N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE

NGR 44 004-120

CUSP REGION PARTICLE PRECIPITATION AND ION CONVECTION FOR NORTHWARD INTERPLANETARY MAGNETIC FIELD

J. L. Burch

Southwest Research Institute, San Antonio, TX 78284
Also at University of Texas at San Antonio, San Antonio, TX 78285

P. H. Reiff and R. W. Spiro

Rice University, Houston, TX 77001

R. A. Heelis

University of Texas at Dallas, Richardson, TX 75080

S. A. Fields

NASA, Marshall Space Flight Center, AL 35812

(NASA-TM-80763) CUSP REGION PARTICLE PRECIPITATION AND ION CONVECTION FOR NORTHWARD INTERPLANETARY MAGNETIC FIELD (NASA) 12 p HC A02/MF A01 CSCL 03B

N81-27006

Unclas
G3/90 27504

Abstract. Data from Atmosphere Explorer D for periods of strong northward interplanetary magnetic field show the following characteristic behavior in the dayside magnetospheric cusp region: Energy-time spectrograms of suprathermal positive ion fluxes exhibit a characteristic 'V' pattern as the spacecraft moves toward higher latitudes; that is, with the peak in the energy spectrum falling in energy and then rising again. Convection velocities follow this pattern closely with strong east-west flows (with antisunward components) occurring in the equatorward half of the 'V' and significant sunward flows occurring in the poleward half of the 'V'. These patterns can be understood qualitatively in terms of a model of ionospheric electric potential produced by the known dependence of Birkeland current densities on magnetic activity.

Introduction

Early results in the study of the low-altitude magnetospheric cusp region revealed the occasional occurrence of a systematic variation of positive-ion energy spectra from harder to softer and then to harder again as the cusp was traversed in latitude. This 'V' signature was first noted by Heikkila and Winningham (1971) who referred to it as a "butterfly" pattern. The Atmosphere Explorer D (AE-D) mission has given us the opportunity to investigate this phenomenon along with associated effects observed in ionospheric convection patterns and in the interplanetary magnetic field (IMF). The statistical relationship between the occurrence of the cusp ion 'V' patterns and the IMF is reported separately by Reiff et al (1979) who established a strong correlation with northward IMF components. The study reported on in this paper investigated the ionospheric convection patterns that accompany the 'V'-shaped ion precipitation patterns.

Experimental Results

An example of the 'V' shaped signature of cusp positive-ion precipitation is provided by the data of AE-D orbit 347, which are shown in Figure 1. For this particular case the poleward segment of the 'V' is much more distinct than the equatorward segment. Also apparent in Figure 1 are narrow regions of accelerated electrons which are grouped near the poleward and equatorward boundaries of the cusp--a behavior observed in several, but not all, of the twelve 'V' signatures identified. Figure 2 contains the corresponding convection data for orbit 347. Three sets of data appear in Figure 2. The first set, shown as a histogram plot in the lower panel, indicates the median positive ion energy as a function of U.T., with invariant latitude and magnetic local time shown along the top of the figure. The median ion energy is defined here as that energy for which the integral counts at higher energies (up to LEE maximum energy of 25 keV/e) and the integral counts at lower energies (down to the LEE minimum energy of 200 eV/e) are equal.

The second set of data shown in Figure 2 contains the components of horizontal ion drift perpendicular to the orbit plane. Positive values of this drift component indicate geographically westward drift components in this case.

The third set of data in Figure 2 contains projections of the measured total vector flow velocities onto the plane containing the spacecraft velocity vector and perpendicular to the orbit plane. The flow vectors are plotted along the top of Figure 2 in the following manner: (1) The spacecraft orbital motion is represented by a straight line; (2) The location of the orbit in Λ-MLT is shown along the top axis; (3) Each flow vector is anchored at the position along the orbit line at which it was measured and is drawn using two measured velocity components (one along the spacecraft velocity vector and the other perpendicular to the orbit plane).

The data of Figure 2 display several important features of convection patterns that accompanied the cusp positive-ion 'V' signature in orbit 347. First, the reversal from westward to eastward convection near the equatorward cusp boundary is a shear reversal of the type discussed by Heelis et al (1976); that is, a near 180° direction change with the magnitude of the velocity being almost zero at the reversal. Secondly, the strong eastward convection components in the equatorward part of the 'V' are accompanied by significant northward, or anti-sunward, components. Thirdly, the decrease of eastward velocity components observed as the spacecraft entered the poleward part of the 'V' was accompanied by a near 90° direction change so that a rotational reversal of the type discussed by Heelis et al (1976) is indicated near the bottom of the 'V'. Finally, the low eastward flow velocities within the poleward half of the 'V' are accompanied by significant southward, or sunward, components.

The convection velocities plotted in Figure 2 contain a component due to corotation. In Figure 3, the same flow vectors are shown in a Λ-MLT polar plot with corotation subtracted out; that is, Figure 3 shows the convection velocities in a coordinate frame which rotates with the earth. Figure 3 shows data for a larger segment of AE-D orbit 347, and it is evident that the sunward velocity components extend significantly poleward of the cusp region. These sunward flows in the polar cap are no doubt related to the sunward flows observed in the single-component measurements reported by Burke et al (1979). An apparent concentration of these sunward flows in the dayside region of the polar cap is indicated by the low probability (15%) with which they are observed in the dawn-dusk orbits of AE-D (Spiro et al, 1979).

The Imp-J IMF data reveal that strong northward magnetic field components existed in the interplanetary medium for about 50 minutes preceding the AE-D cusp crossing of orbit 347. Such conditions have been found to be typical for the 'V' shaped ion precipitation patterns discussed above.

Model Calculations

Several authors have recently developed models of global ionospheric electrostatic potential using Triad field-aligned current data as input functions to the evaluation of the current continuity equation, combined with Ohm's law, using realistic ionospheric conductivity models. Of these studies only that of Gizler et al (1979) included the effects of the cusp region current system. Gizler et al showed that when the cusp region currents alone are considered, sunward convection results in the polar cap. However, when considering cusp region currents along with Region 1 currents, Gizler et al included only one branch of the cusp region currents (that is, only upward currents or only downward currents) in order to simulate the effects of positive and negative IMF B_y. Therefore, as a first step toward a convection model which includes the full set of current systems observed by Triad, we have formulated an extremely simple model which has proven to be quite instructive. The model has the following features: (1) A flat, uniformly resistive ionosphere is used; (2) The cusp region, Region 1, and Region 2 Birkeland current systems (Iijima and Potemra 1976a,b) are represented by curvilinear charge distributions on the assumed ionospheric surface; (3) The charge distributions are aligned along arcs of circles with centers at $\Lambda = 87°$, MLT = 00 hours (Meng et al, 1976), with radii (or polar angles) of 13.5° (cusp region), 16.5° (Region 1), and 20° (Region 2); and (4) The angular extent of the circular current segments measured from the noon meridian are $\pm 10°$ to $\pm 20°$ (cusp region), $\pm 5°$ to $\pm 90°$ (Region 1), and $\pm 15°$ to $\pm 90°$ (Region 2). In this model, downward Birkeland currents are represented by positive charge densities, upward currents by negative charge densities. The magnitudes of the charge densities for the three current systems for quiet and disturbed conditions are assigned relative values according to the current densities published by Iijima and Potemra (1976a,b). These numerical values are as listed in Table 1, which reflects a rather strong dependence of Region 1 and Region 2 current densities on magnetic activity but no such dependence of cusp region currents. Implicit in this study is the identification of periods of strong northward IMF as magnetically quiet.

In Figure 4 are plotted electric equipotentials calculated with the model described above for quiet conditions (top panel) and disturbed conditions (bottom panel). Also shown are the corresponding flow directions. The voltage drop between adjacent equipotentials is the same for both panels of Figure 4; therefore, it is immediately evident that much stronger flows result in the disturbed model. Also clear in comparing the two plots of Figure 4 is the appearance of much stronger poleward flow components in the throat region (near the noon meridian and just poleward of the Region 1 current system) for the disturbed case.

Examining now the post-noon (~13 hrs MLT) region of the flow pattern for quiet conditions (upper panel) of Figure 4, we note that as one moves poleward the three distinct flow regimes found in Figures 2 and 3 appear. That is, westward flow equatorward of the Region 1 current system, eastward flow between the cusp region and Region 1 systems, and sunward flow near and just poleward of the cusp region currents. The character of the two flow reversals is also reproduced properly; that is, a 180° shear reversal at the Region 1 system and a more gradual rotation of the flow near and poleward of the cusp region currents. It is worthy of note that in the quiet-conditions plot of Figure 4 (top panel) the region of sunward flow is much more localized to the day side of the polar cap than in the previous models of Burke et al and Maezawa et al (1979).

Some qualitative features of the 'V' signatures of precipitating ion fluxes in the cusp region can also be explained in terms of the quiet-time model of Figure 4. Assume that injection of solar-wind ions into the cusp occurs at a region of weak magnetic field at the high-latitude dayside magnetopause (neutral point entry) and that this region maps magnetically down to the ionosphere to a region near the noon meridian and overlapping the $\Phi = 0$ contour of Figure 4. During transit of the ions from the magnetopause to the ionosphere they would convect away from the noon meridian (east and west) while converging toward the $\Phi = 0$ contour, as shown by the flow contours of Figure 4 (upper panel). At the same time cross-field diffusion, driven perhaps by the turbulence that is generally present in the cusp, would tend to transport the ions both equatorward and poleward from the injection latitude. The lower-energy ions would spend more time in transit from the magnetopause to the ionosphere and hence would tend to accumulate near the $\Phi = 0$ contour. Also, as noted by Reiff et al (1979), the more energetic ions would diffuse more rapidly away from the injection latitude since the diffusion velocity is expected to increase along with the ion gyroradius. These effects would tend to form a 'V'-shaped ion energy-latitude precipitation in that the highest energy ions would cover the widest range of latitudes. Other possible ion injection mechanisms are discussed by Reiff et al (1979).

Acknowledgments. This work was supported in part by NSF Grant ATM78-26762 and NASA Grant NSG-5418 to the University of Texas at San Antonio; NSF Grant ATM 77-12619 and NASA Grant NGR 44006137 to Rice University; and NASA Grant NGR 44-004-120 and NASA Contract NAS 114-07 to the University of Texas at Dallas.

References

Burke, W.J., M.C. Kelley, R.C. Sagalyn, M. Smiddy, and S.T. Lai, Polar cap electric field structures with a northward interplanetary magnetic field, Geophys. Res. Lett., 6, 21, 1979.

Gizler, V.A., V.S. Semenov, and O.A. Troshichev, Electric fields and currents in the ionosphere generated by field-aligned currents observed by Triad, Planet. Space Sci., 27, 223, 1979.

Heelis, R.A., W.B. Hanson, and J.L. Burch, Ion convection velocity reversals in the dayside cleft, J. Geophys. Res., 81, 3803, 1976.

Heikkila, W.J., and J.D. Winningham, Penetration of magnetosheath plasma to low altitudes through the dayside magnetospheric cusps, J. Geophys. Res., 76, 883, 1971.

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, 1976a.

Iijima, T., and T.A. Potemra, Field-aligned currents in the dayside cusp observed by Triad, J. Geophys. Res., 81, 5971, 1976b.

Maezawa, K., Magnetospheric convection induced by the positive and negative Z components of the interplanetary magnetic field: Quantitative analysis using polar cap magnetic records, J. Geophys. Res., 81, 2289, 1976.

Meng, C.-I., R.H. Holzworth, and S.-I. Akasofu, Auroral circle--delineating the poleward boundary of the quiet auroral belt, J. Geophys. Res. 82, 164, 1977.

Reiff, P.H., J.L. Burch, and R.W. Spiro, Cusp proton signatures and the interplanetary magnetic field, submitted to J. Geophys. Res., 1979.

Spiro, R.W., P.H. Reiff, J.L. Burch, and R.A. Heelis, High latitude plasma convection and the IMF, EOS Trans. AGU, 60, 915, 1979.

TABLE 1.

Current System	Relative Charge Density	
	Quiet	Disturbed
Cusp Region	2.5	2.5
Region 1	0.8	2.0
Region 2	0.2	0.5

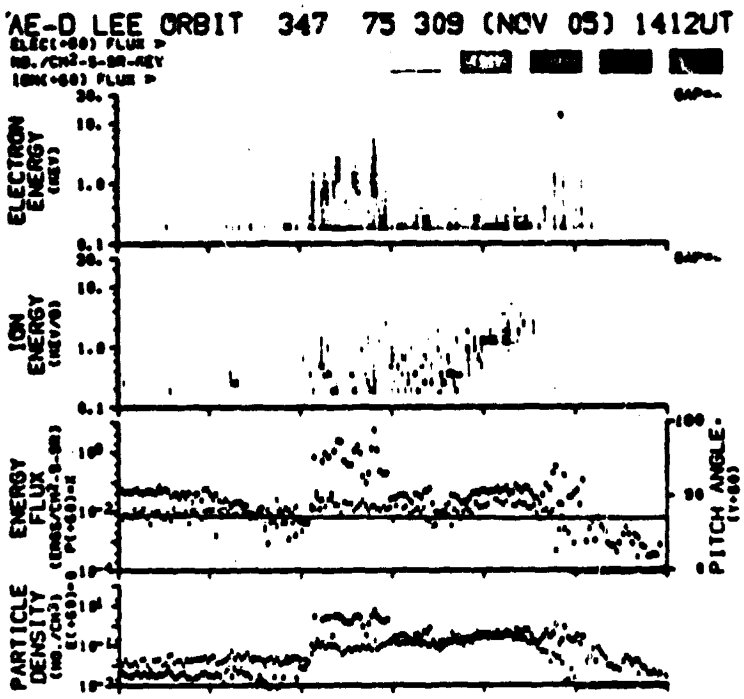
FIGURE CAPTIONS

Fig. 1. Energy-time spectrogram of electron and positive-ion differential number fluxes for AE-D orbit 347.

Fig. 2. (Bottom Panel) Median energy of precipitating ions (histogram) and east-west convection velocity components (positive westward) for AE-D orbit 347 on 5 November 1975. (Top Panel) Ion convection velocity vectors in the horizontal plane (perpendicular to the orbit plane).

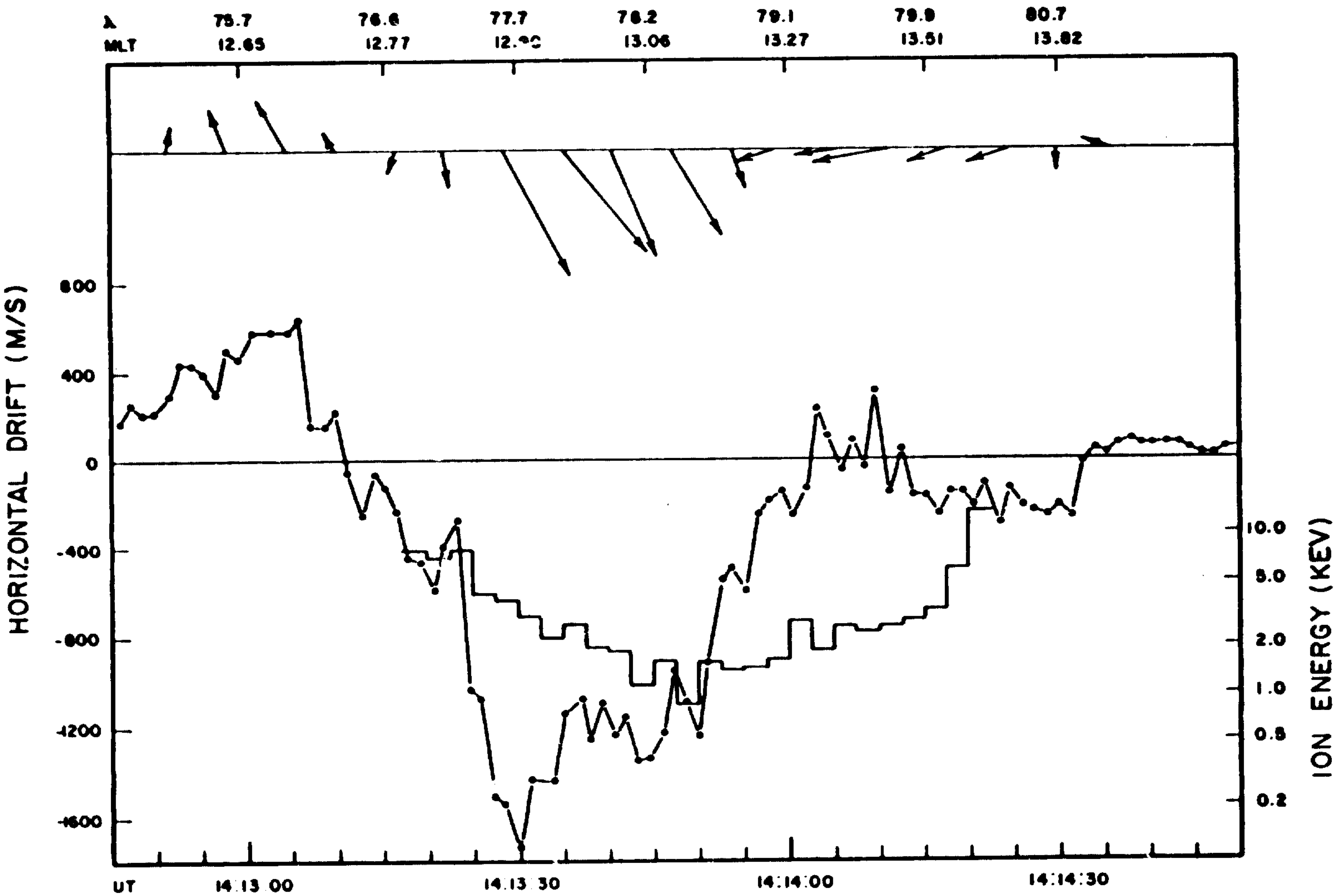
Fig. 3. Polar plot of ion convection data for AE-D orbit 347 on 5 November 1975. Convection velocity vectors are plotted in a coordinate frame which rotates with the earth.

Fig. 4. Results of model calculations on ionospheric convection based on Triad Birkeland current data for quiet (top panel) and disturbed (bottom panel) conditions.

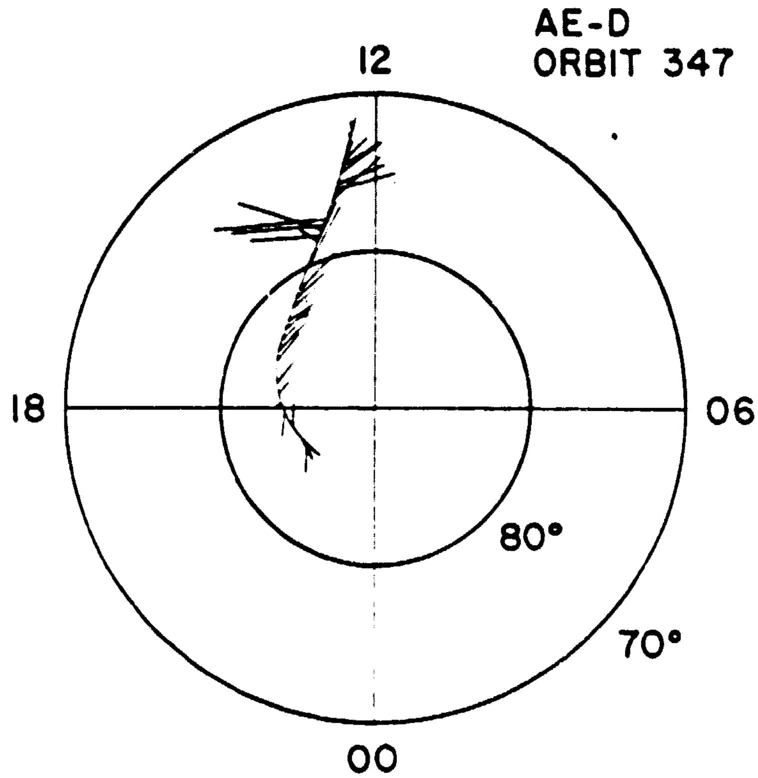


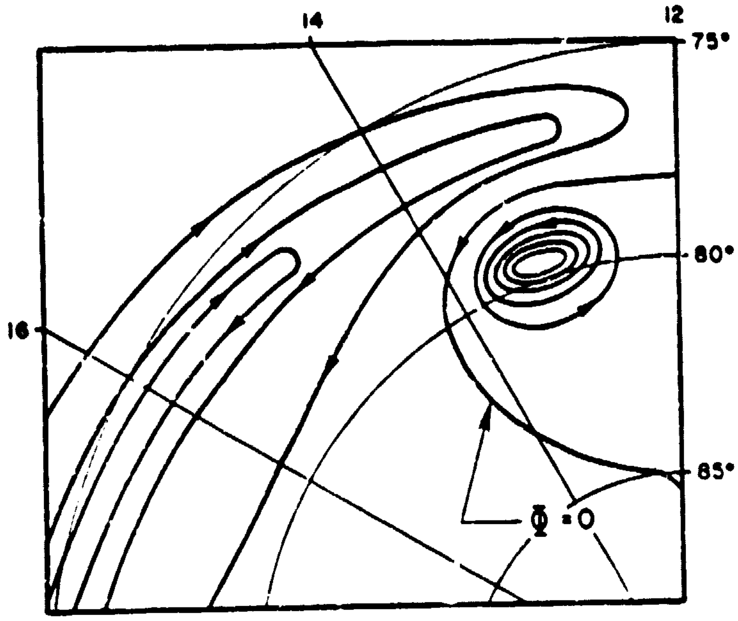
UT	1413	1414	1415
INV.LAT.	75.7	79.1	82.2
MLT	12.6	13.3	14.8

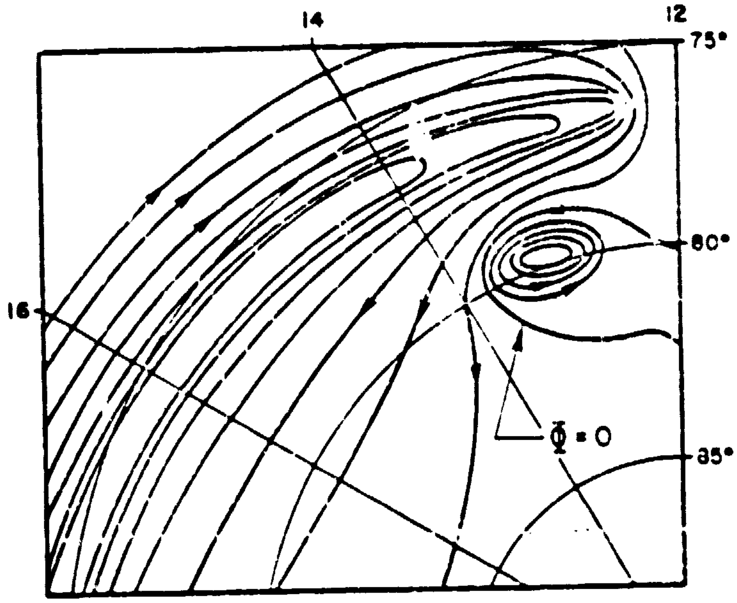
ORIGINAL PAGE IS
OF POOR QUALITY



λ
MLT
75.7
12.65
76.6
12.77
77.7
78.2
13.06
79.1
13.27
79.9
13.51
80.7
13.82
HORIZONTAL DRIFT (M/S)
800
400
0
-400
-800
-1200
-1600
ION ENERGY (KEV)
10.0
5.0
2.0
1.0
0.5
0.2
UT
14:13:00
14:13:30
14:14:00
14:14:30


AE-D
ORBIT 347
12
18
06
80°
70°
00


14
12
75°
80°
16
85°
$\Phi = 0$


14
12
75°
80°
16
$\Phi = 0$
85°