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Studies of High Latitude Current Systems Using Magsat Vector Data

Investigation #M-40

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STATEMENT OF WORK M-40

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OBJECTIVES:

The objective is to analyze disturbance fields caused by global external current systems in order to:

a. Gain an improved understanding of the physical processes which control high latitude current systems.

b. Increase the confidence level in the identification of internal (anomalous) field levels.

APPROACH:

The basic approach is to:

a. Categorize the vector data by those physical parameters (geomagnetic activity, interplanetary conditions, etc.) important for investigation of external current systems.

b. Map the disturbances for appropriate conditions.

c. Model the currents which might cause the mapped disturbances.

d. Correlate results with data from other sources.

TASKS:

a. Develop sub-sets of vector data, from both polar regions, which are sorted by geomagnetic activity, interplanetary magnetic field conditions and solar illumination of the ionosphere.

b. Investigate the distribution of vector residuals caused by external currents in the auroral oval and polar caps for various conditions. Some of the more immediate problems are:

(1) Cusp-related disturbances during magnetically quiet conditions.

(2) Polar cap disturbances during northward interplanetary magnetic field (IMF) movement.

(3) Interhemispheric asymmetries in polar cap disturbances as a function of IMF sector structure.

(4) The dependence of dayside disturbances in the northern hemisphere upon solar elevation angle.

c. Determine the spatial distribution of field-aligned current systems in each data subset as a function of geomagnetic latitude and local magnetic time.

d. Construct models of typical global ionosphere-magnetosphere current patterns for each subset, using ground based magnetometers and the derived distribution of field-aligned currents as data bases.

e. Correlate the characteristics of inferred field-aligned currents with auroral arcs observed by the Defense Meterological Satellite Program (DMSP) satellites' optical and particle instrumentation on near-simultaneous high latitude transits of Magsat and the DMSP satellite.

The final report shall specifically describe, at a minimum, the results of each of the above tasks. The specific methodologies and interpretation techniques (including programs) applied to address each shall be discussed in sufficient detail so that they can be completely understood. References to other publications are acceptable if their level of detail is adequate. If references as noted above are utilized, copies or excerpts from these references shall be provided along with the final report. The final report shall identify and discuss any significant results derived as a result of the Magsat project. The report shall describe any new models constructed as a result of this project as well as describe how they were constructed, and how they differ from the existing model(s).

1. Personnel

Drs. T.J. Hughes, Margaret D. Wilson, D.D. Wallis and the author have been involved in defining the investigative approach and developing analytical tools for the past year. Dr. Wilson has been responsible for data processing operations and software development; Dr. Hughes has been responsible for current modelling techniques and software; Dr. Wallis has been responsible for definition of coordinate systems and related analytical work, development of a data base of correlative magnetic measurements and establishing contact with ground-based magnetic and optical observations.

2. Techniques

2.1 Data Processing

Data processing work has been directed towards developing programs for the reduction and presentation of data in a variety of formats. Routines have also been developed to diagnose problems on the source (Chronicle) tapes and in the processing software.

Data processing programs are designed to use CHRONFIN or CHRONINT tapes as input. Standard primary processing generates a MAGEDT output tape which is used as input both for plotting routines and further analysis. This tape contains data records of 62.9 seconds duration in which the spacecraft position (in geocentric coordinates), scalar and vector residuals and model field (resolved in NEV components) are computed at ~1 second resolution. CHRONFIN vector data is filtered with a 17 point Bartlett filter and decimated to every 16th point before the residuals are computed by subtracting the GSFC MGST 06/80 field model. For the X and Y residual components, a 'fluctuation parameter' is computed which provides a measure of the small scale structure present in the data prior to filtering and decimation. This parameter is computed about once per second (i.e., every 16 data points).

2.2 Data Display

A number of formats for displaying the data have been developed. Standard and variable format plots of three orthogonal components of the vector residuals versus universal time are most frequently generated. The fluctuation parameters and scalar magnetometer residuals may also be selected for display in these formats. Standard plots are limited to poleward of 50^{o} eccentric dipole latitude because of the principal interest of this investigation. However, the variable format plots are unrestricted as to universal time or latitude. Polar plots of the residual vectors in the plane perpendicular to either the vertical direction or the model field direction may be produced with varying time intervals between successive vectors. Figures 1 and 2 show a test pass plotted in universal time and polar coordinates. The positional coordinates and frame of the residuals are based on an eccentric dipole system.

2.3 Coordinate Systems

Studies of the correlation of external field residuals with geophysical parameters are strongly influenced by the coordinate system chosen for the analysis. Considerable investigation of different coordinate systems has been undertaken. Figures 3 and 4 show polar plots of the same test pass in two other coordinate systems. Figure 3 uses the HDZ usually used for ground-based measurements. In figure 4, the coordinate frame for the residuals uses the model field direction, U, and the vector to the eccentric dipole origin, Z'. Differences in the orientation of the residuals in different coordinate frames is evident, as expected. Work will continue to establish the best coordinate frame for data analysis.

3. Accomplishments

3.1 Software Development

Data from both intermediate and fine attitude chronicle tapes have been selected for processing and display. Since the fine attitude tapes are significantly better for studies of vector data, it has been decided not to use significant computing resources to routinely process intermediate attitude tapes because this work will only be duplicated later with the fine tapes. The CHRONFIN test tapes provided have been used to develop and test software. A list of some of the programs and subroutines is attached as Appendix A. Although not complete, it indicates the types of capabilities that have been developed.

3.2 Correlative Studies

Various magnetic parameters of the magnetosphere and interplanetary medium have been acquired for inclusion in a correlative data base. The AE, AL, AN indices are not yet available. As indicators of auroral electrojet activity, it is expected that they will be among the most useful for correlative studies.

Discussions with ground-based observers of visual aurora in Alaska and Scandinavia have identified some observing periods when Magsat made close crossings. Comparisons of auroral morphology and currents in the auroral oval, inferred from Magsat, will be initiated when fine attitude data for these periods becomes available.

Due to some operational failures of DMSP satellites, the satellite coverage of optical aurora during Magsat's lifetime is less than anticipated. A computer search for simultaneous observing periods has not yet found any occasions that are suitable for study.

3.3 Modelling of Current Systems

Software is now available for modelling of global ionospheric/magnetospheric current distributions poleward of 60° geomagnetic latitude. This forward modelling procedure is based on Kisabeth's method of specifying current distributions in the ionosphere in cells 0.5° in latitude and 4° in longitude and computing the resulting disturbance fields along the Magsat orbit due to these currents and the field-aligned currents which are necessary to maintain current continuity. Current distributions are adjusted to obtain optimal fits to the vector components of the residual field measured by Magsat. An example using data from the fine attitude test tape is shown in figures 5 and 6. Figure 5 shows the ionospheric current in each cell of the model. Figure 6 shows the disturbance residuals at 300 km altitude along the spacecraft track due to this current.

4. Publications

A paper (No. 3.4.6) entitled "Small scale current sheets in the magnetosphere near the auroral ionosphere" by J.R. Burrows, Margaret D. Wilson and D.D. Wallis was presented at the 23rd COSPAR Plenary meeting in Budapest in June, 1980. It was based on data from the CHRONINT test tape. The paper was not submitted for publication in the conference proceedings because fine attitude data was not yet available for that period by the submission deadline.

5. Data Quality and Delivery

A principal concern at present is the high frequency noise which is introduced into the fine attitude test tape data by the method that the Project Office has adopted for computing the fine attitude. Some method for smoothing the individual attitude solutions needs to be developed before standard production of fine attitude tapes is started. Discussions with the Project Scientist are continuing and a satisfactory solution is likely to be reached.

The early derivation and distribution of Magsat field models by the Project Office has been very much appreciated since they are the keystone for our data analysis and subsequent interpretation.

6. Conclusions

The Magsat data set appears to have remarkably high precision and quality. It should permit major advances to be made in modelling current distribution at high latitudes in the ionosphere and magnetosphere.

APPENDIX A

Data Processing and Diagnostic Programs

MAGATT Programme to read the attitude flag data from the Magsat input tapes and plot and/or list the data.

MAGDUM Programme to dump data from Magsat chronicle input tapes (CHRONINT, CHRONSC and CHRONFIN types). Under input card control the program will function in a variety of modes.

MAGLST Programme to list the contents of a MAGEDT output tape from orbit and decimated data records (the tape can be either normal or extended type).

MAGPAL Programme to plot data from the MAGEDT tapes created by TEMEDT. Under input control, either decimated or undecimated data can be plotted, residuals or vectors can be rotated, time and latitude ranges can be set and several sets of data can be plotted in one job.

SHMITS Programme to compute the Schmidt normalized coefficients for one or more field models and produce, for each model, an object module containing these coefficients.

SPLTST Programme to investigate the differences between the computed and spline fitted values of the model field components using different separations of the grid points for the spline fit.

TEMEDT Standard processing programme to create an edit tape, MAGEDT, from Magsat CHRONINT or CHRONFIN input tapes. The MAGEDT tape will always contain records of filtered decimated data and optionally may contain records of unfiltered, undecimated data.

Data Processing and Diagnostic Subroutines

MAGFLD Assembler subroutine which computes the model field components BR, BT, BP for a given spacecraft position. Called by TEMEDT, SPLTST.

MAGGET Subroutine to read data from Magsat chronicle tapes. Called by TEMEDT, MAGDUM, MAGATT.

FORMIT Assembler subroutine which formats the orbit data and the scalar/vector data for listing. Called by TEMEDT, MAGDUM.

STDPRE Subroutine to prepare data for the plotting subroutine STDPLT of TEMEDT. North and south polar data (from 50^{o} eccentric dipole latitude) are plotted versus Universal Time. The vector residuals are rotated to the HDU frame. Scalar, vector and fluctuation data are plotted with an x-scale of 120 seconds/inch and a plot decimation length of 4. Called by TEMEDT.

STDPLT Subroutine to produce the standard decimated data plot for TEMEDT. Data to be plotted have been transferred to the arrays by STDPRE. Called by TEMEDT.

POLPLT Subroutine to plot the polar diagram for Magsat transpolar plots. Called by STDPLT, MAGPLT.

MAGROT Subroutine to rotate Magsat NEV residuals to one of five other systems. Called by STDPRE, PREPAL.

GEOCEN Subroutine to convert inertial coordinates to geocentric for 128 minutes of Magsat orbit data. Called by MAGGET.

MAGSPL Subroutine to compute cubic spline interpolation coefficients for various functions y(x) using successive sets of 6 grid points and storing in the output array the coefficients at the third grid point in each set. Grid points are assumed to be 60.000 seconds apart. Called by TEMEDT, SPLTST.

GETRTP Assembler subroutine computes polar coordinates R, T, P from cartesian coordinates X, Y, Z. Called by MAGGET, TEMEDT.

ECDIP Subroutine transforms geocentric cartesian points to eccentric dipole cartesian coordinates. Called by TEMEDT.

FILTM Subroutine to filter and decimate a Magsat data time series. Called by TEMEDT.

FLDTRC Subroutine to compute the position of a point in geocentric cartesian coordinates when traced down the magnetic field, specified by its direction cosines, to a reference altitude above the earth's surface. Called by TEMEDT.

GETXYZ Subroutine to obtain geocentric cartesian coordinates of points having coordinates R, T, P where R is the vector magnitude either relative to the geocentric origin or to the earth's surface, T is latitude in radians and P is longitude in radians. Called by TEMEDT.

PREPAL Subroutine to prepare data from MAGEDT tapes for plotting, using either decimated data or extended (undecimated) data. Called by MAGPAL.

MAGPLT Subroutine to plot the Magsat residual data accumulated in arrays by PREPAL. Called by MAGPAL.

SYNTHS Subroutine to produce synthetic scalar data from the decimated X, Y, Z vector data. Called by PREPAL.

RECONS Subroutine to reconstruct measured vector data from model field and residuals stored in MAGEDT tapes, as required either for the rotation of these vectors to obtain fluctuation parameters in the rotated frame, or for the computation of synthetic scalar data from the corresponding X, Y, Z components of vector data. Called by PREPAL, MAGPAL.

FLUCTR Subroutine to compute the X and Y fluctuation parameters from rotated, reconstructed, undecimated X and Y vector measurements. Called by PREPAL.

POLVEC Subroutine to produce a polar plot of the residuals in the horizontal plane or plane perpendicular to the model field direction. The spacecraft position is normally specified in eccentric dipole latitude and eccentric dipole magnetic local time. Called by MAGPAL.

Current and Magnetic Perturbation Modelling Programmes

CELSAM This code is designed to read data from FT10, which has been generated by DATPRP. The latter reads MAGEDT tape, and reformats the data for plotting using TJH's plot routines (to be used with model data). The code converts all latitudes and longitudes to the corresponding cell positions (observer kernel positions), computes the cell numbers, locates the data point closest to the cell observation point. The closest point is the minimum sum of squares of differences between the real point and the cell point (longitude is normalized to a distance via sin (colat). Output is hard copy and FT11.

EWFAD1 Driver to examine the integration of the EW system uses Biot-Savart; integrations are done by a Romberg scheme applied to intervals of different sizes (input).

FILRES Programme to compute the impulse and/or the Heaviside response of recursive type filters.

FILTER A general code for examining the frequency response of a number of filter types (i.e., non-recursive, non-cascaded; non-recursive, cascaded; recursive).

MODEL4 This code generates kernels for use with the grid cell model of Kisabeth. This code is not generalized. It is assumed that there are 90 cells 4 degrees long (longitude) and 54 current rings 0.5 degrees in latitude (58 to 85 degrees N) and that there are 77 observer positions (50 to 88 degrees north in 0.5 degree steps. Maximum use of symmetry has been used, and only 46 kernels per current ring are actually computed and stored. Singly dimensioned variables are used throughout for efficiency. The magnetization term for the north-south current system perturbations is not calculated, but it is assumed that the Z-transform will look after this where appropriate. Output is to 77 files, one for each observation ring. Each file is DDEFed with two sequence numbers (001 and 002) to accommodate the NS (001) and EW (002) systems, so that in fact there are 154 separate files of kernels.

NSDRIV Driver for north south current system B field perturbations using Kisabeth's equivalent charge method, and using Romberg integration scheme exclusively. The code uses Kisabeth's charge formulation to compute the B field due to a north south current system. This involves integration along lines of charge whose geometry is that of dipole field lines placed at the ends (E/W) of the N-S current. The integrations along these lines is carried out in three steps, depending on the position of the observer. See "NSSUB2" and the parameter "DEL" in that subroutine for the locations of the sub-intervals. The form of Romberg used in this code has been modified to carry out three integrals simultaneously, for the sake of efficiency. However, each integral is done only until convergence is reached. See ROMB3A and ROMB3B for details.

NSGL2 The code uses Kisabeth's charge formulation to compute the B field due to a north south current system. This involves integration along lines of charge whose geometry is that of dipole field lines placed at the ends (E/W) of the N-S current. Gaussian (2 point) integration is used for both integrals approx. 35 sub-intervals along the field line, and either 1 or 4 in latitude, depending upon the obs. position.

TFAVG Programme to compute the transfer function, modulus of same, and phase of cascaded simple averaging filters, and then the result of decimation based on textbook by Blackman.

ZTILT This code is designed to handle tilted ovals, in the sense that the current flows EW/NS in a system whose pole is offset towards midnight an amount "TILT" degrees. The oval is specified by its poleward border at PHI=90 degrees (dawn) (pollat) and the approximate eastern and western boundaries (approximate because these change in the rotated system). The code defaults (ICUR=0) to constant current density everywhere with J(NS)=0.5* cur amp/m, and J(EW)=-1.0* cur amp/m. Otherwise subroutine "CURRENT" must exist, and is used to compute the current densities for each cell. Observer positions are rotated from the tilted oval system to that in which the oval is a centered circle (the primed system). The closest positions for which there are computed kernels are then found, and these are reverse transformed to the tilted system for future reference, plotting, etc. The defined current densities are transformed to the primed system where the appropriate totals are computed for each cell. Finally, H', D', Z' are projected into the observer frame to give H, D, Z due to a tilted current system.

Current and Magnetic Perturbation Modelling Subroutines

CHGFUN Computes the integrands for the integrals used in Kisabeth's equivalent charge method for calculating the magnetic perturbations due to a north south current system. The integrand is computed as a function of observer position, field line - ionosphere intersection position and position along the field line. No integrals are carried out. Along the field line, resolution in colatitude is variable as specified below. The distance in kilometres from the observer to the position on the field line is also computed.

CLOSEST Subroutine to compute the spherical geocentric co-latitude angle describing a point of a specified field line which is closest to a given observer position.

ROMB3 This code computes three integrals simultaneously. If J1, J2, or J3 is equal to zero, the corresponding integral is not calculated. The code is ideal for use in calculating the three components of the magnetic field, where many of the factors and terms are the same for each component. When convergence in a component has been achieved, the appropriate flag is set to zero so that further calculations on this component are not carried out. High precision and rapid convergence depend on the existence of all derivatives in the closed integration interval (A, B). Any singularities will cause a poor answer, and waste computer time. The advantage of this method over Gauss-Legendre is that the precision of the solution is easily estimated. For a description of the method, see 'A 1ST Course in Numerical Analysis', Ralston, 1965.

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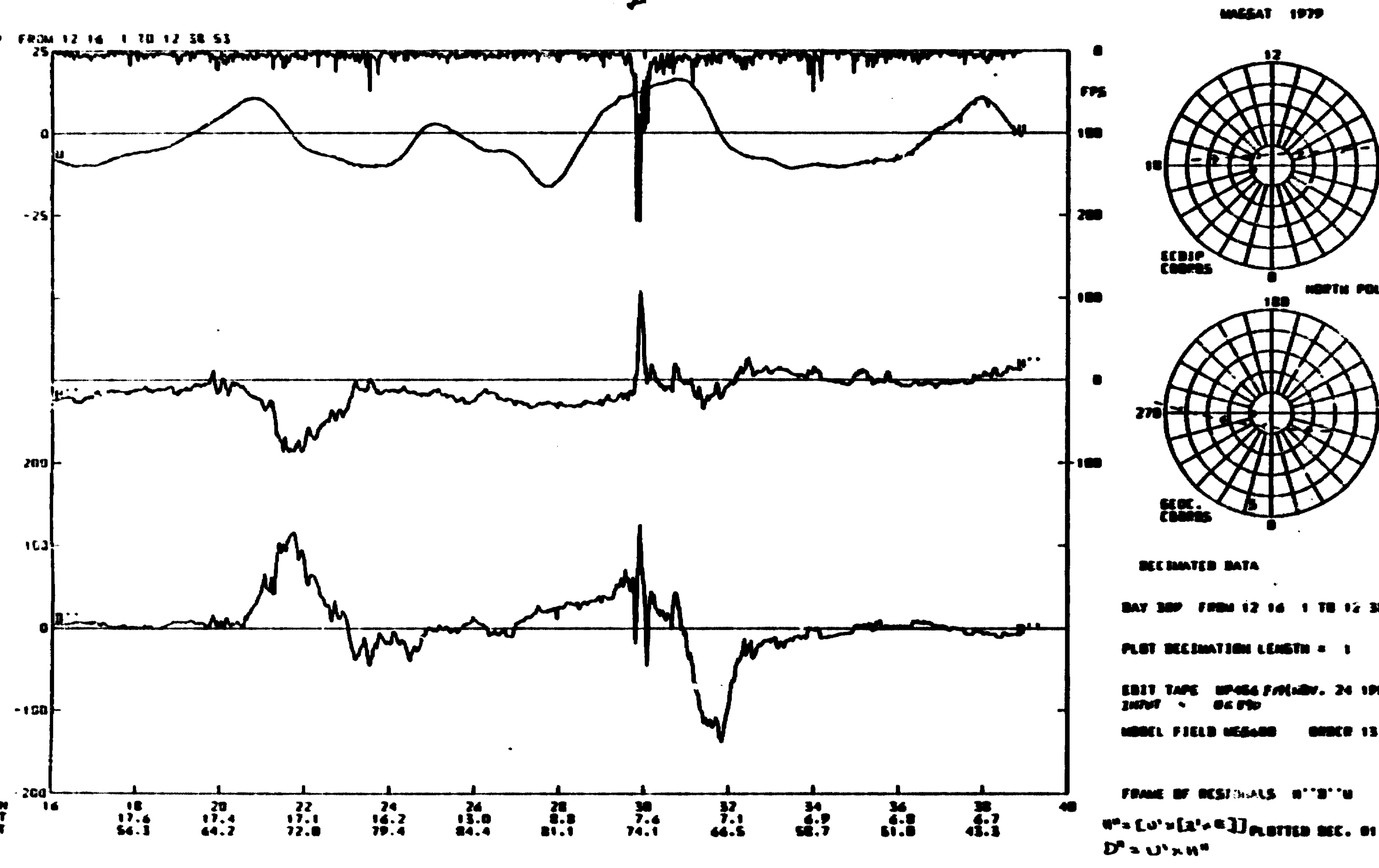

1522

$H'' = [U' \times [Z' \times E]]$
$D'' = U' \times H''$

MAGSAT 1979 DAY 309 FROM 12 18 56 TO 12 33 41

FRAME OF RESIDUALS H''D''U'

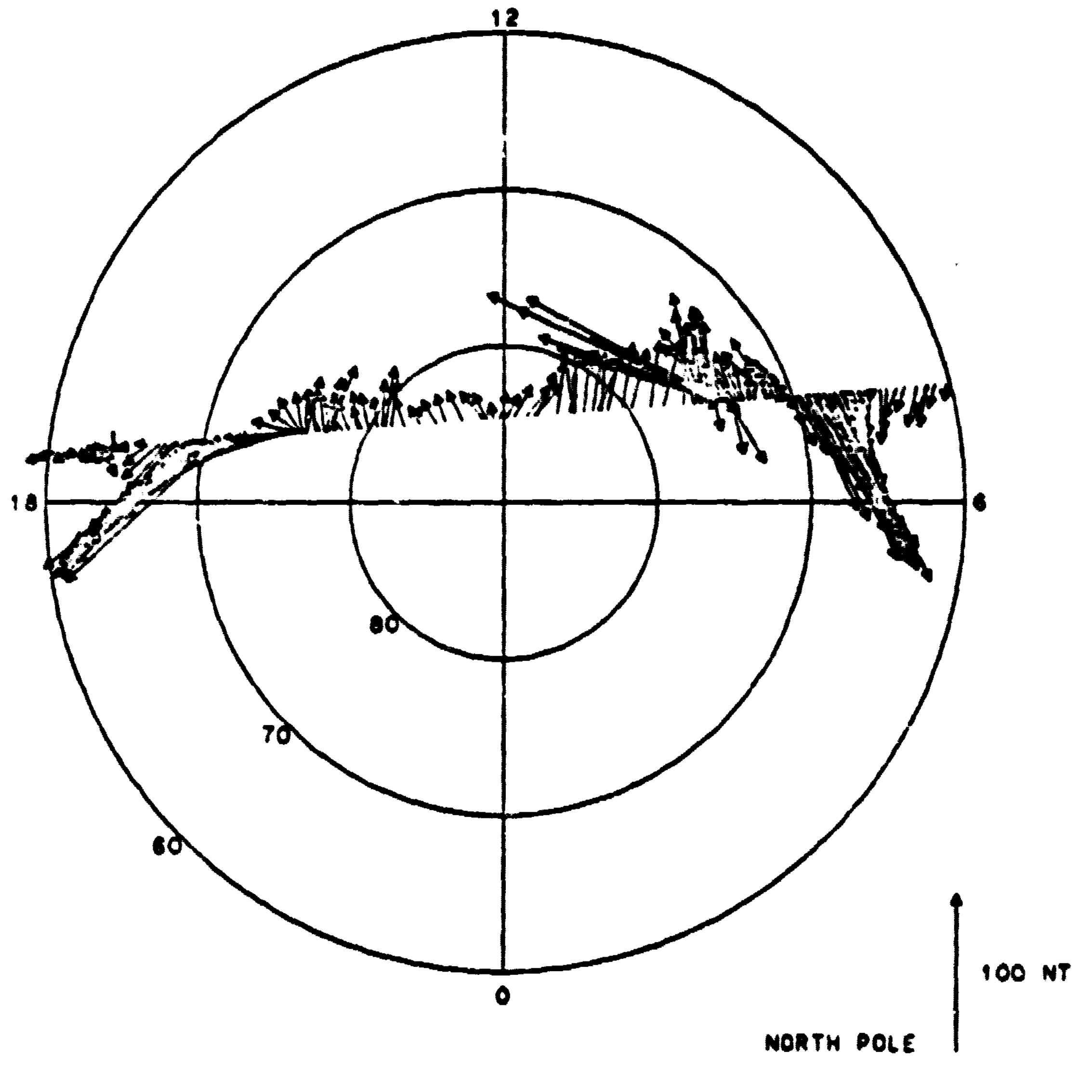

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Fig. 2

1522

$D = [\hat{z} \times U]$
$H = D \times \hat{z}$

MAGSAT 1979 DAY 309 FROM 12 18 56 TO 12 33 41

FRAME OF RESIDUALS HDZ

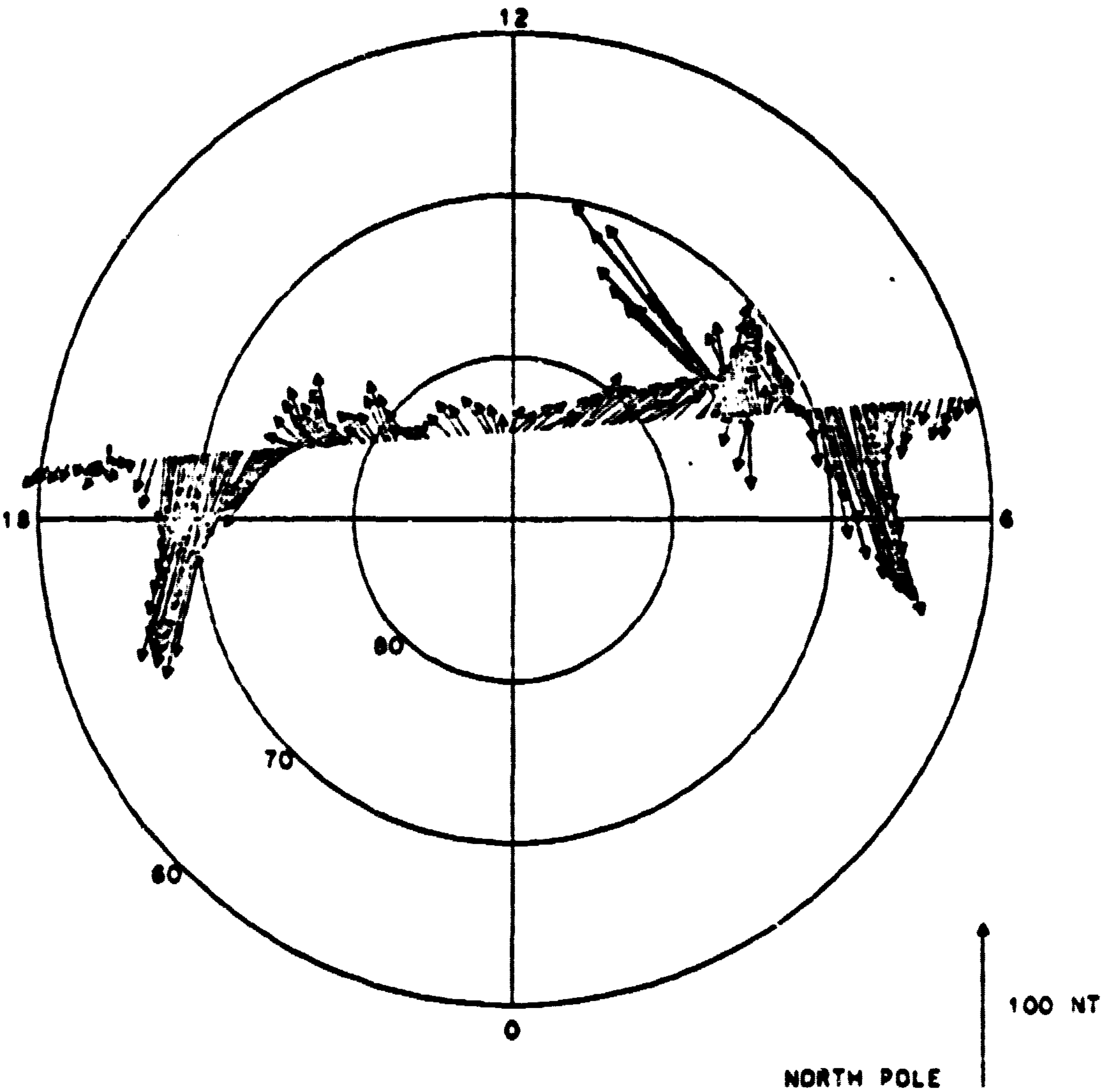

Fig. 3

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$D' = [Z' \times U]$
$H' = D' \times Z'$

MAGSAT 1979 DAY 309 FROM 12 18 56 TO 12 33 41

FRAME OF RESIDUALS H' D' Z'

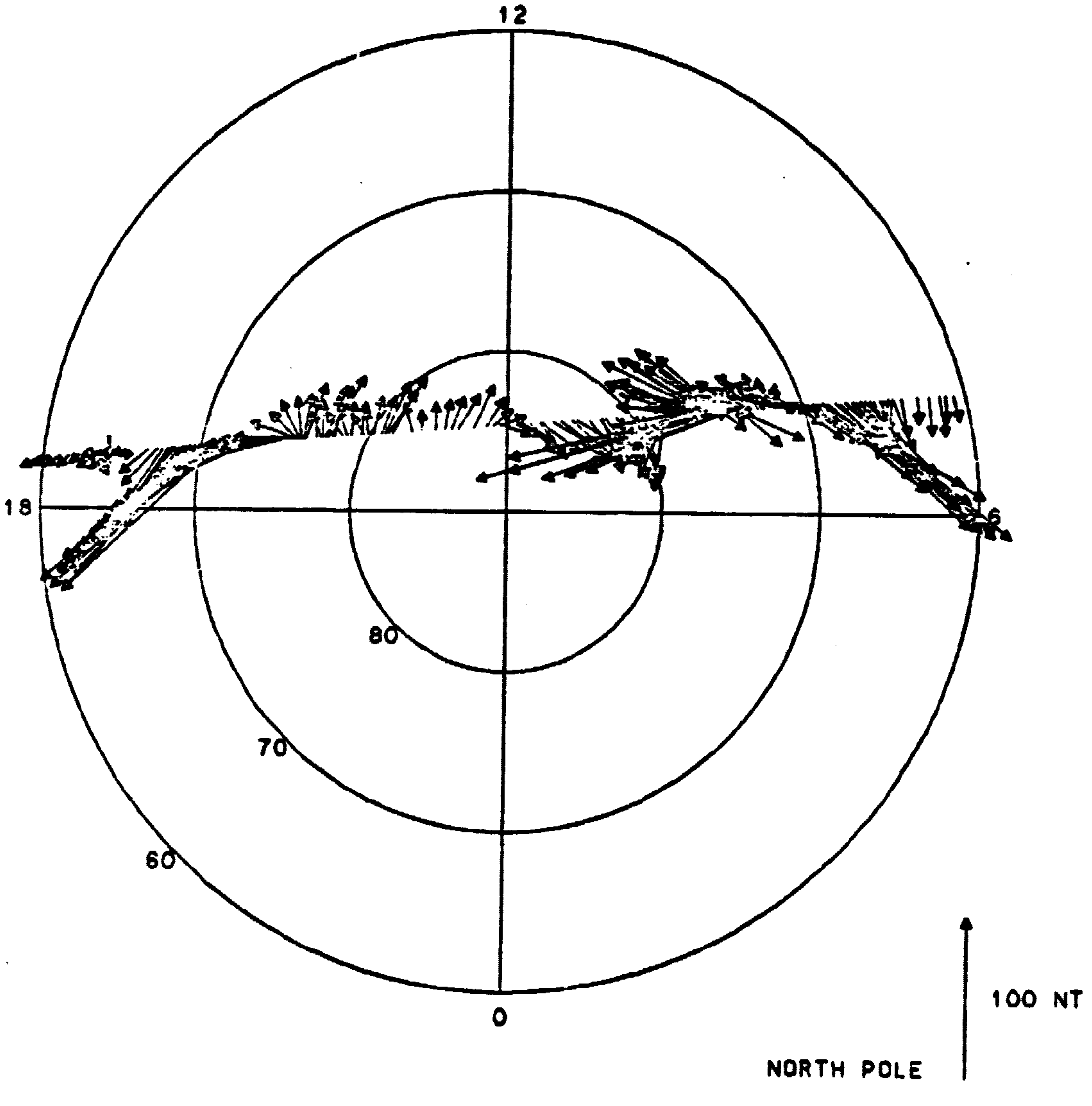

Fig. 4

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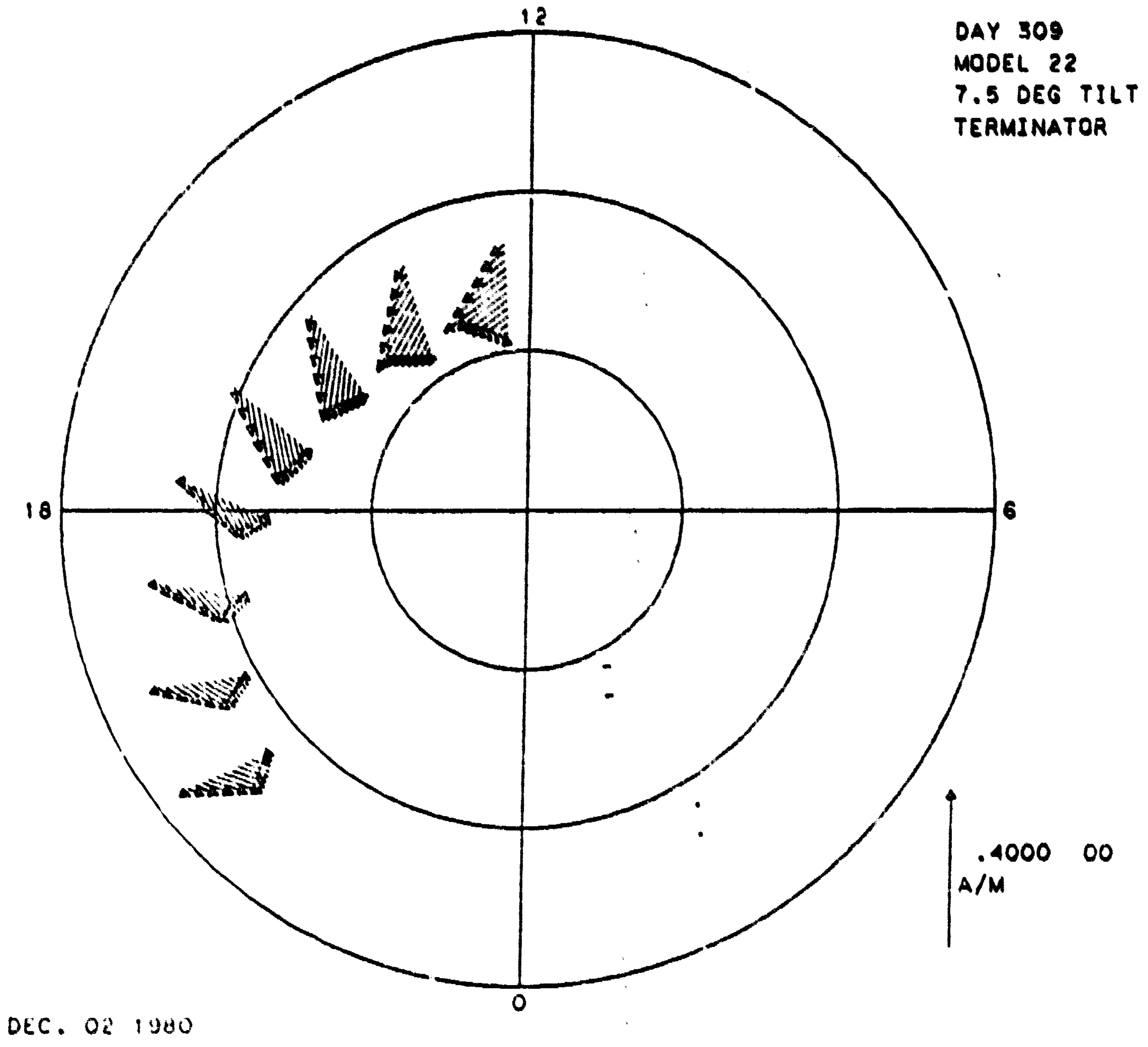
12
18
6
0
DAY 309
MODEL 22
7.5 DEG TILT
TERMINATOR
.4000 00
A/M
DEC. 02 1980

Fig. 5

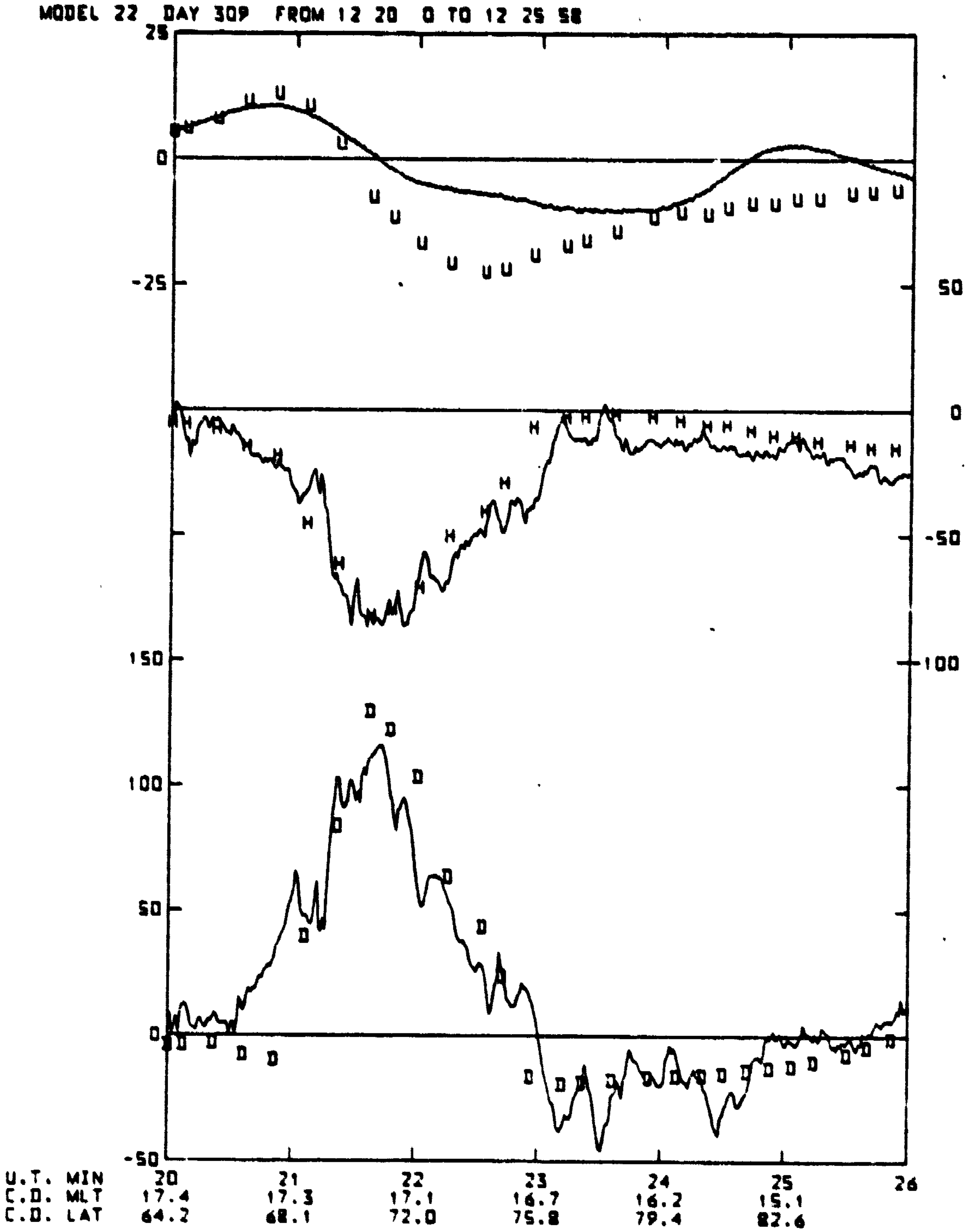
MODEL 22 DAY 309 FROM 12 20 0 TO 12 25 58
25
0
-25
50
0
-50
150
-100
100
50
0
-50
U.T. MIN 20 21 22 23 24 25 26
C.D. MLT 17.4 17.3 17.1 16.7 16.2 15.1
C.D. LAT 64.2 68.1 72.0 75.8 79.4 82.6

Fig 6