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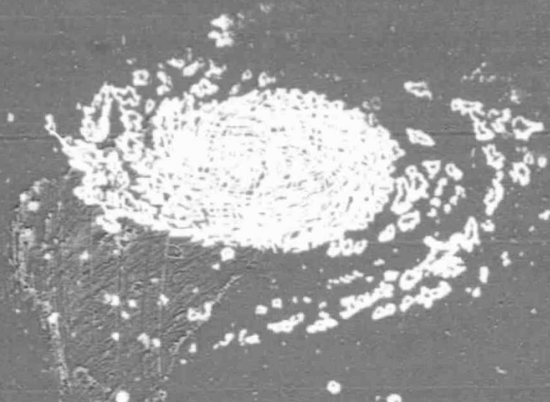

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Studies of High Latitude Current Systems Using Magsat Vector Data

Investigation #M-40

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1. Introduction

The objective of our investigations is to analyse the magnetic disturbance fields caused by global external current systems with particular emphasis on improving the understanding of the physical processes which control high latitude current systems. These objectives and approach have been outlined in detail in Triennial Progress Report #1 (December 1, 1980).

Work towards these objectives has progressed satisfactorily, as outlined below.

2. Techniques

2.1 Data Display

Following processing of the data as described in Report #1, the data is routinely plotted in the Universal Time (UT) format (Figure 1) as well as in a polar plot format (Figure 2). These plots have now been standardized to consist of the data in the H'D'U' coordinate system (see below). The polar plot of the H'D' components also has a panel showing the U' component. Both standard plots are labelled with ΣK_p, K_p, Dst and the X, Y and Z components of the interplanetary magnetic field (IMF) corresponding to the time of the highest latitude of that transpolar segment of the orbit.

2.2 Coordinate System

The H'D'U' coordinate system has been adopted as the standard for representing the Magsat residual magnetic field vectors (i.e., the measured field - GSFC MGST 06/80 model field). This system is defined as follows:

Let $\hat{E}$ = unit vector in the direction of the eccentric dipole axis derived from the value of the coefficients g_1^0, g_1^1 and h_1^1 in the MGST 06/80 model.

Let $\hat{U}'$ = unit vector tangent to the MGST 06/80 model field at the point of observation. $\hat{U}'$ is antiparallel to the field in the southern hemisphere, parallel to the field in the northern hemisphere.

Let $\hat{Z}'$ = unit vector from the point of observation to the eccentric (i.e., offset) dipole origin derived from the coefficients g_2^0, g_2^1 and h_2^1 in the MGST 06/80 model.

Then $\hat{H}' = \hat{U}' \times (\hat{Z}' \times \hat{E})$; note that $\hat{H}'$ lies in the meridional plane of the eccentric dipole and is perpendicular to the model field vector. $\hat{H}'$ always has a northward component, but is not usually horizontal.

$\hat{D}' = \hat{U}' \times \hat{H}'$; $\hat{D}'$ is always eastward directed but is not necessarily horizontal, because of the declination of $\hat{U}'$.

It is felt that a field-aligned system is more natural than a vertically aligned system for spacecraft data because of the sensitivity of high altitude magnetometers to field-aligned current (FAC).

2.3 Data Selection

It has become necessary to select subsets of the Magsat data set for particular studies. For example, to date, only hourly averages of the IMF from the ISEE-3 satellite have been available. It has been found in preliminary correlative studies of the polar cap magnetic field and the IMF B_y that most significant results are obtained during periods of high IMF stability. The "stability" is represented by a five-digit number derived from parameters from the ISEE-3 data tape, as follows:

First (highest order) digit = 1 if the sign of B_x, B_y and B_z of the IMF (in GSE coordinates) during the UT hour of interest is the same as during the previous hour.

= 0 otherwise.

Second digit = IP = [10f]

where [] = "largest integer in"

f = fraction of milliseconds in the UT hour for which IMF data exists

and IP is set to 0 if IP < 0
IP is set to 9 if IP > 9.

Remaining digits = [10d]: where $d = \{(\langle B_i\rangle)^2/\langle B_i{}^2\rangle\}^{\frac{1}{2}}$

for digits 3, 4, 5 and i = x, y, z (in GSE coordinates):

where <> indicates hourly averages.

3. Accomplishments and Work in Progress

3.1 Data Management

a) A data file containing the following parameters has been generated

i) IMF B_x, B_y, B_z (GSM coordinates); hourly averages from ISEE-3 only and IMF stability
ii) Dst, and daily average Dst. The values are those provided on Sugiura's tape, augmented by NASA-Goddard values when the Sugiura data are not available
iii) A_p
iv) C_p
v) f10.7
vi) 3-hour K_p
vii) daily ΣK_p

b) A computer code (TPOLAR) has been developed to generate, from the orbital elements, the time, latitude and MLT of the extremum latitude of each transpolar segment of orbit. The results of TPOLAR are stored on disk.

c) A computer code (SEARCH) has been developed to identify passes (transpolar orbit segments) for which any of the indices described in a) fall into any desired range. It is possible for example to list all passes in the southern hemisphere with $B_y < 0$, $B_z > 0$ and f10.7 > 200.

d) A computer code is being developed to determine equatorward and poleward boundaries of the regions of transverse perturbation vectors which are thought to characterize the auroral oval. The code examines the direction and magnitude of the high latitude perturbation vectors. The criteria for boundary specification are being refined at this time.

3.2 Modelling

The existing magnetic field modelling code, using a refinement of Kisabeth's grid cell system (see Report #1), is being used to examine theoretical models of auroral current systems and to predict Magsat observations. The computer code in use at NRCC permits specification of the current strength with a resolution of 0.5^o in latitude and 4^o in longitude, with a similar resolution in the magnetic field calculations. For modelling satellite observations, this provides a distinct advantage over previous systems which had resolution of 2^o-3^o in latitude and 15^o in longitude.

At present, because of numerical quadrature restrictions, the grid cell system does not extend beyond 85^oN (centered dipole). An additional system for modelling the perturbation magnetic field due to currents above 85^oN is under development. This system replaces "cells" by transpolar current "strips". In a manner similar to the cell system, ΔB due to current in each strip will be computed and stored (kernels). Superposition of a number of these strips, at different orientations, and weighted appropriately, will generate resultant polar cap current systems of sufficient complexity to satisfy most modelling needs (Figure 3).

As in the case of the cell system, all quadrature associated with the solution of the Bio-Savart law is carried out only once for a basic strip system. All other systems can be generated from this set of kernels.

3.3 Data Analysis

a) A study of the orientation of the polar cap residual vectors in the H'D' plane has been undertaken. Polar transits satisfying high IMF stability criteria, and having "well-ordered" vectors have been examined. To date, "well-ordered" remains subjective, and implies perturbation vectors which are reasonably uniform in magnitude and direction, directed sunward in the northern hemisphere and antisunward in the southern hemisphere. Only data from transpolar passes whose polar cap vectors extend at least 5^o on either side of the noon-midnight meridian, and with a total extent of at least 15^o poleward of the auroral oval are considered. Figure 4 shows examples of acceptable transits for both hemispheres. Most of these passes occur at times when the Z-component of the IMF is negative, and their frequency increases with K_p.

If the average orientation of polar cap vectors in this data subset is defined as the average angle of those vectors falling in the central 60 seconds of data (i.e., ±30 s from the noon-midnight meridian), then a correlation coefficient of ~0.7 is obtained between this average vector direction and the Y-component of the IMF. This is true in both hemispheres.

A similar attempt to examine the average vector magnitude has been somewhat inconclusive, indicating, to date, only that this quantity is larger in the sunlit (southern) polar cap than in the dark polar cap.

b) A statistical analysis of the fluctuation parameter (FP) (a measure of the high frequency content of the magnetic perturbation vectors; see Report #1) has been performed using two months of Magsat data (November 1979, January 1980). Data have been sorted into bins 1^{o} of latitude by 1 hour of magnetic local time, and examined for the presence of significant FP as a function of K_p (3 bins: 0 to 1+; 2- to 3+, >3+) and IMF B_y ($B_y < 0$; $B_y > 0$). The selection criteria were such that 26 days are included in the low K_p case, and only 7 in the high K_p case. Figure 5 shows the frequency of occurrence plots for the K_p analysis.

Now that Magsat data up to May 1980 have been distributed, this analysis will be performed on the expanded data set. In the meantime, no definitive interpretation of the results has been made.

3.4 Cooperative Activities

a) Discussions with other Magsat investigators brought to light a problem with the method of computing Magsat magnetic field residuals with acceptable accuracy. At NRCC (as at a number of institutions), the model field was initially computed at one-minute intervals along the orbit, and then interpolated from these values to 1-second values, using a cubic spline interpolation scheme. Because of rapid changes in the field in the neighbourhood of the poles, this method introduces oscillations there up to 40 nT in the θ and ϕ components. Use of a 5-point Lagrange interpolation code leads to even higher amplitude oscillations. However, altering the scheme so that the model field is calculated every 15 s, and then interpolated to 1 s values, removes the oscillations. Figure 6 is a comparison of the two methods of interpolation.

b) A cooperative study with Rothwell et al. (University of Southampton) has been undertaken. Auroral video data from Longyearbyen, Spitzbergen for January 15, 1980 at 0715 UT indicates an arc near noon MLT which is coincident with a Magsat orbit. The analysis is incomplete at this time. (See Daytime auroral motions imaged with an all-sky low light level TV camera in Spitzbergen, P.A. Rothwell, B. Lanchester, R.W. Thomas, IAGA, Edinburgh, 1981, paper 2C.08).

3.5 Data Processing Status

We have at present processed 38 days of Magsat data from the interval launch through January 1980. We are ready to process the remainder of the Magsat data.

4. Significant Results

The unprecedented precision of the vector data set from Magsat has made it necessary to undertake an extended exploratory phase for data analysis procedures, modelling techniques and phenomenology. Although a number of significant preliminary results have been obtained, as outlined above, the studies are still in progress and have not yet been submitted for publication.

5. Publications

a) Comparison of quiet day B-field variations in the summer and winter auroral zones.
M.D. Wilson, T.J. Hughes, J.R. Burrows
Spring AGU 1981, paper GP45.

b) The role of crustal magnetic anomalies in modelling ionospheric current systems.
T.J. Hughes, D.D. Wallis
Spring AGU 1981, paper GP44.

Papers are in preparation for the Magsat special issue of Geophysical Research Letters.

6. Problems

We reiterate our concern expressed in Report #1 regarding the high frequency noise that has been introduced into CHRONFIN data by the fine attitude calculation. We had hoped to study currents at the maximum spatial resolution permitted by the Magsat data rate. Introduction of this "solution noise" has reduced this resolution considerably.

In an attempt to understand the source of residual errors in the fine attitude solutions and perhaps develop a 'work-around' solution to them, we have made a limited study of the attitude flags and corresponding attitude solutions. There appears, on occasion, to be an unexpected inconsistency in them. An example is described in Appendix A. This situation has inhibited our attempts to develop an algorithm for correcting motion model segments of the fine attitude solution. The study is temporarily suspended.

7. Recommendations

No further recommendations at this time.

8. Conclusions

Although there have been no definitive results to date, preliminary investigations are encouraging. Analysis should proceed reasonably quickly now that data from most of Magsat's lifetime has been distributed.

Figure Captions

Fig. 1. An example of the NRCC standard UT plot of magnetic perturbations in the H'D'U' coordinate system.

Fig. 2. An example of the NRCC standard polar plot of magnetic perturbation vectors.

Fig. 3. Schematic of the strip current system for polar cap currents. In practice, up to 45 strips and 45 rotations may be used.

Fig. 4. Examples of "well-ordered" polar cap perturbation vectors.

Fig. 5. Polar plot of frequency of occurrence of significant fluctuation parameter (FP > 8 nT) for combined north and south hemispheres, for November 1979 and January 1980. Contours are drawn at 20%, 40%, 60% and 80%, with the 60% contour heavier. No coverage occurs where the plot is blank.
a) $0 \le K_p \le 1+$
b) $1+ < K_p \le 3+$
c) $K_p > 3+$.

Fig. 6(a). Magnetic perturbations relative to the MGST 06/80 model field calculated every minute along the orbit and interpolated to values 1 second apart. Note the H' and D' components between minutes 46 and 48.

(b). The perturbations relative to the model field computed every 15 seconds and then interpolated to 1 s values. The character of all 3 components has been changed significantly from that in Figure 6(a).

Fig. 7. Plot of magnetic perturbations for day 316 1979 near 0440 UT. See Appendix A for discussion.

Appendix A

There appears, on occasion, to be a problem with the attitude solutions and their flags. For example, day 316 (1979), near 04:40 UT (Figure 7): there is a distinct negative-going step of 95 nT in the X-component, and 11 s later, a return (positive-going) step of 149 nT. This latter step is flagged as a shift out of the motion model (flags 7608 to 1022), whereas the first shift occurs in the middle of a period of motion model. This is not expected from our understanding of the attitude solutions and the flags. That is, we do not expect to see such shifts in the data except when there has been a change in type of attitude solution. It is not known at this time if other such unflagged shifts are in the data.

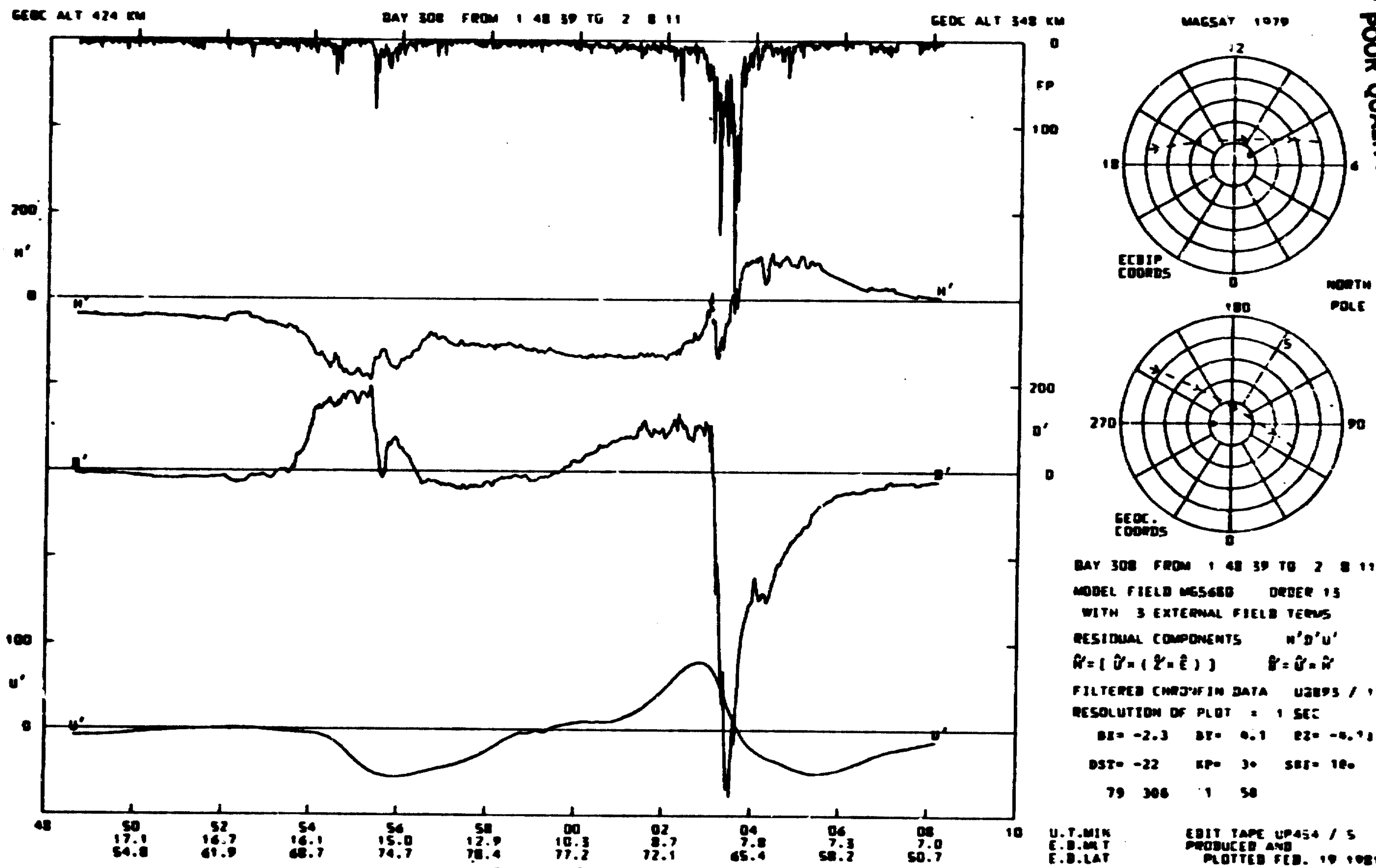
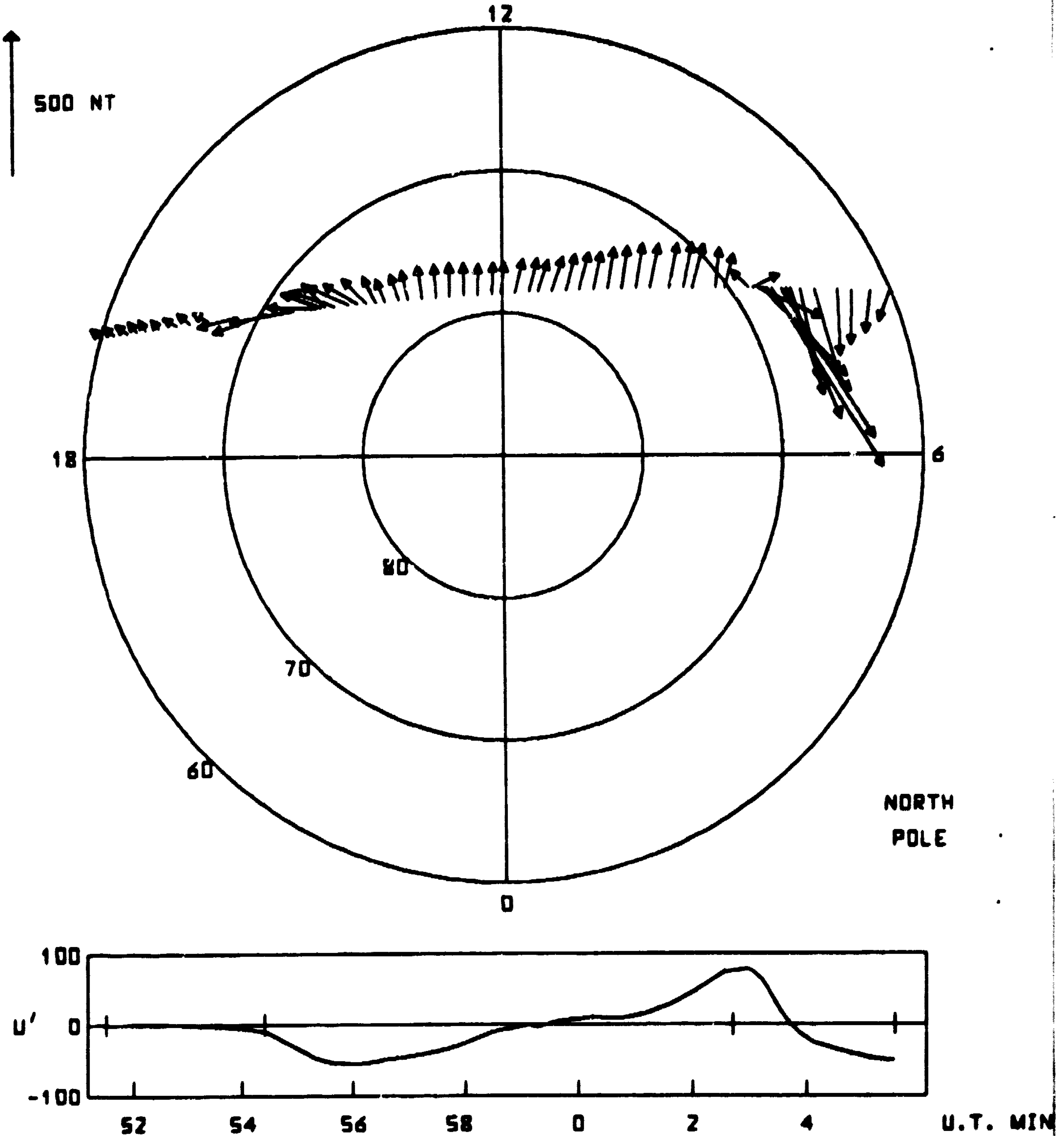

GEOC ALT 424 KM
DAY 308 FROM 1 48 39 TO 2 8 11
GEOC ALT 348 KM
FP
H'
D'
U'
U.T.MIN
E.B.MLT
E.B.LAT
MAGSAT 1979
ECBIP COORDS
NORTH POLE
GEOC. COORDS
DAY 308 FROM 1 48 39 TO 2 8 11
MODEL FIELD MGS660 ORDER 13
WITH 3 EXTERNAL FIELD TERMS
RESIDUAL COMPONENTS H'D'U'
FILTERED CHRONFIN DATA
RESOLUTION OF PLOT = 1 SEC
DST= -22 KP= 3+
79 306 1 58
EDIT TAPE UP454 / 5
PRODUCED AND
PLOTTED FEB. 19 1981
Figure 1

Figure 2

MAGSAT 1979

DAY 308 FROM 1 51 29 TO 2 5 31

RESIDUAL COMPONENTS H′D′U′



BX= -2.3 BY= 4.1 BZ= -4.1

DST= -22 KP= 3+ SKP= 18.

79 308 1 58

$\hat{H}' = [\, \hat{U}' \times (\, \hat{Z}' \times \hat{E}\,)\,]$ $\hat{D}' = \hat{U}' \times \hat{H}'$

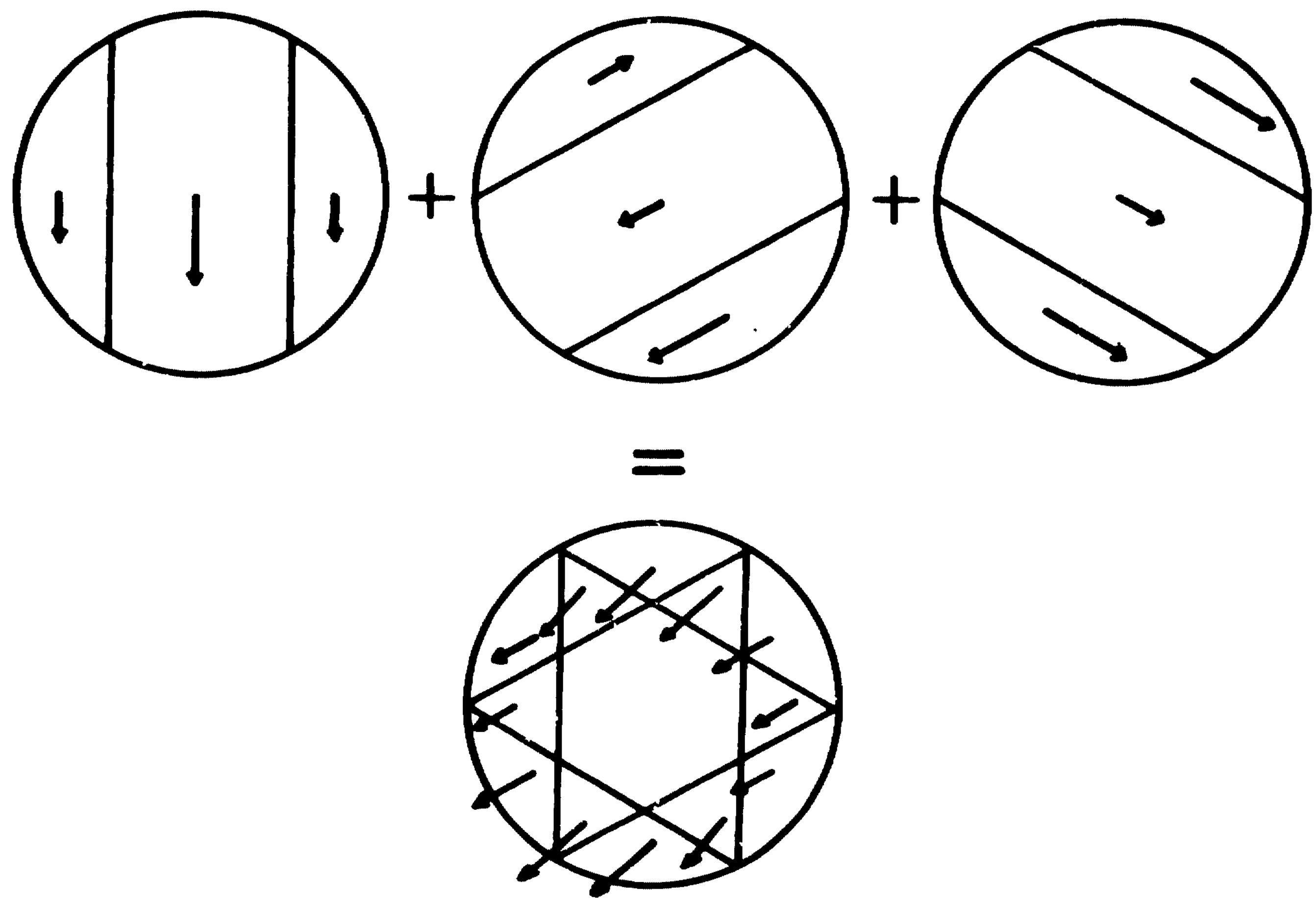


Figure 3

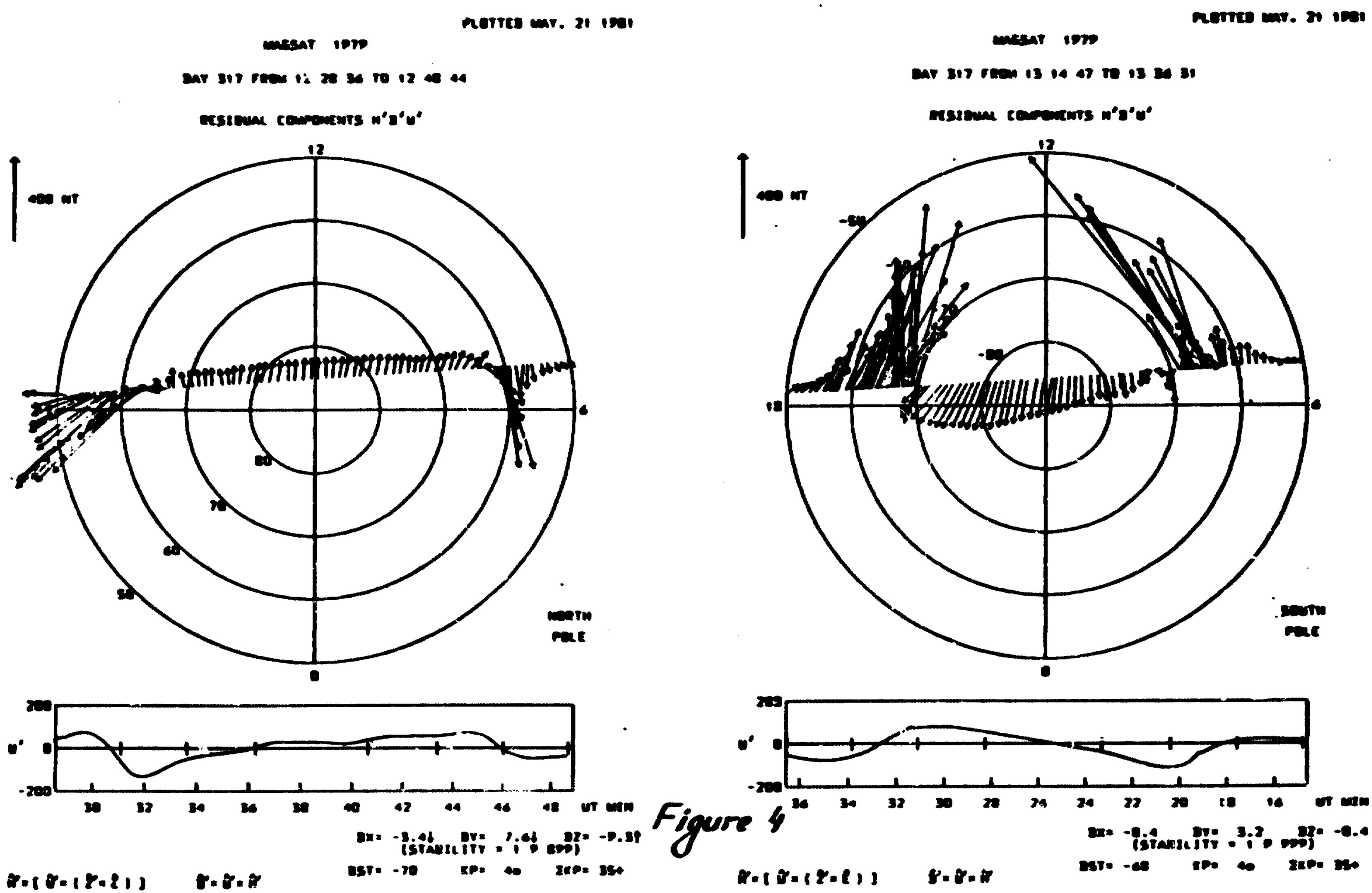
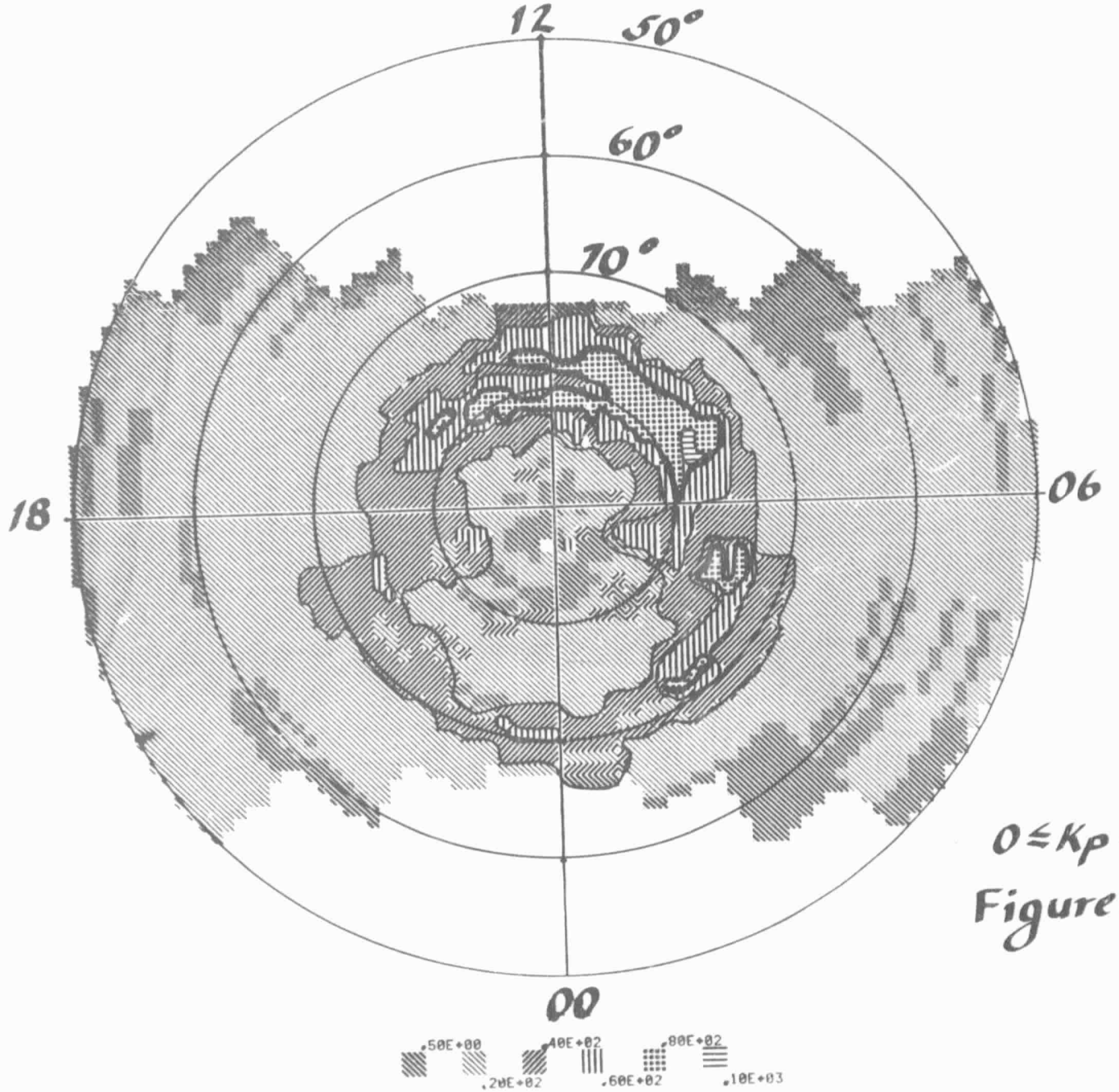

PLOTTED MAY. 21 1981
MAGSAT 1979
RESIDUAL COMPONENTS
400 NT
12
6
0
18
80
70
60
50
NORTH
POLE
SOUTH
POLE
200
0
-200
UT MIN
STABILITY

Figure 4

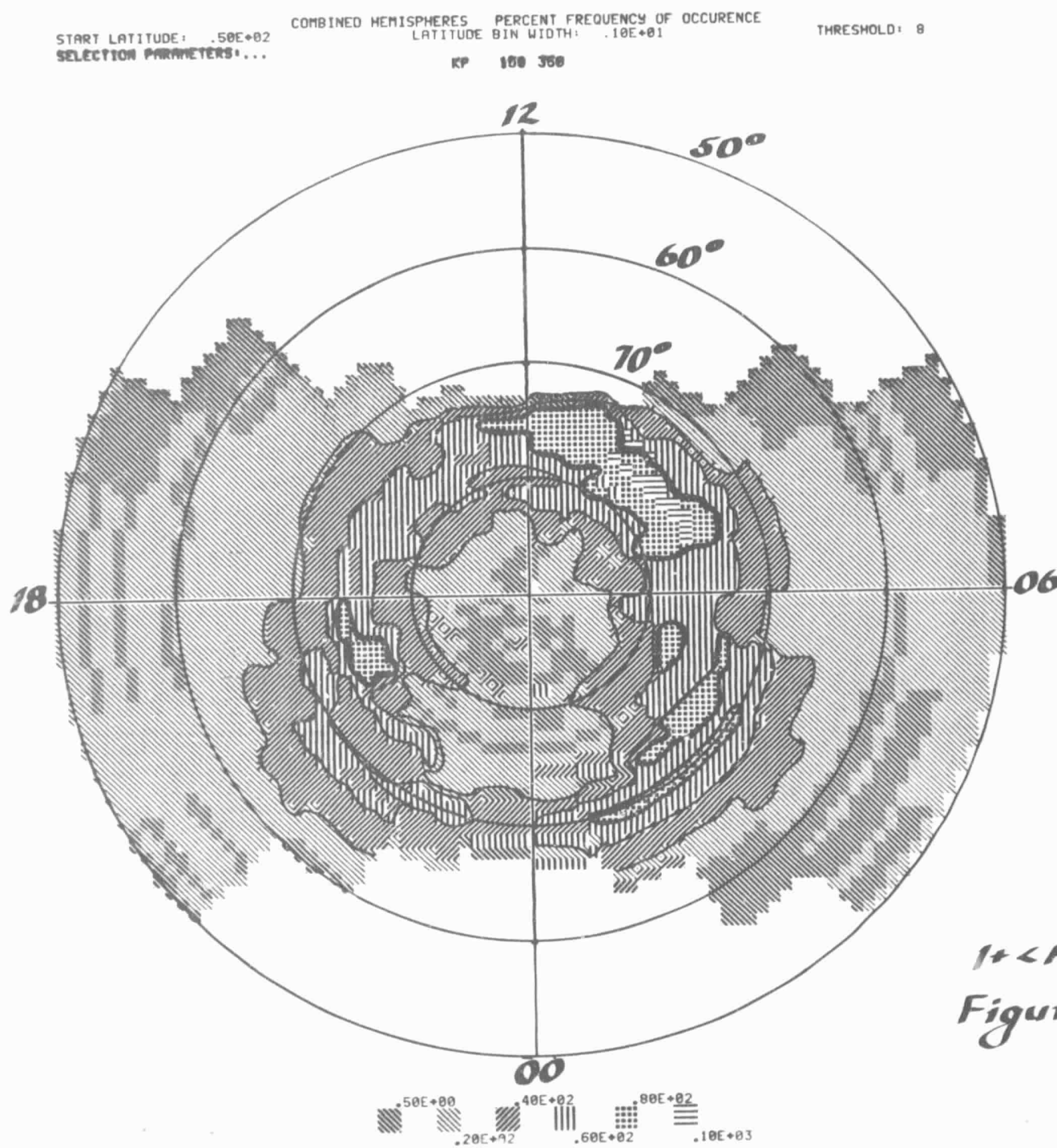
COMBINED HEMISPHERES PERCENT FREQUENCY OF OCCURENCE THRESHOLD: 0

START LATITUDE: .50E+02 LATITUDE BIN WIDTH: .10E+01
SELECTION PARAMETERS:...
KP 0 150



$0 \leq K_p \leq 1+$

Figure 5a



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BLACK AND WHITE PHOTOGRAPH

1+ < Kp ≤ 3+
Figure 5b

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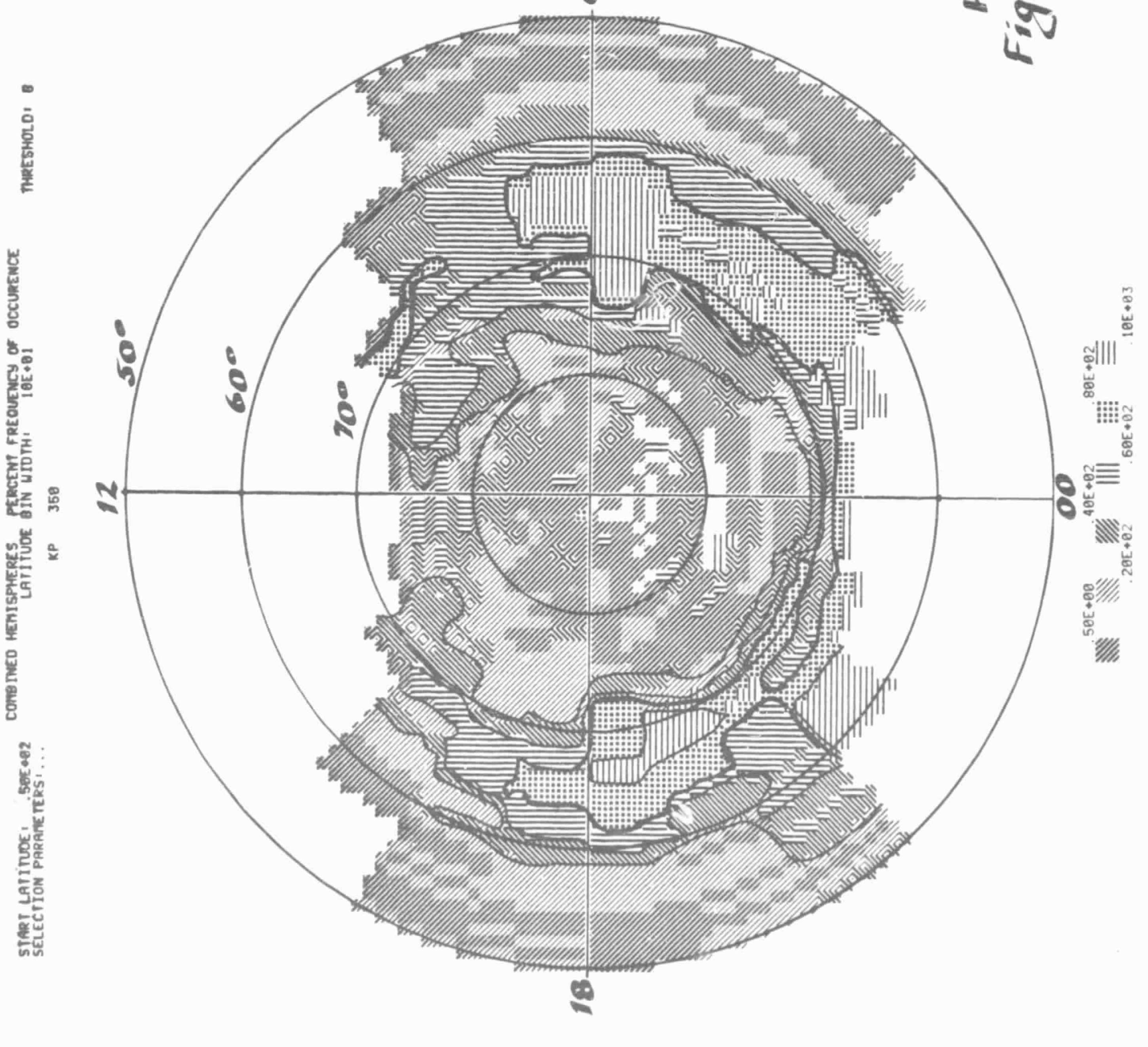

Kp > 3+
Figure 5c

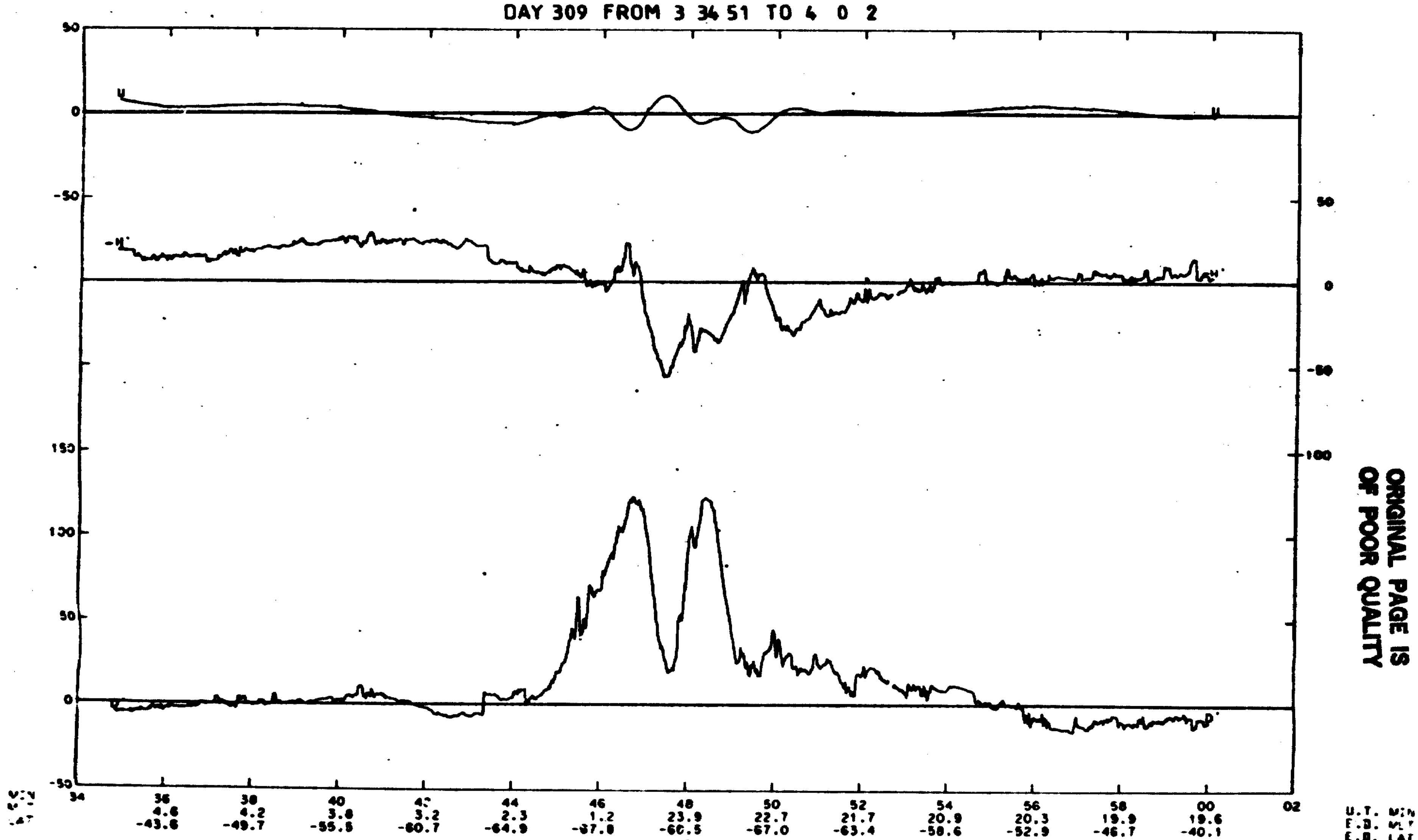

Figure 6a

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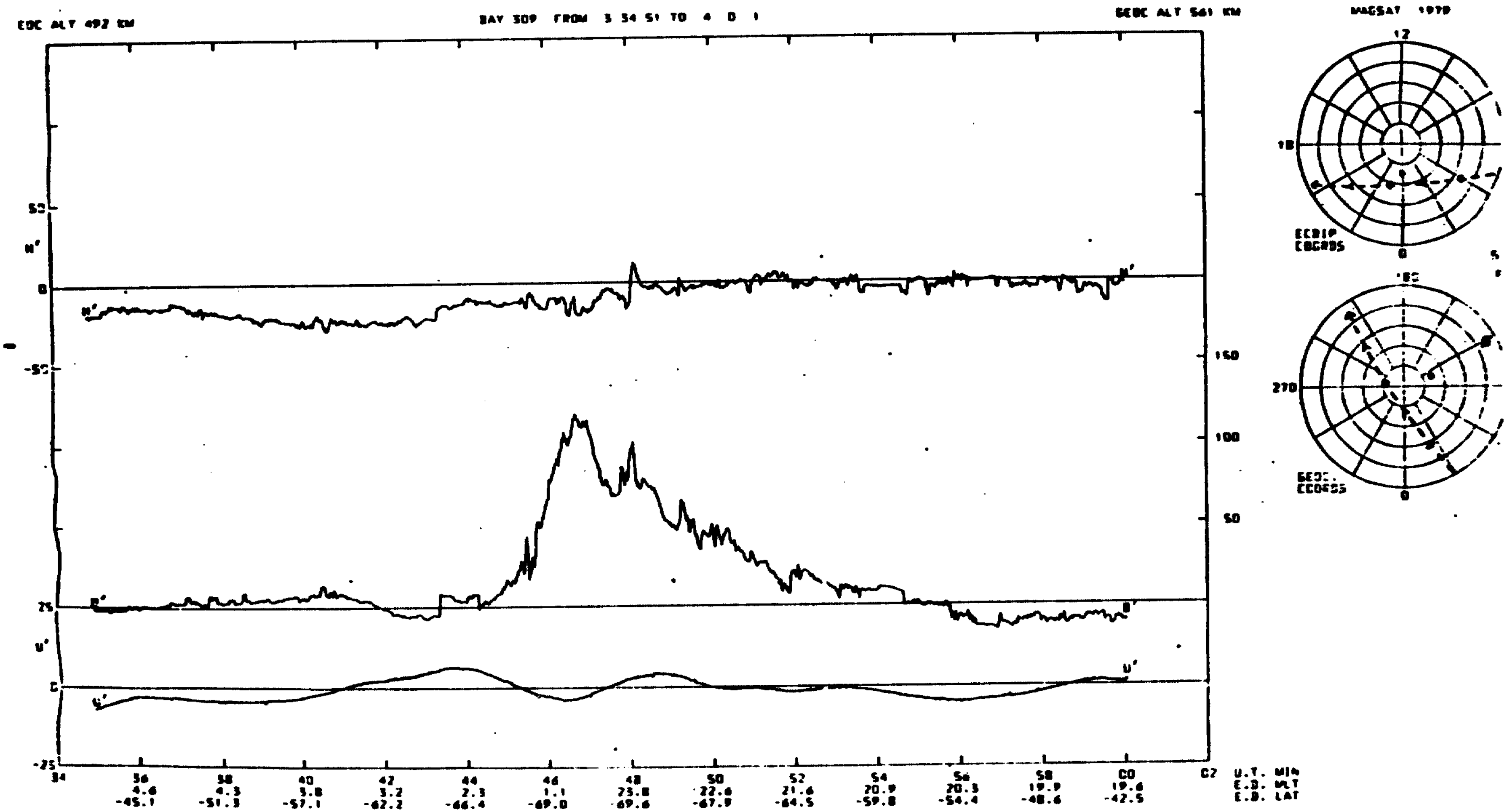

Figure 6b **** SPLINE FITTING TO GRID POINTS EVERY 15 SECONDS ****

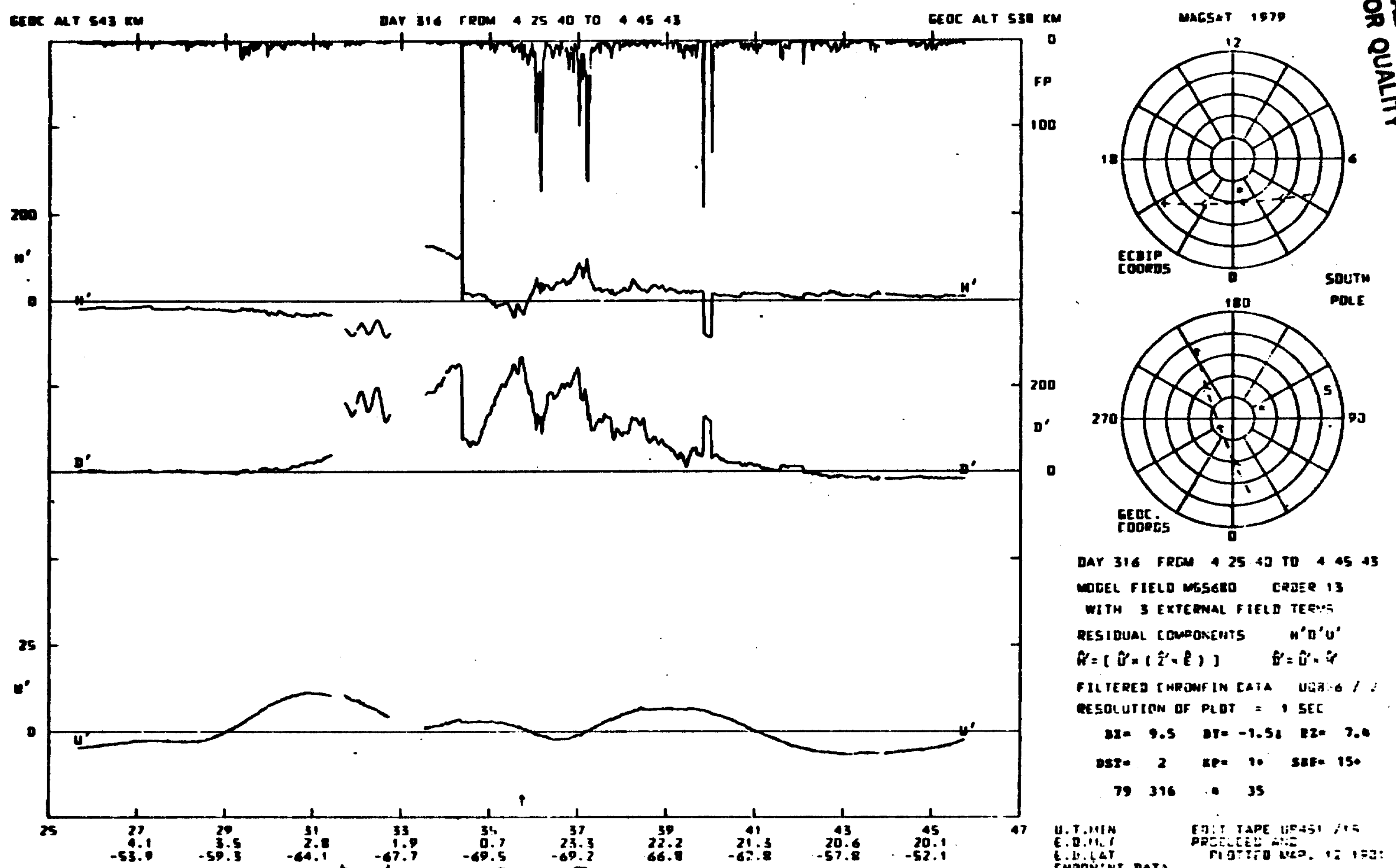
GEOC ALT 543 KM
DAY 316 FROM 4 25 40 TO 4 45 43
GEOC ALT 538 KM
FP
H'
D'
U'
MAGSAT 1979
ECBIP COORDS
SOUTH POLE
GEOC. COORDS
DAY 316 FROM 4 25 40 TO 4 45 43
MODEL FIELD MGS680 ORDER 13
WITH 3 EXTERNAL FIELD TERMS
RESIDUAL COMPONENTS H'D'U'
FILTERED CHRONFIN DATA
RESOLUTION OF PLOT = 1 SEC
BX= 9.5 BY= -1.5 BZ= 7.4
DST= 2 KP= 1+ SBF= 15+
79 316 4 35
U.T.MIN
E.D.MLT
E.D.LAT
CHRONINT DATA
PLOTTED MAR. 12 1981

Figure 7