FINAL REPORT

INVESTIGATION OF MAGSAT AND TRIAD MAGNETOMETER DATA TO PROVIDE CORRECTIVE INFORMATION ON HIGH-LATITUDE EXTERNAL FIELDS

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SUMMARY

The chief objective of these studies has been to identify and evaluate disturbances in the MAGSAT magnetometer data set due to high latitude phenomena. Much of the categorization of disturbances due to Birkeland currents, ionospheric Hall currents, fine structure and wave phenomena has been done with our MAGSAT data catalog, an example of which has been enclosed. We have developed a color graphics technique for the display of disturbances from multiple orbits, from which one can infer a "global-image" of the current systems of the auroral zone, also enclosed.

One of the principal results of this study is that the MAGSAT 4/81 magnetic field model appears to represent the Earth's main field at high latitudes very well for the epoch 1980. MAGSAT's low altitude allows analysis of disturbances in the magnetometer data due to ionospheric electrojet currents. These current distributions have been modeled properly for single events as a precursor to the inference of the Birkeland current system. During the first six weeks of MAGSAT's operational lifetime, the orbit was approximately shared with that of the Navy/APL TRIAD satellite. This good fortune allowed space-time studies of the magnetic disturbance signatures to be performed, the result being an approximately 75% agreement in, as well as high frequency of, signatures due to Birkeland currents. Thus the field-aligned currents are a steady-state participant in the Earth's magnetospheric current system. We hope that this information can be used to improve the understanding of the undisturbed geomagnetic field at high latitudes.

1.0 INTRODUCTION

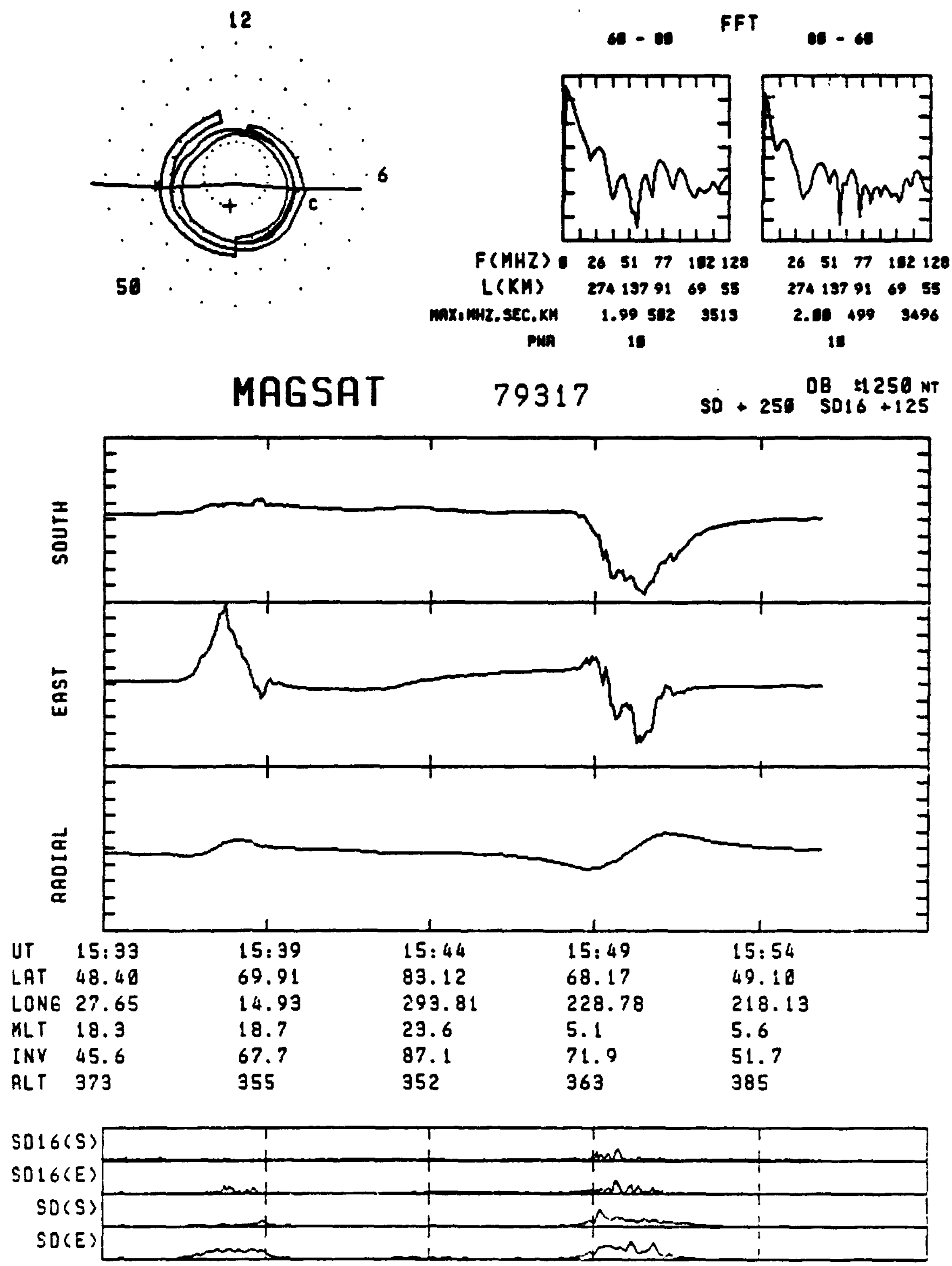
The current systems of the terrestrial magnetosphere occupy a region of space many tens of times the size of the Earth. While the majority of these current paths are quite distinct from the vicinity of the Earth, an important component of these circuits is the ionosphere. The ionospheres of the north and south polar regions are joined to the outer magnetosphere by means of Birkeland or field-aligned currents which directly intersect the orbit of MAGSAT. Since the prime mission of MAGSAT is to assess the internal field of the Earth, such currents may easily alter the magnetic signatures at 400 km altitude.

In the sections that follow we encapsulate our investigations of the effects of the magnetosphere's current systems on the MAGSAT magnetometer data set. Examples of the tools for analysis are displayed which clearly show major disturbances at high latitudes. These phenomena have been catagorized according to the observations and theories of the Earth's magnetosphere at the present state of knowledge. The attempt to approach the surface of the earth for higher crustal anomoly disturbance amplitudes has welcomed large effects from the strong ionospheric current systems in addition to perturbations from the Birkeland current system.

2.0 REVIEW OF MAJOR CONTRIBUTIONS FROM ANALYSIS OF THE MAGSAT MAGNETOMETER DATA SET

2.1 MAGSAT Data Catalog

As of April 1, approximately half of the MAGSAT data set has been through our magnetic disturbance and wave analysis process. An example of this product is shown in Figure 1. The MAGSAT catalog plots display in the center the difference fields in nanoTesla (nT) as measured by the vector magnetometer. These data result from the subtraction of the MAGSAT (4/81) magnetic field model from the observed field for day 317 (November 13), 1979. The three values are the geographic south, east and radial vector components, each scaled from zero to $\pm$ 1250 nT. The ordinate describes Universal Time (UT), Geographic Latitude (LAT) and Longitude (LONG), Magnetic Local Time (MLT), Invariant Latitude (INV) and Satellite Altitude (ALT). To retain the high resolution information lost in the above three traces, two sets of standard deviations (for the vector components transverse to the main field) were calculated which perform as "band pass filters". These data are illustrated in the four graphs at the bottom. For example, SD16(S) is the standard deviation of the 16 values per second of the south difference vector from the half second average, calculated every half second. The SD traces use 1/2 second resolution data for 10-second intervals. The graphs at the top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MLT 18.3 18.7 23.6 5.1 5.6
INV 45.6 67.7 87.1 71.9 51.7
ALT 373 355 352 363 385
SD16(S)
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SD(S)
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FIGURE 1

right display the power versus frequency of the Fourier transform for the transverse difference vector at dusk (~ 18 MLT) and at dawn (~ 5 MLT), labelled 60-80 and 80- 60 respectively. In the top left hand corner is the satellite track plotted versus a magnetic local time-invariant latitude grid. The sun direction is at the top (12 MLT). Superimposed are the statistical data points of the Region 1-Region 2 field-aligned current system (Iijima and Potemra, 1978) as well as a cross for the north geographic pole and the locations of the Kiruna (K) and Chatanika (C) ground stations.

2.2 Electrojet and Birkeland Current Signatures

Relative to other satellite orbits, MAGSAT's orbit was very close to the highly conductive layers of the ionosphere (~ 100-120 km), thus ionospheric currents as well as field-aligned currents perturb the magnetometer data. This was the subject of a study resulting in a contribution to the MAGSAT special issue of Geophysical Research Letters (Zanetti et al., 1982). Most of the perturbations in the east component of the main field (Figure 1) and some of the perturbation in the south component are due to MAGSAT flying through the field-aligned current sheets. In addition to these disturbances, the radial component (assumed to be in the direction or the main field) shows two signatures of ionospheric electrojet currents at 15:37 UT and 15:52 UT (Figure 1). Equal amplitude disturbances must also exist in the components transverse to the main field. Figures 2 and 3 are from Zanetti et al. (1982) who addressed this problem. Since the variations in the radial components are smooth and not usually as large as the amplitudes of the effects on day 317, 1979 (Figure 1), a necessary starting point is a proper magnetic field model.

Figure 2 emphasizes the necessity and superiority of an accurate magnetic field survey of the present epoch. The three-axis MAGSAT data over the north polar region are displayed in each panel of three traces with various model fields subtracted. For a quiet period with no effects from external currents, all traces would be zero. This is basically true for the first set of graphs except for the Birkeland current signatures. The IGRF75 and the Barraclough models have been extrapolated too far in time and no longer provide a proper baseline.

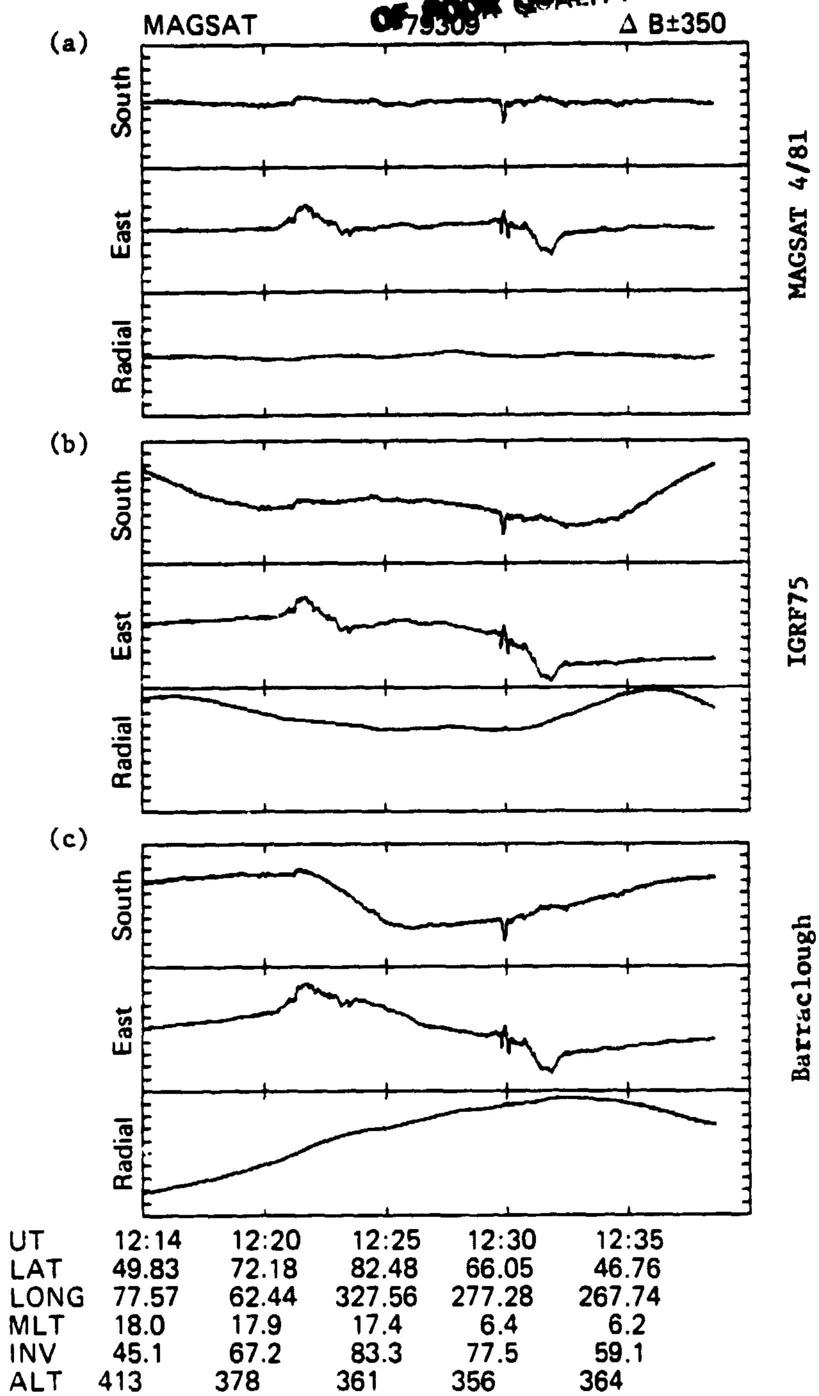

FIGURE 2 Geographic south, east and radial components are displayed versus universal time and other orbital parameters described in Figure 1 for a northern hemisphere pass on November 5, 1979 (day 309). Various magnetic field models were subtracted from the data, specifically: (a) MAGSAT 4/81; (b) IGRF75; and (c) Barraclough (1975). Improper baselines for the vector components are evident in (b) and (c).

Figure 3 shows the modelling of ionospheric currents (with Dr. Sugiura) and their effects (broken lines) at the altitude of MAGSAT. The radial component is assumed to be along the main field direction and the transverse components were rotated to approximate a geomagnetic coordinate system. Birkeland current signatures are evident primarily in the BPHI direction, with the equatorward field-aligned current out of the ionosphere at dawn from 63° invariant latitude (INV) to 67° INV and the field-aligned current into the ionosphere from 67° INV to 72° INV.

2.3 Global Magnetic Disturbance Analysis

The previous section described analyses of a single dawn overpass. We have also developed a procedure to display magnetic disturbance data for several orbital passes at once. Due to the geographic dawn-dusk orbital plane and the "wobble" of the magnetic poles around the geographic poles, the MAGSAT orbits "walk" across the auroral oval during the day. This would give a global picture of the distribution of Birkeland and ionospheric currents. As mentioned above, both field-aligned and ionospheric current signatures are evident in the vector components perpendicular to the main field (approximately south and east at high latitudes). Figure 4 displays the transverse magnetic disturbance vector as color intensities along an orbit trajectory over the southern polar regions. Approximately a one half days worth of data are shown in Figure 4, the orbit tracks plotted versus magnetic local time and invariant latitude from 50° to 90°. The intensity of color is linear with the magnitude of the disturbance, again the MAGSAT 4/81 magnetic field model has been subtracted from the vector data. The vector data were rotated into the magnetic reference frame of Figure 4 such that one vector points toward the invariant pole while the other is orthogonal, that is in the east-west plane. It is when the latter component changes sign that the color changes from blue to yellow. Thus the auroral oval is outlined as intense blue due to magnetic disturbances from a combination of Birkeland and ionospheric electrojet currents where as the yellow in the polar cap indicates a sunward directed (1200 MLT) ionospheric Hall current permitted by increased conductivity due to photoionization.

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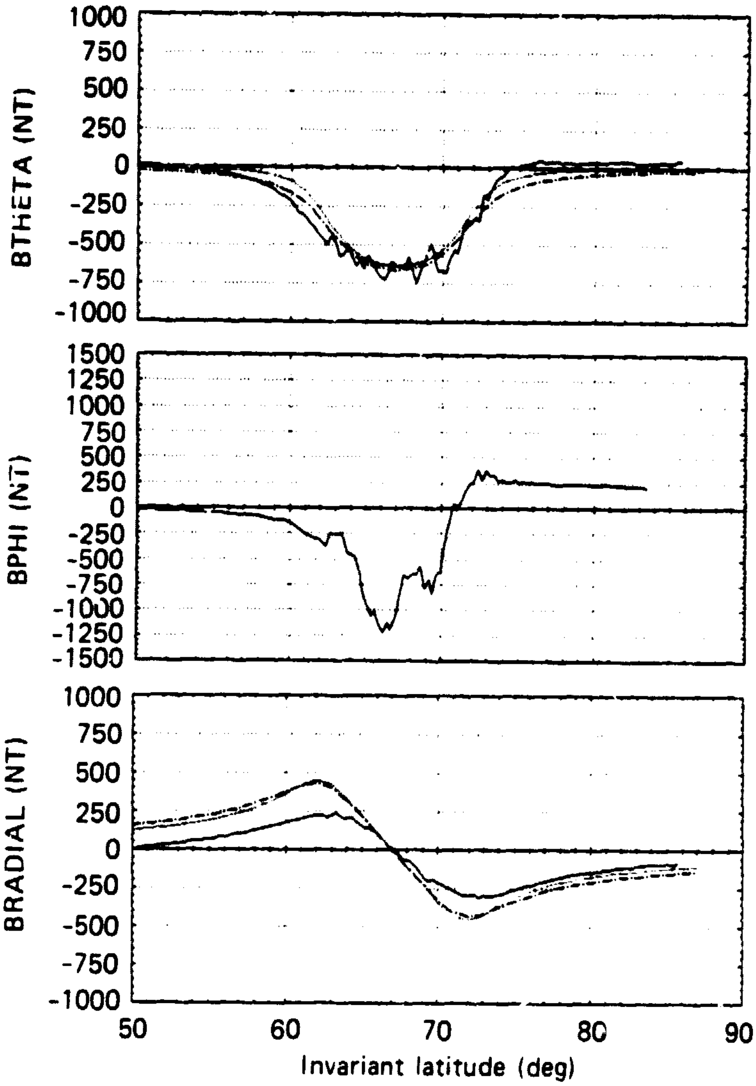

FIGURE 3 The data from Figure 1(a) at dawn (~ 15:45 UT) are rotated 23° to approximate geomagnetic ϕ (east) and θ (south) and plotted versus invariant latitude (from low to high). The dot-dash traces in the ϕ and r components are disturbances due to a model westward electrojet current at 250 km below the MAGSAT altitude with a current intensity of 1.5 A/m and 1000 km width. The dotted curves are disturbances due to a similar electrojet but of 2.25 A/m with a 50% image induction current (-1.12 A/m) below the Earth's surface.

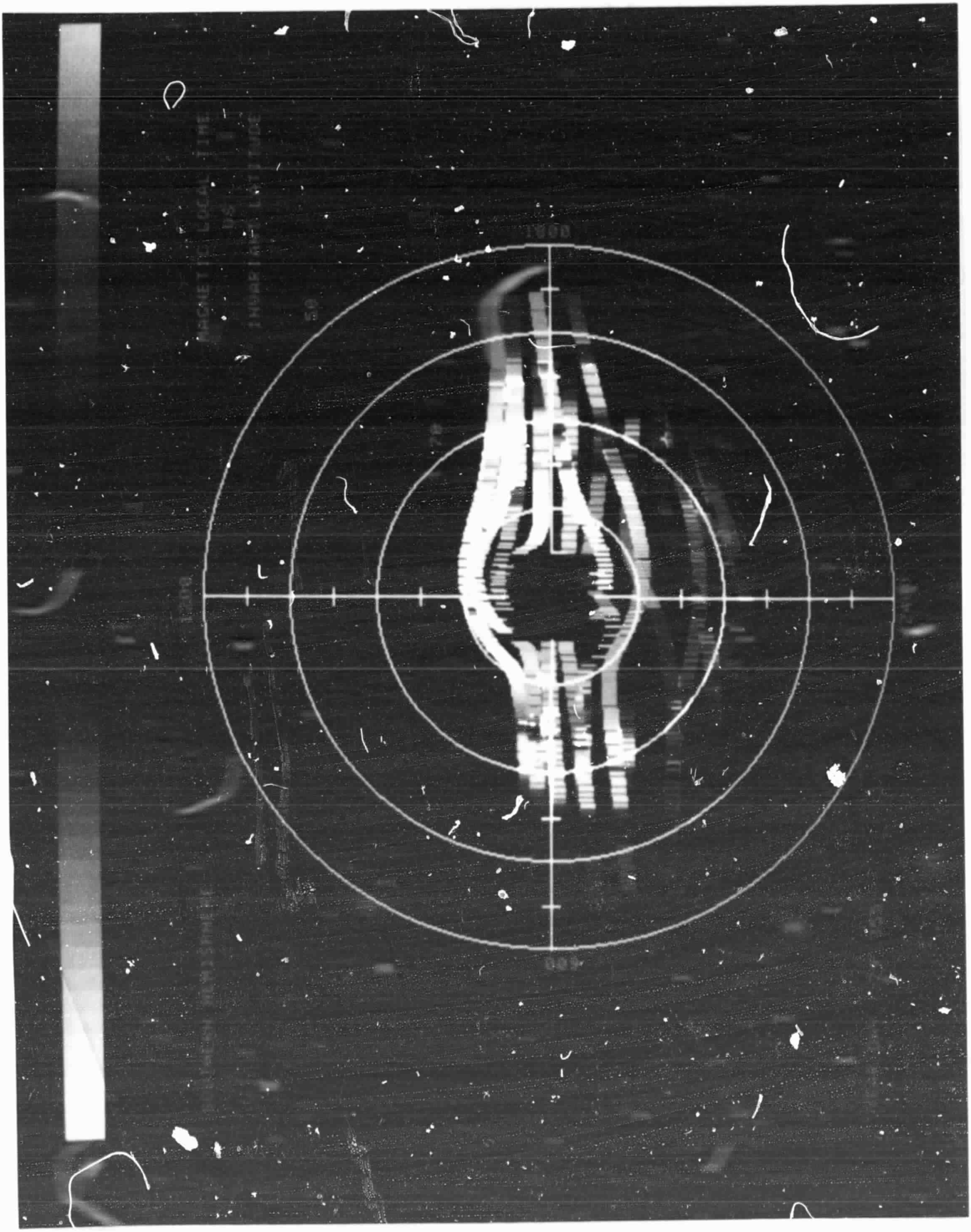

FIGURE 4

2.4 MAGSAT and TRIAD Data Correlations

Figures 5 and 6 are a summary of the results from our publications in the MAGSAT special issue of Geophysical Research Letters (Zanetti and Potemra, 1982). During the first six weeks of MAGSAT's lifetime, the Navy/APL TRIAD satellite was occupying approximately the same orbital plane as that of MAGSAT. The orbital periods were slightly out of phase due to the differing altitudes, MAGSAT being at an average of 400 km altitude whereas the TRIAD satellite is 800 km above the Earth's surface. There are several interesting questions that may be addressed. For example, do the Birkeland currents form infinite sheets stretching from the magnetosphere down to the ionosphere as assumed? Does some of this current short out between field lines between 400 km and 800 km altitude? If the inferred current is different and not a temporal effect, then the larger observed current would indicate the source of field-aligned currents, the ionosphere or the magnetosphere. Just what are some of the temporal and spatial effects as a function of overall magnetic activity? Is the large-scale Birkeland current system a continuous feature? Even questions such as; Is the calibration of the TRIAD magnetometer still proper after more than 10 years of service?

The results of this study have been quite reassuring as evidenced in Figure 5. These are four examples of magnetic disturbances in the magnetic azimuthal direction as observed by MAGSAT (light traces) and by TRIAD (heavy traces). The measurements were made over nearly the same regions of space but may differ in time by as much as 40 or 50 minutes. The signatures in these cases are incredibly identical, even in some cases down to the fine structure.

For the approximately six week period from November to mid-December the MAGSAT and TRIAD magnetometer disturbances were examined for agreement or disagreement. An average of five TRIAD data sets were recorded daily at Fairbanks, Alaska, two or three near dusk and a similar number near dawn. Data were acquired during successive orbits, that is, time differences were less than the period of one orbit. The criteria for "agreement" were as follows: agreement of the peak amplitude of the transverse disturbances (vector

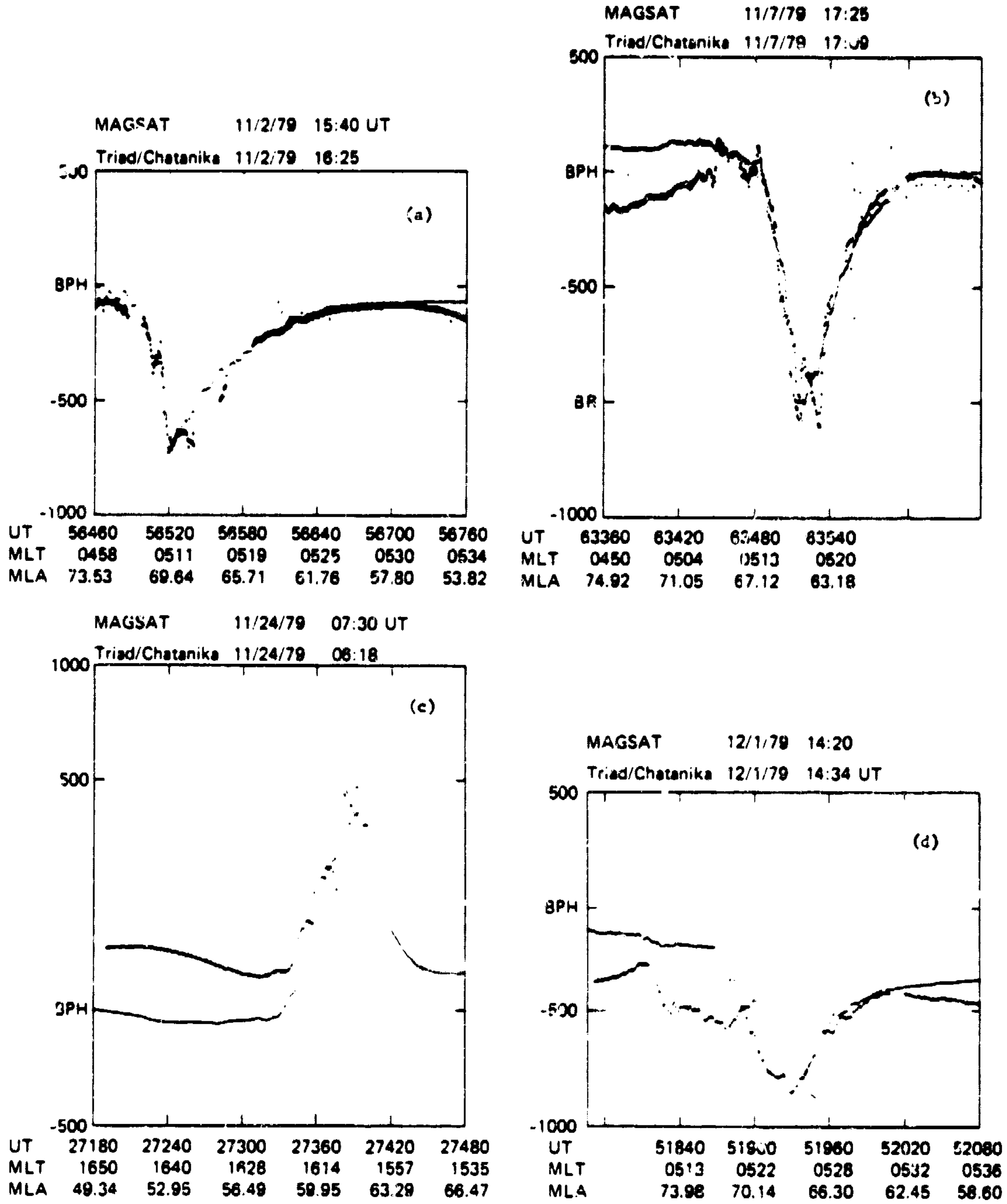

FIGURE 5 All panels are the comparison of the east-west disturbance of the magnetic field as observed by the TRIAD (heavy trace) and MAGSAT (light trace) satellites. The abscissa is UT time of the MAGSAT pass in seconds; magnetic local time and magnetic latitude are also given. The ordinates are field strength in nT. Panels (a), (b) and (d) are observations of approximately the dawn terminator. Figure 1(c) is near local dusk. All observations are near Chatanika, Alaska, where the TRIAD data were received on a real time basis.

sum of south and east) to within 15-20%; qualitative agreement in the shape of the transverse fields.

Figure 6 is the collection of the results of the survey described above for November 4 through December 17. The abscissa is the day of the month and the ordinate for Panel 1 in each comparison event. Solid blocks denote agreement and open boxes indicate disagreements. Panel 2 is the ΔKp for each day. Panel 3 is the daily average of the time differences between the TRIAD and MAGSAT observations. Panel 4 deals with the percent difference in the magnitude of the observed disturbance. For example, if the MAGSAT disturbance was 200 nT and the TRIAD disturbance was 100 nT, the percent difference from the average disturbance of the two observations (150 nT) is plotted, i.e., 100 nT/150 nT or 67% in the MAGSAT direction. On the average, the TRIAD observations were higher by 7% which is within the precision of the measurement and most likely not significant.

Considering the comparison study for November 4 through December 17, 1979, the time differences between observations (Panel 3) do not appear to affect the agreement of the disturbance signatures. Examining a few individual cases supports this notion. Disagreements may exist between nearly simultaneous satellite observations, whereas one may observe identical Birkeland current signatures over as many as five or six consecutive orbits. Gustafsson et al. (1981) has reported identical signatures for three consecutive orbits of TRIAD. The time scale of the Birkeland current system may range from a few minutes to nearly half a day, but the large-scale features seem to persist.

Panel 4 is provided to investigate the altitude variation of transverse disturbances and possibly the sources of field-aligned currents. If ionospheric current generators were operating a signficant amount of time, MAGSAT, at a lower altitude, would detect larger transverse disturbances than TRIAD if these currents couple across field lines before they reached TRIAD's altitude. Similarly, if the field-aligned currents generated at much higher altitudes were shorted across field lines before reaching MAGSAT's altitude, TRIAD's observations of ΔB would generally be higher in magnitude. Neither of these postulations are substantiated by Panel 4. The disturbances observed by TRIAD were 7% larger than those observed by MAGSAT for this time period, which

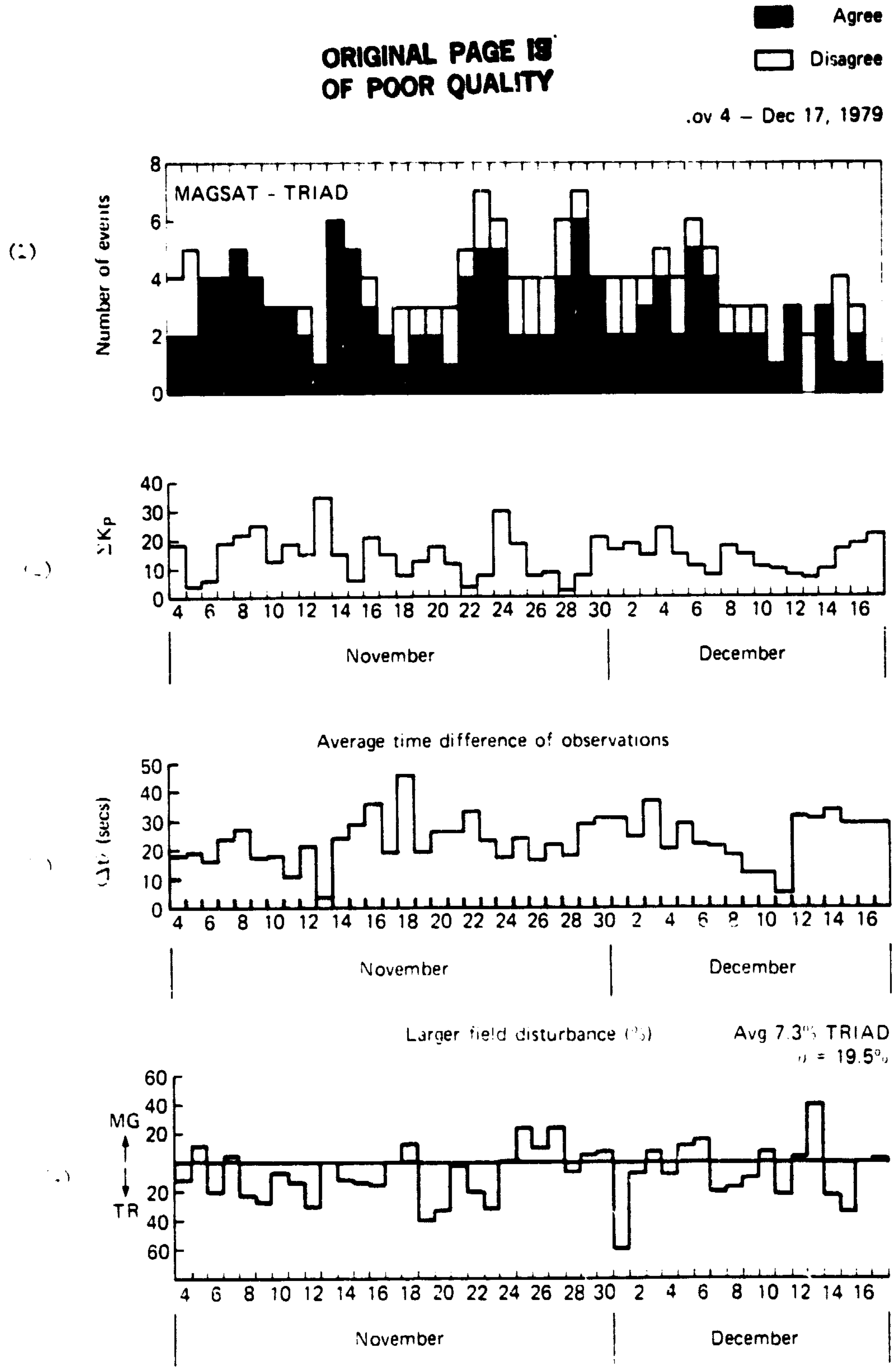

FIGURE 6 Panel 1 contains the comparison of MAGSAT and TRIAD magnetic disturbance signatures for November 4 through December 17, 1979. Each event is a comparison of signatures from the two satellites. If there was similarity in shape and the magnitudes were within 15-20% of each other, the event was classified as agreement (dark). Disagreements are given as white rectangles. Panel 2 is a histogram of the ΣKp for each day. Panel 3 is a histogram of the daily average of time differences between the observation by TRIAD and that by MAGSAT. Panel 4 compares the daily average of the difference in the maximum amplitudes of the disturbances as measured by each satellite.

is smaller than the uncertainties in the measurements. There appears to be continuity in the field-aligned current intensity from 800 km to 400 km.

The remaining correlation with the summation of Kp for the day (Panel 2) tends to show that for higher magnetic activity there is better agreement in the current signatures at 800 km and 400 km. This statement may be a comment on the nature of the generation of the field-aligned currents. A high level of Kp may be interpreted as an indication of well-developed and extensive magnetospheric current systems, implying a strong generator and suitable conduction paths. If the generator is strong, a well-defined steady-state large scale Birkeland current system is maintained. If the generator is rather weak and weak current exists elsewhere in the magnetosphere (i.e., ΣKp is low), the field-aligned currents will be sporadic or localized. These localized currents, however, do not have to be small in intensity [see for example, Figure 5(d) and 5(c)]. Most likely the disagreements are temporal fluctuations since the satellites are nearly colocated although local enhancements in ionospheric conductivity may favor current completion at small sections of longitude. MAGSAT is always sunlit and on the terminator while TRIAD may be in darkness. Coplanar orbits are only approximate and also geographically based, thus a real time difference could also produce a signficant local time difference.

We would like to emphasize the fact that for this time period there was significant agreement between the two sets of observations. Approximately 250 comparisons of Birkeland current signatures observed by the TRIAD and MAGSAT satellites at nearly the same location revealed 75% agreement in shape and magnitude. The disagreements are most likely due to temporal changes in the current systems. Ground magnetograms at College, Alaska (near the Chatanika receiving station) were checked to identify storm activity. Of the remaining 25% of the cases that did not agree, half showed significant storm activity, implying temporal changes were likely. Thus, only ~ 12% of the comparisons between MAGSAT and TRIAD disagree and are not thoroughly explained at this point.

There were very few passes during this survey which did not show the large scale field-aligned current signatures. These observations enforce the idea that the Birkeland currents are a permanent feature of the overall magnetospheric current system (Iijima and Potemra, 1976, 1978). The time scale of the field-aligned currents may be as long as half of a day. The tendency of well-defined and steady field-aligned currents correlated with Kp, which reflects the overall current activity, reinforces the idea of continuous participation of Birkeland currents in the Earth's magnetospheric current system. The MAGSAT satellite magnetometer observations have provided an essential ingredient in separating space and time for near earth field-aligned current studies.

3.0 REFERENCES

Gustafsson, G., T. A. Potemra, S. Favin and N. A. Saflekos, Distant magnetic field effects associated with Birkeland currents, J. Geophys. Res., 86, 9219, 1981.

Iijima, T. and T. A. Potemra, Large-scale characteristics of field-aligned currents associated with substorms, J. Geophys. Res., 83, 599, 1978.

Iijima, T. and T. A. Potemra, The amplitude distribution of field-aligned currents at northern high latitudes observed by TRIAD, J. Geophys. Res., 81, 2165, 1976.

Zanetti, L. J. and T. A. Potemra, Correlated Birkeland current signatures from the TRIAD and MAGSAT magnetic field data, Geophys, Res. Lett., 9, 349, 1982.

Zanetti, L. J., M. Sugiura and T. A. Potemra, Evaluation of high latitude disturbances with MAGSAT (The importance of the MAGSAT geomagnetic field model), Geophys, Res. Lett., 9, 365, 1982.

APPENDIX

Publications

Zanetti, L. J. and T. A. Potemra, Correlated Birkeland current signatures from the TRIAD and MAGSAT magnetic field data, Geophys. Res. Lett., 9, 349, 1982.

Zanetti, L. J., M. Sugiura and T. A. Potemra, Evaluation of high latitude disturbances with MAGSAT (The importance of the MAGSAT geomagnetic field model), Geophys. Res. Lett., 9, 365, 1982.

Presentations

Potemra, T. A., L. J. Zanetti, M. Sugiura, J. R. Burrows, D. M. Klumpar, Preliminary observations of field-aligned currents with MAGSAT, Spring AGU, Toronto, May 1980.

Potemra, T. A., L. J. Zanetti and S. Favin, Coincident observations of Birkeland currents from TRIAD and MAGSAT, Gall AGU, San Francisco, December 1980.

Potemra, T. A. and L. J. Zanetti, Preliminary evaluation of distant magnetic field disturbances from Birkeland currents using MAGSAT data, Spring AGU, Baltimore, Maryland (MAGSAT Special Session), May 1981.

Zanetti, L. J., T. A. Potemra and M. Sugiura, Preliminary evaluation of distant magnetic field disturbances from Birkeland currents using MAGSAT data, IAGA Meeting, Edinburgh, Scotland, August 1981.

Zanetti, L. J. and T. A. Potemra, Correlated Birkeland current signatures from the TRIAD and MAGSAT magnetic field data, Fall AGU, San Francisco, December 1981.

Bythrow, P. F. and T. A. Potemra, The response of Birkeland currents observed near the dawn dusk meridian to variations in the IMF, COSPAR, Solar Terrestrial Physics Symposium, Ottawa, Canada, May 1982.

Zanetti, L. J., T. A. Potemra, W. Baumjohann and P. F. Bythrow, Inferred ionospheric currents and electric fields from the MAGSAT satellite, Spring AGU, Philadelphia, May 1982.