JOULE HEATING AND FIELD-ALIGNED CURRENTS: PRELIMINARY RESULTS FROM DE-2

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There are three main processes by which energy is transferred from the magnetosphere to the thermosphere. These are, not necessarily in the order of importance: (a) charge exchange of the ring current particles; (b) precipitation of charged particles; and (c) joule dissipation by the magnetosphere-ionosphere current systems. The importance of this last process has been recognized and the rate of joule heating has been estimated by many workers (references given in Table 1).

Observations of the electric (E) and magnetic (B) fields from DE-2 are providing a new set of data on field-aligned currents. One of the remarkable features found in these observations is the high correlation between an orthogonal pair of the E and B field components (Siguira et al., 1982, 1984; Sugiura, 1984; general references on field-aligned currents are given in these papers). Figure 1 shows an example, where ΔB is the perturbation magnetic field obtained by substracting a model internal field from the observed field. The north-south component of the electric field is well correlated with the east-west component of the magnetic field. The correlation is 0.94, using ½ second averages. Figure 2, which gives high-pass filtered data of the same set as Figure 1, shows that the correlation between the orthogonal E and B components is equally good for the fluctuating components; the correlation coefficient is 0.93.

Figure 3 demonstrates this reasoning. Figure 3 shows the spacecraft X, Y, and Z components of ΔB and the spacecraft X component of E during a northern polar pass. The interplanetary magnetic field was northward ($B_z>0$), and hence the size of the polar cap was small. Figure 4 shows how the angle, α, between the orbit plane and the dipole meridian plane changes along the pass; the definition of the angle α is illustrated in Figure 5. The interval between 1417 and 1423 UT was further divided into 1-minute intervals and the correlation coefficient between ΔB_z and E_x was calculated for each of these 1-minute intervals. The results are shown in Table 2. We conclude that the proportionality between the orthogonal B and E components is invariant with respect to rotation of the coordinate system. Hence the missing E_z must be proportional to ΔB_x to the same extent that E_x is correlated to ΔB_z.

Comparing ΔB_z with E_x for the evening auroral oval pass in Figure 3, ΔB_z changes are very small, but are correlated with E_x as seen in the correlation coefficient, r, for intervals D and E. The ΔB_z amplitudes are small in these intervals because the ionosphere was not illuminated and hence the conductivity was low. The precipitating electrons did not have energies large enough to produce appreciable ionization in the E region of the ionosphere (according to the LAPI plasma observations); hence field-aligned currents could now flow, and the electric field was large, being not short-circuited. The solar elevation angle along the pass is indicated in Figure 3.

Figure 6 shows a pass on the following day when IMF B_z became southward. Now the size of the polar cap has expanded, and there are appreciable field-aligned currents in the auroral oval in darkness (near midnight) because of enough ionization from auroral electrons. Note the good correlation in interval C where α changed rapidly.

From the DE-2 observations of $\underline{E}$ and $\Delta\underline{B}$, we conclude that the electric field and the perturbation magnetic field are orthogonal and that their magnitudes are proportional. Their directional relation is such that $\underline{E} \times \Delta\underline{B}$ is downward. This relation between $\underline{E}$ and $\Delta\underline{B}$ is frequently observed, especially on the dayside.

It can be shown that when the above relation between the electric and magnetic fields holds, the following equations constitute a particular solution of the current continuity equation.

$$\Sigma_p - k/\mu_o = 0 \quad (1)$$

$$\nabla \cdot \underline{J}_H = 0 \quad (2)$$

where Σ_p is the ionospheric Pedersen conductance, k the constant of proportionality between the orthogonal perturbation magnetic field and electric field components, μ_o the permeability of free space, and $\underline{J}_H$ the height-integrated Hall current. If (1) holds, then with the proportionality between the electric and perturbation magnetic fields, we obtain a relation that the vertical component of Poynting's vector equals joule dissipation, namely that the vertically downward energy flow equals joule dissipation; that is, the divergence of the horizontal energy flux is zero. The energy flux from below the ionosphere is expected to be negligible because the perturbation magnetic vector is parallel to the electric field; this is because the magnetic field below the ionisphere is mainly from the Hall current. It seems reasonable that the divergence of the Hall current is zero to the same extent as the plasma convection flow is horizontally divergence free. If this is true, then the field-aligned current sheets are parallel to the convective flow pattern or the equipotential surfaces.

If we accept the above solution, then the Polynting vector $\underline{E} \times \Delta\underline{B}/\mu_o$ provides the energy flux from the magnetosphere that is expended in the ionosphere by joule dissipation. During the magnetic storm of September 6, 1982 the peak energy flux reached 200 mW/m^2 in the cusp region. In an auroral oval pass the peak energy flux is typically a few tens of mW/m^2 under moderately dislturbed conditions.

In recent years, observational data have accrued concerning the relationship between the interplanetary magnetic field and the size of the polar cap and also about the evolution of a substorm or a magnetic storm. It is suggested that these findings be incorporated in future model calculations.

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JOULE DISSIPATION BY ELECTRIC CURRENTS

COLE	1962	Austr. J. Phys., 15, 223
	1971	Planet. Space Sci., 19, 59
	1975	J. Atmos. Terr. Phys., 37, 939
KATO	1962	Planet. Space Sci., 9, 939
REES and WALKER	1968	Annls. Geophys., 24, 193
MAYR and VOLLAND	1972	Planet. Space Sci., 20, 379
	1974	J. Atmos. Terr. Phys., 36, 2025
BATES	1973	Planet. Space Sci., 21, 2073
HAYS et al.	1973	Planet. Space Sci., 21, 559
CHANG et al.	1974	J. Atmos. Terr. Phys., 36, 889
BANKS and SIREN	1974	EOS, 56, 1157
WICKWAR et al.	1975	J. Geophys. Res., 81, 4364
RICHMOND and MATSUSHITA	1975	J. Geophys. Res., 80, 2839
TAEUSCH and HINTON	1975	J. Geophys. Res., 80, 4346
STRAUSS and SCHULTS	1976	J. Geophys. Res., 81, 5822
BANKS	1977	J. Atmos. Terr. Phys., 39, 179
BANKS et al.	1981	J. Geophys. Res., 86, 6869
THIELE et al.	1981	Planet Space Sci., 29, 455
VICKREY et al.	1982	J. Geophys. Res., 87, 5184
NISBET	1982	J. Atmos. Terr. Phys., 44, 797
KAMIDE et al.	1982	J. Geophys. Res., 87, 8228
BAUMJOHANN and KAMIDE	1984	J. Geophys. Res., 89, 383

Table 1

DAY 81251 8 SEPTEMBER 1981

INTERVAL UT	ANGLE α DEGREES	MLT HRS	CORR. COEFF.	Σp MHOS
1417-1418	151-137	13.4-14.4	0.99	11.3
1418-1419	137-109	14.4-16.5	0.98	7.4
1419-1420	109-68	16.5-19.3	0.99	6.0
1420-1421	68-40	19.3-21.0	0.90	2.8
1421-1422	40-27	21.0-21.8	0.97	4.1
1422-1423	27-20	21.8-22.2	0.97	2.7

Table 2

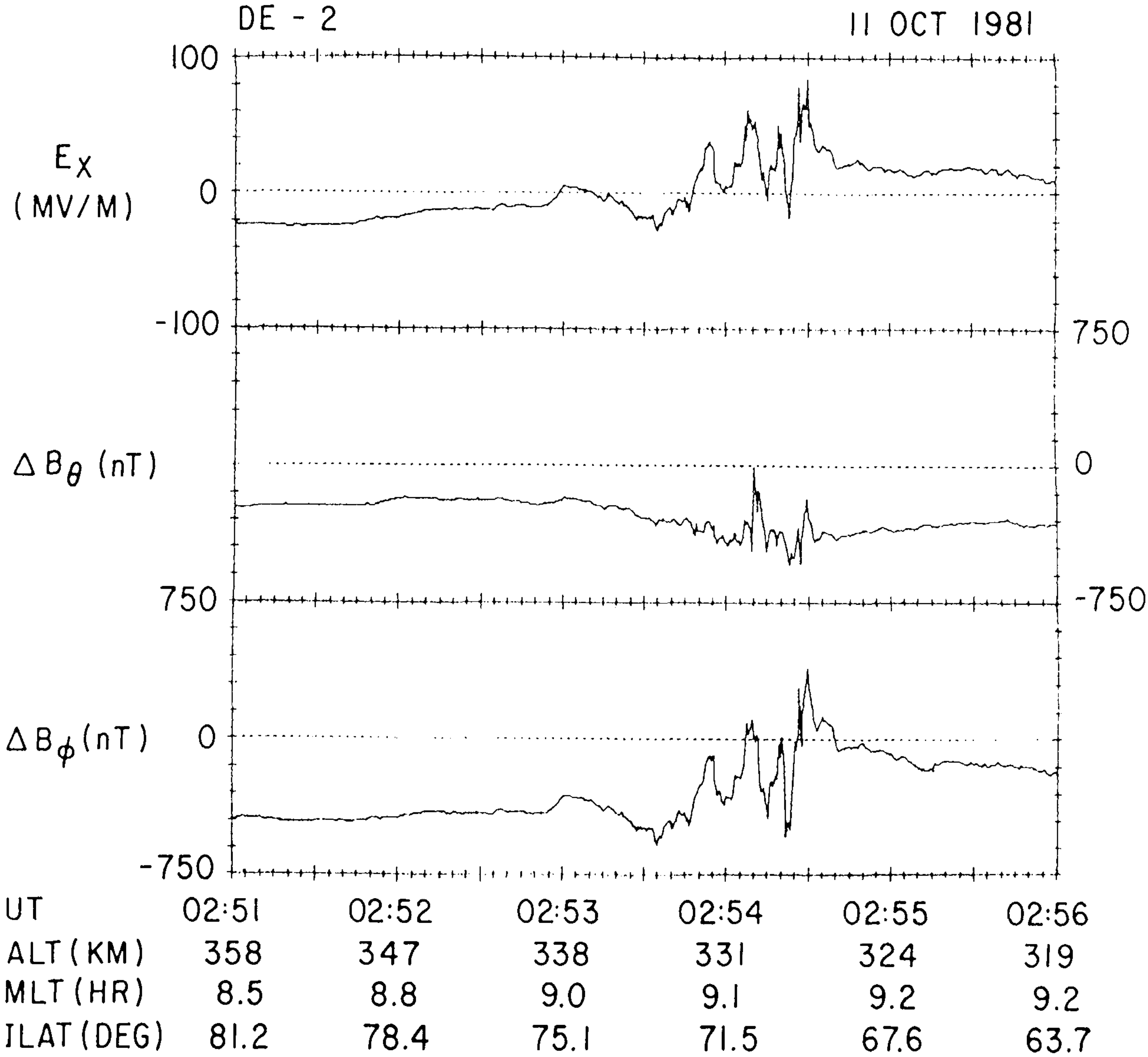

Figure 1. The north-south component of E, the north-south and east-west components (in dipole coordinates) of the peturbation B field.

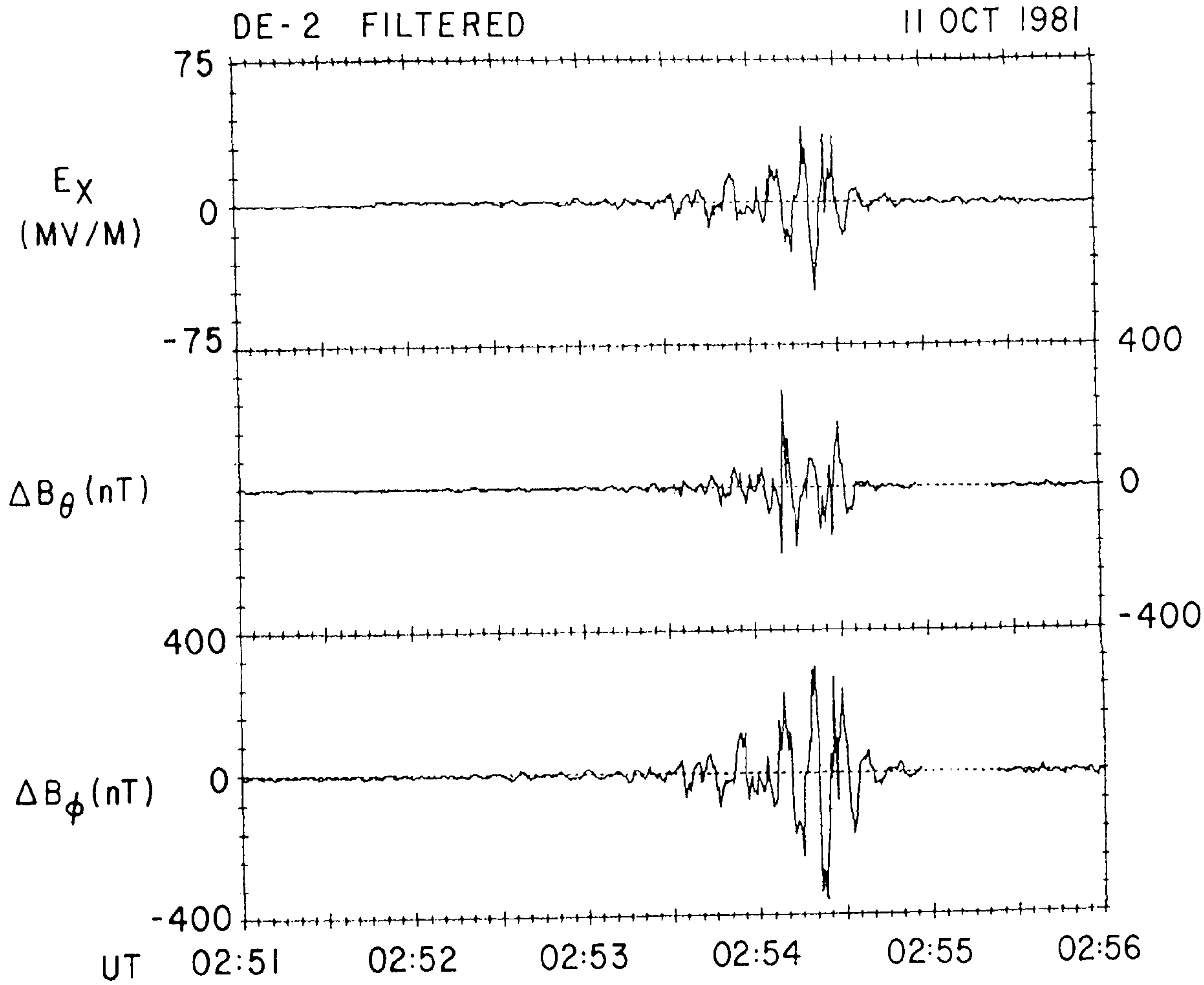

Figure 2. Data in Figure 1 were passed through a high-pass filter to extract fluctuating components. The orthogonal components of E and B are still well correlated.

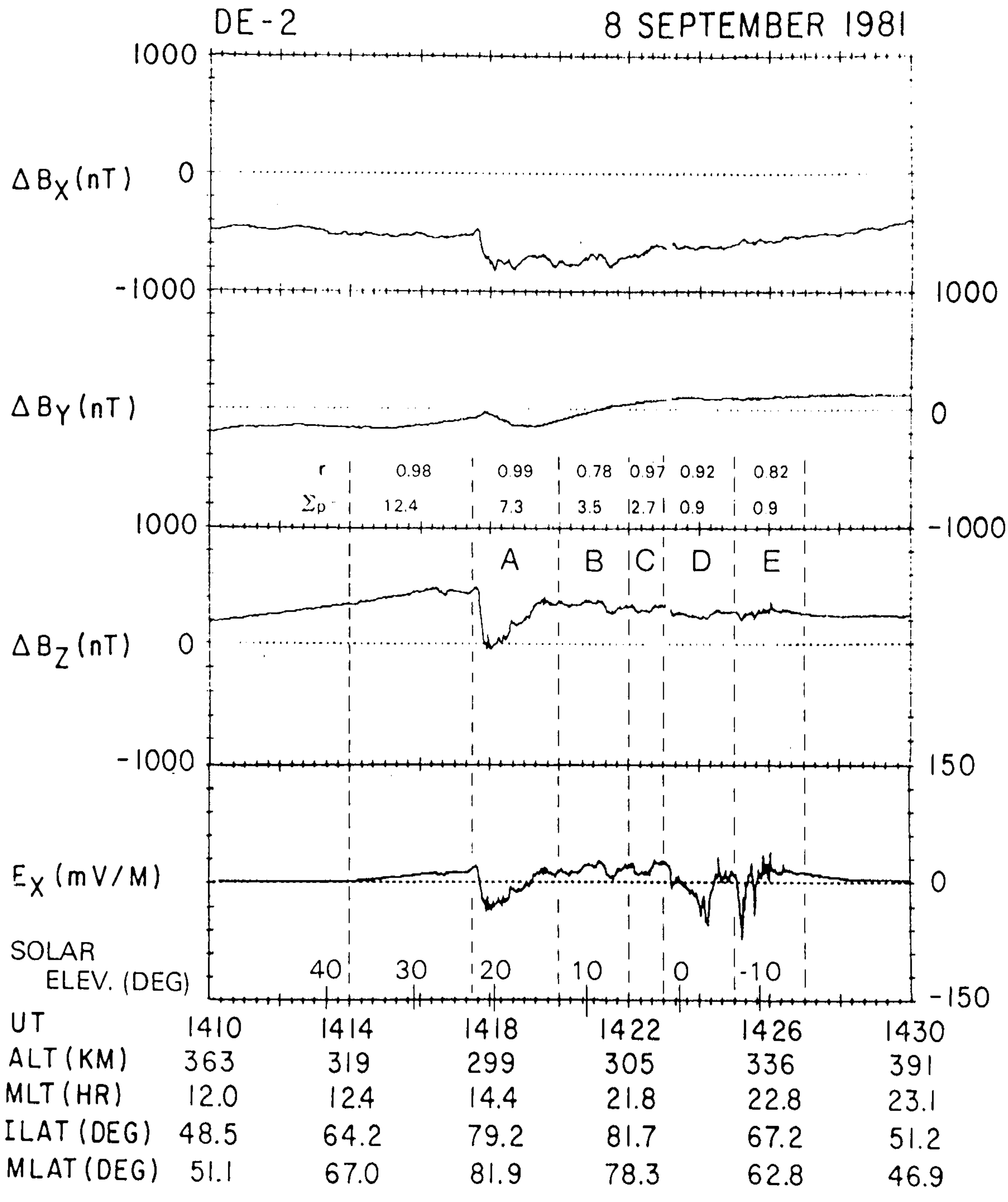

Figure 3. A northern polar pass of DE-2 on 8 September 1981 during IMF $B_z > 0$. The correlation between the orthogonal pair of *B* and *E* components (i.e., ΔB_z vs. E_x) is high even when the angle α (Fig. 4) changes rapidly as in intervals A and B.

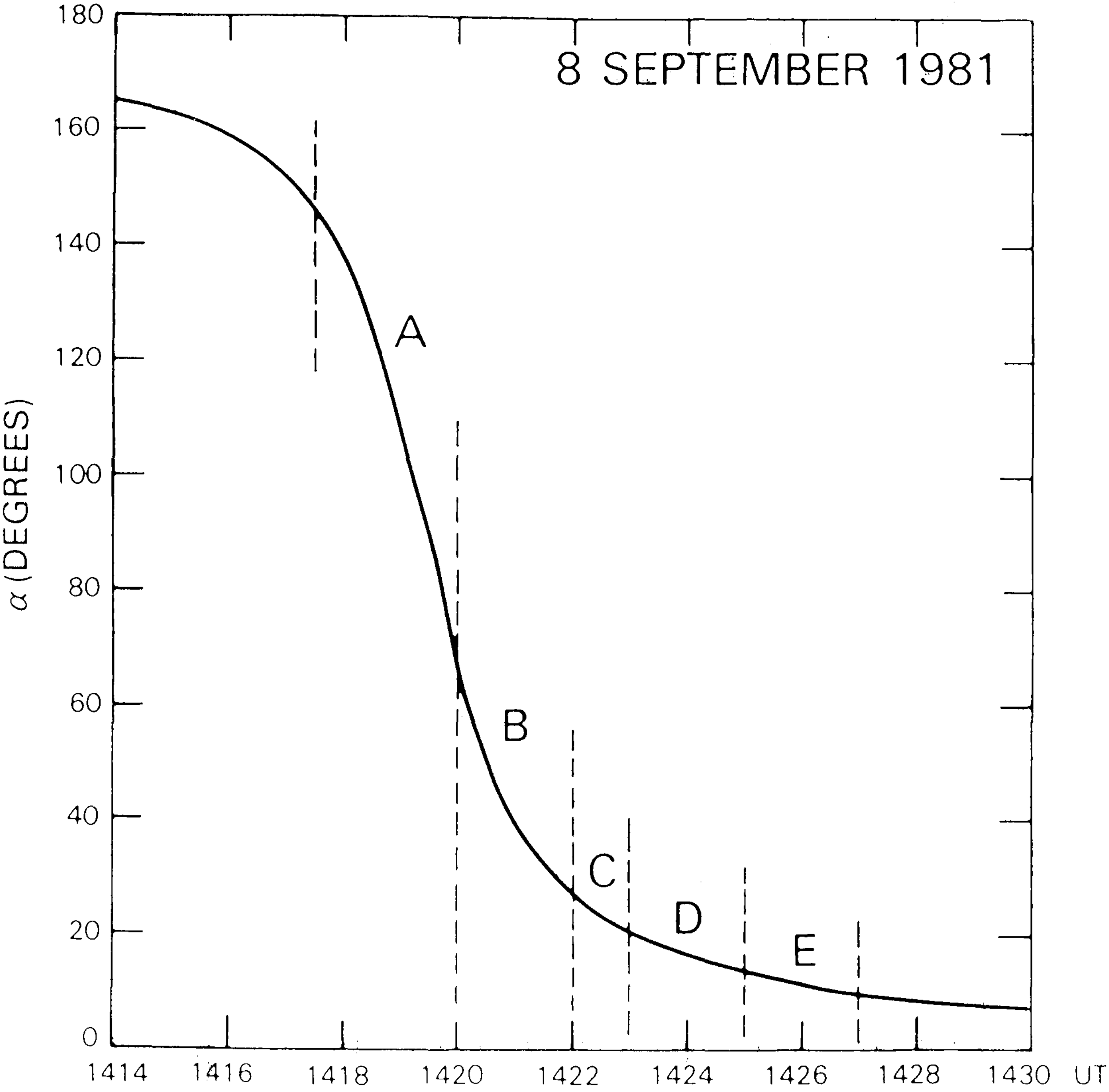

Figure 4. Angle α along the pass in Fig. 3.

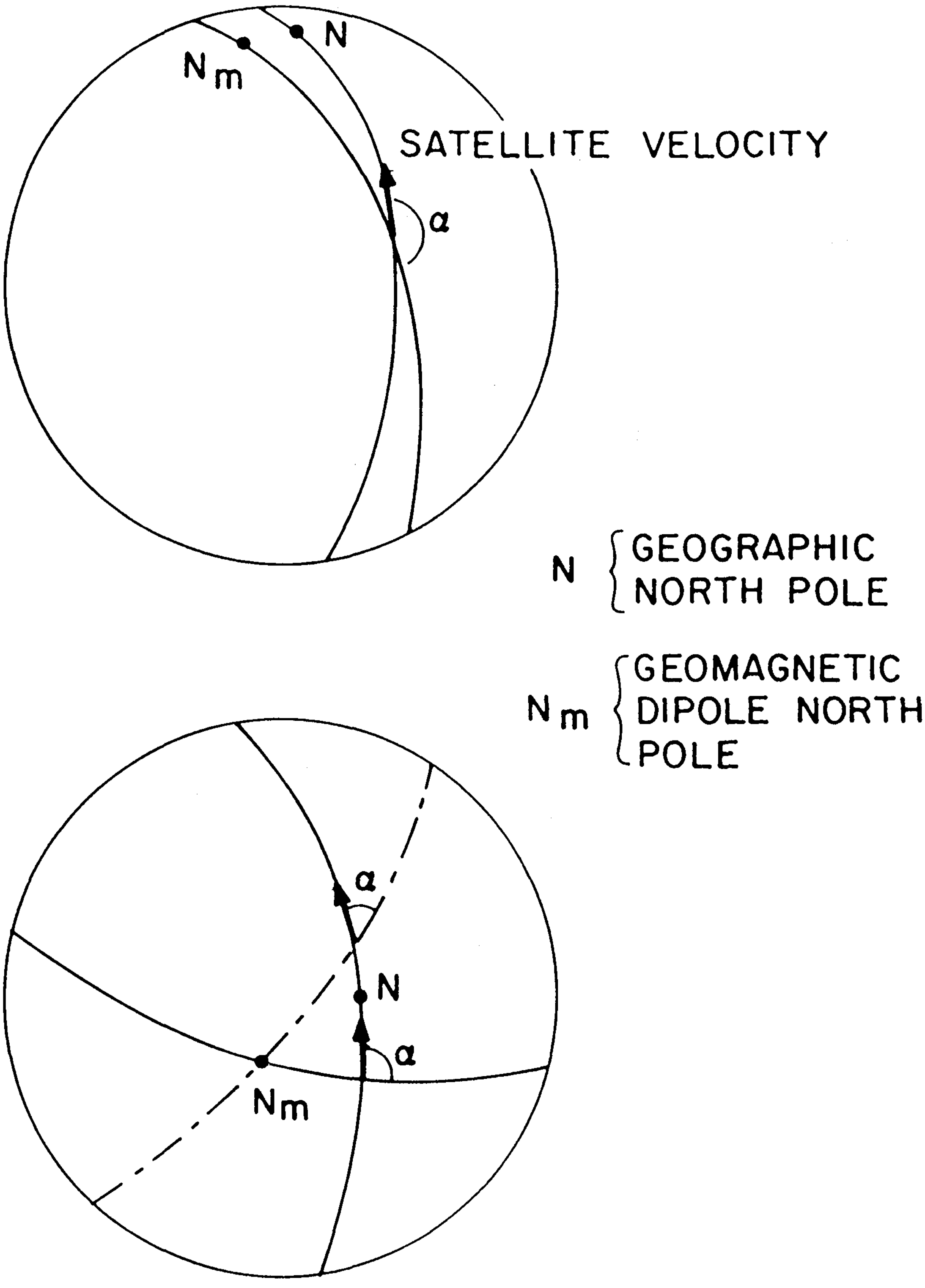

Figure 5. Angle, α, between the orbit plane and the dipole meridian plane; α is measured from the dipole south direction to the direction of the spacecraft velocity.

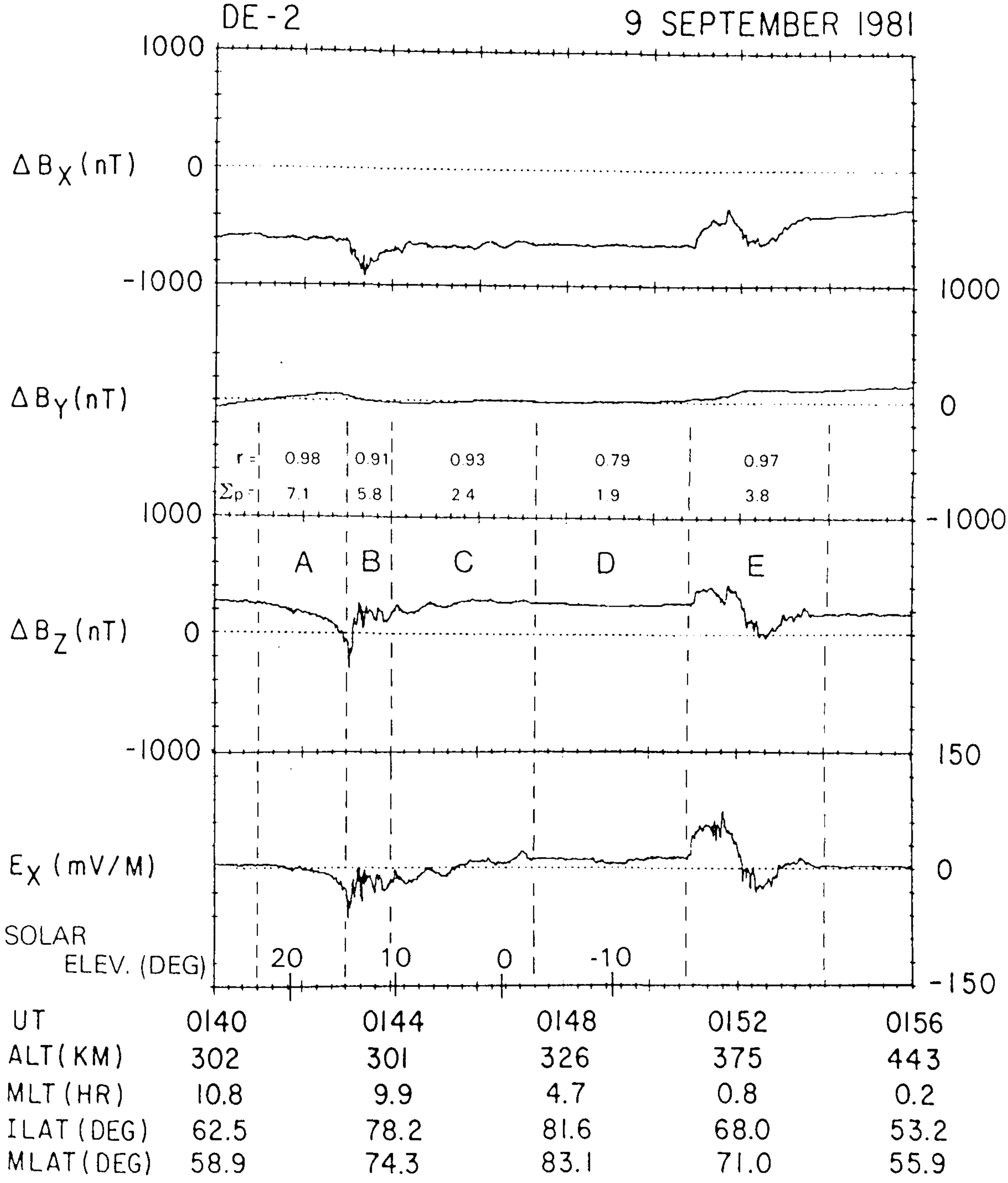

Figure 6. A northern pass when IMF B_z < on September 1981. The angle α changed rapidly from intervals B to C. The field-aligned current was appreciable on the nightside because of auroral electrons.