit even if the satellite is displaced longitudinally from the substorm disturbed region, and that such enhancements will be delayed with respect to the associated electrojet intensification by some time related to the drift velocity of the energetic particles. However, for such cases there will be dispersion noted among the energy channels (see DeForest and McIlwain, 1971) and these may easily be identified by that signature.

We also note that, when the satellite sees impulsive enhancements of energetic particle fluxes, there are generally several rises and falls in particle fluxes before peak fluxes are reached. The short time scale of this characteristic structure on the leading edge of the rise in particle flux suggests that these are adiabatic changes associated with oscillations in the position of the edge of the plasma sheet or other regions of strong radial gradients. The intensity of these rapid variations in flux suggests that there is considerable turbulence in the plasma sheet at least at the times of substorms.

Finally, we have shown for all the events treated in this paper that when the poleward border of the substorm intensified auroral electrojet has expanded poleward so that it lies north of the nominal position of the foot of the ATS field line, few impulsive particle effects are noted even though the ATS field line then drops into the heart of the auroral electrojet. As we have pointed out in the text, under these conditions the particle fluxes, while relatively stable, are considerably enhanced relative to the pre-substorm levels. The lack of impulsive particle effects at this time, despite the many impulsive intensifications of the auroral electrojet which may take place after the poleward border of the electrojet has passed to the north of the foot of the satellite field line, indicates that any further particle injections occur radially outside the ATS orbit and therefore cannot be observed by that satellite. We have further shown that the fluxes are sufficiently large after the injection has occurred on the drift shell occupied by the satellite, to support a precipitating flux capable of maintaining the auroral electrojet.

On the basis of the observations noted above, we feel that we may conclude the following facts about the substorm process. Firstly, we conclude that the observations are consistent with a model in which the substorm onset represents the initiation of a disturbance on field lines connecting to the ionosphere in the region of the initial electrojet intensification. This disturbance, which produces a heating and precipitation of energetic particles, moves outward in impulsive steps during the expansive phase of the substorm, which is seen in the ionosphere as the electrojet northern border intensifying impulsively and moving poleward. Prior to the substorm onset, there may be a decrease in energetic particle fluxes similar to the thinning observed by the VELA satellites deep in the tail (Hones et al., 19 ) and under unusual circumstances (such as on Day 244) ATS may even enter the lobe of the tail at which point the energetic electron fluxes drop to extremely low values. The sharp increases in particle fluxes may then be compared to the plasma sheet thickenings observed by the VELA satellites. This aspect of the behaviour of the particle fluxes at ATS will be discussed in paper III of this series (Hones and Rostoker, 1974).

Finally we wish to point out that, the fact that impulsive increases in particle fluxes (showing no dispersion) occur only when the foot of the satellite field line penetrates the region of the northern border of the substorm excited electrojet, allows one to map magnetic field lines from synchronous orbit to the ionosphere. It is, of course, clear that this mapping technique can only be used at one time during the substorm namely when the satellite is on a field line which penetrates the poleward border of the electrojet. However, when carefully used, the technique described above may be extremely useful in the process of mapping field lines from the ionosphere to the outer magnetosphere.

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## APPENDIX

Coordinates, Code Names, and Sensitivities of Magnetometers in North American Sector

| Site | Code Name | Corrected Geomagnetic Latitude (°N) | Corrected Geomagnetic Longitude (°E) | Sensitivity (I γ) H(X) | Sensitivity (I γ) D(Y) | Sensitivity (I γ) Z |
|---|---|---|---|---|---|---|
| Alert | ALER | 86.5 | 122.6 | 137 | 139 | 133 |
| Churchill | CHUR | 70.0 | 326.0 | 84 | 86 | 92 |
| Great Whale | WHAL | 68.2 | 353.8 | 138 | 138 | 146 |
| College | COLL | 64.9 | 260.3 | 78 | 37 | 78 |
| Leirvogur | LEIR | 66.3 | 72.0 | 138 | 138 | 138 |
| Huancayo | HUAN | − 0.6 | 353.8 | | | |
| Fredricksburg | FRED | 51.8 | 352.2 | 24 | 29 | 30 |
| Boulder | BOUL | 49.3 | 315.7 | 24 | 32 | 34 |
| Newport | NWPT | 55.3 | 299.5 | 45 | 53 | 64 |
| Victoria | VICT | 53.9 | 292.6 | 25 | 58 | 41 |
| Honolulu | HOLU | 21.1 | 265.5 | 25 | 41 | 26 |

# FIGURE CAPTIONS

FIGURE 1 ATS-5 data on Day 204, 1970.

FIGURE 2 Station line magnetograms on Day 195, 1970.

FIGURE 3 Magnetograms from standard observatories in the North American sector, Day 195, 1970.

FIGURE 4 ATS-5 data on Day 195, 1970.

FIGURE 5 Latitudinal profiles on Day 195, 1970.

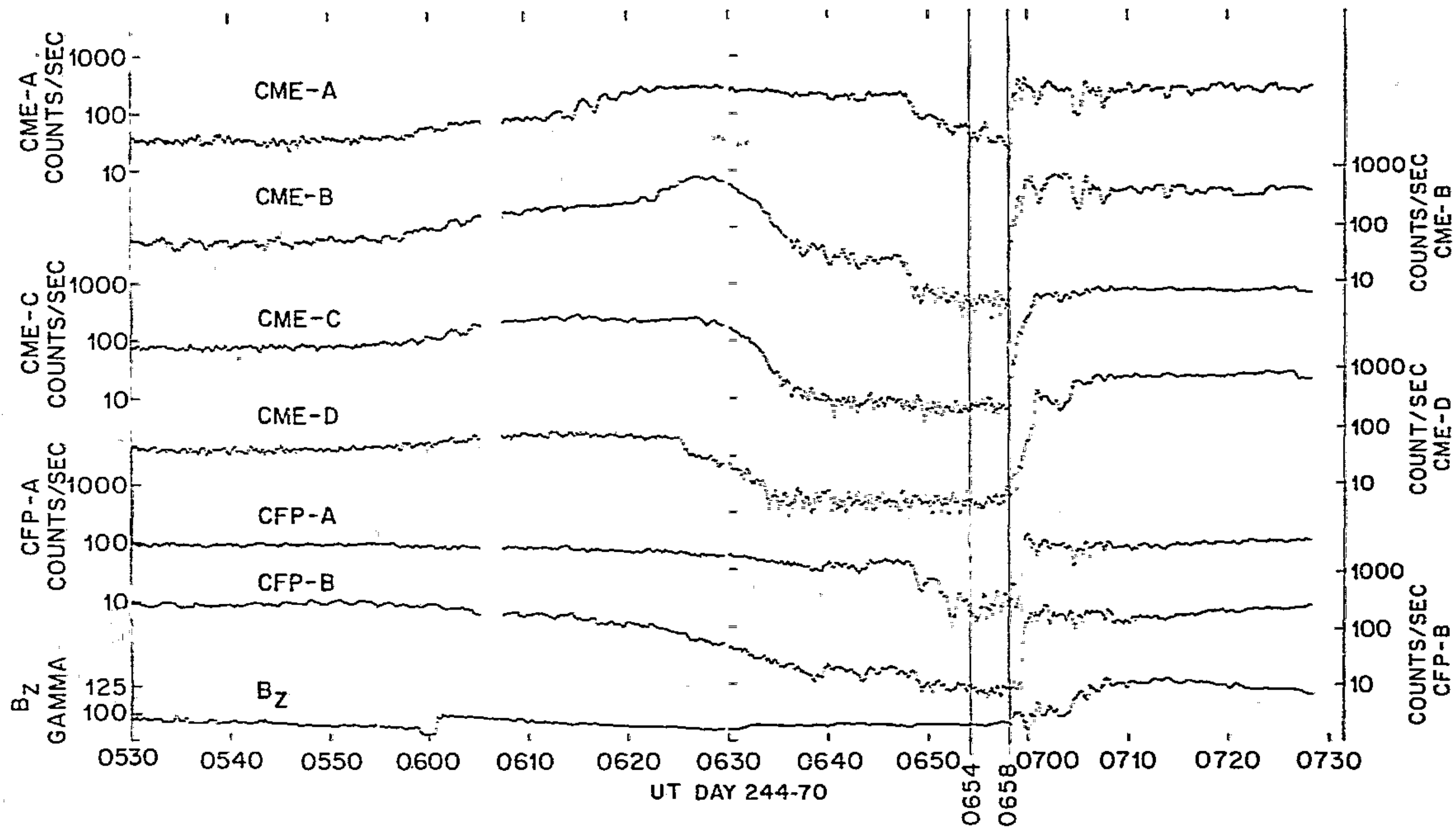
FIGURE 6 Latitudinal profiles on Day 195, 1970.

FIGURE 7 Station line magnetograms on Day 183, 1970.

FIGURE 8 Magnetograms from standard observatories in the North American sector, Day 183, 1970.

FIGURE 9 ATS-5 data on Day 183, 1970.

FIGURE 10 Latitudinal profiles on Day 183, 1970.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1000
100
10
CME-A
CME-B
1000
100
10
COUNTS/SEC
CME-B
CME-C
COUNTS/SEC
CME-C
CME-D
COUNT/SEC
CME-D
CFP-A
COUNTS/SEC
CFP-A
CFP-B
COUNTS/SEC
CFP-B
$B_Z$
GAMMA
125
$B_Z$
0530
0540
0550
0600
0610
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0630
0640
0650
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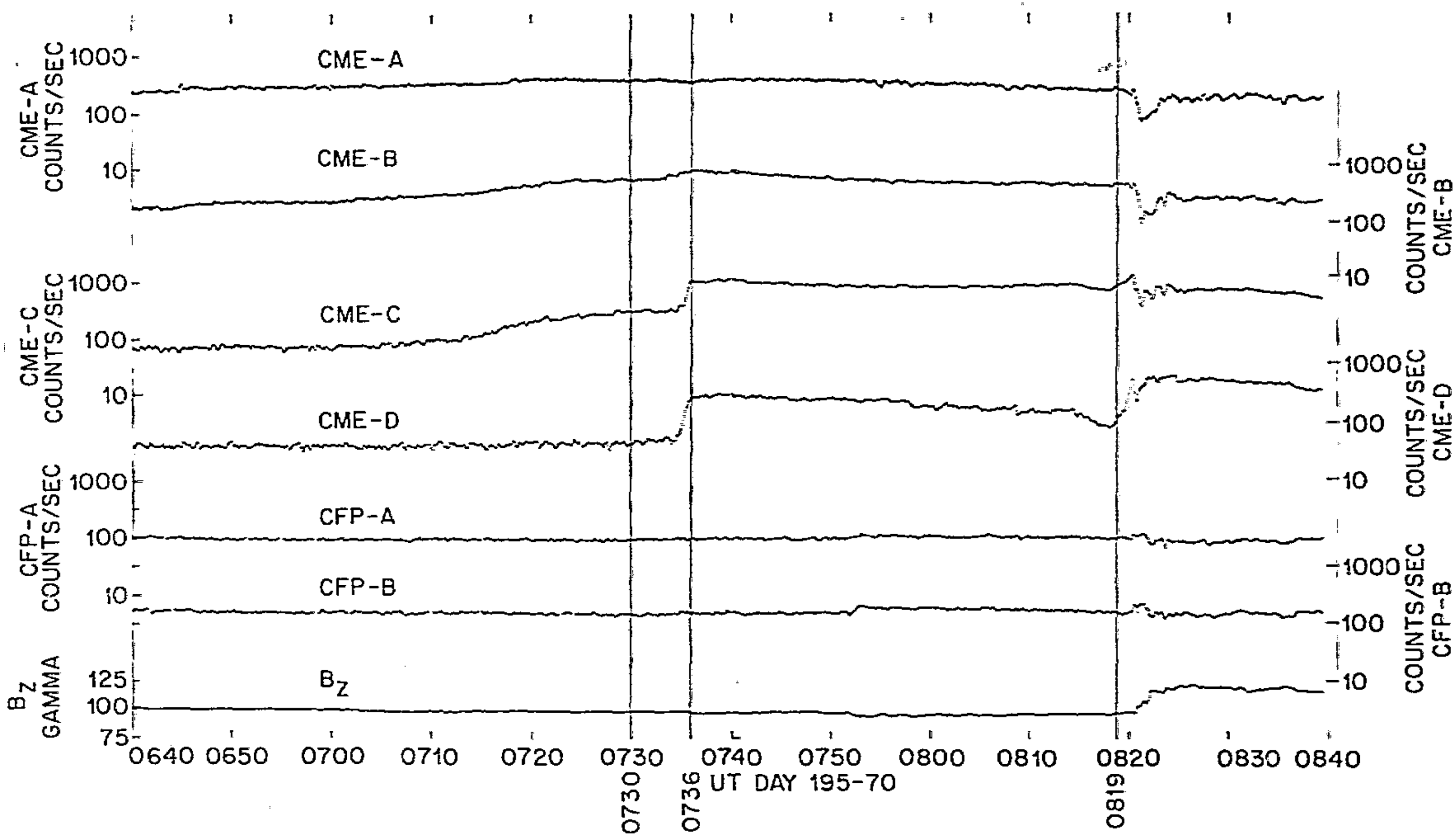
0658
0700
0710
0720
0730
UT DAY 244-70

Figure 1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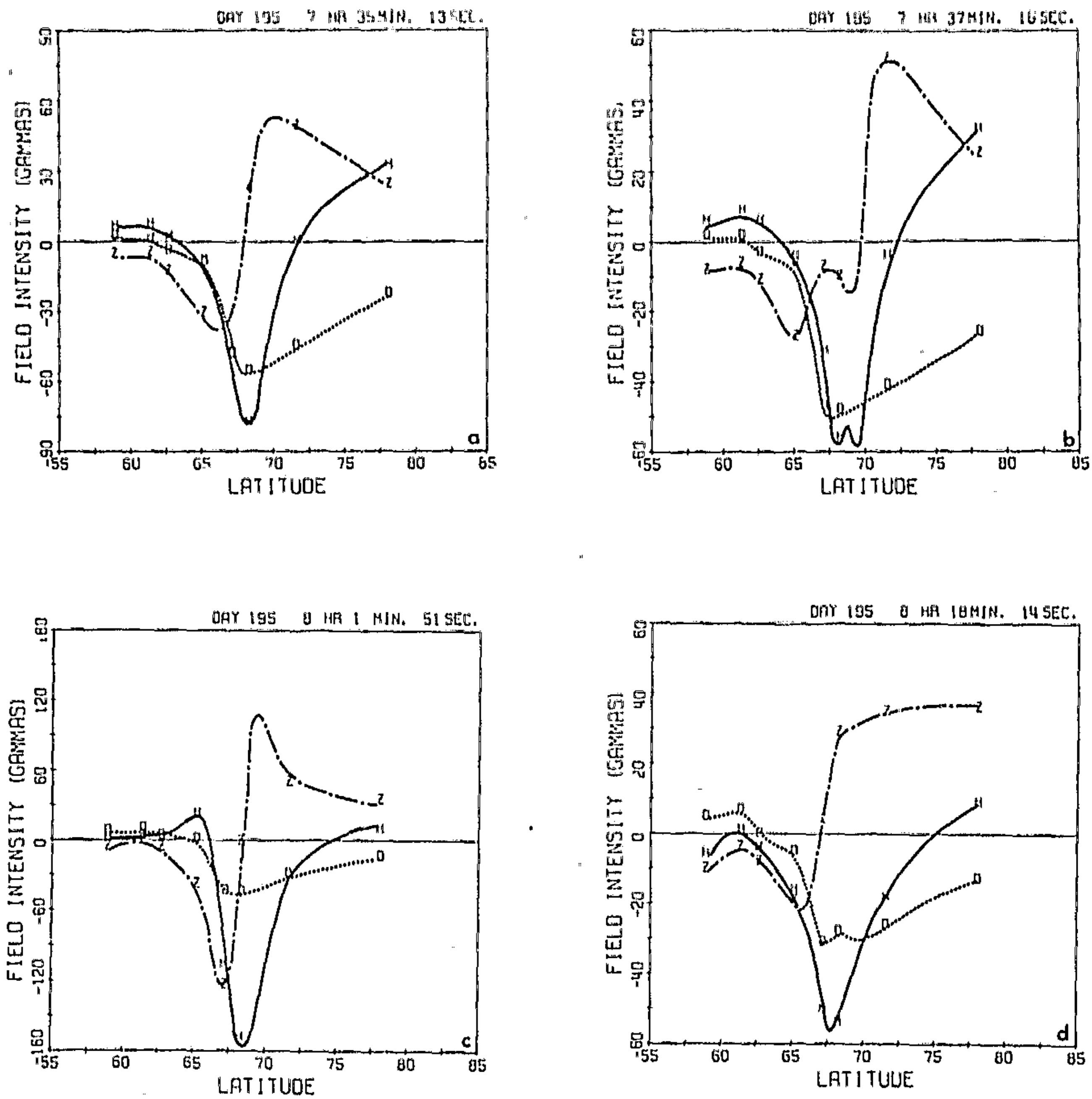
COUNTS/SEC
1000
100
10
CME-B
COUNTS/SEC
CME-B
1000
100
10
CME-C
COUNTS/SEC
1000
100
10
CME-C
CME-D
COUNTS/SEC
CME-D
1000
100
10
CFP-A
COUNTS/SEC
1000
100
10
CFP-A
CFP-B
COUNTS/SEC
CFP-B
1000
100
10
$B_Z$
GAMMA
125
100
75
$B_Z$
0640 0650 0700 0710 0720 0730 0740 0750 0800 0810 0820 0830 0840
UT DAY 195-70
0730
0736
0819

Figure 4



DAY 195 7 HR 35MIN. 13SEC.
DAY 195 7 HR 37MIN. 16SEC.
DAY 195 8 HR 1 MIN. 51SEC.
DAY 195 8 HR 18MIN. 14SEC.
FIELD INTENSITY (GAMMAS)
LATITUDE
a
b
c
d


Figure 5

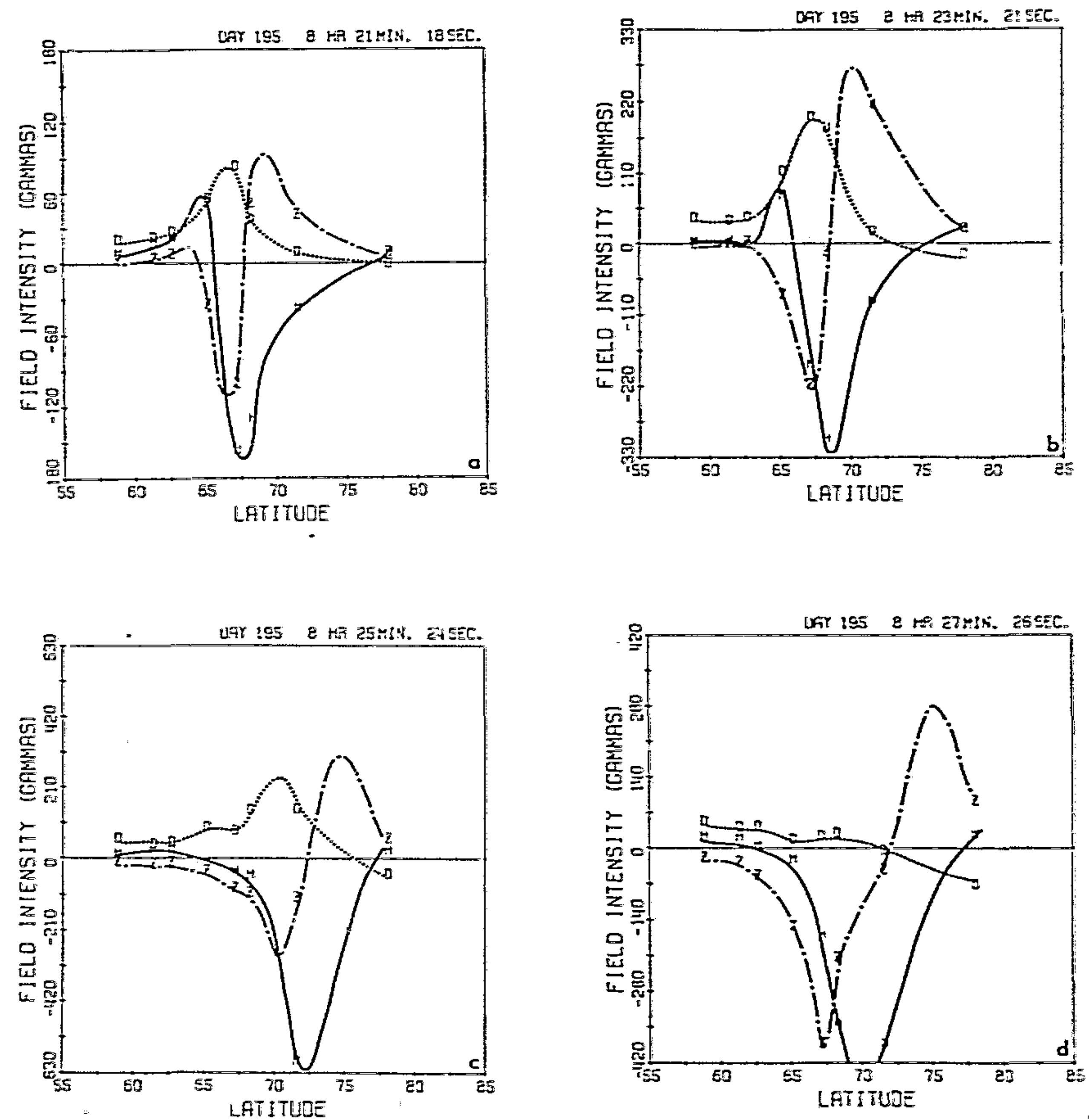

DAY 195 8 HR 21 MIN. 18 SEC.
FIELD INTENSITY (GAMMAS)
LATITUDE
a
DAY 195 8 HR 23 MIN. 21 SEC.
FIELD INTENSITY (GAMMAS)
LATITUDE
b
DAY 195 8 HR 25 MIN. 24 SEC.
FIELD INTENSITY (GAMMAS)
LATITUDE
c
DAY 195 8 HR 27 MIN. 26 SEC.
FIELD INTENSITY (GAMMAS)
LATITUDE
d

Figure 6

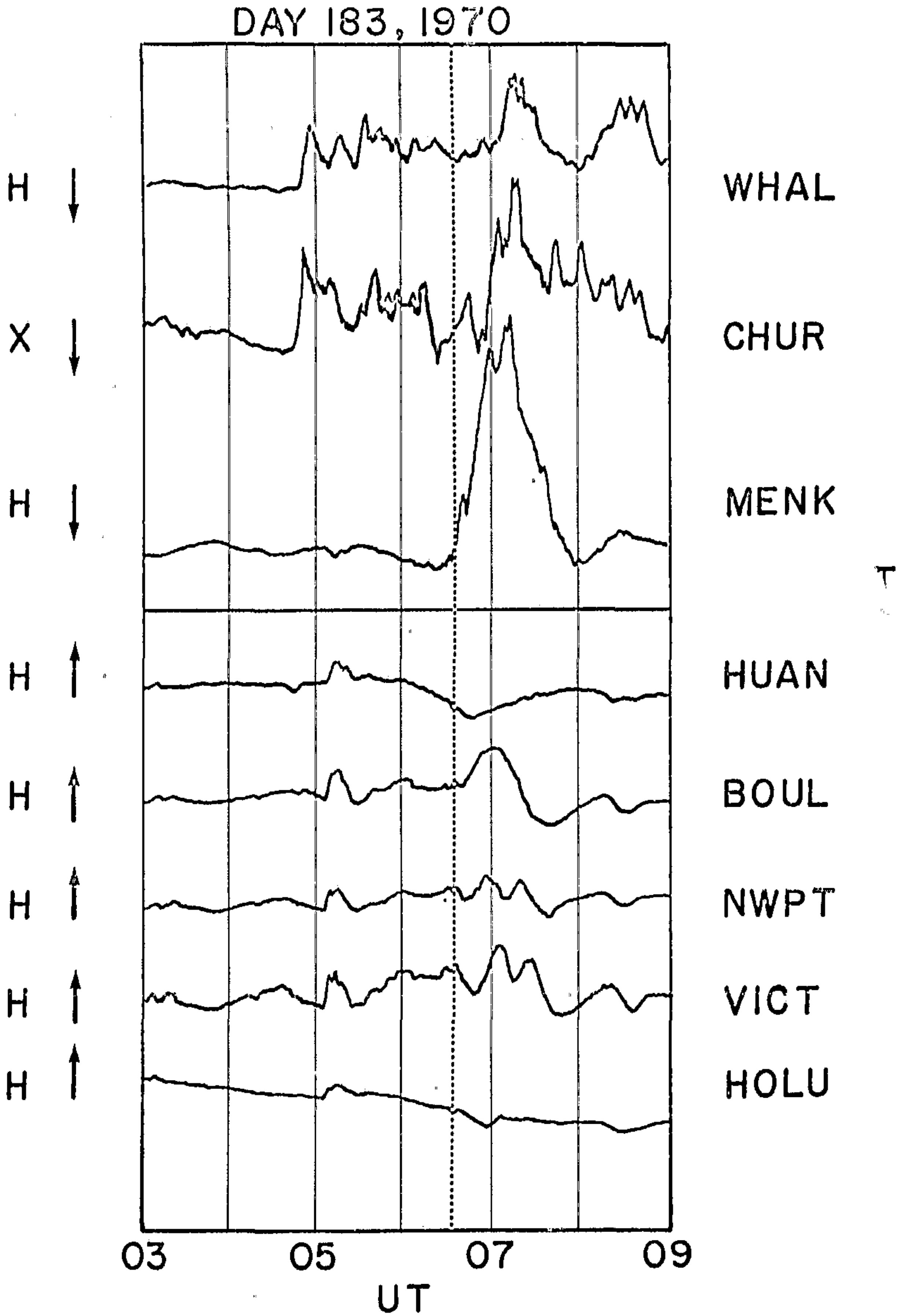

DAY 183, 1970
H
X
H
H
H
H
H
H
WHAL
CHUR
MENK
HUAN
BOUL
NWPT
VICT
HOLU
03
05
07
09
UT

Figure 8

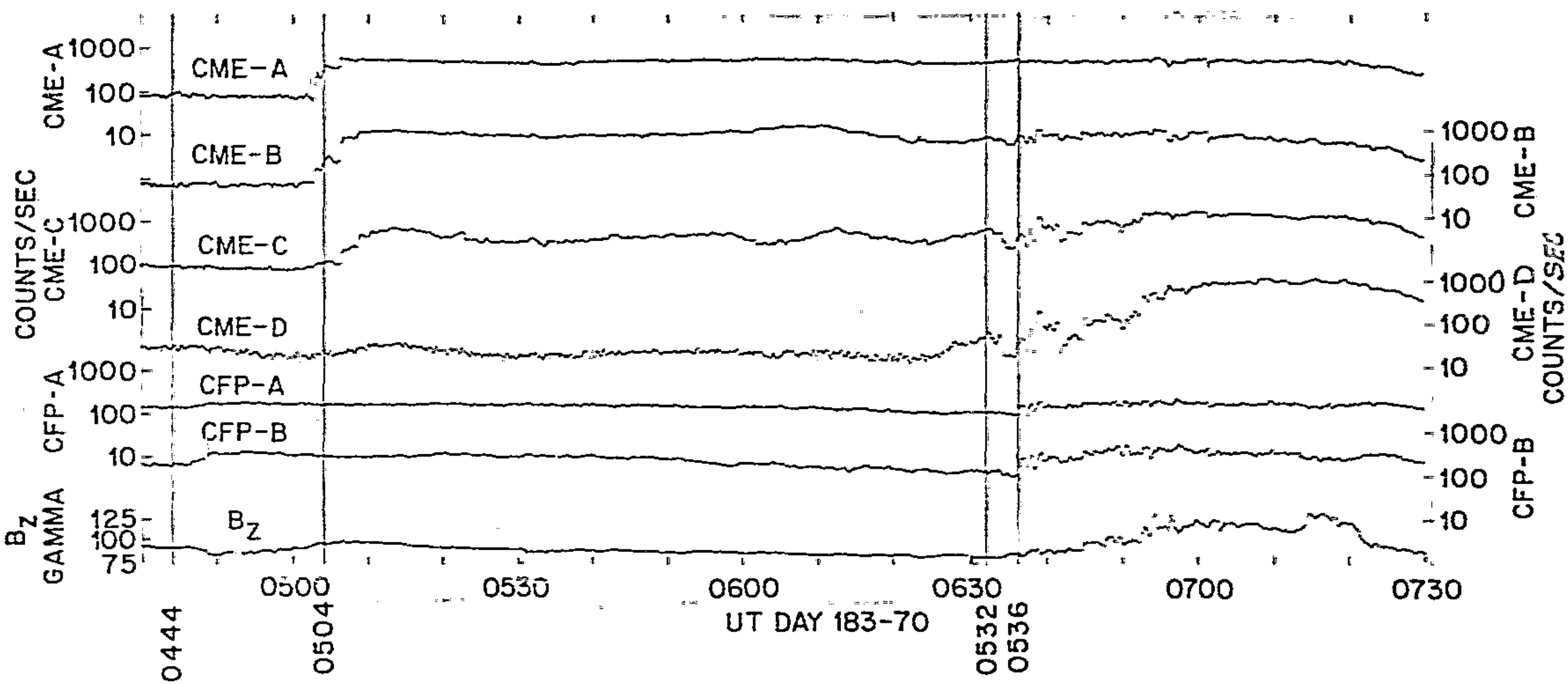

CME-A
CME-B
CME-C
CME-D
CFP-A
CFP-B
$B_Z$
COUNTS/SEC
GAMMA
1000
100
10
125
100
75
0500
0530
0600
0630
0700
0730
UT DAY 183-70
0444
0504
0532
0536

Figure 9

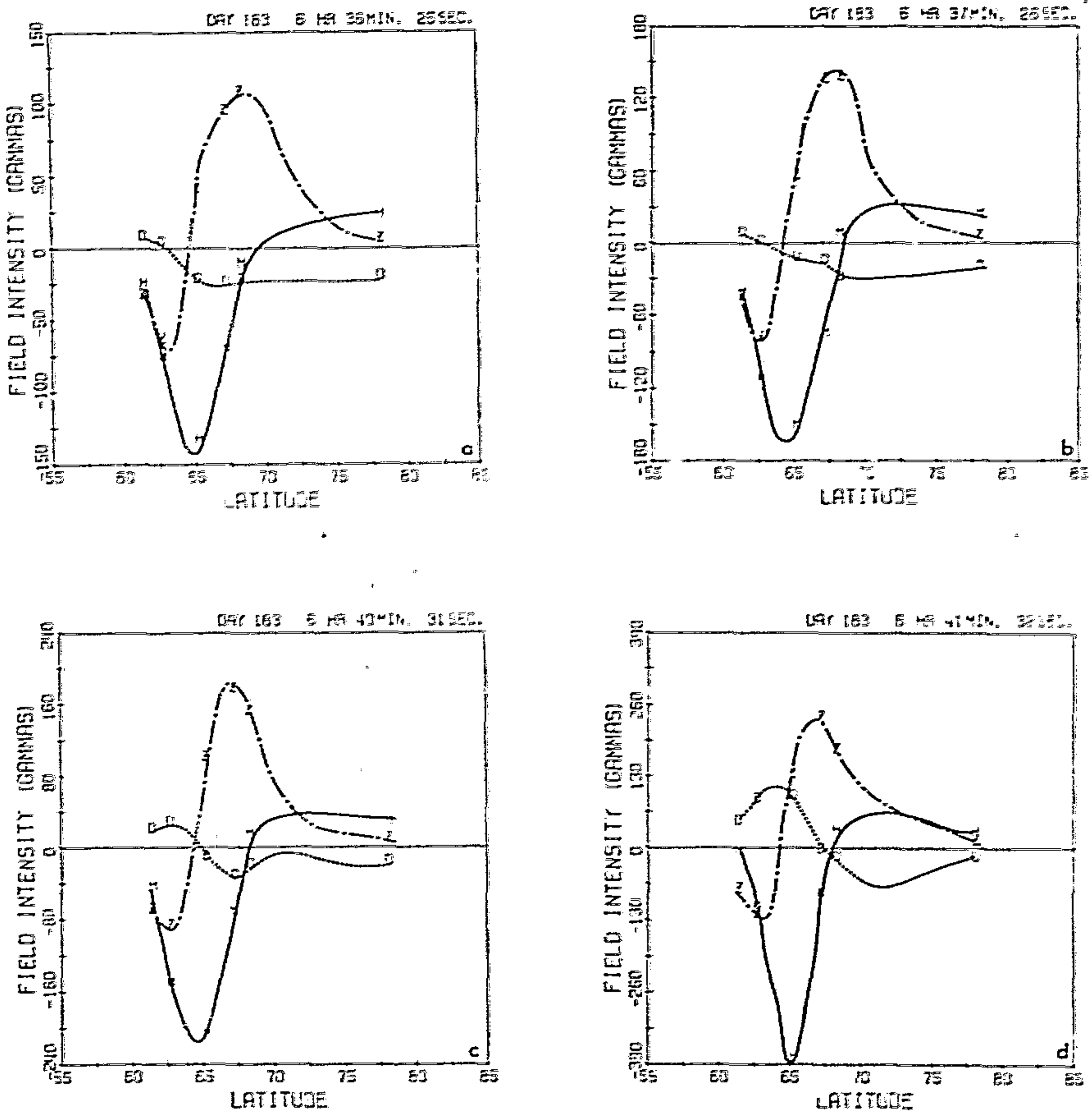
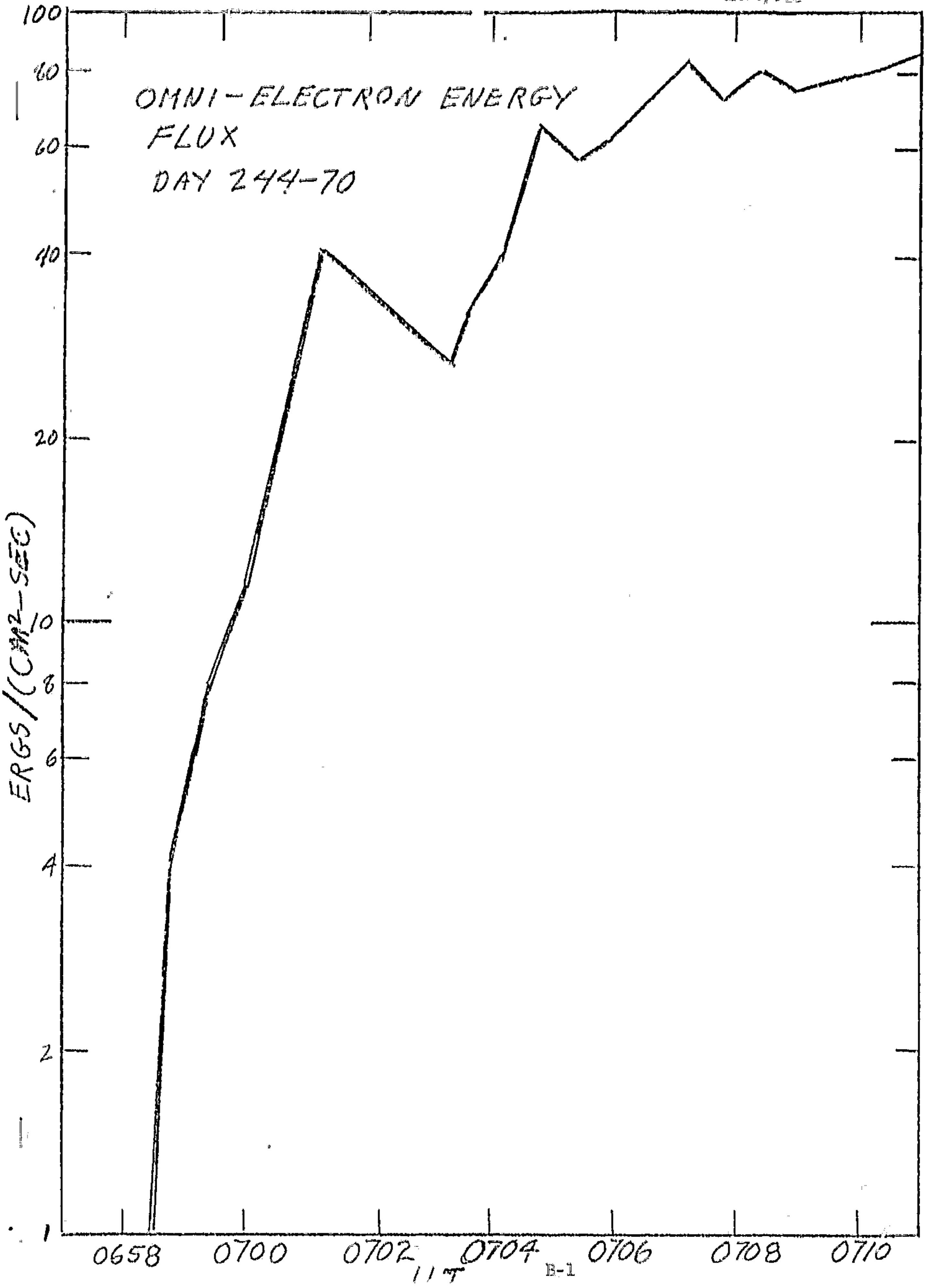
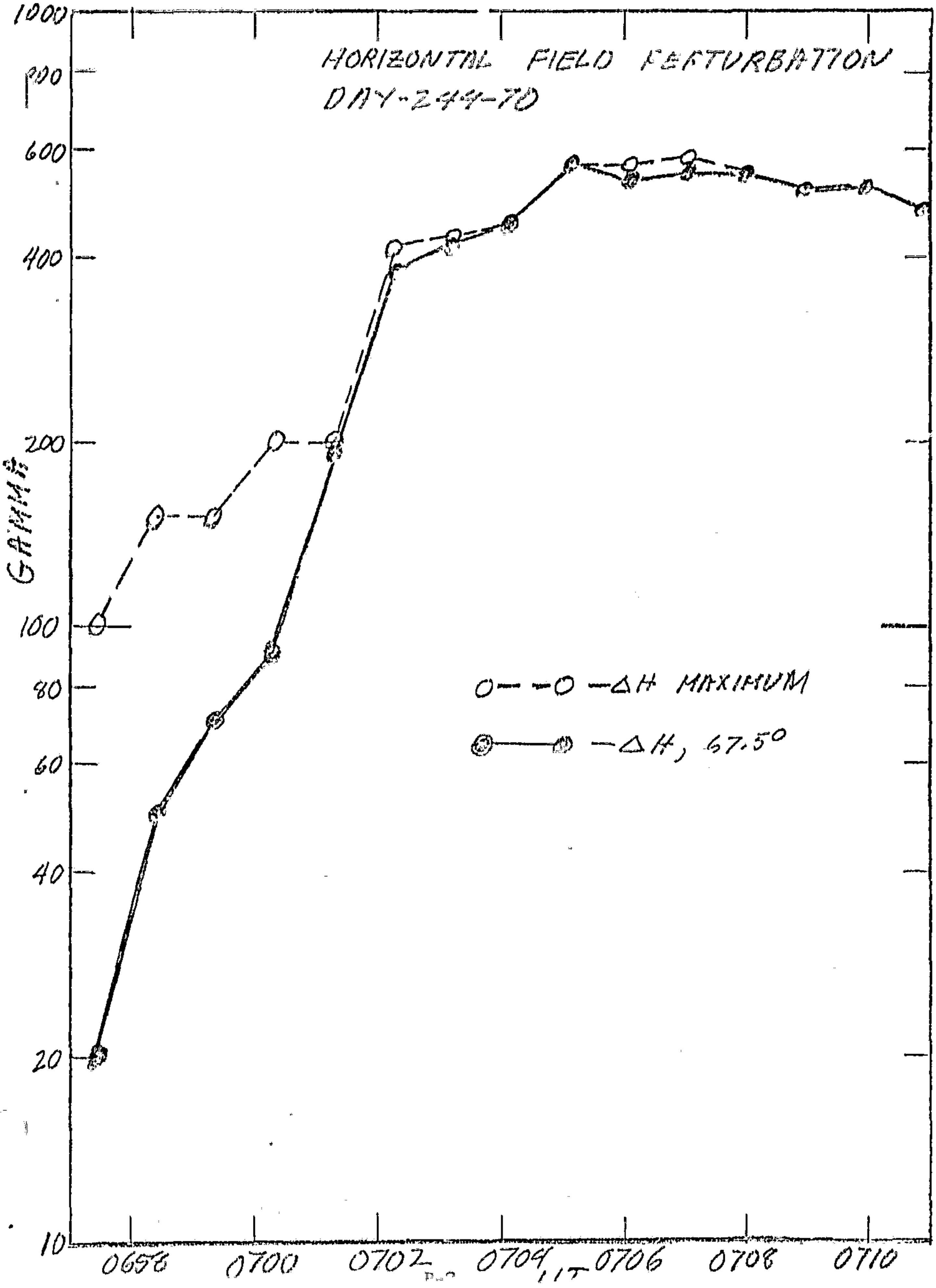


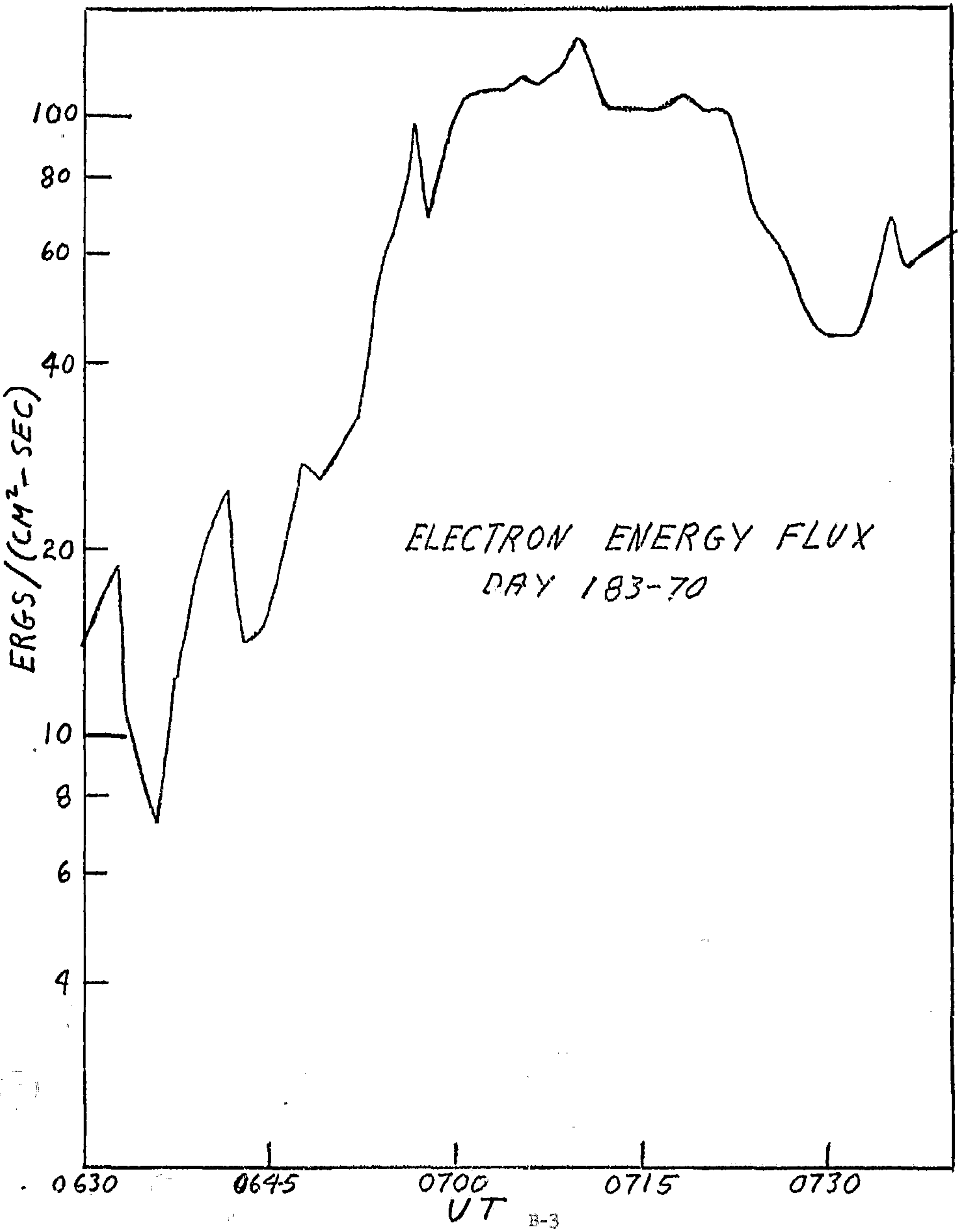

Figure 10

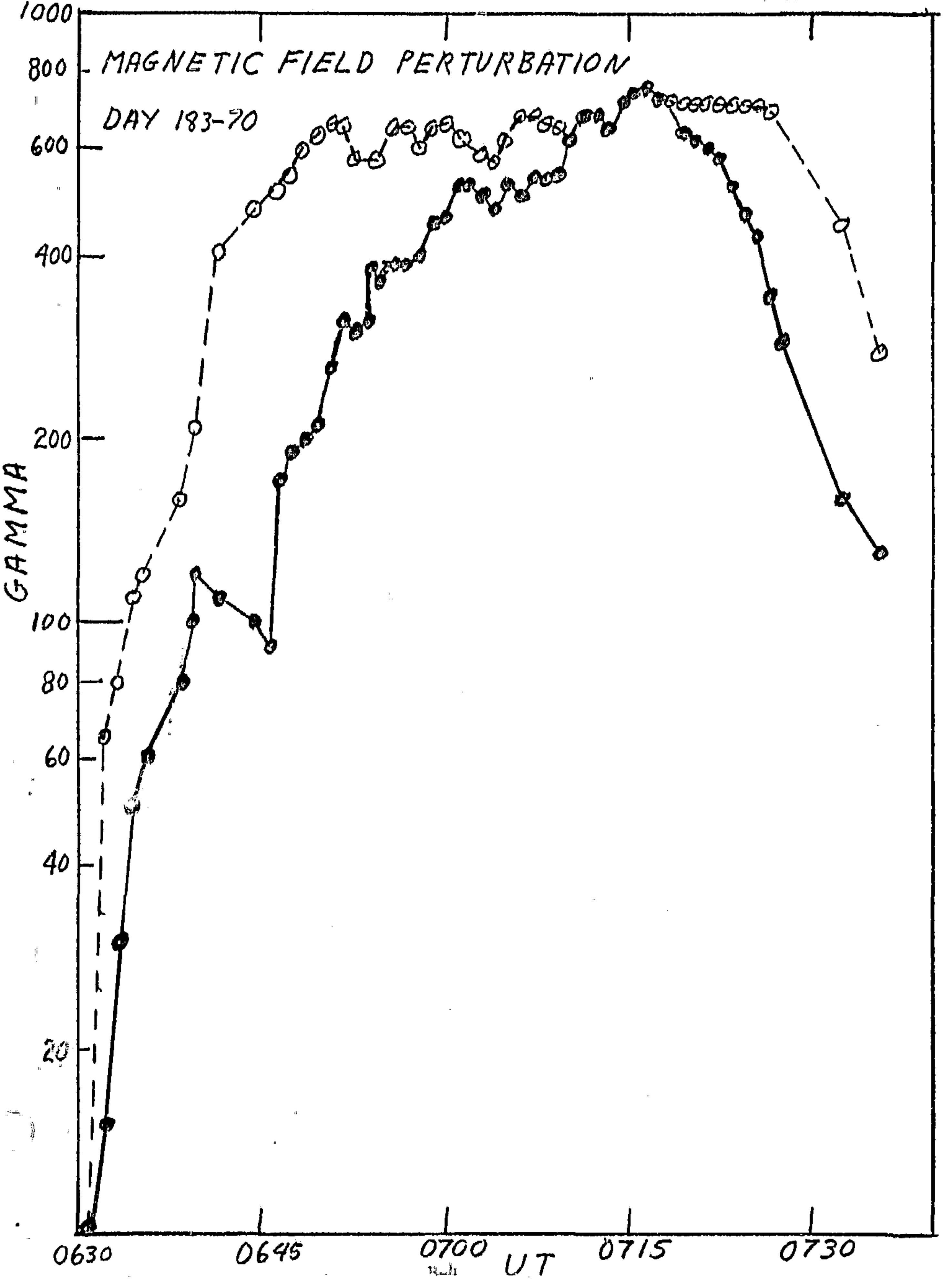
# APPENDIX B

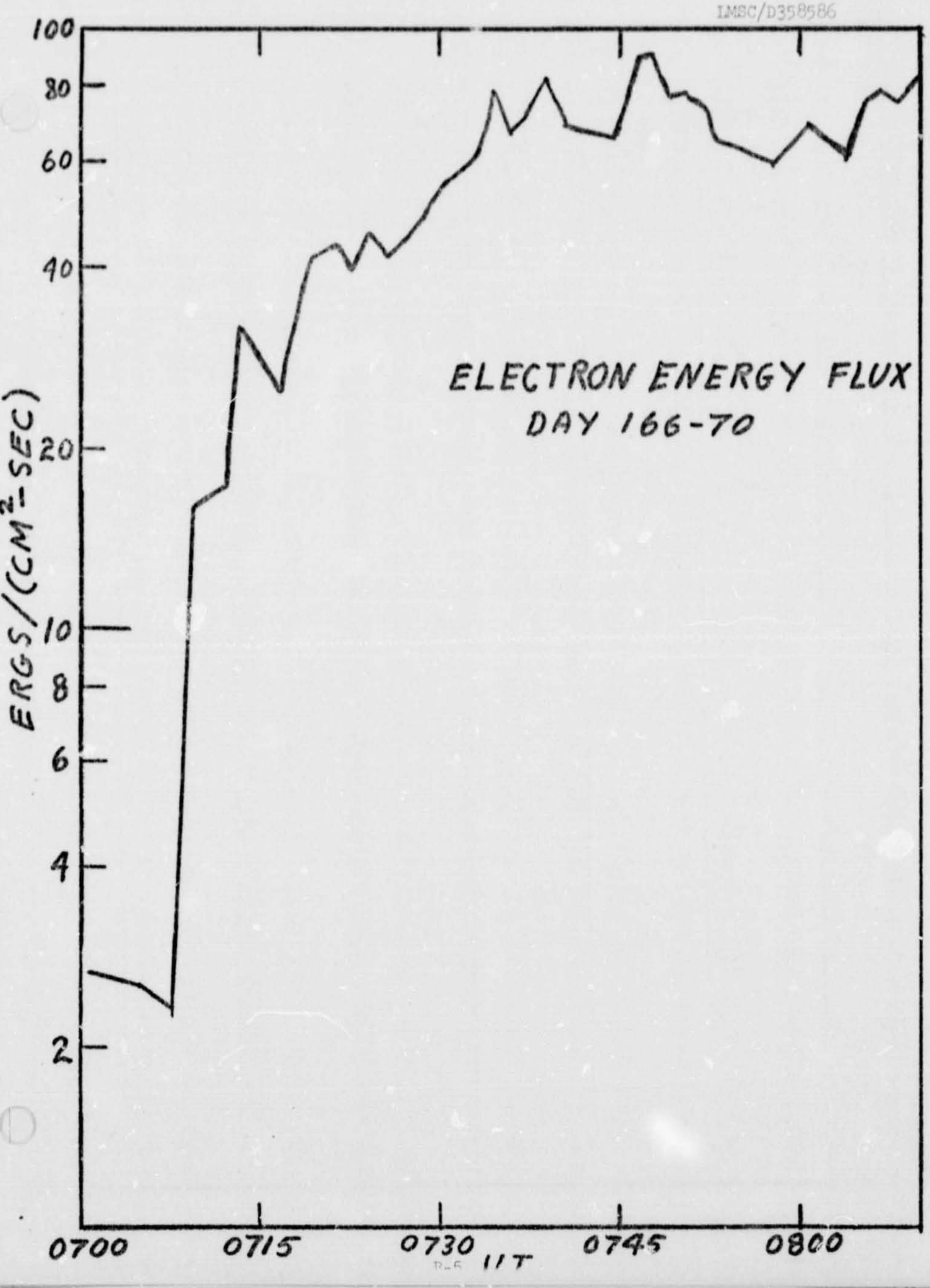
PRELIMINARY WORKING DRAWINGS SHOWING THE
RELATIONSHIP BETWEEN PARTICLE FLUXES
AND THE AURORAL ELECTROJET

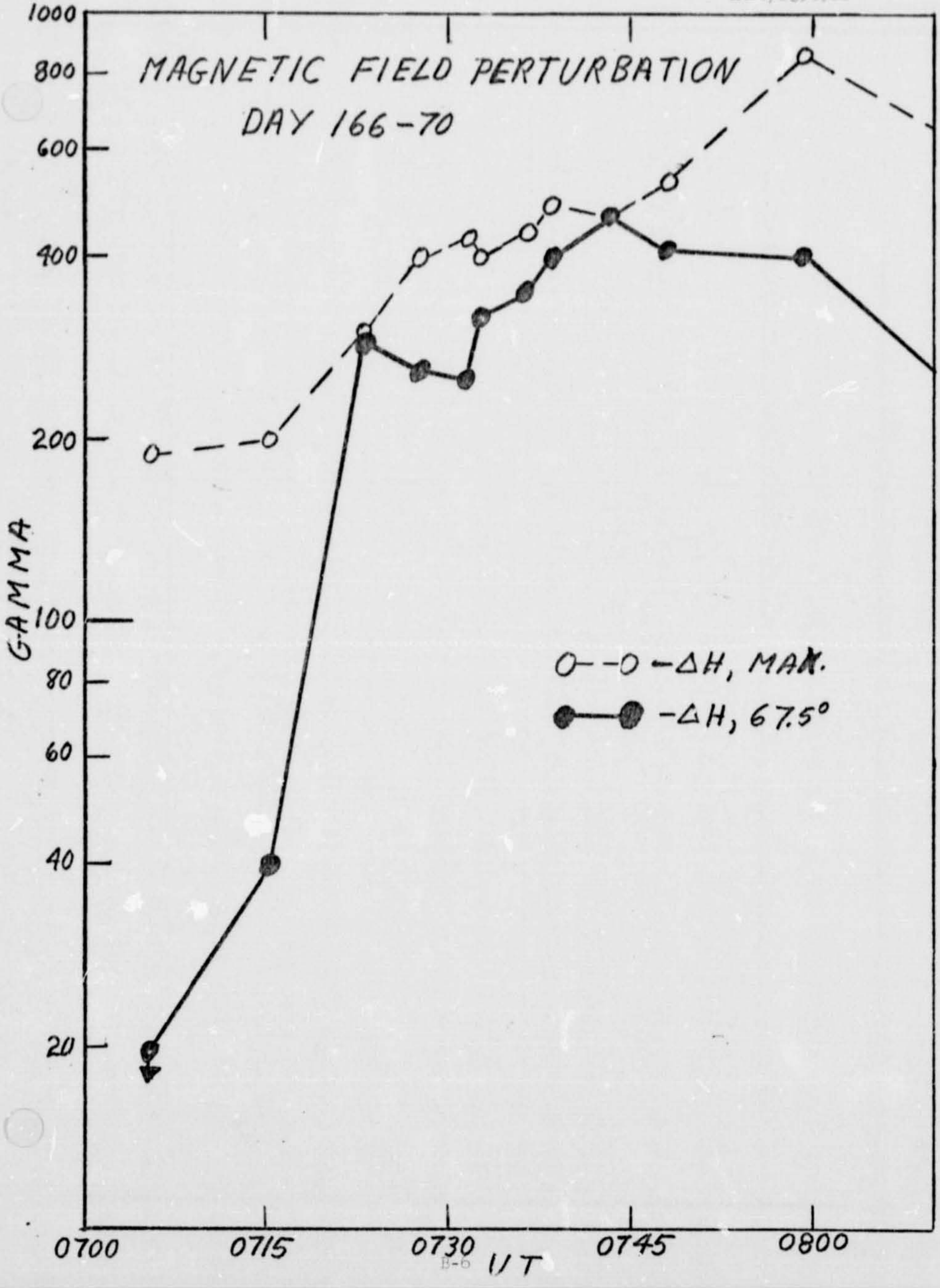

OMNI-ELECTRON ENERGY
FLUX
DAY 244-70
ERGS/(CM²-SEC)
100
80
60
40
20
10
8
6
4
2
1
0658
0700
0702
0704
0706
0708
0710
UT

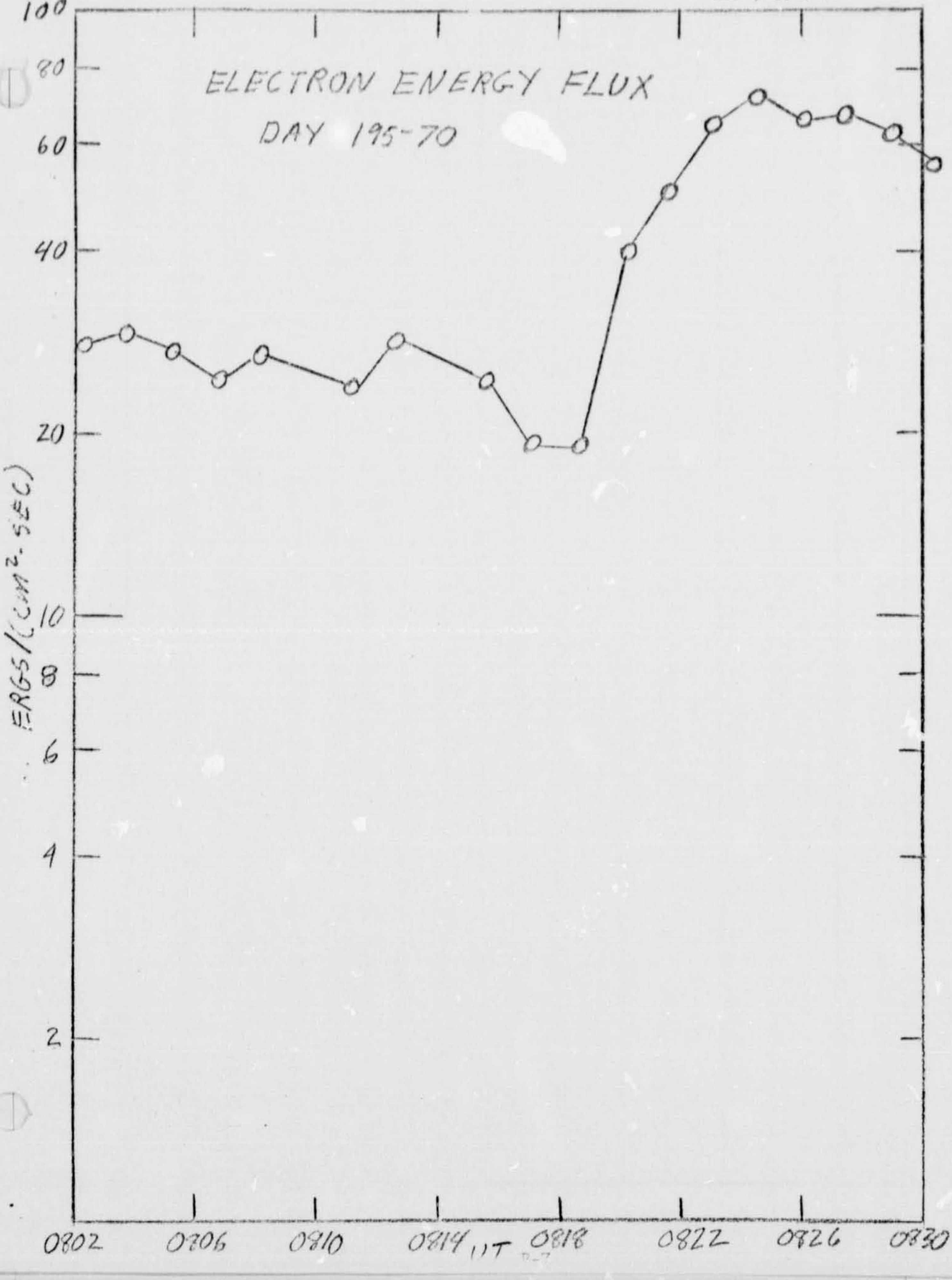

HORIZONTAL FIELD PERTURBATION
DAY-244-70
1000
800
600
400
200
100
80
60
40
20
10
GAMMAS
0—— —0 —ΔH MAXIMUM
⊗——⊗ —ΔH, 67.5°
0658
0700
0702
0704
UT
0706
0708
0710


ELECTRON ENERGY FLUX
DAY 183-70
ERGS/(CM²- SEC)
100
80
60
40
20
10
8
6
4
0630
0645
0700
0715
0730
UT

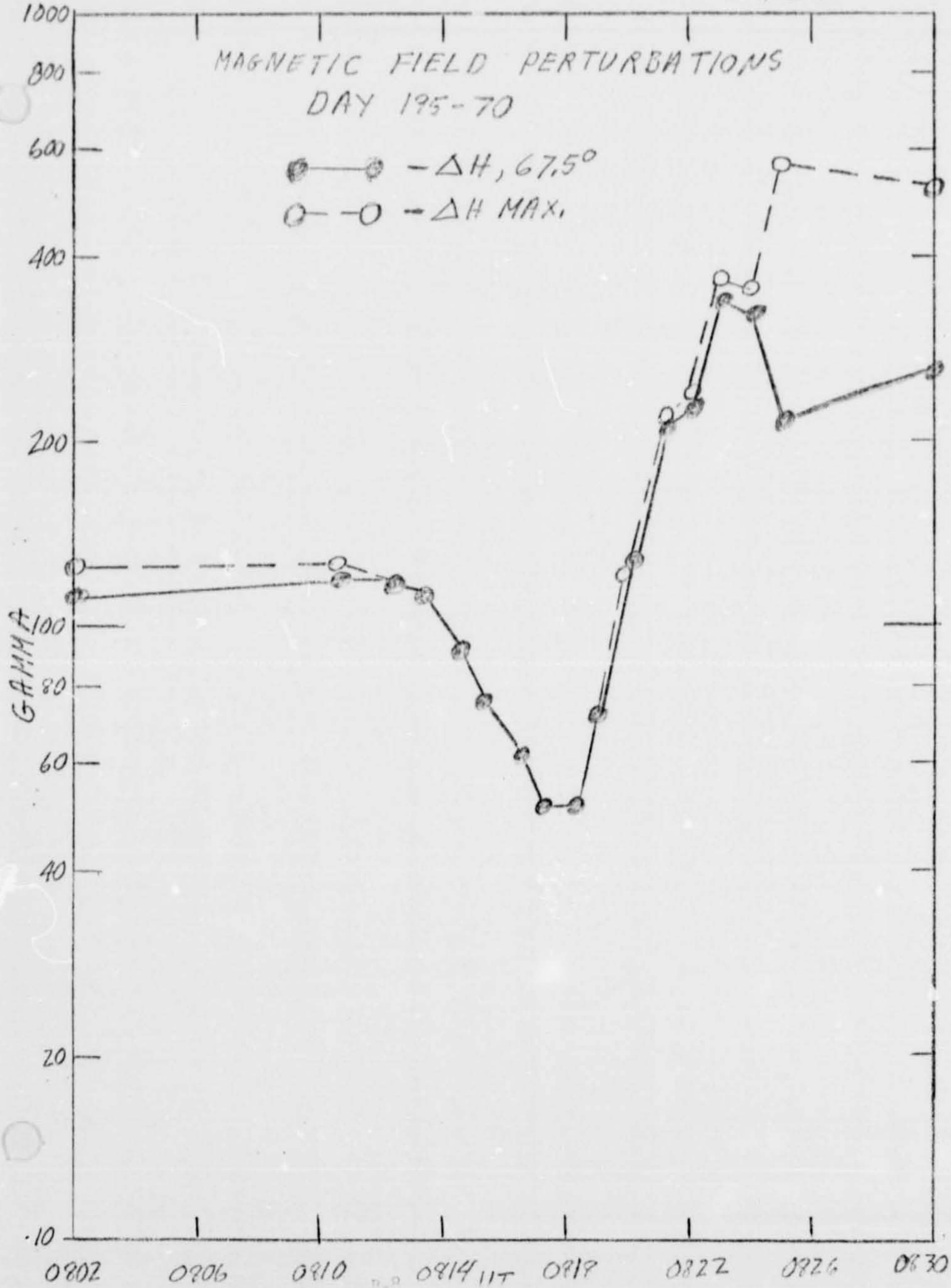

MAGNETIC FIELD PERTURBATION
DAY 183-70
GAMMA
1000
800
600
400
200
100
80
60
40
20
0630
0645
0700
0715
0730
UT


ELECTRON ENERGY FLUX
DAY 166-70
ERGS/(CM²-SEC)
100
80
60
40
20
10
8
6
4
2
0700
0715
0730
0745
0800
UT


MAGNETIC FIELD PERTURBATION
DAY 166-70
1000
800
600
400
200
100
80
60
40
20
GAMMA
O--O -ΔH, MAX.
●—● -ΔH, 67.5°
0700
0715
0730
0745
0800
UT



ELECTRON ENERGY FLUX
DAY 195-70
ERGS/(CM².SEC)
100
80
60
40
20
10
8
6
4
2
0802
0806
0810
0814
UT
0818
0822
0826
0830


MAGNETIC FIELD PERTURBATIONS
DAY 195-70
- ΔH, 67.5°
- ΔH MAX.
1000
800
600
400
200
100
80
60
40
20
.10
GAMMA
0802
0806
0810
0814
UT
0818
0822
0826
0830