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STUDIES OF DYNAMO FIELD STRUCTURE AND RELATED EFFECTS
DE SATELLITE PROJECT GUEST INVESTIGATOR PROGRAM

Principal Investigator
W. R. Coley

DE GI FINAL REPORT

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Coley & McClure

This study has been directed toward the establishment of the latitudinal and longitudinal structure of the low latitude dynamo electric field using primarily data from the Unified Abstract (UA) files of the Atmosphere Explorer E satellite. Our results are described in detail in the atached paper which has been submitted for publication to the Journal of Geophysical Research. The results are briefly summarized below in this section.

Figure 1a shows a "mass plot" of vertical drift data from AE-E obtained from the 15 second average values of the UA files. All vertical drift values in the file for DLAT < 20° and in the August-September 1978 time period are plotted versus Solar Local Time (SLT). During this period the satellite was in a circular orbit of 360-390 km altitude. Figure 1b shows the same data set averaged into 30 minute bins. The dotted line represents the 24-hr average vertical drift. For comparison, Figure 1b also shows incoherent scatter radar results from Jicamarca for two different levels of solar activity (Fejer et al., 1979) as well as the low latitude model generated by Richmond, 1980. In all cases we see the same general features: downward flow at night reversing at 0600 SLT, a daytime peak followed by a decline to a prereversal enhancement between 19 and 20 SLT, and a reversal to downward flow at night.

AE-E was active and in circular orbit from the end of 1976 through mid 1981. We have at UT-Dallas UA data only through the end of 1979: the 1980/1981 data is in principle available via the Sigma-9 computer, but not yet via the World Data Center. We have informally requested this 1980/1981 data several times but not yet received it, presumably because other Sigma-9 projects have had a higher priority. At present we repeat our request based on the excellent quality of the AE UA data through late 1979 that we have been working with on this project and on the scientific results that we are now finding it possible to extract from this data set.

We have searched our AE data base for variations of the various components of drift velocity (e.g. vertical ion, horizontal ion, horizontal neutral,perpendicular ion, etc.)with dip latitude, longitude, season, altitude, etc.. This examination has been accomplished by "binning" the data appropiately. Over 500 different runs of our very flexible averaging algorithm have been made in the past year using "summary tapes" that hold highly condensed versions of our original UA tapes. Twelve of the original tapes exist for each year, whereas a single summary tape usually holds a year or more of data. As was discussed in the earlier report, latitudinal structure is evident in the vertical drift during solstice periods (Coley and McClure, 1984), one interpretation of this structure being that the dynamo induced ion velocities are being modified by neutral wind flow,the meridional component of which flows generally from the summer to winter hemisphere under solstice conditions.

Further latitudinal effects can be seen in Figure 2a which shows ion velocity vectors in the meridian plane versus dip latitude. The UA data is put into one degree bins of DLAT and only daytime data from 12-16 SLT is used. This 10 month average of 1979 data clearly shows the equatorial "fountain effect" which occurs during the day and which is responsible for the Appleton anamoly in the ionosphere. Similarly Figure 2b shows the downward motion of the F-region ionosphere occurring during the midnight to 0400 SLT sector.

Further evidence of interhemispheric seasonally dependent ion flow also comes out of this form of data presentation. Figures 3a and 3b show respectively the northern hemisphere summer and northern hemisphere winter ion velocity vectors for the 18-22 SLT (sunset) sector. At low values of DLAT both plots show summer to winter hemisphere flow. At higher latitudes there is seen a tendancy for upward motion in the summer hemisphere and downward motion in the winter. This is consistent with predictions of the vertical ion velocity in this time sector made by Dachev and Walker, 1982.

Resolving the measured ion and neutral (from NATE) motions into components parallel and perpendicular to the geomagnetic field allows determination of the ion diffusion velocity along B. The upper panel of Figure 4 shows a typical example of the correspondence between the parallel ion and neutral velocities for a full orbit of AE-E. The two traces are similar in both large- and medium-scale features with an average offset of approximately 80 m/s. At about 78500 seconds U.T. there is a discontinuity in both the parallel ion and neutral traces. This stepfunction is a result of the independent calculation by NASA of the spacecraft attitude parameters (α and δ, the siderial coordinates of the momentum wheel axis) for the first and last halves of this orbit and not the result of an instrumention problem or a geophysical effect. In the center panel the perpendicular ion trace reverses from upward to downward flow near 19 hrs SLT after a slight pre-reversal enhancement of the upward flow.

Investigation of longitude effects utilizing the UA data was delayed by the discovery of errors in the geographic longitude of AE-E on the UA data tapes. We traced the errors to faulty values of G.S.T. and informed the World Data Center-A of this : they have taken extensive steps to fix this problem on their master tapes. Also, through the use of Universal Time values and other orbital parameters correctly listed on the data tapes, and an approximate expression for the equation of time, we generated our own longitude values correct to within approximately ±0.2°, because we still have not received a full set of corrected tapes from Goddard Space Flight Center.

In our longitude studies we obtained the average variation of the vertical ion drift velocity component, nearly proportional to E_{ew}/B, in the region near and immediately east of Jicamarca, where the geomagnetic field strength B has an absolute minimum (Figure 5a). A similar average diurnal curve (Figure 5b) was obtained for an equatorial region centered near Malasia, where B is on the average 33% larger than in the Peru-Brazil- South Atlantic B-minimum region. The drift velocities are not signifignantly different in the two regions. Thus we conclude that the average east-west electric field is not constant with longitude as assumed in a model calculation by Dachev and Walker (1982). Instead, as one might expect based on simple dynamo theory, if the induced dynamo field is proportional to U **X** B where U is the neutral wind velocity responsible for the dynamo fields, and also is to first order independent of longitude, the field is then approximately proportional to B and the vertical drift E_{ew}/B, not the electric field E_{ew}, is then approximately independent of B.

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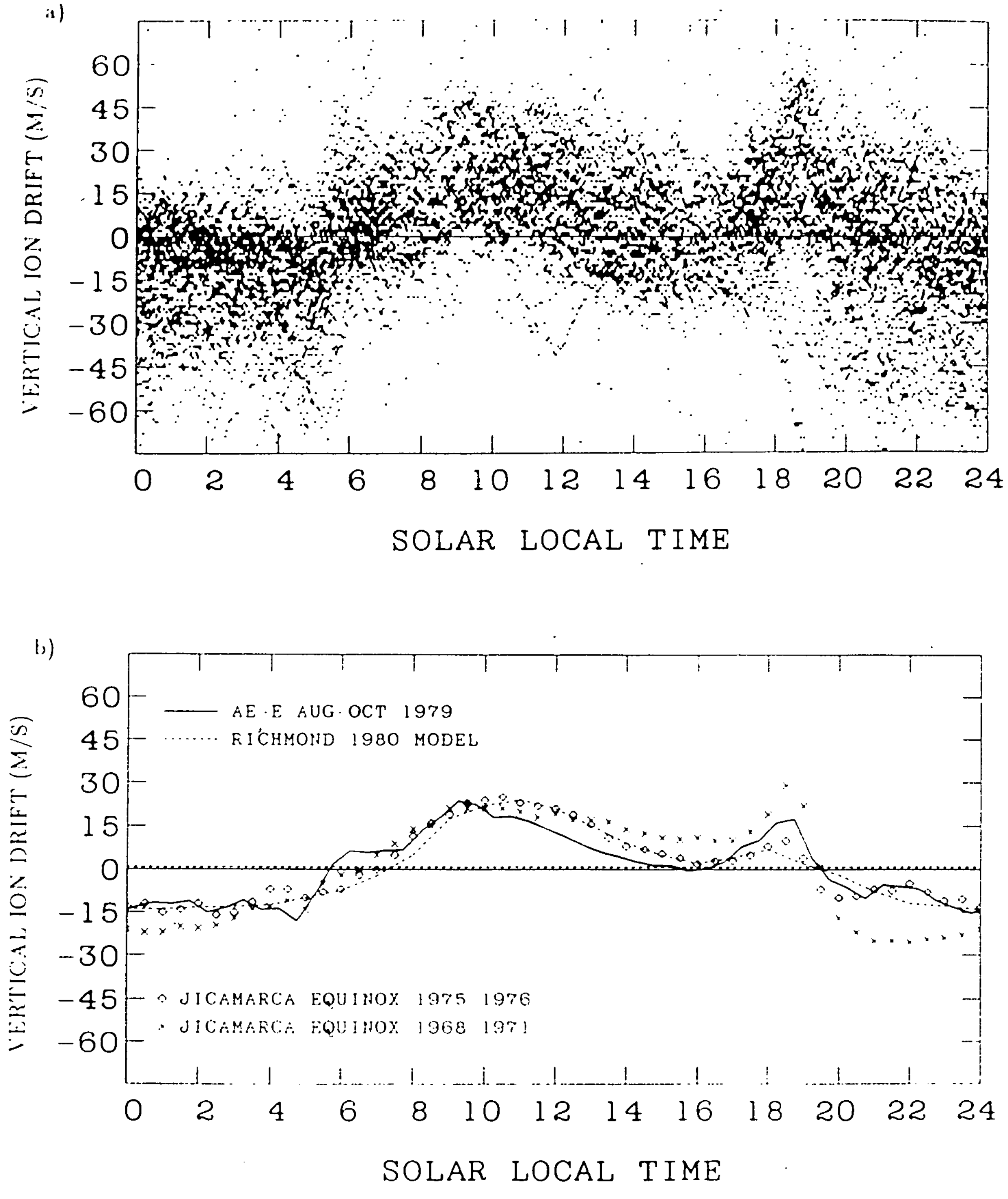
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VERTICAL ION DRIFT (M/S)
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-30
-45
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0 2 4 6 8 10 12 14 16 18 20 22 24
SOLAR LOCAL TIME
b)
VERTICAL ION DRIFT (M/S)
AE-E AUG-OCT 1979
RICHMOND 1980 MODEL
JICAMARCA EQUINOX 1975 1976
JICAMARCA EQUINOX 1968 1971
60
45
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-30
-45
-60
0 2 4 6 8 10 12 14 16 18 20 22 24
SOLAR LOCAL TIME

Figure 1

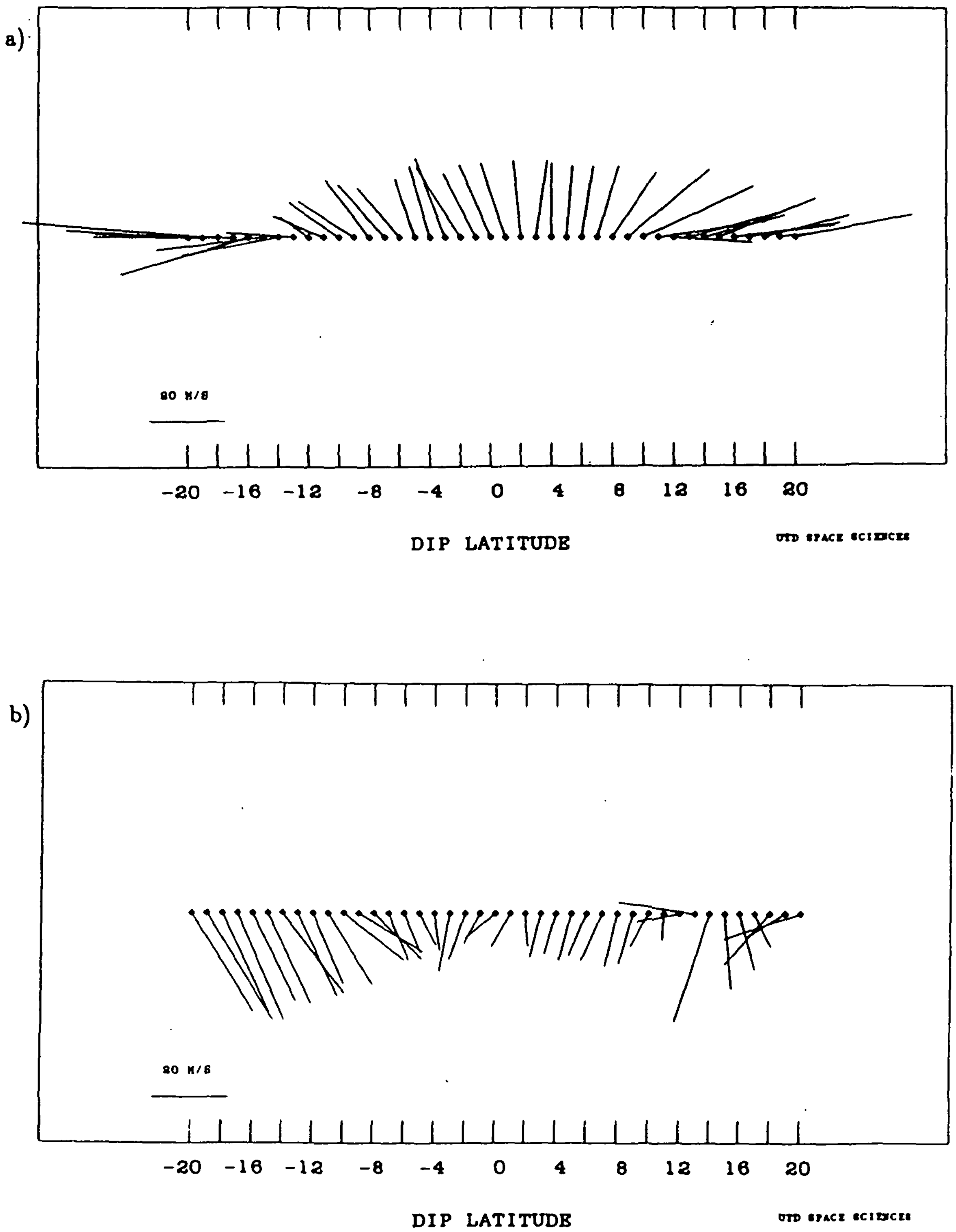
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Figure 2

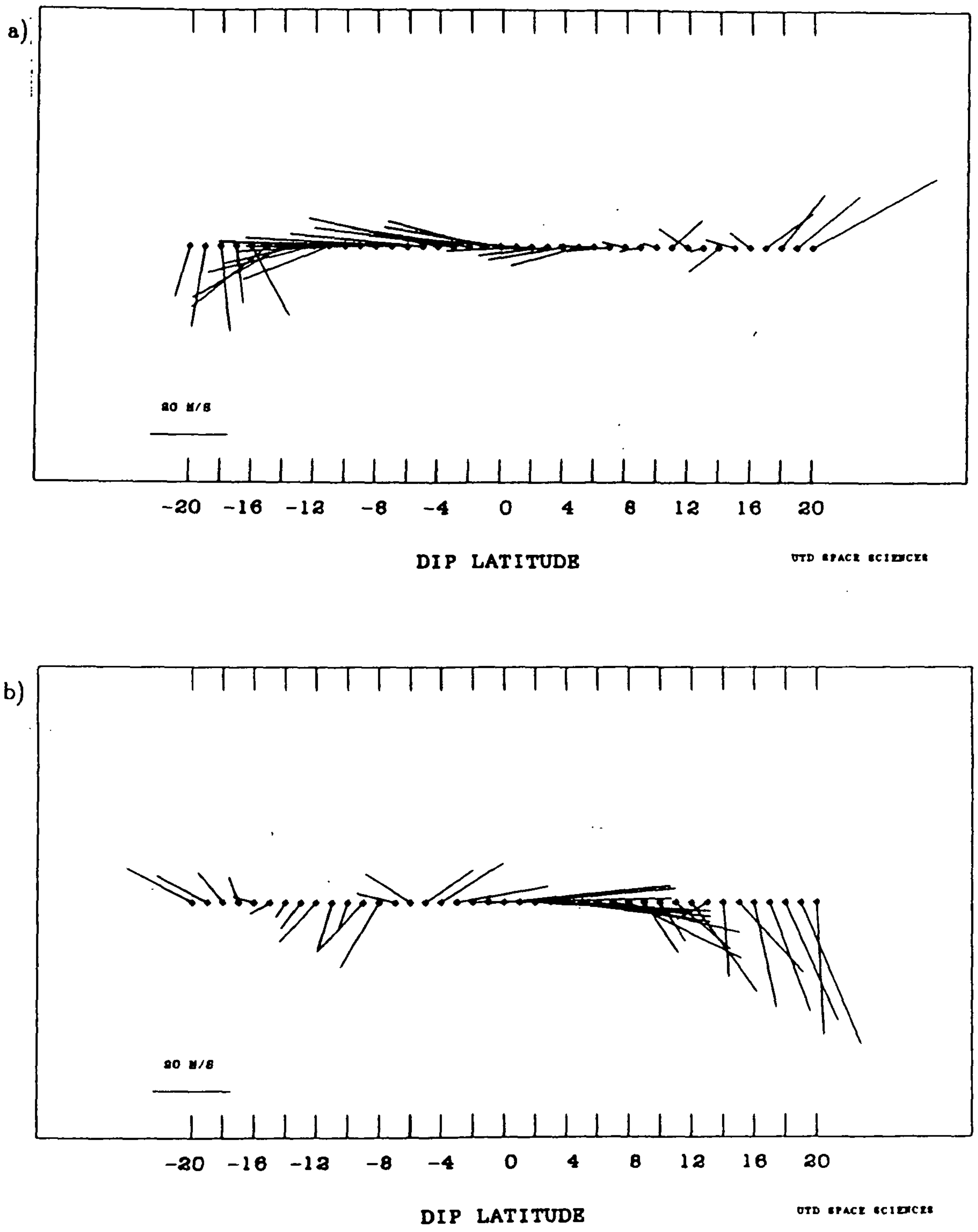
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Figure 3

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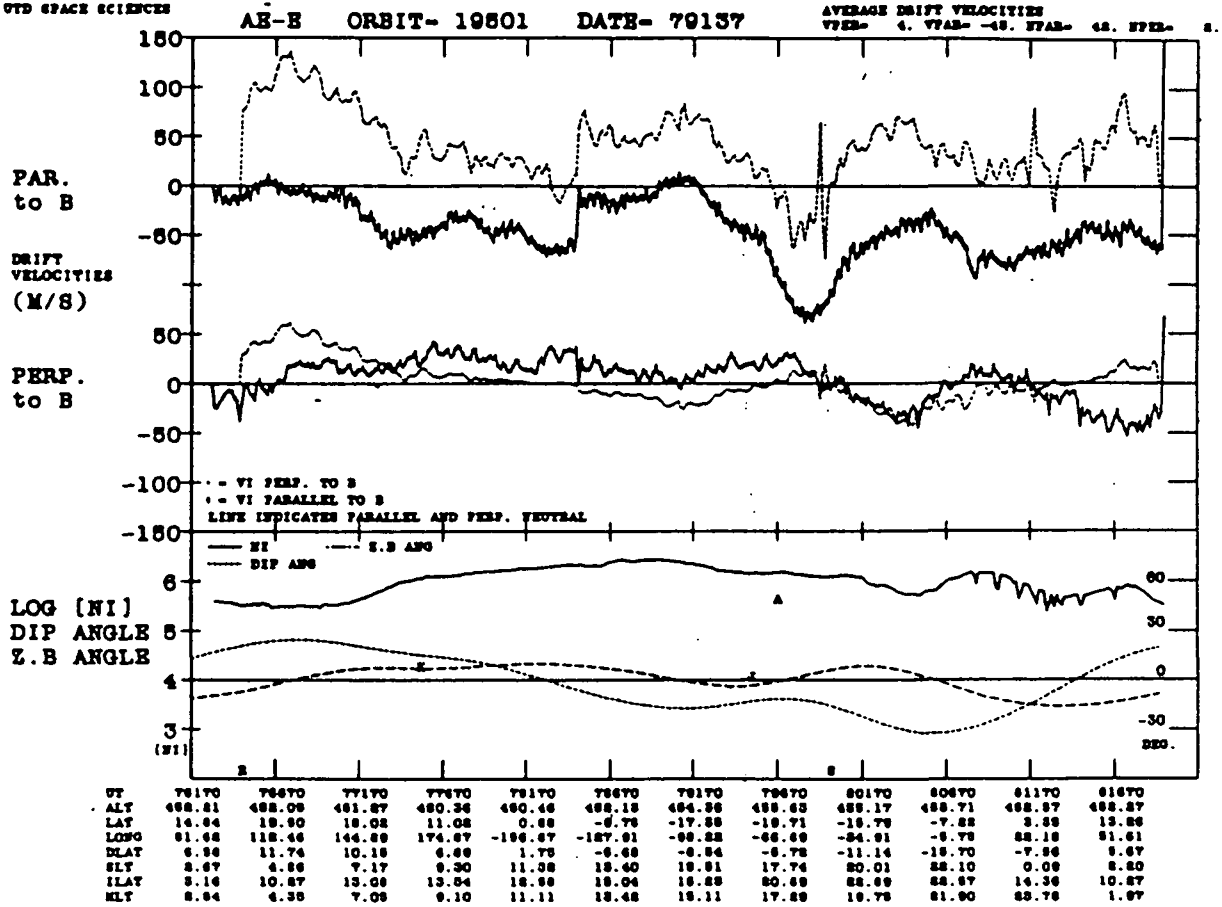
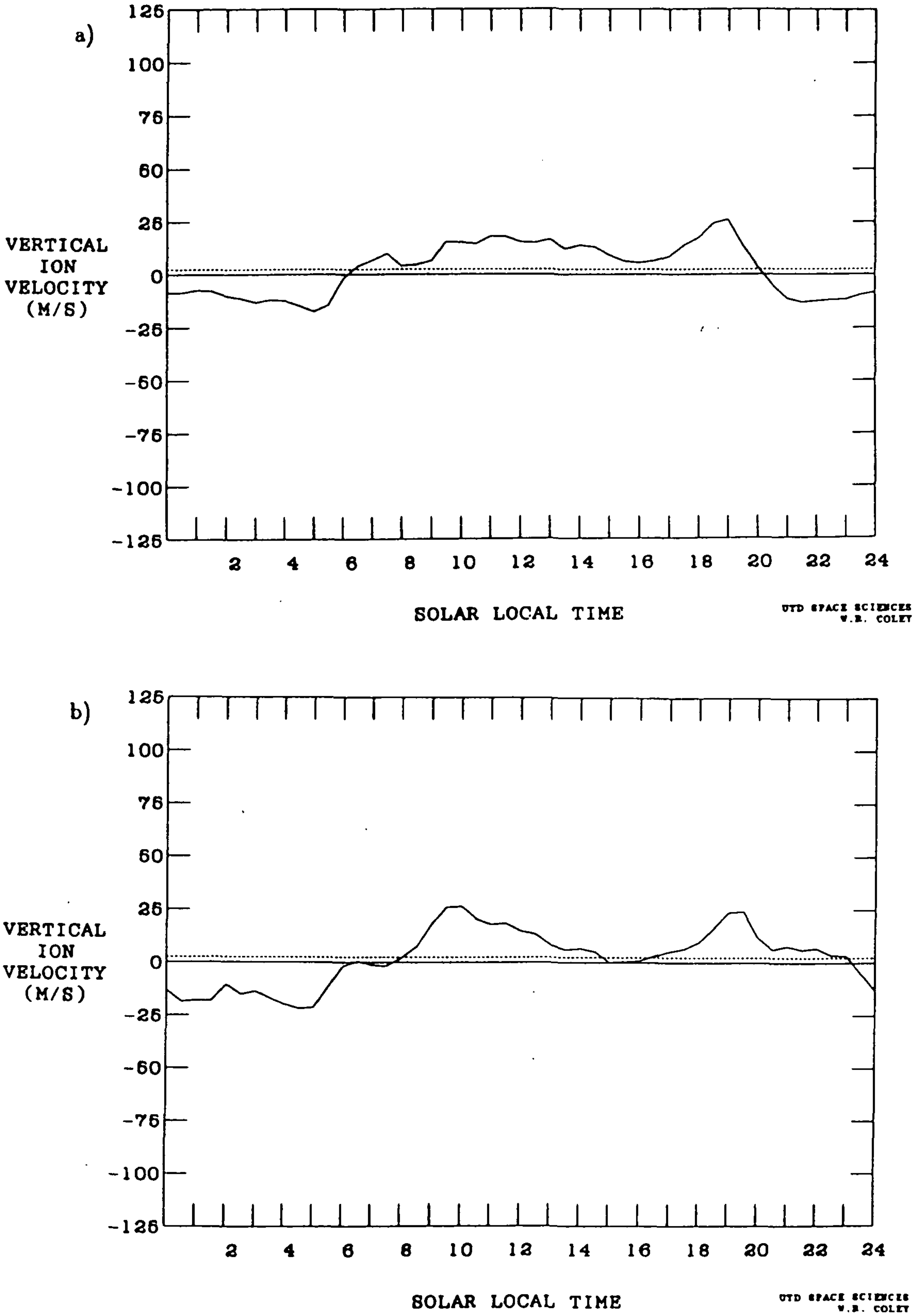


Figure 4

a)
125
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75
50
25
0
-25
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-125
VERTICAL ION VELOCITY (M/S)
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4
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8
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14
16
18
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22
24
SOLAR LOCAL TIME
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b)
125
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VERTICAL ION VELOCITY (M/S)
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SOLAR LOCAL TIME
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Figure 5

EQUATORIAL FOUNTAIN EFFECT AND DYNAMO DRIFT SIGNATURES FROM AE-E OBSERVATIONS

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Abstract

Vertical and horizontal ion drift velocities for 1977–1979 from the Unified Abstract files of the satellite Atmosphere Explorer E were used in preliminary studies of the behavior of the low latitude (-20° to 20° dip latitude) F region. Sample diurnal variations obtained near the September 1979 equinox are very similar to those measured by the incoherent scatter radar at Jicamarca, Peru. Latitude profiles of the vector drift values clearly show the classic "fountain effect" responsible for the Appleton anomaly during the day. By breaking the data set into latitude bins systematic variations of the vertical drift with latitude become evident. Investigation of longitude effects revealed that the average vertical drift velocity V_v is independent of longitude, implying that the average east-west electric field is proportional to B.

Introduction

In this paper we discuss spacecraft observations of ionospheric plasma motions in the vertical and horizontal (approximately north-south) directions at low latitudes. Such plasma drift results from the magnetic east-west dynamo electric field E_{ew}, plasma diffusion, gravity, and the magnetic meridional neutral wind, which act together to produce flow patterns commonly refered to as the "fountain effect" [*Martyn*, 1955; *Hanson and Moffett*, 1966]. We present average diurnal variations of the horizontal and/or vertical drift in various latitude and/or longitude sectors. In addition to confirming that the fountain effect actually exists in forms quite similar to those theoretically predicted decades ago, we also present the first experimental verification of the approximate constancy with longitude of the average vertical drift $V_v = E_{ew}/B$ at the dip equator. The geomagnetic field magnitude B varies more than 60% with longitude, but elementary dynamo theory predicts that $E_{ew} = \vec{U} \times \vec{B}$, where $\vec{U}$ is the average wind field component responsible for E_{ew}. Thus, on the average, we find as expected that E_{ew} is proportional to B and V_v is independent of B (or longitude).

The ion drift meter (IDM) on the Atmosphere Explorer satellite AE-E was the source of our data [*Hanson et al.*,1973]. Similar data were (and are still being) used to study magnetospheric convection at high latitudes [e.g. *Heelis et al.*, 1981; *Heelis*, 1982; *Rich et al.*, 1984] and to study the much weaker drift irregularities, sometimes as small as a few m s^{-1} peak-to-peak, associated with equatorial "bottomside sinusoidal irregularities" (BSS) [*Valladares et al.*, 1983; *Cragin et al.*, 1985]. In contrast with these applications, our use of data from the IDM presents a special problem. The absolute calibration of the drift velocity data must be quite accurate if useful studies of dynamo electric fields are to be made, whereas only relative drift values were required for the above studies of BSS irregularities, and for high latitude convection studies absolute calibrations need be accurate only to about 100 m s^{-1} because convection drifts are much larger than dynamo drifts. One of our important conclusions is that by simple averaging of the IDM data processed routinely many years ago we now obtain reasonable vertical plasma drift values near the equator.

Most information on the vertical dynamo drift at the dip equator has been obtained at the Jicamarca Radar Observatory in a series of measurements that began in 1968 [*Woodman*,1970; *McClure and Peterson*, 1972; *Fejer et al.*, 1979; *Fejer et al.*, 1981]. Our average diurnal drift variation results agree well with the Jicamarca curves. *Richmond et al.* [1980] generated an empirical model of low-solar activity ionospheric electric fields from four major incoherent scatter radars at middle and low latitudes. The model covers the latitude range of the AE-E satellite, which had an orbital inclination of 19.76°, allowing comparison with AE-E data obtained in different latitude and longitude regions. The purpose of this paper is to introduce a data set that will compliment and extend the current ground based data, allowing the incorporation of more accurate latitudinal, longitudinal, and solar cycle variations into future models of low latitude dynamo fields.

Instrumentation

The IDM data presented here were obtained from the Unified Abstract (UA) files of the satellite Atmosphere Explorer-E, which contains 15-second averages of the original IDM measurements. The AE-E IDM measured the horizontal and vertical components of ion drift perpendicular to the spacecraft velocity vector with a sensitivity of 0.016° per bit, corresponding to a transverse velocity near 2.2 m s^{-1}; higher resolution drift values, not used here, have a bit size near 1.1 m s^{-1}. The satellite was in orbit from the end of 1975 through June 1981, first in an elliptical and later, after November 1976, in nearly circular orbits at altitudes between 230 and 480 km. The circular orbits were well suited for the observation of low-latitude ion drifts caused by dynamo electric fields. We used data between January 1977 and December 1979. This large data base can be examined for variations of the ion drift with latitude, longitude, season, solar cycle, altitude, and magnetic activity. This paper will deal primarily with latitudinal and longitudinal variations of the drift features.

Figure 1 details UA AE-E data from a single orbit, 13406, a circular pass at $\approx$ 315 km altitude. The lower panel presents the dip angle of the geomagnetic field and the log of the ion density (N_i) versus UT and various other parameters. One of our primary parameters for plotting and averaging the data is solar local time (SLT), also abbreviated as LT. The post-sunset minima in N_i at approximately 19 and 21 hrs LT are examples of the plasma "bubbles" or depletions discussed by *McClure et al.* [1977]. The upper two panels present the components of ion velocity that are parallel to the geomagnetic field ($\vec{B}$) and perpendicular to $\vec{B}$ in the magnetic meridian plane. As the component of ion velocity in the direction of satellite motion (v_x) was not generally available, the parallel and perpendicular drifts were computed from the measured IDM values assuming that v_x was zero. For most data this is a reasonable assumption because $\hat{x} \cdot \vec{B}_{horizontal}$ is generally small. Just prior to sunset at about 18 hrs LT there exists a pre-reversal enhancement in the perpendicular drift, with a reversal to downward flow at 19 hrs LT. This is consistent with the typical evening equatorial vertical drift signature seen by the incoherent scatter radar at Jicamarca, Peru [*Woodman*, 1970; *Fejer et al.*,1979]. In examining other individual orbits we often see examples of this signature, but on many other occasions the post sunset drift enhancement is absent. In order to begin to separate out the geophysical reasons for the variations of this and other features it is necessary to deal with the data in sufficient quantity such that meaningful average values can be determined.

Observations

We have made a preliminay search the AE-E data base in the period of circular orbits between the end of 1976 through the end of 1979 for variations of the various components of ion drift velocity (e.g. vertical, horizontal, perpendicular, etc.) with dip latitude, longitude, season, etc. A flexible data averaging algorithm was used to generate the samples shown in Figures 2a and 2b. Figure 2a is a "mass plot" of vertical ion drift data. Almost all vertical drifts in the UA file between $-20°$ and $20°$ dip latitude (DLAT) for the August to October 1979 time period are plotted versus LT. A few points were arbitrarily excluded from the average, including those having $N_i < 10^4$ cm^{-3} (even though the drift measurements are usually valid down to $N_i = 3 \times 10^3$ cm^{-3} or lower) and points having a magnitude greater than 125 m s^{-1}. Data were used from times when the spacecraft was spinning (about 4 rpm) and when it was despun. In all there are some 11200 data points included. The number of data points included in each plot of this type is often a strong function of local time, depending on the spacecraft duty cycle. During this period the satellite was in a circular orbit of 360 to 390 km altitude. From examination of individual orbits it can be seen that the day to day variability of the data is as great or greater than the magnitude of the average velocity. Figure 2b shows the same data averaged into 30-minute bins. The horizontal dotted line represents the 24 hour average vertical drift. For comparison Figure 2b also shows some incoherent scatter radar results from Jicamarca for the equinox months in 1968–1971 (sunspot maximum) and in 1975–1976 (sunspot minimum) [*Fejer et al.*,1979]. In both the UA and Jicamarca data we see the same general features: downward flow at night reversing to upwards near 06 hrs LT, a daytime peak followed by a decline to a pre-reversal enhancement (PRE) around 19 hrs LT and a reversal to downward flow at night. *Richmond* [1980], in modeling low latitude electric fields, used only data from magnetically quiet solstice and equinox periods. The resulting model for the Jicamarca region at equinox, also shown on Figure 2b, is more sinusoidal in appearance than curves produced from UA data and lack the prominent PRE that is usually apparent in averages drawn from both magnetically quiet and active periods.

Latitudinal effects in the data base can be seen in Figure 3a, which shows ion velocity vectors perpendicular to the satellite velocity vector versus dip latitude. The UA data has been put into 1° bins of dip latitude and only daytime data from 12 to 16 hrs LT was used. This 10 month average of 1979 data clearly shows the equatorial fountain effect which occurs during the day and which is responsible for the Appleton anomaly in the F-region [*Martyn*, *1955*; *Hanson and Moffett*, 1966]. Similarly, Figure 3b shows the downward motion of the F-region occurring during the midnight to 04 hrs LT time period.

Evidence of seasonally dependent interhemispheric ion flow also comes out of this data presentation format. Figures 4a and 4b show respectively the northern hemisphere summer and northern hemisphere winter ion velocity vectors for the 18 to 22 hrs LT (sunset) sector. At low values of DLAT both plots show summer to winter hemisphere flow. At higher latitudes there is a tendency for upward motion in the summer hemisphere and downward motion in the winter. This is consistent with similar previous results of *Wharton et al.* [1980] and *Dachev and Walker* [1982].

Figures 5a and 5b show vertical ion drift data covering May to July 1979 from $-20°$ to $20°$ DLAT. The spacecraft was in a circular orbit during this period at an altitude range of 450 to 475 km. There are some 17,000 points plotted on Figure 5a, most falling in a band some 75 m s^{-1} wide. The exception is the large spread in velocity in the post-sunset time period. The averaged data shows a more or less classical Jicamarca drift pattern, with an evening reversal at 20 hrs LT preceeded by a PRE. Morning reversal is at 06 hrs LT. This compares with median values of 19 hrs LT and 06 hrs LT respectively found by *Woodman et al.* [1977] from Jicamarca data. As expected, the average value for the drift velocity falls very near 0.

The same data set was then broken up up into four 10° wide bins of dip latitude : 10° to 20°, 0° to 10°, $-10°$ to 0°, and $-20°$ to $-10°$. The mass plots from the northernmost and southernmost bins are shown in Figure 6. They indicate a generally much smaller spread of from 30 to 50 m s^{-1} in the vertical ion velocity at any given local time, except immediately after sunset. The averaged plots for the four bins (Figure 7) indicate a systematic variation of the velocity with latitude. The largest average upward velocity is found in the most northerly latitude bin (summer hemisphere). The most southerly bin (winter hemisphere) has a net downward drift. Other features also show latitude dependence; the evening pre-reversal enhancement is strong in the summer hemisphere and weak or nonexistent in the winter hemisphere. Other data covering the November 1977-January 1978 interval show a similar pattern, with an upward bias of the drift during the summer and a downward bias in the winter. Our interpretation of this pattern is that, as in the "fountain effect" figures above (Figures 3 and 4), the dynamo-induced ion velocities are being modified by neutral wind flow, the meridional component of which flows generally from the summer to winter hemisphere under solstice conditions. Due to the inclination of the geomagnetic field lines such a wind would cause an upward drift component in summer and a downward drift in winter.

The magnitude of B varies greatly (from 25000 to nearly 41000 nT at the surface, or more than 60%) with longitude at the dip equator. We investigated possible longitude effects in the average magnitude of the vertical ion drift velocity $V_v = E_{ew}/B$. We obtained an average diurnal curve (Figure 8a) for a wide (-130° to 5°) longitude sector near and immediately east of Jicamarca, where B has an absolute minimum, and a similar curve (Figure 8b) for a zone centered near Malaysia (60° to 160° longitude). B is on the average approximately one-third larger in the later region. Other arbitrary data selection criteria were similar to those used for Figure 2: $N_i > 10^4$ cm^{-3} and DLAT from -20° to 20°. Data from March through December 1979 were used, which yielded nearly 20000 points for Figure 8a and nearly 10000 points for Figure 8b.

If we compare the average magnitude of the vertical drift over 24 hours of local time for the two regions, it is found that the values are close: 11.0 m s^{-1} for the low B region and 10.7 m s^{-1} for the high B region. The algebraic drift averages were 2.6 and 2.5 m s^{-1}, respectively. From these similarities in the diurnal curves we conclude that the average value of V_v is not proportional to B. Instead, as one might expect based on simple dynamo theory, if the induced dynamo field is proportional to $\vec{U} \times \vec{B}$ where $\vec{U}$ is the neutral wind velocity responsible for the dynamo fields and also $\vec{U}$ is to first order independent of longitude, the electric field E_{ew} is then approximately proportional to B and the vertical drift $V_v = E_{ew}/B$ is then approximately independent of B [*Richmond*, 1980]. In a model calculation by *Dachev and Walker* [1982] the assumption was made that E_{ew} was constant.

Based on the above, a better assumption would be that E_{ew}/B is constant.

Summary

We made mass plots of the vertical ion drift values from the UA files of satellite AE-E for the years 1977, 1978, and 1979. The average diurnal variation of V_v within 20° of the dip equator is remarkably similar to that obtained at Jicamarca in the same years by *Fejer et al.* [1981]. The average meridional ion drift velocity vectors, obtained as a function of latitude by combining the average vertical and horizontal (nearly north-south) ion drift values from AE-E, showed the expected variations with local time and season based on the well known equatorial fountain effect theory [*Martyn*, 1955; *Hanson and Moffett*, 1966].

The average diurnal variation of the vertical drift was found for four different ranges of dip latitude for a northern solstice season. The effect of transequatorial neutral winds was as evident in this plotting format as in the meridional vector or "fountain effect" format just mentioned, consistent with the results of previous studies using data from AE-E [*Wharton et al.*, 1980; *Dachev and Walker*, 1982. Finally, the average vertical drift velocity V_v, not the east-west electric field E_{ew}, was found to be approximately independent of longitude, as expected from dynamo theory [*Richmond et al.*, 1980].

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Figures

Figure 1. Ion drift velocities parallel and perpendicular to the geomagnetic field for AE-E orbit 13406 using data taken from the Unified Abstract (UA) files. The lower panel shows the ion density N_i and the dip angle of the geomagnetic field.

Figure 2. a) Mass plot of vertical ion drift data taken between -20° and 20° dip latitude during the August to September 1979 time period. b) The same data averaged into 30 minute time bins (solid line). The symbols indicate Jicamarca incoherent scatter radar vertical drifts taken during equinox months for the 1968–1971 and the 1975–1976 time periods [*Fejer et al.*, 1979]. The dashed line is the empirical model of *Richmond* [1980] for the Jicamarca region.

Figure 3. a) AE-E ion velocity vectors versus dip latitude during the 12–16 hrs LT interval for the last 10 months of 1979. b) Same as a) for midnight to 04 hrs LT

Figure 4. a) Northern hemisphere summer ion velocity vectors for the 18–22 hrs LT sector for the years 1977 and 1978. b) Same as a) for northern hemisphere winter.

Figure 5. a) Mass plot of vertical ion drift from May to July 1979 from -20° to 20° DLAT. b) Same data averaged into 30 minute bins

Figure 6. a) Mass plot using only data from Figure 5 in the 10° to 20° DLAT range. b) Same as a) in the -20° to -10° DLAT range.

Figure 7. a)-d) Averaged drifts obtained by breaking the data set of Figure 5 into four 10° wide bins of DLAT from north to south respectively.

Figure 8. a) Average diurnal curve for low-B longitude region (-130 ° to 5° longitude). b) average diurnal curve for high-B longitude region (60° to 160° longitude).

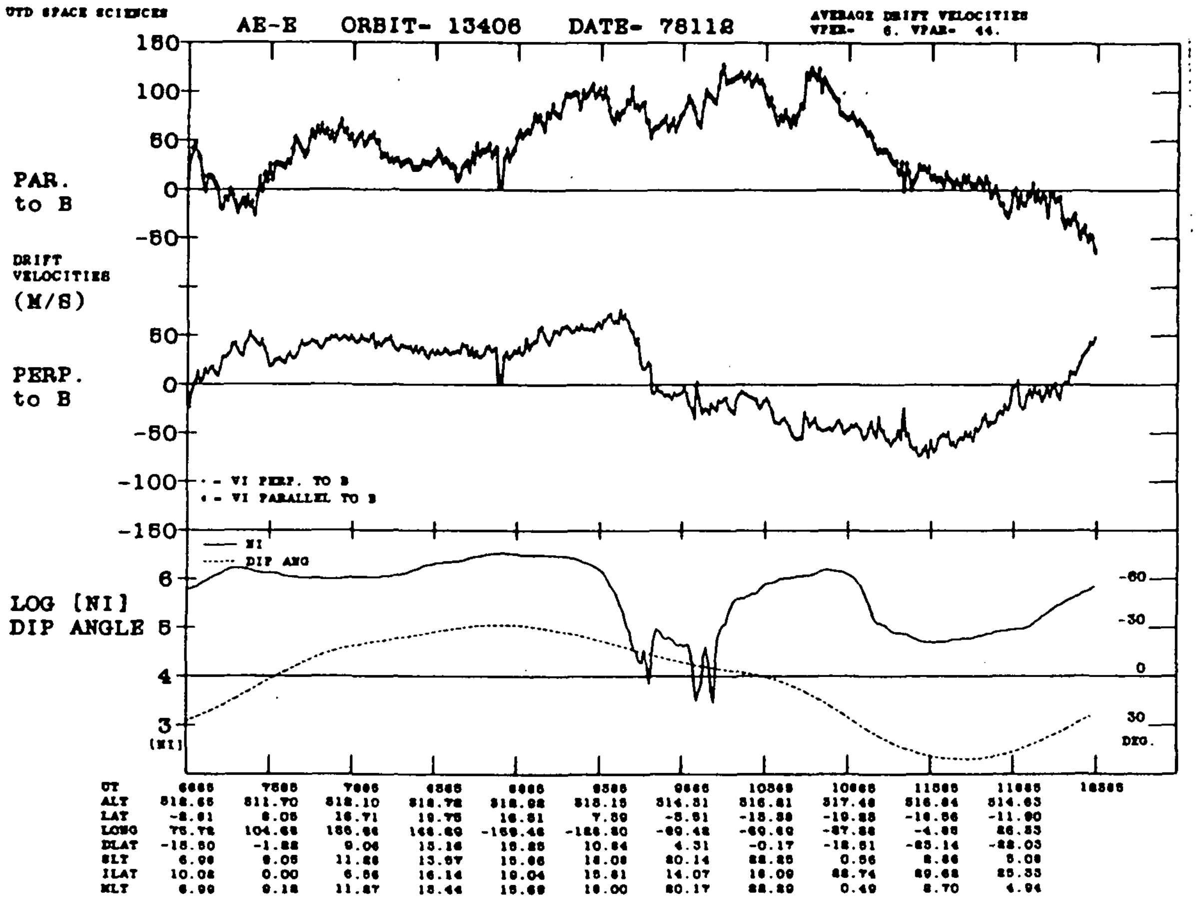
UTD SPACE SCIENCES
AE-E ORBIT- 13406 DATE- 78118
AVERAGE DRIFT VELOCITIES
VPER- 6. VPAR- 44.
150
100
50
0
-50
PAR. to B
DRIFT VELOCITIES (M/S)
50
0
-50
-100
-150
PERP. to B
- VI PERP. TO B
- VI PARALLEL TO B
— NI
······ DIP ANG
LOG [NI]
DIP ANGLE
6
5
4
3
(NI)
-60
-30
0
30
DEG.
UT 6666 7566 7666 6566 6666 9566 9666 10566 10666 11566 11666 12566
ALT 512.65 511.70 512.10 512.72 512.92 513.15 514.31 516.81 517.46 516.84 514.63
LAT -2.61 6.05 16.71 19.75 16.81 7.59 -5.51 -15.58 -19.25 -16.56 -11.90
LONG 75.72 104.68 155.96 166.69 -159.46 -126.50 -69.42 -60.60 -37.86 -4.85 26.53
DLAT -15.50 -1.82 9.06 15.16 15.25 10.64 4.31 -0.17 -12.51 -23.14 -22.03
SLT 6.99 9.05 11.26 13.67 15.66 16.06 20.14 22.25 0.56 2.86 5.06
ILAT 10.02 0.00 6.66 16.14 19.04 15.61 14.07 16.09 22.74 29.62 25.53
MLT 6.99 9.12 11.27 13.44 15.69 16.00 20.17 22.29 0.49 2.70 4.94

Figure 1

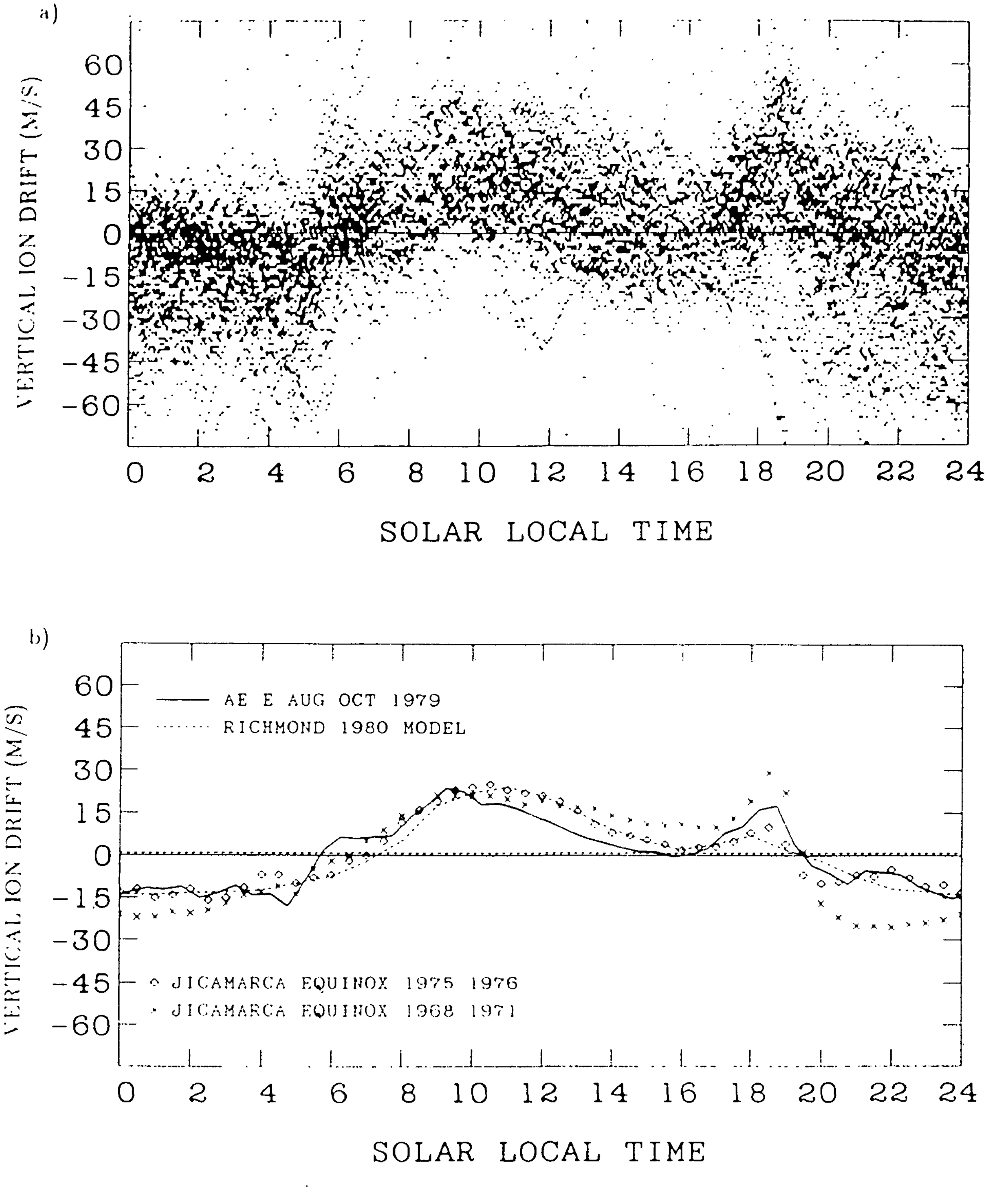
a)
VERTICAL ION DRIFT (M/S)
60
45
30
15
0
-15
-30
-45
-60
0 2 4 6 8 10 12 14 16 18 20 22 24
SOLAR LOCAL TIME
b)
AE E AUG OCT 1979
RICHMOND 1980 MODEL
JICAMARCA EQUINOX 1975 1976
JICAMARCA EQUINOX 1968 1971
VERTICAL ION DRIFT (M/S)
60
45
30
15
0
-15
-30
-45
-60
0 2 4 6 8 10 12 14 16 18 20 22 24
SOLAR LOCAL TIME

Figure 2

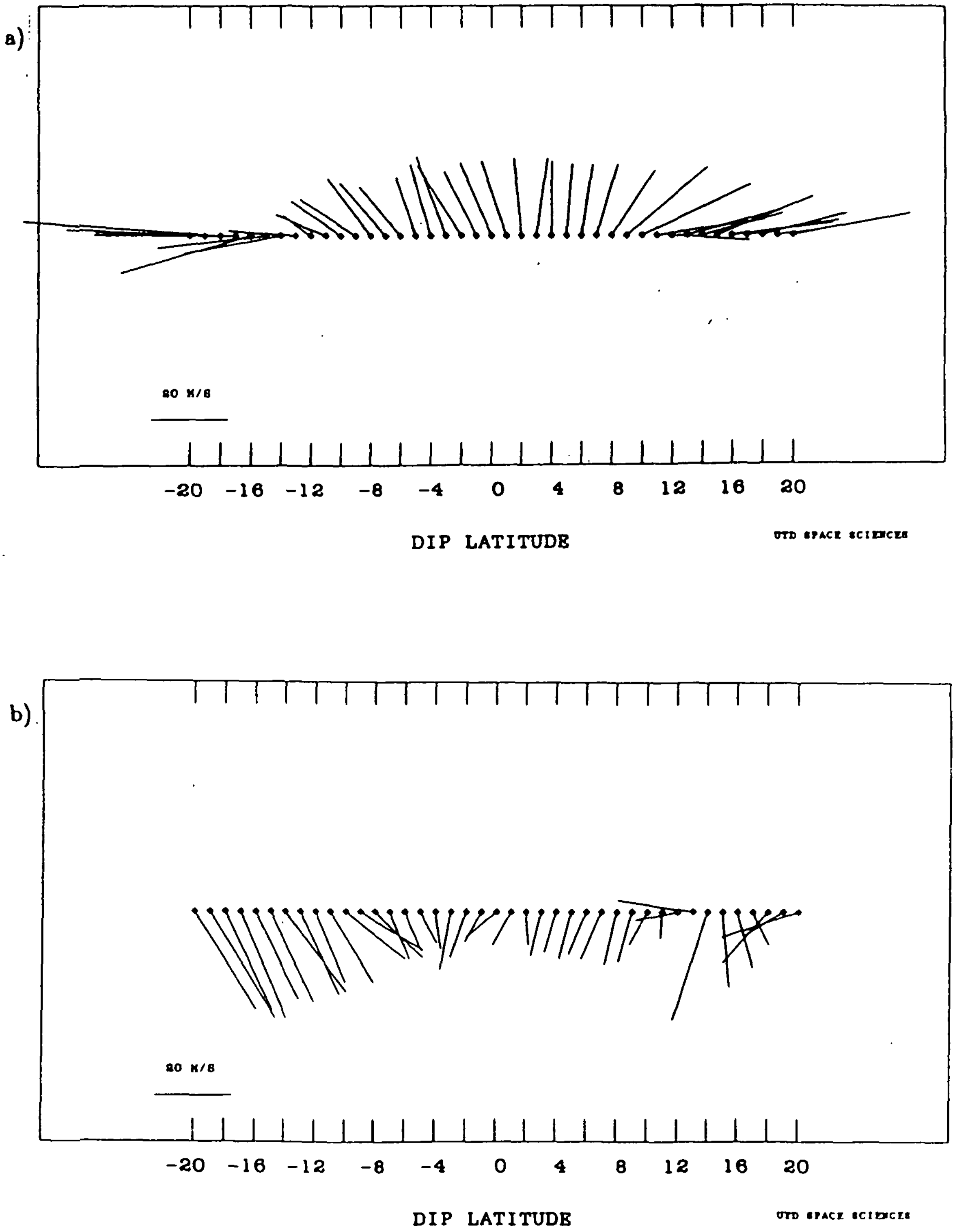
a)
20 M/S
-20 -16 -12 -8 -4 0 4 8 12 16 20
DIP LATITUDE
UTD SPACE SCIENCES
b)
20 M/S
-20 -16 -12 -8 -4 0 4 8 12 16 20
DIP LATITUDE
UTD SPACE SCIENCES

Figure 3

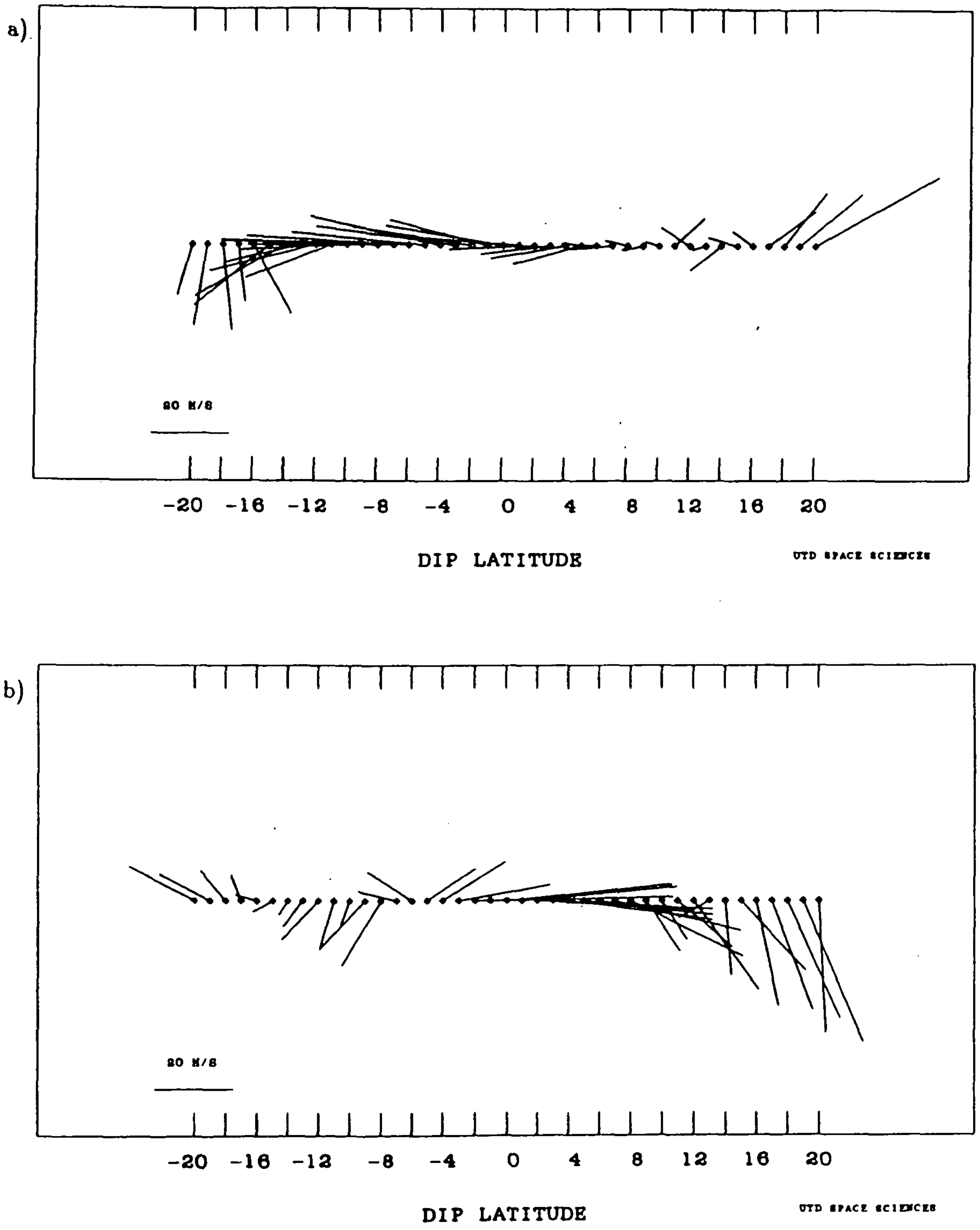
a)
20 M/S
-20 -16 -12 -8 -4 0 4 8 12 16 20
DIP LATITUDE
UTD SPACE SCIENCES
b)
20 M/S
-20 -16 -12 -8 -4 0 4 8 12 16 20
DIP LATITUDE
UTD SPACE SCIENCES

Figure 4

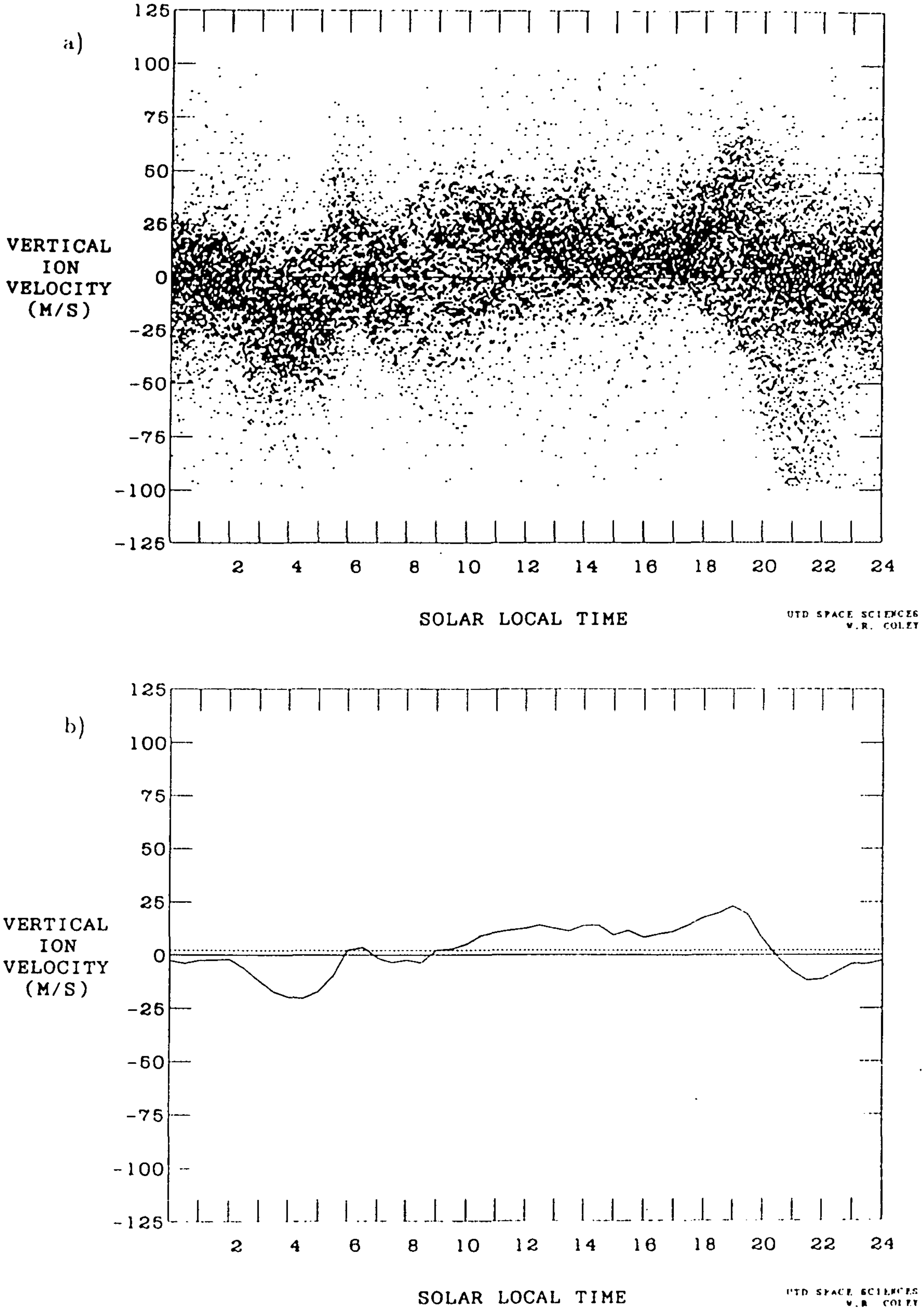
a)
b)
VERTICAL ION VELOCITY (M/S)
125
100
75
50
25
0
-25
-50
-75
-100
-125
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
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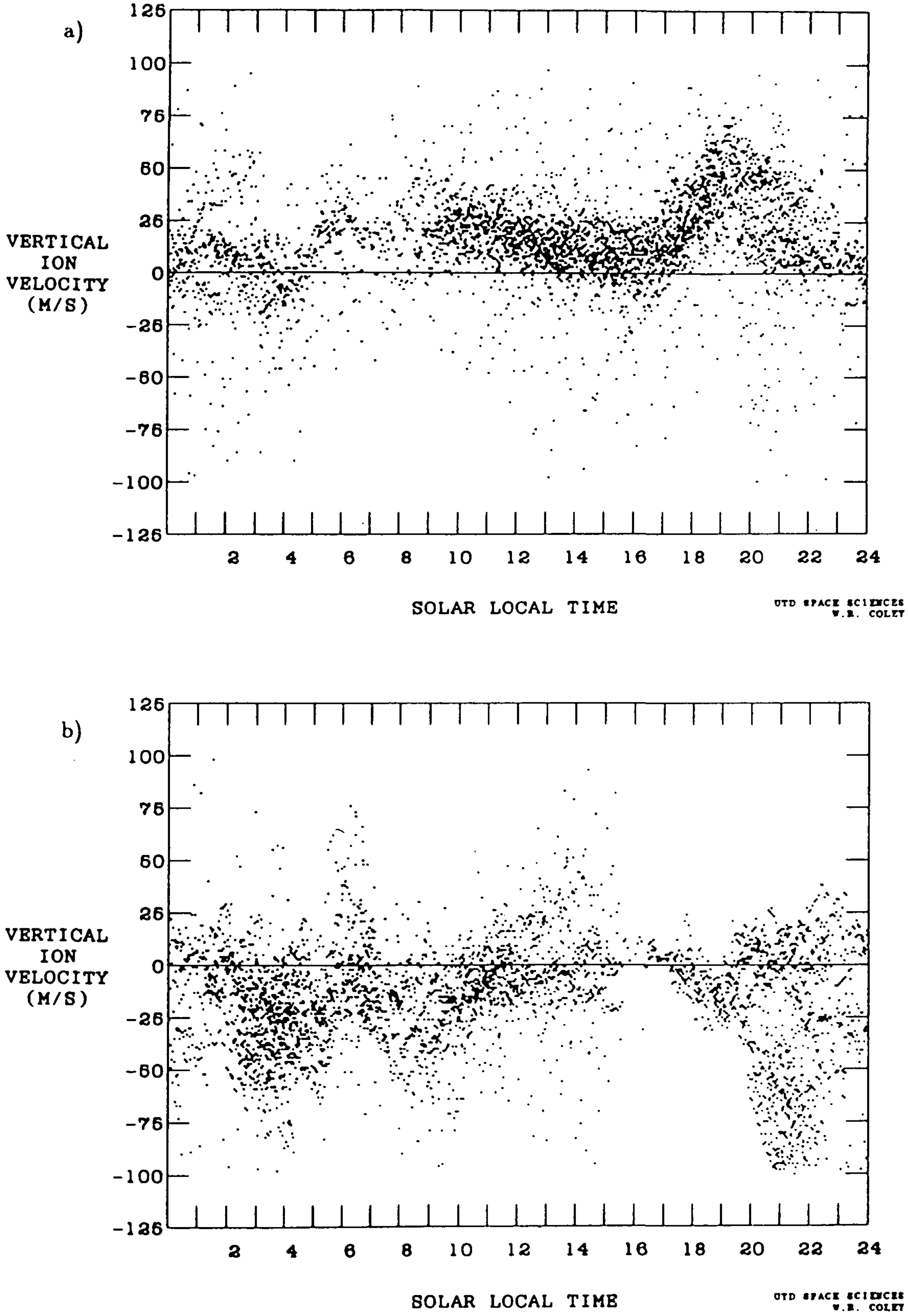
Figure 5


a)
VERTICAL ION VELOCITY (M/S)
125
100
75
50
25
0
-25
-50
-75
-100
-125
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
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b)
VERTICAL ION VELOCITY (M/S)
125
100
75
50
25
0
-25
-50
-75
-100
-125
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
UTD SPACE SCIENCES
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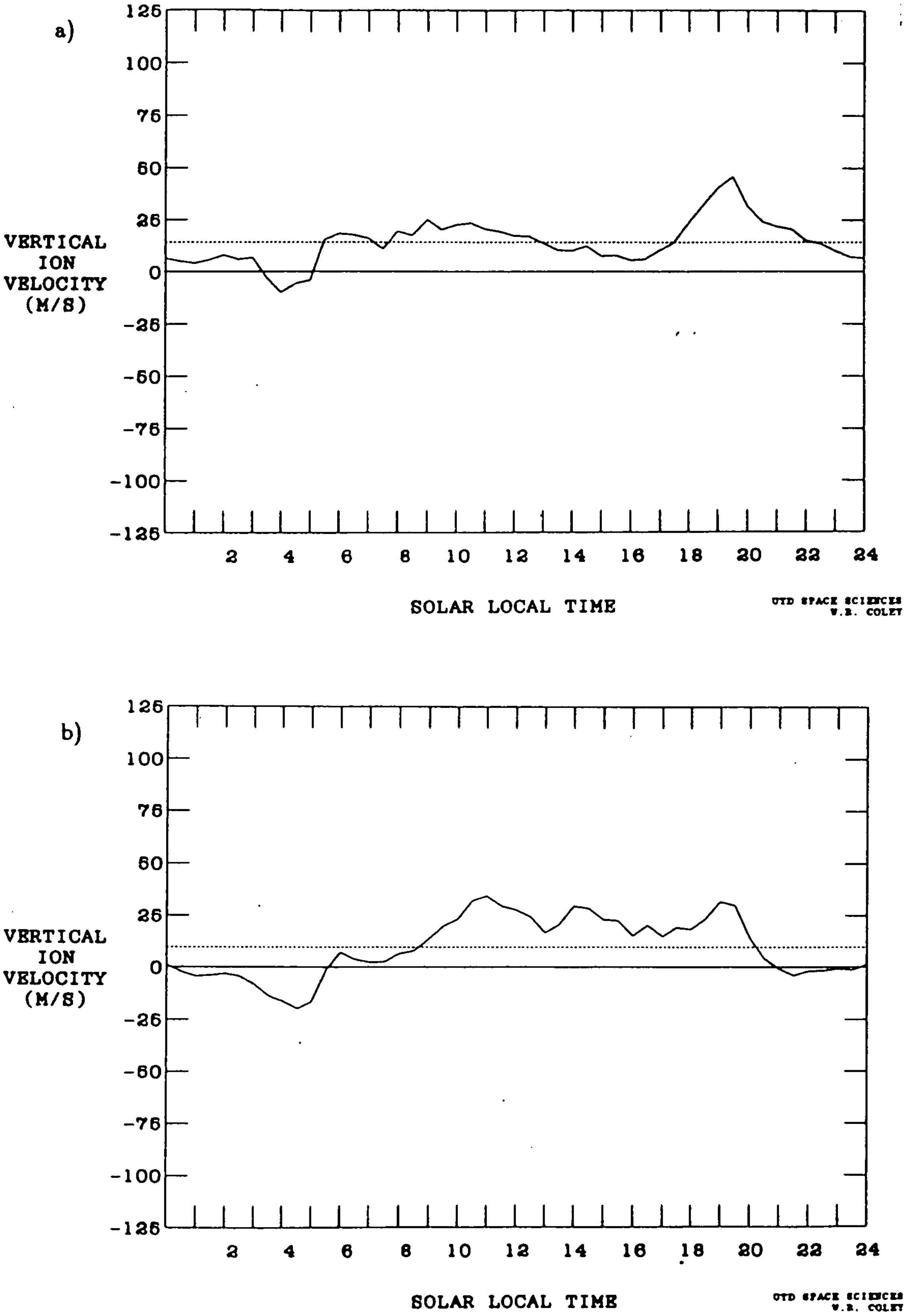
Figure 6


a)
125
100
75
50
25
0
-25
-50
-75
-100
-125
VERTICAL
ION
VELOCITY
(M/S)
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
UTD SPACE SCIENCES
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b)
125
100
75
50
25
0
-25
-50
-75
-100
-125
VERTICAL
ION
VELOCITY
(M/S)
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
UTD SPACE SCIENCES
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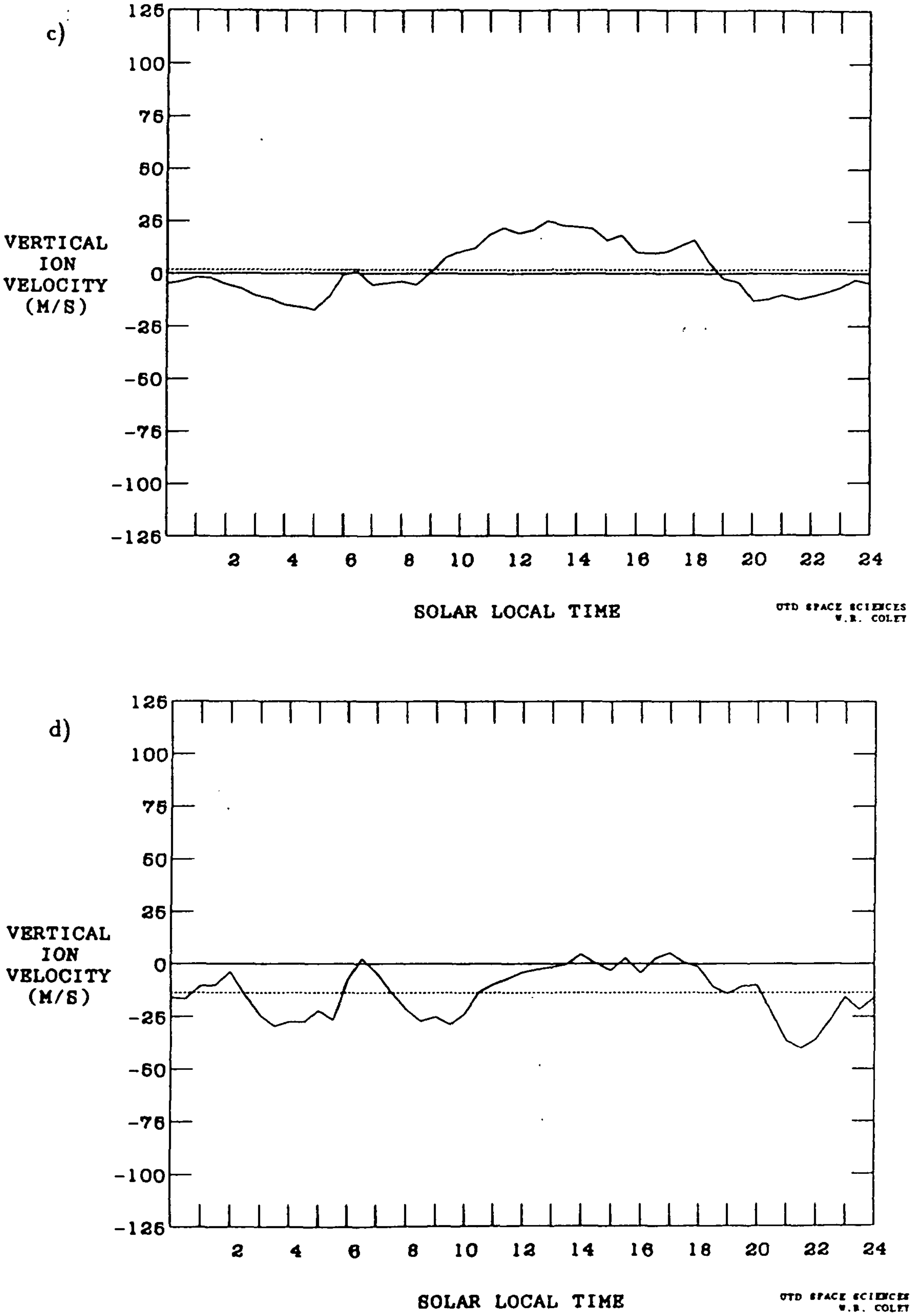
Figure 7


c)
VERTICAL ION VELOCITY (M/S)
125
100
75
50
25
0
-25
-50
-75
-100
-125
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
OTD SPACE SCIENCES
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d)
VERTICAL ION VELOCITY (M/S)
125
100
75
50
25
0
-25
-50
-75
-100
-125
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
OTD SPACE SCIENCES
W.R. COLEY

Figure 7

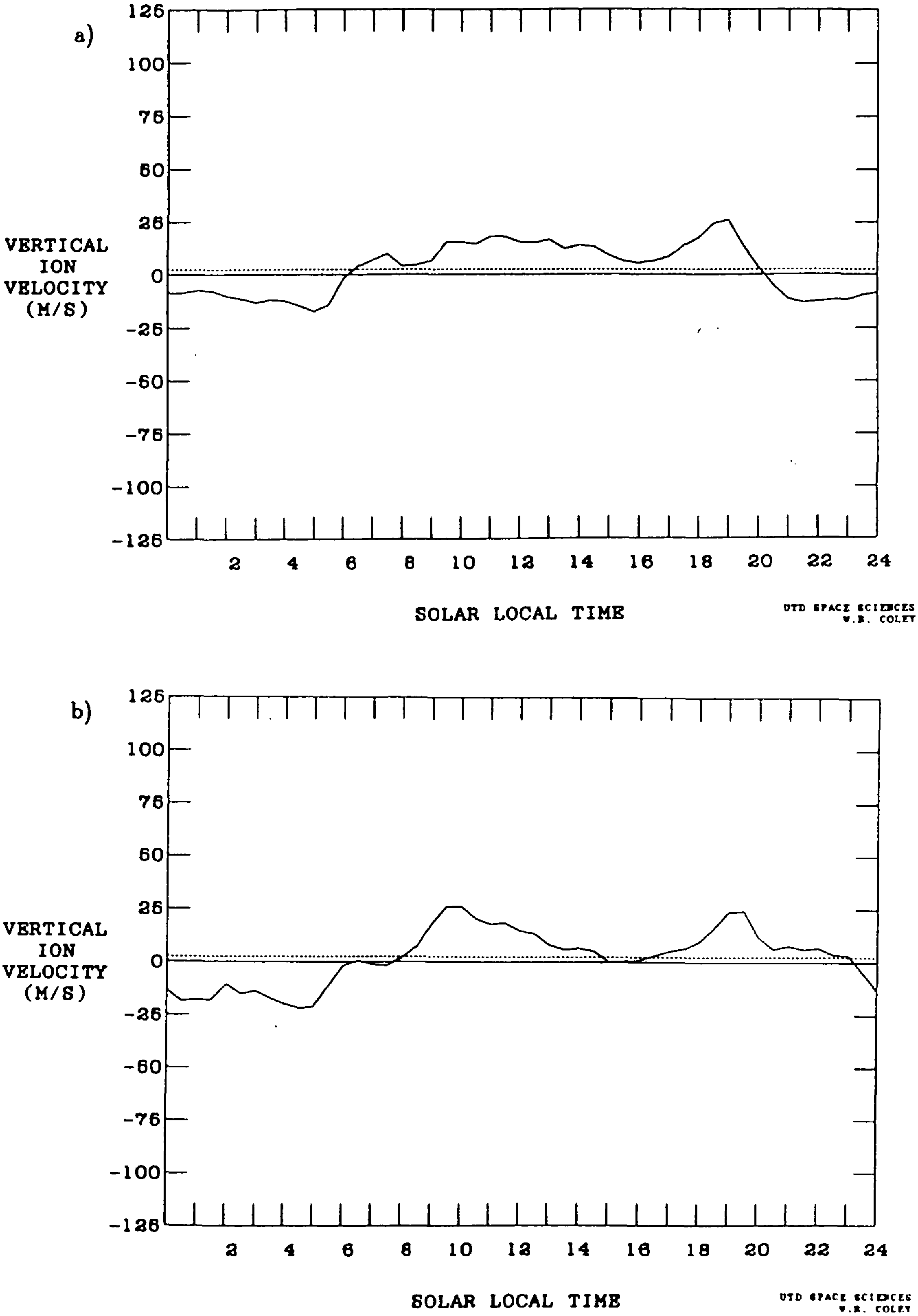
a)
b)
VERTICAL ION VELOCITY (M/S)
125
100
75
50
25
0
-25
-50
-75
-100
-125
2
4
6
8
10
12
14
16
18
20
22
24
SOLAR LOCAL TIME
UTD SPACE SCIENCES
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Figure 8