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FOURTH QUARTERLY REPORT
FOR
LOCKHEED EXPERIMENT ON ATS-5

(1 June through 31 August 1970)

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ABSTRACT

The Lockheed experiment on ATS-5 has been operating successfully for over a year and is continuing to provide much useful information on the low-energy (auroral) particle environment at synchronous altitude. One prominent feature of the data is an energy dependent time dispersion observed in the onset of the electron flux enhancements during magnetospheric substorms. A method is described for inferring plasma sheet convection velocities from these observations.

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INTRODUCTION

The Lockheed auroral particles experiment on ATS-5 has now been operating successfully for over a year and is continuing to provide a large quantity of useful and interesting data. The analysis is continuing with particular emphasis on the characteristics of the magnetospheric substorms which are a dominant feature of the data, and the quasi-periodic oscillations which are often observed in the particle fluxes during disturbed times.

During this reporting period two oral presentations have been made. One, entitled "Auroral Particle Measurements from Satellites," was presented at the Advanced Study Institute on Aurora and Airglow at Queens University, Kingston, Ontario, Canada, on 12 August by R. D. Sharp. The second, entitled "Plasma Sheet Convection Velocities Inferred from Electron Flux Measurements at Synchronous Altitude," was presented at the Symposium on Upper Atmospheric Currents and Electric Fields at Boulder, Colorado, on 20 August by E. G. Shelley. Two papers have been accepted for publication after minor modifications suggested by the referees: "Preliminary Results of a Low-Energy Particle Survey at Synchronous Altitude," by R. D. Sharp, E. G. Shelley, R. G. Johnson and G. Paschmann, will appear in the Journal of Geophysical Research; and "Absolute Efficiency Measurements for Channel Electron Multipliers Utilizing a Unique Electron Source," by G. Paschmann, E. G. Shelley, C. R. Chappell, R. D. Sharp and L. F. Smith, will appear in the Review of Scientific Instruments. A third paper, entitled "Plasma Sheet Convection Velocities Inferred from Electron Flux Measurements at Synchronous Altitude," by E. G. Shelley, R. G. Johnson and R. D. Sharp, has been submitted to Radio Science.

DISCUSSION

Status of Experiment

A detailed examination of the status of the experiment after approximately one year's operation has been performed utilizing the various capabilities of the several in-flight calibration techniques which were designed into the instrument (Reed et al., 1969). Table I shows some of the ratemeter in-flight calibrations performed during the first year of operation. It is seen that ten of the eleven ratemeters have accurately maintained their calibration curves. The eleventh (CFE) experienced a considerable change during July of 1970, after about ten months' operation. Utilizing the four-point calibration obtained every 5.82 hours from the in-flight calibration oscillators, the shape of the curve can be redetermined. The data subsequent to the malfunction is in this way recoverable with only a small loss in accuracy.

A potentially more serious problem is pulse amplitude degradation in the channeltrons (Reed et al., 1969). Two of the eleven channeltrons have suffered serious pulse amplitude degradation and are no longer producing useful data. Fortunately, one of these (CFP-2A) is a completely redundant channel in the present (spinning) mode of the ATS-5. It was designed to perform angular distribution measurements in the vicinity of the loss cone in conjunction with CFP-1A, but in the present spinning mode they are both scanning the same region of pitch angles. The other degraded channel (CFP-1C) is a proton foil threshold detector, and since these detectors are integral devices, the protons in this region of the spectrum are still being detected by the lower threshold detectors. The loss is in the accuracy of the spectral determination at the high-energy end. Two other channels (CME-1C and CFP-1A) have experienced some degradation but their outputs are still well within the range of the correction which is obtained every 5.82 hours during the calibration mode when a pulse-height analysis is performed on the output pulses from each of the eleven channel multipliers (Reed et al., 1969).

Table I. Ratemeter In-Flight Calibrations

	CMEA	CMEB	CMEC	CMED	CFE	CFPA	CFPB	CFPC	CFPD	CFP2	CMP
CAL 1											
9-4-69	1.44	1.39	1.40	1.42	2.01	1.98	2.04	2.00	1.93	1.99	2.01
1-12-70	1.43	1.38	1.40	1.41	1.97	1.95	2.01	1.98	1.92	1.97	1.98
7-1-70	1.43	1.38	1.39	1.40	1.98	1.95	2.01	1.95	1.91	1.97	1.97
8-11-70	1.42	1.37	1.39	1.40	0.67	1.95	2.00	1.95	1.90+	1.95+	1.97
8-19-70	1.42	1.38	1.40	1.40	0.65+	1.95+	2.00+	1.95+	1.90+	1.95+	1.95+
CAL 2											
9-4-69	2.59	2.44	2.47	2.47	3.03	3.05	3.11	3.01	2.98	3.01	3.01
1-12-70	2.58	2.42	2.46	2.45	3.05+	3.05	3.09	2.99	2.97	3.00	2.98
7-1-70	2.58	2.42	2.44	2.45	3.05+	3.02	3.09	2.98	2.96	3.00	2.98
8-11-70	2.58	2.42	2.45	2.45	1.29	3.02	3.08	2.99	2.96	3.00	2.98
8-19-70	2.57	2.42	2.45	2.45	1.30+	3.03	3.10+	3.00+	2.95+	3.00+	3.00+
CAL 3											
9-4-69	3.58	3.39	3.48	3.50+	3.98	3.97	4.05	3.92	3.94	3.97	3.04
1-12-70	3.56	3.36	3.46	3.47	3.99	3.95+	4.04	3.95+	3.95+	3.95+	3.91
7-1-70	3.56	3.37	3.45	3.46	4.00+	3.96	4.04	3.90	3.92	3.95	3.91
8-11-70	3.57	3.38	3.45	3.46	1.99	3.96	4.03	3.90	3.92	3.95	3.90
8-19-70	3.57	3.37	3.45+	3.45+	2.00+	3.95+	4.05+	3.90+	3.90+	3.95+	3.90+
CAL 4											
9-4-69	4.31	4.12	4.23	4.21	4.68	4.69	4.70+	4.62	4.65+	4.68	4.65+
1-12-70	4.29	4.10	4.19	4.17	4.65+	4.67	4.70	4.60+	4.61	4.68	4.64
7-1-70	4.30	4.10	4.19	4.18	4.70+	4.66	4.70+	4.59	4.61	4.66	4.64
8-11-70	4.30	4.10	4.19	4.18	2.59	4.67	4.70+	4.59	4.60	4.67	4.63
8-19-70	4.30	4.10	4.20+	4.20+	2.60+	4.65+	4.70+	4.60+	4.60+	4.70+	4.65+

+ = comb filter data

Apart from these relatively minor problems, we found that after one year of operation, the experiment is still functioning as designed and is continuing to produce a large quantity of valuable and interesting data.

Plasma Sheet Convection Velocities

Large increases in the low-energy electron fluxes (0.5 to 50 keV) are observed to occur at synchronous altitude on most nights in the local evening or midnight sectors. These increases are found to be generally associated with magnetic substorms. The time of increase in the fluxes is found to be energy dependent with the lower-energy electrons nearly always being observed first for the evening and midnight events. If one interprets these flux increases as resulting from an inward convection of the plasma sheet in connection with a substorm, one can estimate the convection velocity at synchronous altitude from the measured energy dependent time of flux increase and previous measurements (Schield and Frank, 1969; Frank, 1970) of the energy dependent radial structure of the inner edge of the plasma sheet. The median velocity estimated from 38 cases by this technique is approximately 3 km/sec. This implies a westward electric field of approximately 0.36 mV/m, a value consistent with other measurements of this field.

A paper on this subject has been submitted to Radio Science and is included in the Appendix.

Coordinated Measurements with OV1-18 Satellite

The Air Force satellite OV1-18 was launched on 18 March 1969 into a 99° inclination orbit with apogee at 590 km and perigee at 469 km. An experiment by the Lockheed Palo Alto Research Laboratory included an assortment of low-energy particle detectors designed to measure the intensity, angular and energy distributions of the auroral electrons and protons in the energy range below about 50 keV. Of primary interest for a comparison with the ATS-5 results are a set of five instruments similar in design to the Lockheed experiment on ATS-5. They contain forty individual channel multiplier detectors which measure the electron and proton fluxes in specific energy groups and at different angles. During selected intervals in 1969 an effort was made to program the OV1-18 satellite such that it would acquire data in the vicinity of the northern hemisphere conjugate point to ATS-5. Table II shows the most favorable coordinated examples from the presently available data. The OV1-18 coordinates are given at the approximate time of the crossing of the L shell containing the ATS-5 field line. A detailed examination of the coordinated data from some of these examples is in progress. Preliminary results from two cases indicate that the number fluxes are quite comparable at the two locations, i.e., there is no evidence for the highly anisotropic angular distributions peaked in the loss cone that have been suggested in the literature (Hones et al., 1970; O'Brien, 1967).

Quasi-Periodic Oscillations

Work is continuing in the analysis of the quasi-periodic particle flux modulations reported earlier. A computer program has been developed which calculates the power spectral density from the response of any one detector over a specified period of time by a digital technique. At present, the noise must be removed from the data by hand operations before they are analyzed. The program first calculates an auto-correlation function which is then transformed to a power spectrum density vs. frequency function. Figure 1 is an example of a power spectral density function calculated from approximately one hour of data for Day 251 (1969). The raw data were shown in an earlier report. A strong peak is obvious at approximately 0.003 sec^{-1} ($\tau \sim 6$ minutes). The program also includes a digital low pass filter which effectively removes all of the power for frequencies above a specified value. Work is in progress on a cross-correlation analysis program which will be capable of providing a quantitative measure of the correlation between flux variations measured by separate particle detectors or flux variations and other physical parameter measurements such as magnetic field.

Table II. Coordinated Data Acquisitions with OV1-18

1969 Day	UT (secs)	Latitude (North)	Longitude (East)	Altitude (km)	Magnetic Local Time (Hours)
268	65216.	54.75	277.78	569	12.60
271	29082.	57.99	274.18	538	02.25
272	66789.	54.78	271.95	570	12.51
304	67110	54.57	276.71	496	12.99
307	30797.	55.04	273.92	462	02.82
308	35366.	56.79	255.97	462	02.51
308	68455.	55.02	271.65	485	12.88
309	67355.	54.46	276.69	482	13.04
311	70883.	56.28	261.48	477	12.60
314	34490.	56.21	260.46	467	02.69
325	72448.	56.65	257.43	461	12.64
328	69055.	54.97	272.97	461	13.14
329	67924.	54.69	278.00	461	13.29
342	37060.	57.37	255.71	538	03.02
033	37918.	55.91	262.23	472	03.79
068	38484.	55.53	266.59	484	04.20
086	42420.	57.13	254.64	528	04.12
091	41146.	56.42	260.57	536	04.29

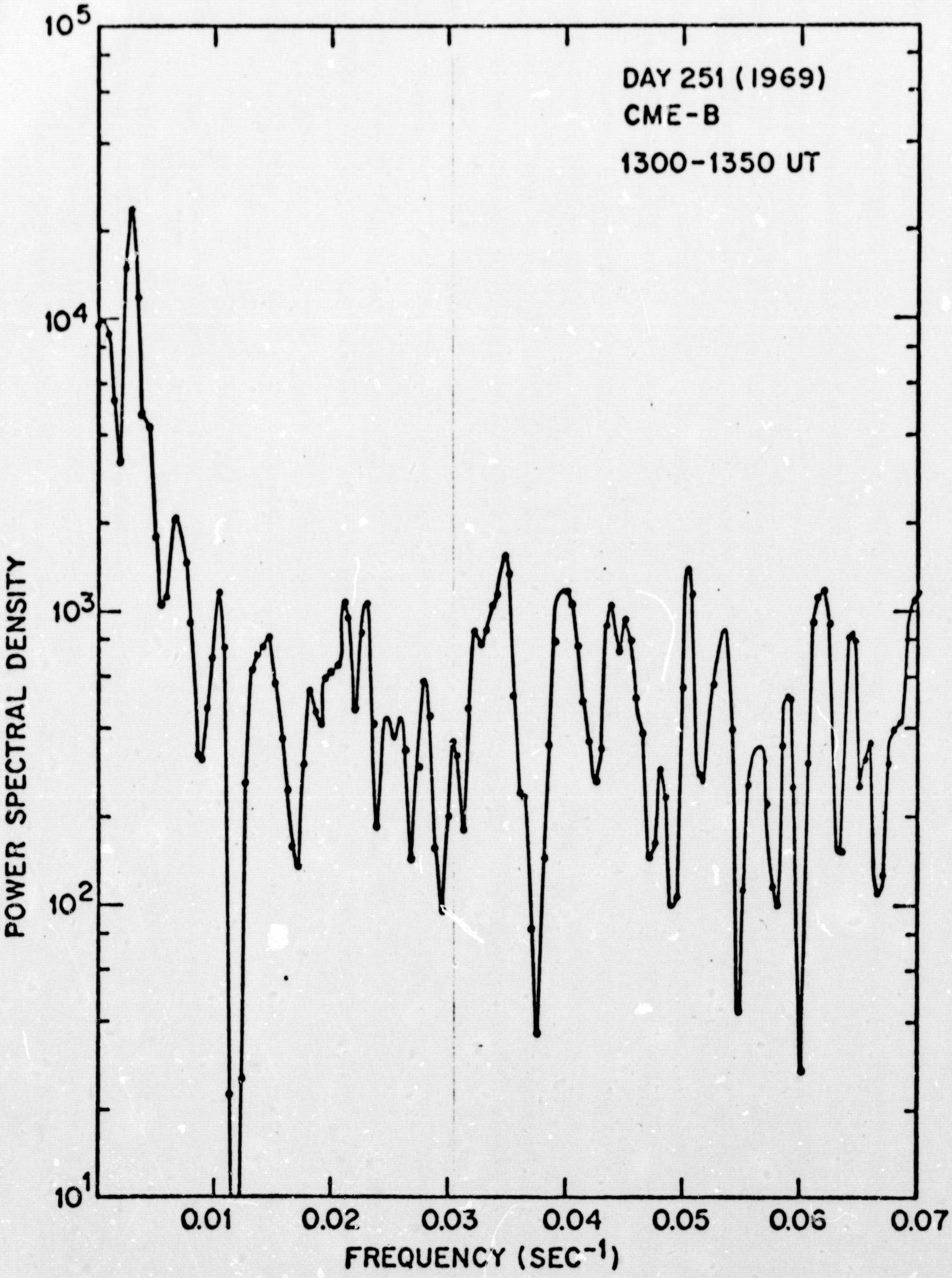

Figure 1. Power Spectral Density Function for Instrument CME-B, Day 251 (1969).

PROGRAM FOR NEXT REPORTING INTERVAL

We will continue our analysis along the lines outlined in our post-launch data analysis plan as submitted on 15 October 1969.

CONCLUSIONS AND RECOMMENDATIONS

After one year, the experiment is still operating successfully and producing much interesting data. The principal new results are in the characteristics of magnetospheric substorms, particularly the westward directed convection electric fields which are prominent in the development phase of the substorms.

REFERENCES

Frank, L. A., "On the Relationship of the Plasma Sheet, Ring Current, Trapping Boundary and Plasmapause Near the Magnetic Equator and Local Midnight, Univ. of Iowa Report 70-33 (1970).

Hones, E. W., Jr., J. R. Asbridge, S. J. Bame and S. Singer, "Comparisons of Particle Spectrums in the Plasma Sheet with Those Measured by Rockets over the Auroral Zone," Los Alamos Scientific Laboratory Report LADC 11571 (April 1970).

O'Brien, B. J., "Interrelations of Energetic Charged Particles in the Magnetopause," in Solar Terrestrial Physics, edited by J. W. King and W. S. Newman, Academic Press, London, pp. 169-211 (1967).

Reed, R. D., E. G. Shelley, J. C. Bakke, T. C. Sanders and J. D. McDaniel, "A Low-Energy Channel-Multiplier Spectrometer for ATS-E," IEEE Trans. Nucl. Sci., NS-16, 359 (1969).

Schield, M. A., and L. A. Frank, "Electron Observations between the Inner Edge of the Plasma Sheet and the Plasmasphere," University of Iowa Technical Report 69-46 (1969).

APPENDIX

PLASMA SHEET CONVECTION VELOCITIES INFERRED FROM ELECTRON FLUX MEASUREMENTS AT SYNCHRONOUS ALTITUDE

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ABSTRACT

Large increases in the low energy electron fluxes (0.5 to 50 keV) are observed to occur at synchronous altitude on most nights in the local evening or midnight sectors. These increases are found to be generally associated with magnetic substorms. The time of increase in the fluxes is found to be energy dependent with the lower energy electrons nearly always being observed first for the evening and midnight events. If one interprets these flux increases as resulting from an inward convection of the plasma sheet in connection with a substorm, one can estimate the convection velocity at synchronous altitude from the measured energy dependent time of flux increase and previous measurements [Vasyliunas, 1968; Schield and Frank, 1969; Frank, 1970] of the energy dependent radial structure of the inner edge of the plasma sheet. The median velocity estimated from 38 cases by this technique is approximately 3 km/sec. This implies a westward electric field of approximately 0.36 mV/m, a value consistent with other measurements of this field.

INTRODUCTION

ATS-5 was launched on 12 August 1969 into a nearly synchronous orbit. After approximately one month the position of the satellite was stabilized in the vicinity of 105° west longitude. It carried a magnetometer and several particle detectors spanning the energy range from 50 eV to 30 MeV. The Lockheed experiment was designed to perform a survey of particle fluxes of auroral energies. It consists of eleven individual detectors each of which measures protons or electrons in a specific energy interval spanning the range from about one-half to several hundred keV. Primary emphasis was placed on the region below 50 keV which contains most of the auroral particles. In the following discussion we will be concerned primarily with data from four of the electron detectors. Each of these detectors consists of a permanent magnet spectrometer which utilizes 180° deflection to achieve continuous sensitivity over a broad energy interval ($\Delta E/E \cong 100\%$). Together, the four detectors provide continuous and nearly uniform coverage for electrons over the energy range from 0.65 to 53 keV. They are sampled essentially simultaneously (i.e., within a time interval short compared to the ratemeter time constants) twice per telemetry sequence of 5.12 seconds. In addition, the highest and lowest energy channels are sampled more frequently to provide higher time resolution at the energy extremes. The proton data to be presented are from three integral proton detectors with foil determined thresholds at approximately 5, 15 and 38 keV. A detailed description of the instrument and the results of a study of the long-term reliability of the channel multiplier sensors has been presented [Reed et. al., 1969] and a description of the procedures used for calibration of the electron channels will be published shortly [Paschmann et. al., 1970].

OBSERVATIONS

A preliminary report on the general characteristics of the particle fluxes at synchronous altitude has been given [Sharp et. al., 1970, to be referred to as S1 in the following discussion]. It was reported that large increases in the electron fluxes were observed on most nights in the vicinity of local midnight with increases of one or two orders of magnitude occurring within times ranging from a few minutes to the order of an hour and that these electron "events" were generally associated with magnetic substorms as established from auroral zone magnetograms in the vicinity of the foot of the field line passing through ATS-5. It was further reported that in those events occurring in local evening or near local midnight the lower energy fluxes were generally observed to increase in intensity before the higher energy fluxes (see Figures 1 and 2 of S1).

Figure 1 shows in more detail the responses of the four differential electron detectors during the beginning of the event which occurred near local midnight on 1 September 1969 (See Figures 1 and 2 of S1). The values of the horizontal component of the earth's magnetic field at Leirvogur and Great Whale have also been hand drawn approximately to scale at the bottom of the figure for a short time interval. These were scaled from regular run magnetograms so the relative timing may be uncertain to two or three minutes. At this time the approximate geomagnetic longitude of the foot of the field line through ATS-5 was 20°. The coordinates of the observatories are given in Table I.

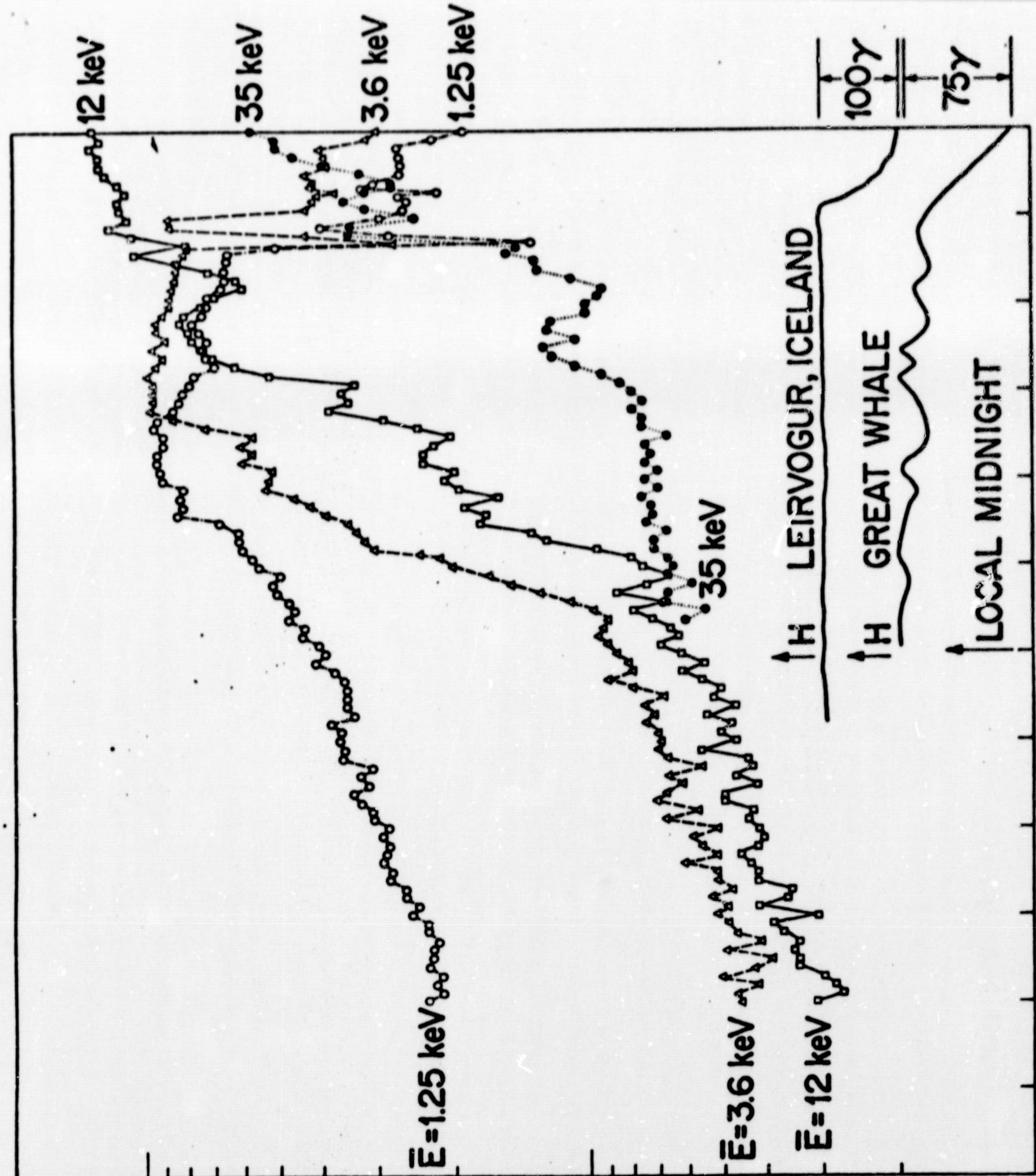

Figure 1 Responses of four broad band differential electron detectors to flux increases at synchronous altitude preceding a magnetic bay in the auroral zone. Note the energy dependence in the time of increase. The geomagnetic longitude of the foot of the ATS-5 field line was approximately 20°; see Table I for observatory coordinates. The approximate number fluxes (electrons/cm^2-sec-ster-keV) can be obtained by multiplying the 1.25, 3.6, 12 and 35 keV count rates by 6×10^4, 3×10^4, 7×10^3 and 3×10^3, respectively.

TABLE I

Geomagnetic Coordinates of Observatories

Station	Latitude	Longitude
College	64.6	256.5
Meanook	61.8	301.0
Baker Lake	73.8	315.2
Fort Churchill	68.7	322.8
Great Whale	66.6	347.4
Leirvogur	70.2	71.0
Honolulu	21.1	266.5
Tucson	40.4	312.2
San Juan	29.6	3.1

This event shows some of the features characteristic of many of the evening and midnight events observed on magnetically quiet days (the 3-hour K_P during this event was 2- and the average K_P over the previous 24 hours was 1+). In particular the lowest energy electron fluxes are observed to increase first, followed in succession by increases in the higher energy electron fluxes with 10 to 20 minutes lag between increases in adjacent channels. At or near the time of the sharp onset of the negative bay at Leirvogur the fluxes in all channels are seen to change rapidly. This latter feature which is shown in more detail in Figure 2, was not always seen, but occured in a sufficient number of the events to indicate that this is not an isolated case.

Another somewhat similar case in which there was a fairly large time lag between the flux increases in different energy channels is shown in Figure 3. Several magnetograms from a selected set of auroral zone observatories spanning the local time region around the position of ATS-5 are shown in Figure 4 together with the 15-minute running average of the Z (approximately North) component of the field at ATS-5. The ATS-5 magnetometer data presented here are preliminary and have not been corrected for changes occurring in vehicle fields. The omnidirectional electron energy flux for this event calculated under the assumption of isotropy is shown at the top of the figure. The dashed line labeled A corresponds to the time indicated by the similarly labeled arrow in Figure 3. This is the time at which there is a sharp onset of magnetic activity in the auroral zone and it is also the time at which the electron spectrum hardens rather rapidly and the energy flux increases significantly. It occurs approximately one hour after the first observed increase in the lower energy electron fluxes at ATS-5. Figure 5 shows the horizontal component from three low latitude observatories

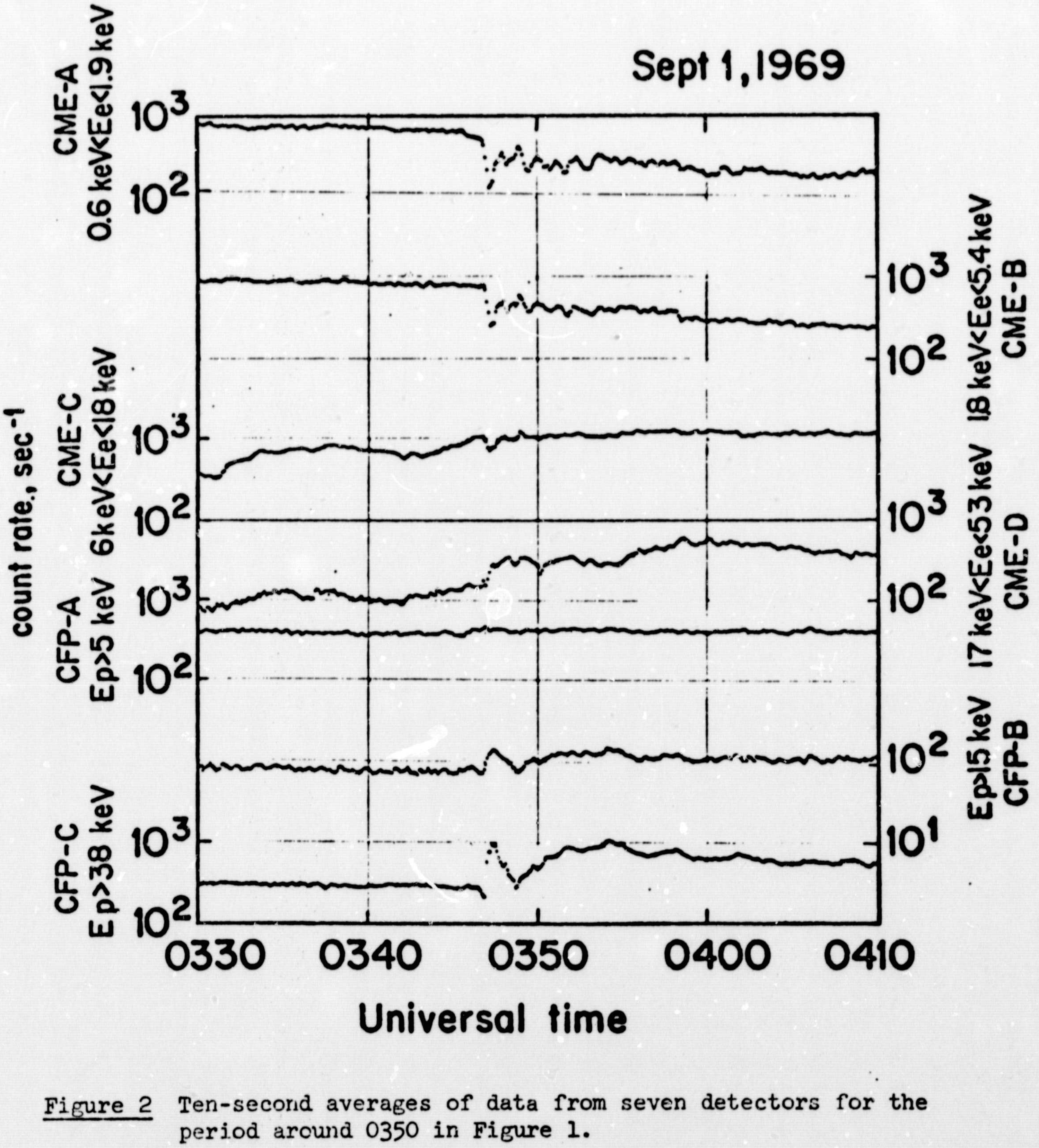

Figure 2 Ten-second averages of data from seven detectors for the period around 0350 in Figure 1.

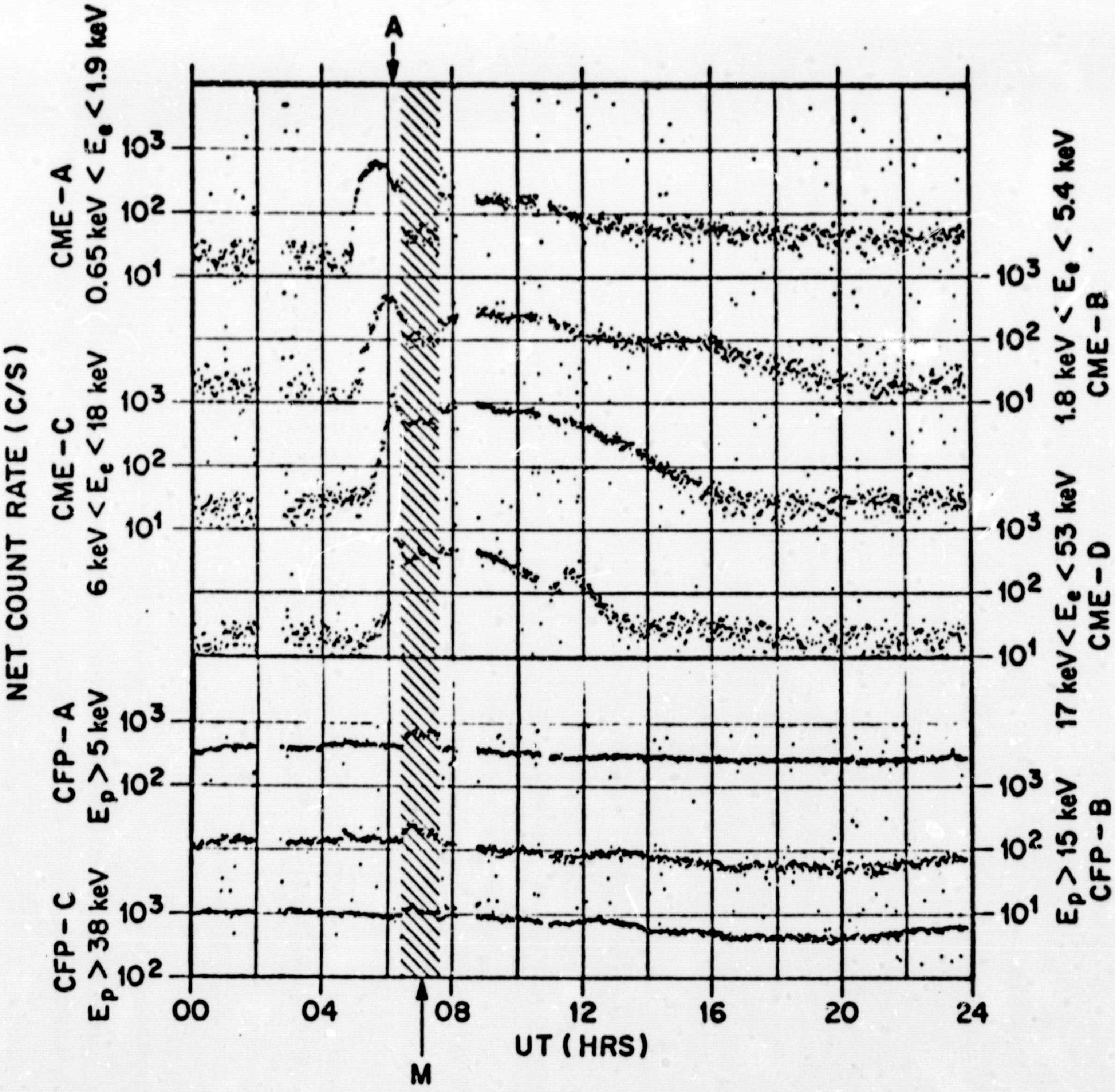

Figure 3 An example of an electron "event" near local midnight on a relatively quiet day (3-hr K_p = 1). Note the relatively large time dispersion in the flux increases as a function of energy. The satellite was in eclipse during the cross-hatched period and the data have not been corrected for vehicle potentials. Local midnight at the satellite is indicated by M. The arrow A corresponds in time to the similarly indicated times in Figures 4 and 5.

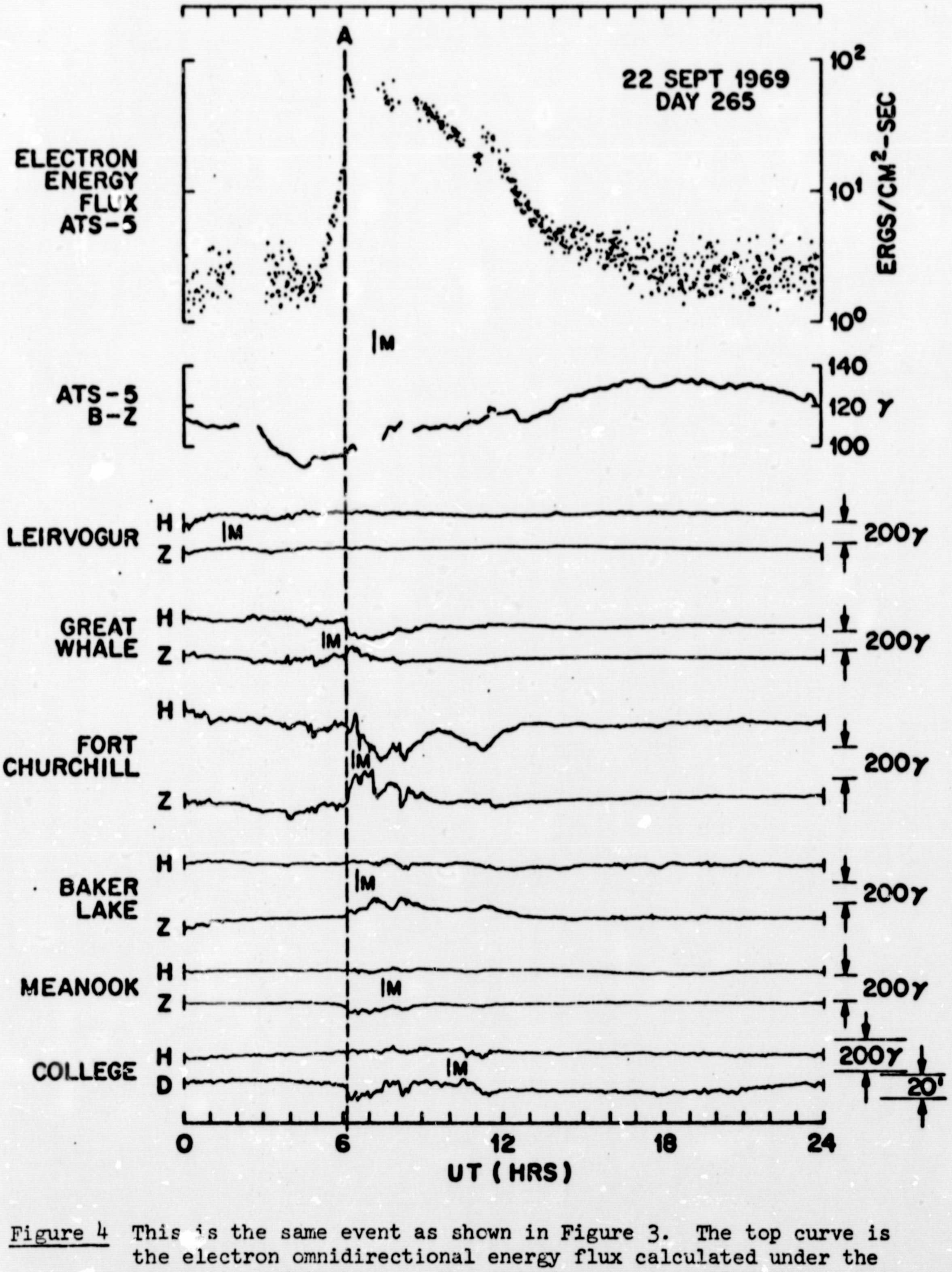

Figure 4 This is the same event as shown in Figure 3. The top curve is the electron omnidirectional energy flux calculated under the assumption of isotropy. The second curve is a 15-minute running average of the Z component of the local magnetic field as measured by the ATS-5 magnetometer (see text for clarification). Below are magnetograms from a selected set of auroral zone observatories spanning the local time region around ATS-5. Local midnight is indicated by M for ATS-5 and for each observatory. See Table I for observatory coordinates. The geomagnetic longitude of the foot of the ATS-5 field line was approximately 318°.

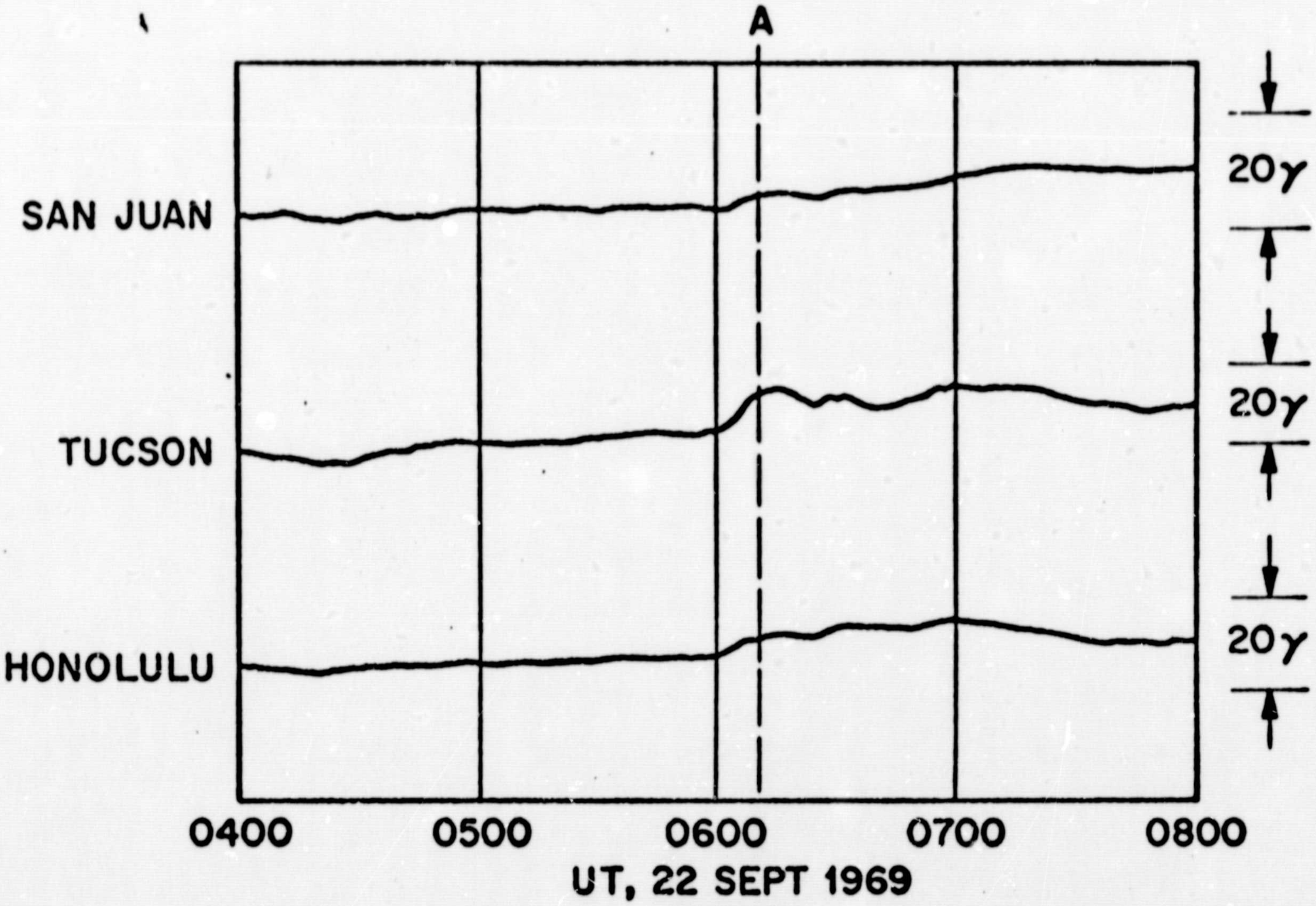

Figure 5 Horizontal field components observed at low latitude stations during the event shown in Figures 3 and 4. See Table I for observatory coordinates.

during this event. There is an obvious increase in the horizontal component at low latitude associated with the substorm, particularly at Tucson which is near the geomagnetic longitude of ATS-5 (~318°). One sees the beginning of a similar behavior in the field at ATS-5, but due to the fact that the satellite went into eclipse shortly after this time not only are the particle data difficult to interpret because of vehicle potentials, but also the resultant variations in solar cell currents had a significant effect on the magnetometer. Cummings et al. [1968] have reported similar correlated effects in the field at ATS-1 and at low latitude stations during substorms.

The two events discussed above showed rather long time lags between increases in the various energy channels. An example of an event in which the time dispersion was much less is shown in Figure 6. At the time of this event (28 August 1969) the geomagnetic longitude of the foot of the ATS-5 field line was approximately 54°. In addition to the relatively smooth rise in the flux levels, one sees first a rapid and apparently reversable increase in intensities which occurs nearly simultaneously in all channels. These more rapid reversable changes in the flux levels which occur simultaneously in several or all channels are frequently observed to be superimposed on otherwise slowly increasing flux levels which clearly show the time lag between channels.

OTHER RELATED OBSERVATIONS

Several authors [Frank, 1968, 1970; Schield and Frank, 1969, referred to as SF1 in the following discussion; Vasyliunas,1968] have reported observation of a "soft" inner edge to the plasma sheet within a few R_E (earth radii) of the synchronous altitude in the evening and midnight sectors near the equator and that this edge moves earthward during substorms. Schield and Frank presented approximately one month's data from OGO-3 for this region

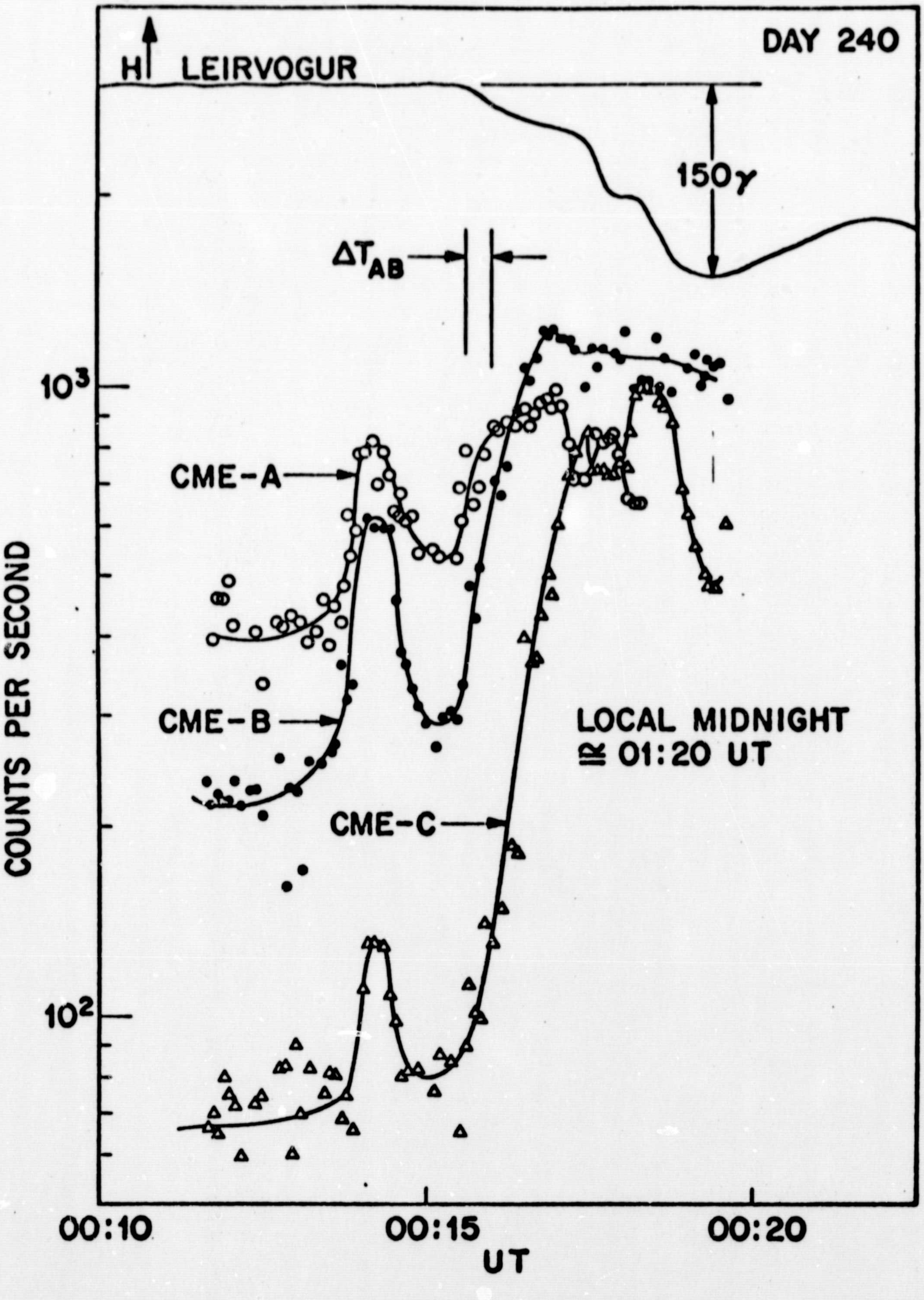

Figure 6 An example of a rapid electron flux increase which occurred near local midnight in conjunction with a magnetic substorm on 28 August 1969. The energy dependent time dispersion of the flux increase is small (~ 30 sec between channels). Note also the sharp reversible flux increase observed simultaneously in all three channels at about 0014 UT. The geomagnetic longitude of the ATS-5 field line was approximately 54°. The H component from Leirvogur was hand drawn by scaling a regular run magnetogram and the relative timing could be in error by several minutes.

of the magnetosphere in a form that included the radial location of the plasma sheet inner edge as observed in two energy intervals (see Figure 8, SF1). These energy intervals, 1.35 ± 0.35 keV and 3.6 ± 1.0 keV match our channels CME-A (1.25 ± .6 keV) and CME-B (3.6 ± 1.8 keV) sufficiently well to justify a direct comparison. In Figure 7 we give a different presentation of the data referred to above. In the lower right section of Figure 7 we show schematically the form in which the data were presented in SF1 (i.e. horizontal bars representing the radial range over which the fluxes changed rapidly in each of the two channels). From these bars we defined two parameters $\overline{R}$ and ΔR as indicated at the left of Figure 7. They are the average position and spatial separation parameters respectively for the inner edge of the plasma sheet as defined by these two energy channels. These parameters were scatter plotted for the 16 cases for which adequate data were presented. The cases at the beinnings of the two magnetic storms were excluded. The shaded area represents one standard deviation about the mean. The independent distributions for the two parameters are plotted along their respective axes.

On the basis of these data we conclude that there is no evidence for a radial dependence to the structure of the edge and that the "soft" character of the inner edge is a persistent, though not necessarily constant feature. These conclusions are consistant with the general statements of the authors cited above. It is also evident that the plasma sheet extends into or beyond the synchronous orbit (indicated by the vertical line in Figure 7) a significant portion of the time in the evening and midnight sector.

Recently, Liszka et al. [1970] have reported a soft low latitude edge to the auroral zone in the local evening near L = 5 which probably corresponds to the precipitation from the inner edge of the plasma sheet. The cases they presented indicated an edge thickness of $\Delta L \sim 0.5$ in the one to six keV range.

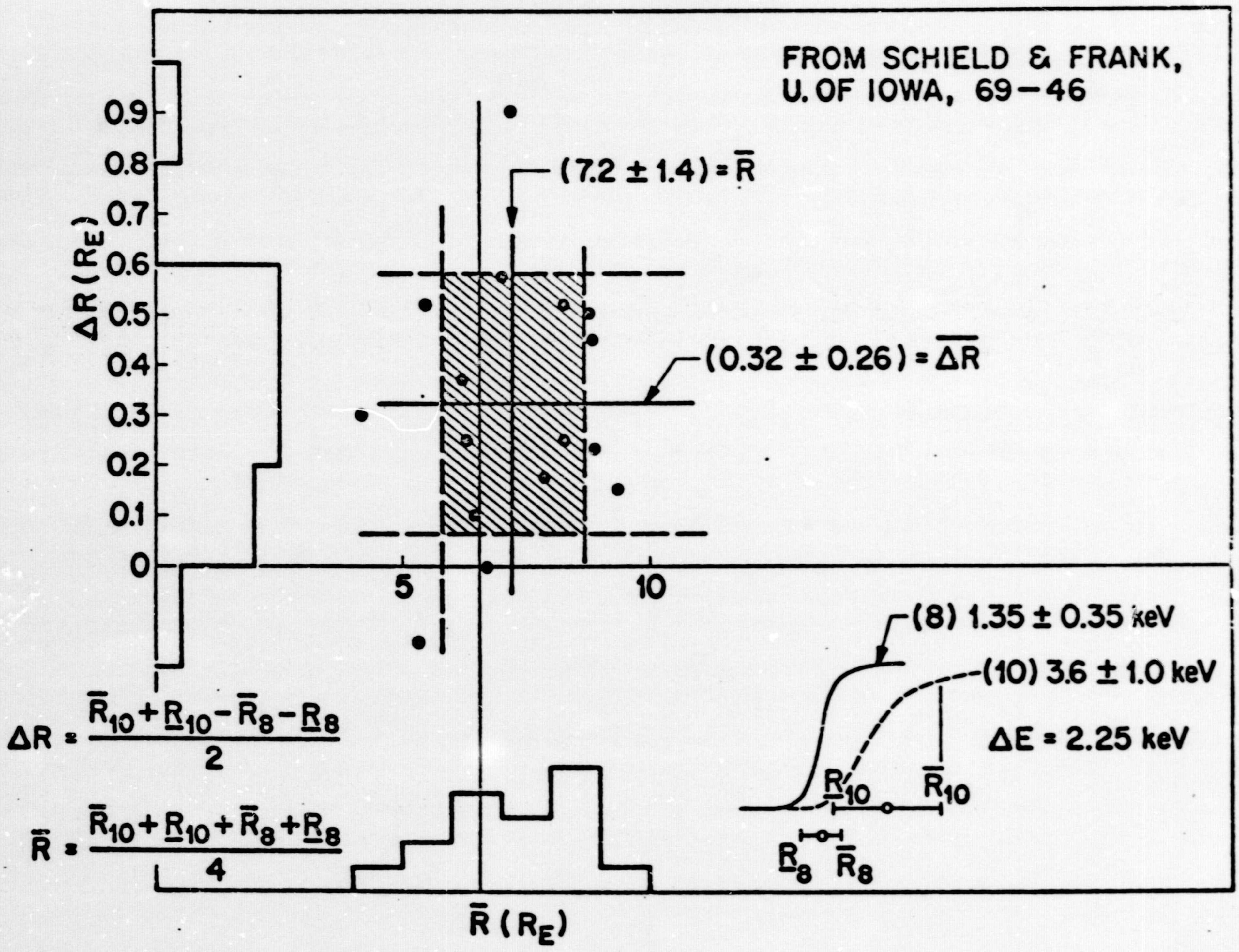

Figure 7 Summary of data presented by Schield and Frank [1969] showing the spatial separation between the radial fall-off positions of electron fluxes at two energies as a function of the position of the inner edge of the plasma sheet. See text for explanation.

This is somewhat less than the "thickness" suggested by Frank [1970], but considering the spread in the parameter ΔR in Figure 7 it is reasonable to assume that this value would fall within the range of soft edge measurements of the plasma sheet near the equator.

INTERPRETATION OF OBSERVATIONS

Let us now consider a model in which the inner edge of the plasma sheet exists at a quasi-stable position one or two R_E outside the synchronous orbit prior to the beginning of a substorm. This is the condition which might have obtained during many of the OGO-3 passes which mapped the radial structure of the edge. Now assume that this equilibrium condition is disturbed, perhaps by an increase in the dawn-to-dusk electric field across the magnetosphere [Axford and Hines, 1961; Axford, 1969]. If the inner edge structure remains reasonably "rigid" as the plasma sheet is convected radially inward, as suggested by the earlier discussion, a time dispersion in the observations of the electron fluxes as a function of energy would occur as the inner edge was convected radially inward past ATS-5. The combination of the spatial structure of the inner edge discussed above with measurements of the time dispersion provides a crude estimate of the velocity of the inner edge of the plasma sheet in the vicinity of 6.7 R_E. If the mean lifetimes of the particles are long compared to the convection time, this velocity would also be approximately equal to the plasma covection velocity. In any case, this velocity would represent a lower limit on the plasma convection velocity in this simple model. As we will see below, the median velocity calculated by this technique would imply an inward convection time (over a distance of one or two R_E) comparable to the "crude estimates" of the minimum lifetimes for 1 to 10 keV electrons made by Kennel [1969]. If this convection is assumed to be the result of an $\vec{E}\times\vec{B}/B^2$ drift, one can calculate the minimum necessary electric field from the estimated velocity and the local magnetic field intensity.

In Figure 8 we present the results of a preliminary analysis of 38 cases of electron flux increases observed on ATS-5 for which a time lag between the two lowest energy channels was definable. We attempted to establish a criterion consistent with that chosen by Schield and Frank [1969]. This consisted of establishing the time region over which the fluxes in each of the two channels increased approximately exponentially toward a "plateau" value and defining ΔT as the time separation of the midpoints of those increases. These values were not unique, partially because of other more rapid variations superimposed on the general increases and also because the slopes occasionally changed significantly during the increases. However, using other criteria such as separation between 10% to 90% intervals or separation of 50% points did not alter the results significantly.

Certain biases are inherent in the present analysis. In most cases it was possible to analyze only the first event observed on any given night since often a significant intensity of lower energy electrons remained in the vicinity of the satellite for many hours after an event, probably resulting from longitudinally drifting particles [McIlwain and DeForest, 1970; Pfitzer and Winckler, 1969]. This fact creates an unintended correlation between local time of observation and magnetic activity since the first observable event tends to occur at an earlier local time during increased magnetic activity. Another bias exists in that the times calculated tend to favor the slower components when there is a change in the slope during the increases.

The distributions were separated into two local time regions, one near local midnight (L.T. between 2130 and 0230) and the other in the evening

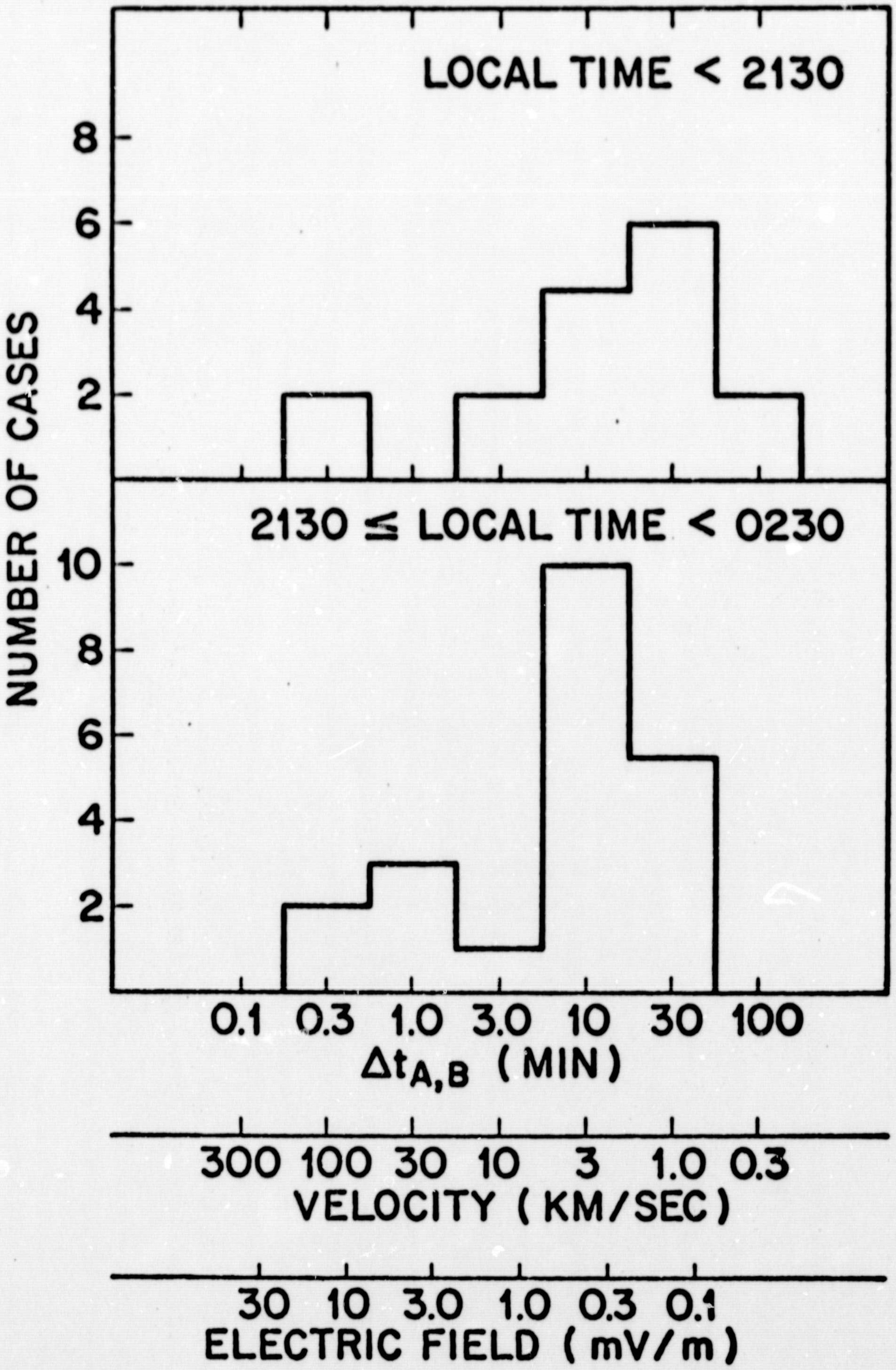

Figure 8 The distribution of time lags between observations of electron flux increases in the 1.25 ± 0.6 keV range and the 3.6 ± 1.8 keV range. The center scale at the bottom shows the corresponding velocities calculated under the assumption of a constant spatial structure to the plasma sheet inner edge. See text and Figure 7. The bottom scale is the corresponding westward electric field required to produce these velocities by an $\vec{E}\times\vec{B}/B^2$ plasma drift.

(L.T. before 2130). This separation was accomplished for several reasons. First, there is more direct information available on the plasma sheet structure in the midnight sector. Second, as stated above, the earlier evening events tend to be associated with increased magnetic activity (no other selectivity on the basis of magnetic activity has been utilized). Third, if a westward electric field across the magnetosphere exists it will have an increasing radial component as one moves toward dusk in the equatorial plane and this field in turn can result in a longitudinal drift of low energy electrons counter to their normal eastward gradient and curvature drifts. Such an effect could result in our observation of a time dispersion for the low energy electrons which had drifted toward evening from a substorm which had occurred at an earlier universal time in the midnight sector. One sees that there is some indication of slightly longer time delays in the evening events, but without clear statistical significance. A further breakdown of the midnight events by separating out those occurring between 2330 and 0230 did not result in an observably different distribution.

As an alternative model to the one described above, a radial electric field could be invoked to explain all of the events independent of local time purely in terms of longitudinal drift occurring after the plasma was injected or accelerated at a point. A lower limit on the radial component of the electric field required for this effect can be estimated from the maximum energy of the electrons which drift westward (i.e., the highest energy channel in which significant flux increases are observed). In some of the evening events [Sharp et al., 1970] electrons are observed only in the two lower channels ($E < 5$ keV). This would imply a radial component of $\sim .4$ mV/m for the electric field, not inconsistent with the evening radial component of typical westward fields estimated below.

In the majority of the events observed near local midnight, significant flux increases were observed in all channels ($E > 17$ keV). This would imply a radial field component greater than 1.4 mV/m. In the analysis below we have chosen the more conventional convection model interpretation with the assumption of a dawn-dusk electric field. More detailed analysis of the individual events utilizing ground station magnetograms to establish the timing of the event should aid in distinguishing between the two models.

The median time lag for the 22 events in the midnight sector was 11 minutes, while that for the evening events was 18 minutes. The first scale below the ΔT scale in Figure 8 shows the velocity calculated on the basis of the 0.32 R_E separation found in Figure 7. Thus the 11 minute median ΔT would correspond to a radial drift velocity of approximately 3 km/sec. The bottom scale in Figure 8 represents the perpendicular electric field component necessary to produce the corresponding radial drift velocity (a magnetic field intensity of approximately 120 gamma was assumed). The median velocity of 3 km/sec corresponds to an electric field of approximately 0.36 mV/m. This value compares reasonably well with the fields estimated by Vasyliunas [1968] and Schield and Frank [1969] by similar techniques in isolated cases (0.24 mV/m and 0.6 mV/m respectively).

In those cases where we have looked in detail at the timing of the "inward convection" relative to the magnetic substorm as determined from the sharp onset of negative bays in the auroral zone magnetograms, the longer time lag events (lower velocities) tend to begin as much as an hour or more before the magnetic substorm (see Figures 1, 3 and 4). This suggests that perhaps an electric field of the order calculated is "turned on" more than an hour before the onset of the magnetic substorm. This agrees with the observations of Carpenter and Stone [1967] on whistler duct motions and the recent suggestion of Mozer and Manka [1970] based on balloon electric field measurements. It is also consistent with the Vela observations at 18 R_E [Hones, 1968; Hones et al., 1967, 1970] in which they observe a thinning of the plasma sheet before the expansive phase of a substorm.

The 1 to 100 km/sec range of inward radial velocities shown in Figure 8 transform [Mozer, 1970] to southward velocities of 25 to 2500 m/sec in the auroral zone. Motions of auroral forms in this direction and of these velocities have been observed [Hultqvist, 1967].

Another possible interpretation of the longer time dispersions we observe could be that the satellite is entering a soft dusk edge of a stationary plasma sheet such as depicted schematically in Figure 8 of Frank [1970]. Such a soft dusk edge might be expected to result if the inward convection velocity were small compared to the longitudinal curvature and gradient drift velocities. The longitudinal drift velocity is energy dependent and would result in a longitudinal energy dispersion. More detailed convection calculations similar to those by Chen [1970, see references therein] are required before one can establish whether or not our results are consistent with such a model.

It was mentioned earlier, see Figure 6, that one frequently finds rapid reversible fluctuations occurring simultaneously in more than one energy channel superimposed on a more gradual rise. In light of the interpretation of the more gradual increases being due to the motion of the inner edge of the plasma sheet over the satellite, one might interpret these rapid reversible flux modulations as resulting from rapid radial motions of flux tubes which carry the plasma with them. Frequently the reversible modulations are quasi-periodic [Shelley et al., 1970]. The implications of such an interpretation for the quasi-periodic events will be covered in a future publication. One possible mechanism leading to such modulations is the drift wave resonance [Cladis, 1970]. Alternatively, the flux modulations could result form poleoidal or toroidal oscillations of the magnetosphere [Saito, 1969].

CONCLUSIONS

Large increases are observed in the fluxes of electrons in the range of one-half to 50 keV at synchronous altitude on the night side in conjunction with magnetic substorms. A time lag between the flux increases in different energy ranges is consistently found with the lower energy fluxes increasing first for events occurring in the local evening and midnight sectors. These time lags are found to be consistent with an inward motion of the plasma sheet with a soft inner edge as described by Frank [1970, 1968], Schield and Frank [1969], and Vasyliunas [1968]. Utilizing the spatial structure of this edge as measured by the above experimenters, we are able to estimate its radial velocity and thereby also estimate the value of the electric field necessary to produce such a velocity by $\vec{E} x \vec{B}/B^2$ drift. The value of the median electric field thus calculated (0.36 mV/m) is consistent with the fields measured by other techniques.

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REFERENCES

Axford, W. I. (1969), "Magnetospheric Convection," Rev. of Geophys., 7, 421.

Axford, W. I., and C. O. Hines (1961), "A Unifying Theory of High Latitude Geophysical Phenomena and Geomagnetic Storms," Can. J. Phys., 39, 1433.

Carpenter, D. L., and K. Stone (1967), "Direct Detection by a Whistler Method of the Magnetospheric Electric Field Associated with a Polar Substorm," Planet. Space Sci., 15, 395.

Cladis, J. B. (1970), "Drift Wave Resonance in the Magnetosphere; Modulation of Trapped Particles and Ionospheric Currents," (to be published).

Cummings, W. D., J. N. Barfield and P. J. Coleman, Jr. (1968), "Magnetospheric Substorms Observed at the Synchronous Orbit," J. Geophys. Res., 73, 6687.

Frank, L. A. (1968), "On the Distribution of Low-Energy Protons and Electrons in the Earth's Magnetosphere," in Earth's Particles and Fields, ed. by B. M. McCormac, Reinhold Book Co., N.Y., pp 57-87.

Frank, L. A. (1970), "On the Relationship of the Plasma Sheet, Ring Current, Trapping Boundary and Plasmapause Near the Magnetic Equator and Local Midnight," Univ. of Iowa Report 70-33.

Hones, E. W., Jr., J. R. Asbridge, S. J. Bame and I. B. Strong (1967), "Outward Flow of Plasma in the Magnetotail Following Geomagnetic Bays," J. Geophys. Res., 72, 5879.

Hones, E. W., Jr. (1968), "Electric Fields and Plasma Convection in the Magnetosphere," in Earth's Particles and Fields, ed. by B. M. McCormac, Reinhold Book Co., N.Y., pp. 403-416.

Hones, E. W., Jr., S. I. Akasofu, P. Perreault, S. J. Bame and S. Singer (1970), "Poleward Expansion of the Auroral Oval and Associated Phenomena in the Magnetotail During Substorms," Los Alamos Scientific Laboratory Report LA-DC-11205 (to be submitted to J. Geophys. Res.).

Hultqvist, B. (1967), "Aurora," in Physics of Geomagnetic Phenomena, ed. by S. Matsushita and W. Campbell, Academic Press, N.Y., p. 664.

Kennel, C. F. (1969), "Consequences of a Magnetospheric Plasma," Rev. of Geophys., 7, 379.

Liszka, L., H. Borg and W. Riedler (1970), "Preliminary Results of FSRO-1A (AURORAE) Observations of Variations in the Low Energy Electron Spectrum, and Their Relation to Magnetic Activity," Kiruna Geophysical Observatory preprint.

REFERENCES (continued)

McIlwain, C. E., and S. E. DeForest (1970), "Plasma Clouds in the Magnetosphere," presented at International Symposium on Solar-Terrestrial Physics 1970 at Leningrad, USSR, May 1970, (to be published).

Mozer, F. S. (1970), "Electric Field Mapping in the Ionosphere at the Equatorial Plane," Planet. Space Sci., 18, 259.

Mozer, F. S., and R. H. Menka (1970), "Magnetospheric Electric Field Properties Deduced from Simultaneous Balloon Flights," Space Sciences Laboratory, University of California, Berkeley, report.

Paschmann, G., E. G. Shelley, C. R. Chappell, R. D. Sharp and L. F. Smith (1970), "Absolute Efficiency Measurements for Channel Electron Multipliers Utilizing a Unique Electron Source," Rev. of Sci. Inst., (to be published).

Pfitzer, K. A., and J. R. Winckler (1969), "Intensity Correlations and Substorm Electron Drift Effects in the Outer Radiation Belt Measured with the OGO-III and ATS-1 Satellites," J. Geophys. Res., 74, 5005.

Reed, R. D., E. G. Shelley, J. C. Bakke, T. C. Sanders and J. D. McDaniel (1969), "A Low-Energy Channel-Multiplier Spectrometer for ATS-E," IEEE Trans. Nucl. Sci., NS-16, 359.

Saito, T. (1969), "Geomagnetic Pulsations," Space Sci. Rev., 10, 319.

Schield, M. A., and L. A. Frank (1969), "Electron Observations Between the Inner Edge of the Plasma Sheet and the Plasmasphere," Univ. of Iowa Technical Report 69-46.

Sharp, R. D., E. G. Shelley, R. G. Johnson and G. Paschmann (1970), "Preliminary Results of a Low-Energy Particle Survey at Synchronous Altitude," J. Geophys. Res. (to be published).

Shelley, E. G., R. D. Sharp and D. L. Carr (1970), "Quasi-Periodic Modulations of Auroral Particles Observed on ATS-5," Trans. Am. Geophys. U., 51, 389 (Abstract).

Vasyliunas, V. M. (1968), "A Survey of Low-Energy Electrons in the Evening Sector of the Magnetosphere with OGO-1 and OGO-3," J. Geophys. Res., 73, 2839.

FIGURE CAPTIONS

Figure 1 Responses of four broad band differential electron detectors to flux increases at synchronous altitude preceding a magnetic' bay in the auroral zone. Note the energy dependence in the time of increase. The geomagnetic longitude of the foot of the ATS-5 field line was approximately 20°; see Table I for observatory coordinates. The approximate number fluxes (electrons/cm^2-sec-ster-keV) can be obtained by multiplying the 1.25, 3.6, 12 and 35 keV count rates by 6×10^4, 3×10^4, 7×10^3 and 3×10^3, respectively.

Figure 2 Ten-second averages of data from seven detectors for the period around 0350 in Figure 1.

Figure 3 An example of an electron "event" near local midnight on a relatively quiet day (3-hr $K_p = 1$). Note the relatively large time dispersion in the flux increases as a function of energy. The satellite was in eclipse during the cross-hatched period and the data have not been corrected for vehicle potentials. Local midnight at the satellite is indicated by M. The arrow A corresponds in time to the similarly indicated times in Figures 4 and 5.

Figure 4 This is the same event as shown in Figure 3. The top curve is the electron omnidirectional energy flux calculated under the assumption of isotropy. The second curve is a 15-minute running average of the Z component of the local magnetic field as measured by the ATS-5 magnetometer (see text for clarification). Below are magnetograms from a selected set of auroral zone observatories spanning the local time region around ATS-5. Local midnight is indicated by M for ATS-5 and for each observatory. See Table I for observatory coordinates. The geomagnetic longitude of the foot of the ATS-5 field line was approximately 318°.

Figure 5 Horizontal field components observed at low latitude stations during the event shown in Figures 3 and 4. See Table I for observatory coordinates.

Figure 6 An example of a rapid electron flux increase which occurred near local midnight in conjunction with a magnetic substorm on 28 August 1969. The energy dependent time dispersion of the flux increase is small (~ 30 sec between channels). Note also the sharp reversible flux increase observed simultaneously in all three channels at about 0014 UT. The geomagnetic longitude of the ATS-5 field line was approximately 54°. The H component from Leirvogur was hand drawn by scaling a regular run magnetogram and the relative timing could be in error by several minutes.

FIGURE CAPTIONS (continued)

Figure 7 Summary of data presented by Schield and Frank [1969] showing the spatial separation between the radial fall-off positions of electron fluxes at two energies as a function of the position of the inner edge of the plasma sheet. See text for explanation.

Figure 8 The distribution of time lags between observations of electron flux increases in the 1.25 ± 0.6 keV range and the 3.6 ± 1.8 keV range. The center scale at the bottom shows the corresponding velocities calculated under the assumption of a constant spatial structure to the plasma sheet inner edge. See text and Figure 7. The bottom scale is the corresponding westward electric field required to produce these velocities by an $\vec{E} \times \vec{B}/B^2$ plasma drift.