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ENVIRONMENTAL DESIGN CRITERIA

by

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Summary Report

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The knowledge of the space environment is a necessity for the design and operation of the space vehicle, Skylab, future space schuttle and spacelab. Complex physical characteristics of the property of the space environment is essential to acquire a systematic investigation to the future advancement of our knowledge.

In this report, we shall present the results of our studies during this period of time (March 1970 - February 1974). In this study, we have covered a wide range of problems in the space environment, i.e., the problems of dynamical behavior of thermosphere, hydromagnetic wave propagation in the upper F2-region, and interplanetary space environment. Most of these studies have resulted in journal publications, which have previously been submitted to the National Aeronautics and Space Administration/Marshall Space Flight Center. They are as follows:

(1) "Propagation of Hydromagnetic Waves in the Upper F2-Region," Planet. Space Sci., Vol. 21, 1973.

(2) "Kinetic Theory Analysis of Solar Wind Interaction With Planetary Objects," in Photon and Particle Interaction With Surfaces in Space (Ed. by R. J. L. Grard), D. Reidel Publishing Company, Dordrecht-Holland, 1973.

(3) "The Dynamical Responses of the Thermosphere Due to a Geomagnetic Storm," AIAA Paper No. 74-217.

(4) "An Analysis of the Upper Atmosphere Wind Observed by LOGACS," Planet. Space Sci., 1974.

An Analysis of the Upper Atmospheric Wind Observed by LOGACS

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AN ANALYSIS OF THE UPPER ATMOSPHERIC WIND OBSERVED BY LOGACS

Abstract - Wind velocities at 140-200 km altitude were observed by a Low-G Accelerometer Calibration System (LOGACS) flown on an Agena satellite during a geomagnetic storm. An interesting wind reversal observed by the satellite at auroral latitudes is satisfactorily explained by the neutral air motion caused by the $\vec{E} \times \vec{B}$ drift deduced from the ground-based geomagnetic data recorded at stations near the meridian of the satellite orbit.

1. INTRODUCTION

High-resolution wind observations in the lower thermosphere were made by an Agena satellite in an experiment designed to measure very small accelerations in the orbital motion. Data from this experiment designated LOGACS (Low-G Accelerometer Calibration System) were analyzed to determine the magnitude and direction of the wind component perpendicular to the orbital plane of the satellite (DeVries, 1972). Observations of the lateral wind component at 140-200 km altitude on 26 May 1967 for different orbits of the satellite are shown in Fig. 1. As seen for the 54th and 56th orbits, a reversal of the lateral wind direction occurred at about 65° N latitude. In order to find a possible cause of this wind reversal, geomagnetic data obtained at a chain of stations near the satellite orbit were examined. As shown in Fig. 1, Dixon Island (DI; 73°33' N, 80°34' E), Sverdlovsk (SV; 56°44' N, 61°04' E), Tehran (TP; 35°44' N, 51°23' E) and Quetta (QU; 30°11' N, 66°57' E) are located near the meridional plane of the 56th orbit. The electromagnetic drift speeds were estimated from

Fig. 1

the geomagnetic variations at these stations, and were compared with the LOGACS wind measurement for the 56th orbit. Since the geomagnetic D component during disturbed periods is strongly controlled by field-aligned electric currents, the H component has mainly been studied to estimate the electric current intensity in the ionosphere, assuming that a significant part of this component arises from ionospheric sources. Whether this assumption is justifiable as a first approximation is one of the purposes of the present research note.

2. METHOD

As given by Chapman and Bartels (1940), the sheet electric current intensity I in the ionosphere can be estimated approximately by the geomagnetic variation field ΔB as follows:

$$I_x = \Delta B_y \ (f/2\pi)$$

$$I_y = -\Delta B_x \ (f/2\pi)$$

where f is a parameter used to eliminate the induction current effect (commonly assumed to be 0.6), and the subscripts x and y represent the southward and the eastward component, respectively. When the geomagnetic H component only is considered, we have

$$I_y \simeq \Delta H \ (f/2\pi) = 0.0955 \ \Delta H \quad . \qquad (1)$$

As discussed by many scientists (e.g., Maeda and Kato, 1966; Matsushita, 1967), the southward electric field E_x can be calculated by the following relation when I_x is ignored:

$$E_x = -I_y \, \Sigma_{xy}/(\Sigma_{xx} + \Sigma_{yy} + \Sigma_{xy}{}^2)$$

$$\simeq -0.0955 \, \Delta H \, \Sigma_{xy}/(\Sigma_{xx} \Sigma_{yy} + \Sigma_{xy}{}^2) \qquad (2)$$

where Σ is the height-integrated electric conductivity. The eastward ion speed V_y due to $\vec{E} \times \vec{B}$ drifts above 140 km altitude can be obtained by

$$V_y = (E_x/B) \operatorname{cosec}\Phi \qquad (3)$$

where B is the earth's main magnetic field and Φ is the magnetic dip angle.

The neutral wind velocity $\vec{V}_n$ can be approximately determined from the ion drift velocity $\vec{V}_i$ as follows:

$$\frac{d\vec{V}_n}{dt} + \frac{1}{\rho_n} \nabla \cdot \mathbb{P}_n = \frac{\vec{V}_i - \vec{V}_n}{\tau_{ni}} \qquad (4)$$

where $\mathbb{P}_n$ is the stress tensor, ρ_n is the neutral density, and τ_{ni} is the neutral-ion collisional time. If we neglect viscosity and assume that the neutral pressure gradient can be expressed in terms of neutral velocity as,

$$-\frac{\nabla p}{\rho_n} = \beta \vec{V}_n \qquad (5)$$

then (4) becomes

$$\frac{d\vec{V}_n}{dt} = \frac{\vec{V}_i - (1 - \alpha)\,\vec{V}_n}{\tau_{ni}} \qquad (6)$$

with $\alpha = \beta\tau_{ni}$, α and β being constants indicating the order of magnitude of the pressure gradient. The solution of (6) is:

$$\vec{V}_n(t) = \int_0^t \exp\left[\frac{1-\alpha}{\tau_{ni}}\ (t' - t)\right] \frac{\vec{V}_i\ (t')}{\tau_{ni}}\ dt' . \qquad (7)$$

This expression indicates that the neutral wind velocity approaches the ion drift velocity with a delay time of approximately $\tau_{ni}/(1-\alpha)$, which is on the order of 5×10^3 sec for $|\alpha| << 1$ (e.g., Banks, 1966; Fedder and Banks, 1972). In other words, through ion-neutral collisions, $\vec{V}_n \simeq \vec{V}_i = \vec{V}_y$ may occur within a few hours. When V_y lasts for a few hours, then, a neutral wind flow which has approximately the same velocity as V_y may be generated. Accordingly, V_y estimated from ΔH using Equations (1), (2) and (3) can be compared with the LOGACS neutral-wind measurements, taking into consideration a few hours time lag.

3. RESULT

As presented in Fig. 2, DI shows a positive variation in the H component, while the three other stations (SV, TP and QU) in lower latitudes than DI show a negative variation, at about 6h UT on 26 May 1967 corresponding to the time of the 56th satellite orbit. To estimate ΔH, the zero level is assumed to be the average value of 6-7h UT on 25 May as shown by the horizontal straight line in Fig. 2. Since the ΔH due solely to ionospheric electric currents is needed to discuss ionospheric winds, ring-current effects must be eliminated. From the equatorial D_{st} values obtained by Sugiura and Cain (1970), $\Delta Dst \cdot \cos\theta$ was computed (broken curves in Fig. 2), where θ is the latitude angle of each station and ΔD_{st} is the deviation from the D_{st} value averaged for 6-7h UT on 25 May. Fig. 2

Deviations of H values from the zero level (solid circles) and those from $\Delta D_{st} \cdot \cos\theta$ (crosses) for the four stations at 6h UT on 26 May are presented in the top diagram of Fig. 3. Solid circles indicate the extreme case with no Dst contribution. It can be noticed that the sign of ΔH changes at 60^{o}-70^{o} N latitude, roughly corresponding to the change-over location of the LOGACS wind direction shown in Fig. 1. Fig. 3

For simplicity, the scaling of ΔH is made for 6h UT on 26 May corresponding to the 56th orbit. As discussed at the end of the preceding section, a few hours are required to produce a neutral wind velocity of the same order as the ion drift velocity. Since the ΔH values remain generally the same during a few hours before 6h UT on 26 May (see Fig. 2), ΔH at 6h UT is acceptable as a representative value of the geomagnetic variation for the present discussion.

To obtain E_x from Equation (2), values of the height-integrated electric conductivity Σ are necessary. Since these values during geomagnetic storms are difficult to estimate accurately, the Σ values during quiet periods (Tarpley, 1969) are substituted, bearing in mind that the resulting $|E_x|$ must be close to the maximum value. The adopted conductivities at four geomagnetic stations are listed in Table 1. Calculated E_x distributions with (crosses) and without (circles) Dst effect are shown in the middle of Fig. 3. Table 1

With E_x from Equation (3), the eastward drift speed V_y can easily be obtained. These V_y are compared with the observed neutral wind speed by LOGACS in the bottom diagram of Fig. 3. Agreement between the two is satisfactory as a first order approximation. However, the absolute values of the LOGACS wind speeds at latitudes higher than 50° N are slightly larger than the calculated $|V_y|$ values which are close to the maximum since they are obtained from the near maximum $|E_x|$ values. One possible explanation of this discrepancy is that $|\Delta H|$ recorded at the ground is smaller than that which can be attributed to an electric current of purely ionospheric origin. Field-aligned electric currents and some magnetospheric variations may cause a reduction of $|\Delta H|$ at the ground. Although various data and careful examination are needed to discuss the details, an interesting conclusion is that the reversal of the LOGACS wind direction near 65° N is understandable in terms of the reversed ionospheric drift directions between Dixon Island and Sverdlovsk inferred simply from the geomagnetic H records at these stations.

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TABLE 1. HEIGHT-INTEGRATED ELECTRIC CONDUCTIVITIES

(in 10^{-9} emu)

	Σ_{xx}	Σ_{xy}	Σ_{yy}
DI	4.27	5.38	4.19
SV	5.79	7.42	5.24
TP	11.5	14.0	78.3
QU	15.5	17.8	89.0

Figure Captions

FIG. 1. Distributions of wind velocities normal to the satellite path at about 150 km altitude measured by LOGACS for its 53rd, 54th and 56th orbits on 26 May 1967 are shown in geographic coordinates (with three Greenwich longitudes and the equatorial semi-circle). The 56th orbit was along the 60°-70° E meridian at approximately 6h UT. Locations of four geomagnetic stations (Dixon Island, Sverdlovsk, Tehran and Quetta) near the 56th orbit are shown by solid circles.

FIG. 2. Geomagnetic H variations (positive upward) recorded at four stations on 25-26 May 1967. The zero level is assumed to be the average value of 6-7h UT on 25 May, and shown by the horizontal straight line. The broken curves indicate $\Delta Dst \cdot \cos\theta$ measured from the zero level, where ΔDst is the deviation from the Dst value (+30γ) averaged for 6-7h UT on 25 May and θ is the latitude angle of each station.

FIG. 3. (top) Deviations of H values from the zero level (solid circles) and those from $\Delta Dst \cdot \cos\theta$ (crosses) at 6h UT on 26 May 1967.
(middle) Southward electric field, E_x, calculated from H deviations.
(bottom) Observed neutral wind speed by LOGACS (small solid circles with a fitted smooth curve obtained from the wind speeds for the 56th orbit in Fig. 1) are compared with calculated eastward drift speed V_y (large solid circles and crosses).

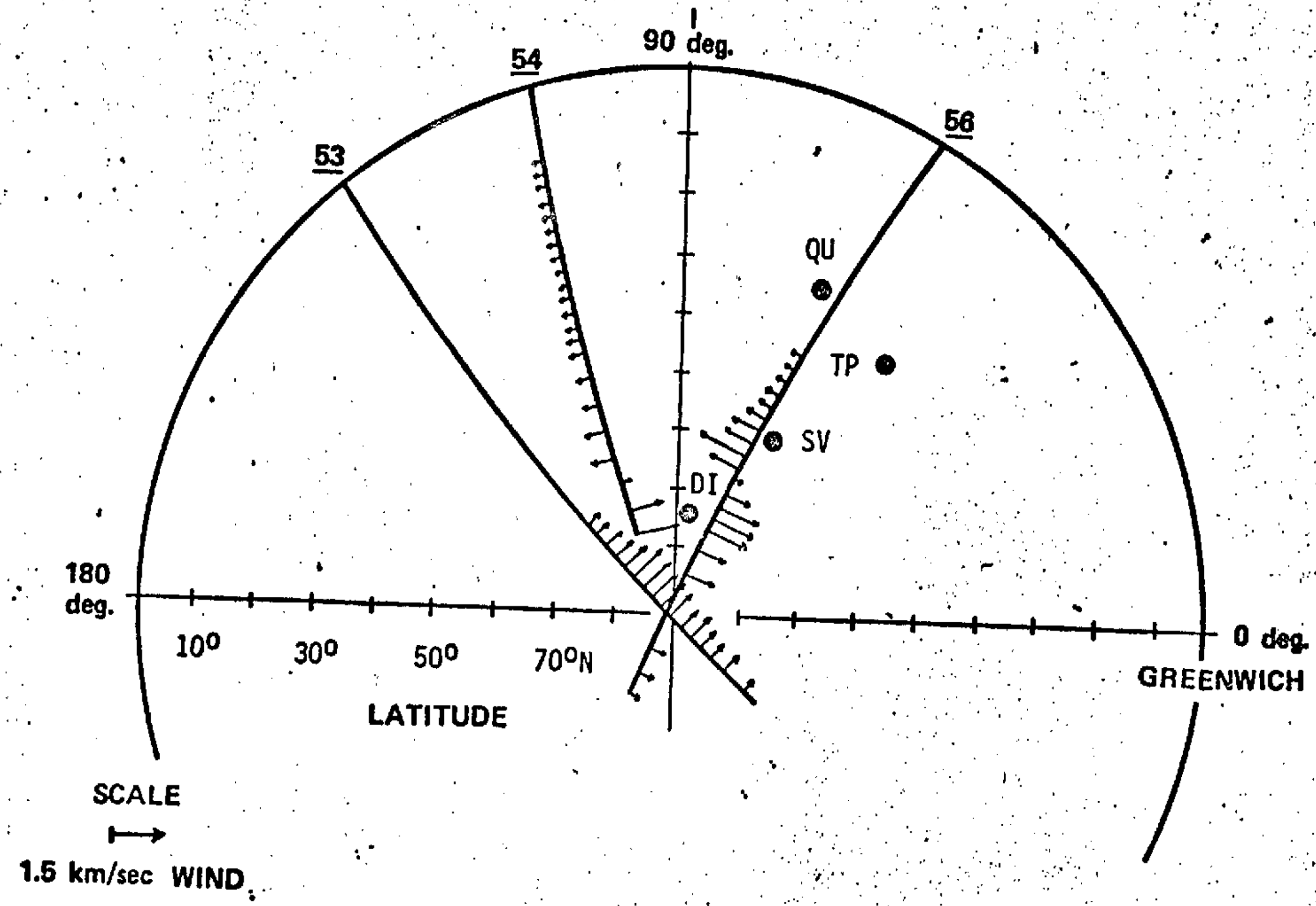

90 deg.
54
53
56
QU
TP
SV
DI
180
deg.
0 deg.
GREENWICH
10°
30°
50°
70°N
LATITUDE
SCALE
1.5 km/sec WIND

Fig. 1

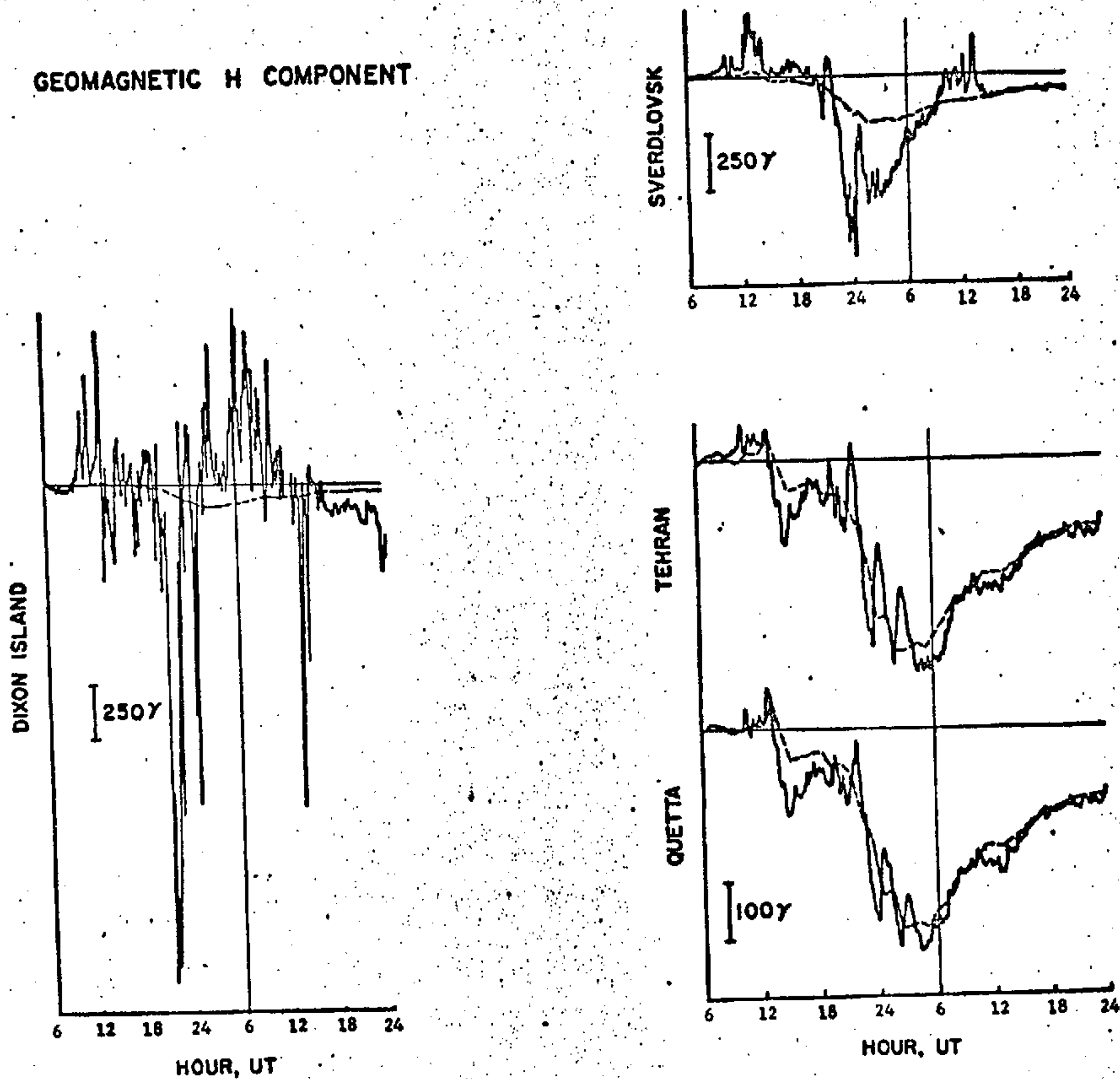
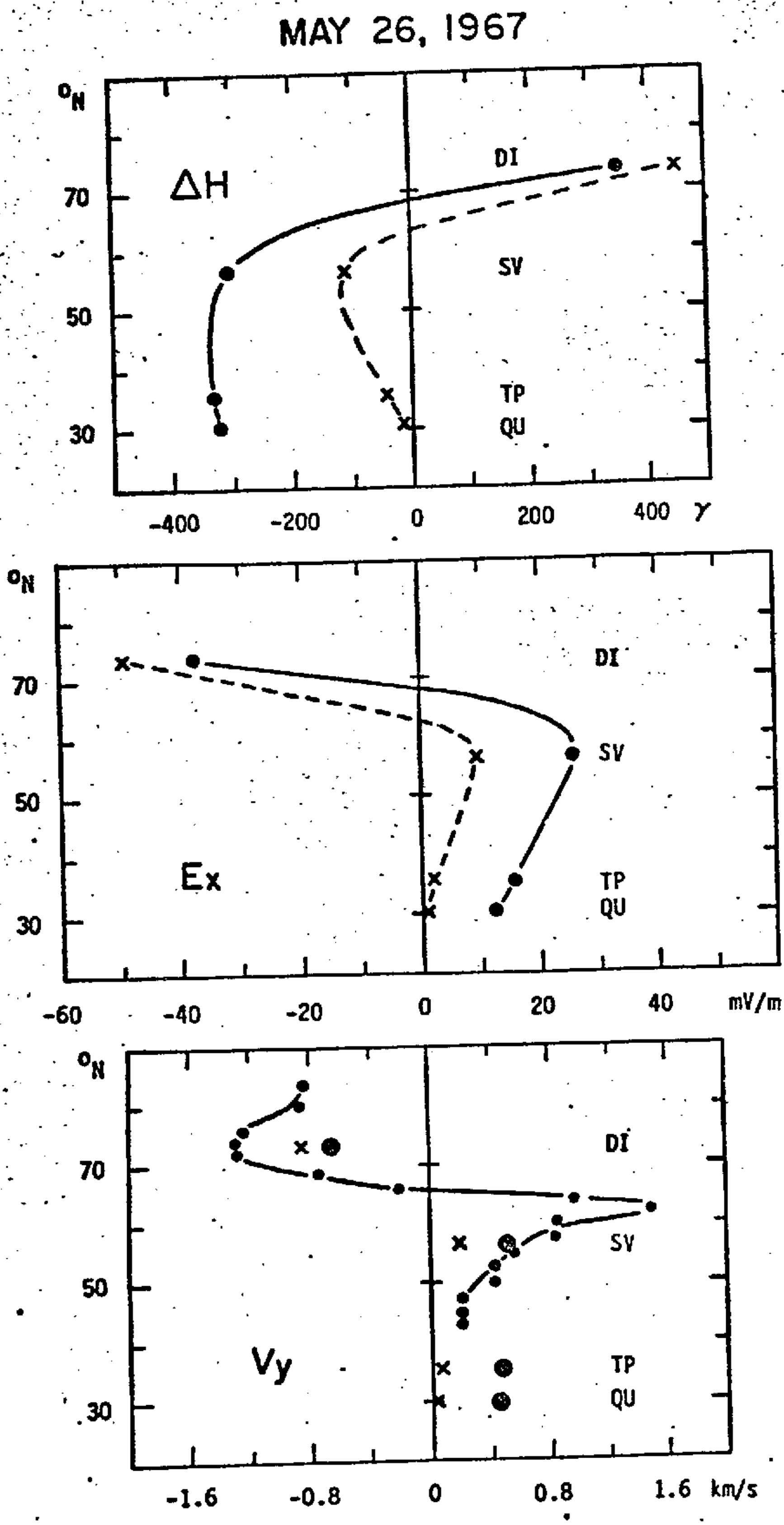

GEOMAGNETIC H COMPONENT
SVERDLOVSK
250γ
DIXON ISLAND
250γ
TEHRAN
QUETTA
100γ
6 12 18 24 6 12 18 24
HOUR, UT
6 12 18 24 6 12 18 24
HOUR, UT

Fig. 2



MAY 26, 1967
°N
ΔH
DI
SV
TP
QU
70
50
30
-400
-200
0
200
400
γ
Ex
-60
-40
-20
20
40
mV/m
Vy
-1.6
-0.8
0.8
1.6
km/s

Fig. 3