1999 CEDAR Workshop
Boulder, Colorado
June 13-18, 1999

Solar-Terrestrial Coupling Processes
Tutorial Lecture II

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Magnetospheric Interactions with the Solar Wind and Ionosphere

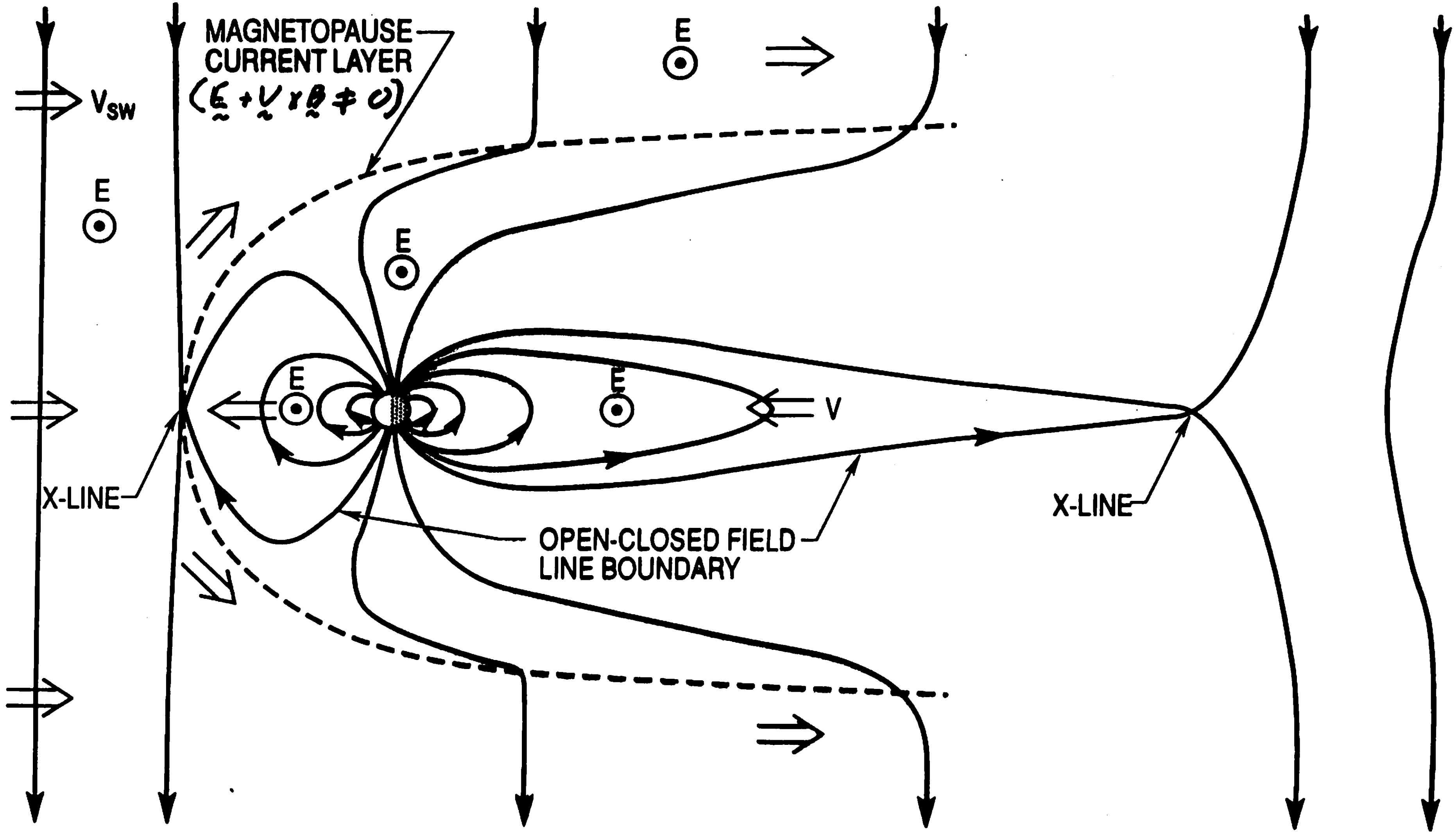
Interplanetary Sources for Geomagnetic Activity

General

- **Convection**: IMF B_z, B_y effects on strength; response to IMF changes
- **Tail plasma source**: dependence on convection strength?
- **Strong convection**: Earthward penetration of plasma sheet and resulting large distortion of **B**

Geomagnetic disturbances: Characteristics of, distinctions between types, relations to interplanetary conditions.

- **Poleward boundary intensifications**
- **Substorms**
- **Convection bays**
- **Storms,** including newly discovered response to pressure pulses



MAGNETOPAUSE
CURRENT LAYER
(E + V x B ≠ 0)
E
V_SW
E
E
E
E
V
X-LINE
X-LINE
OPEN-CLOSED FIELD
LINE BOUNDARY

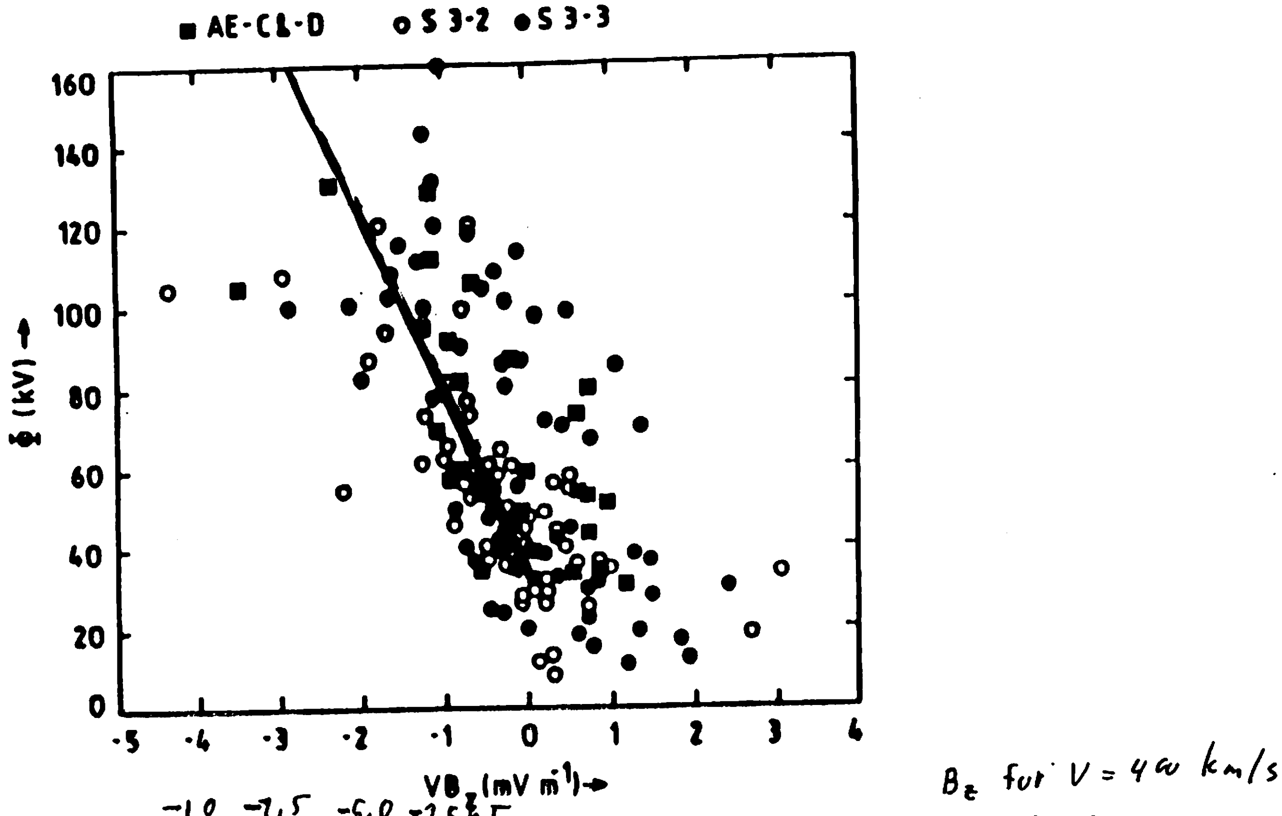


Fig. 1. Total transpolar voltage measured by four low-altitude spacecraft plotted versus simultaneous vB_z in the solar wind (from COWLEY, 1984).

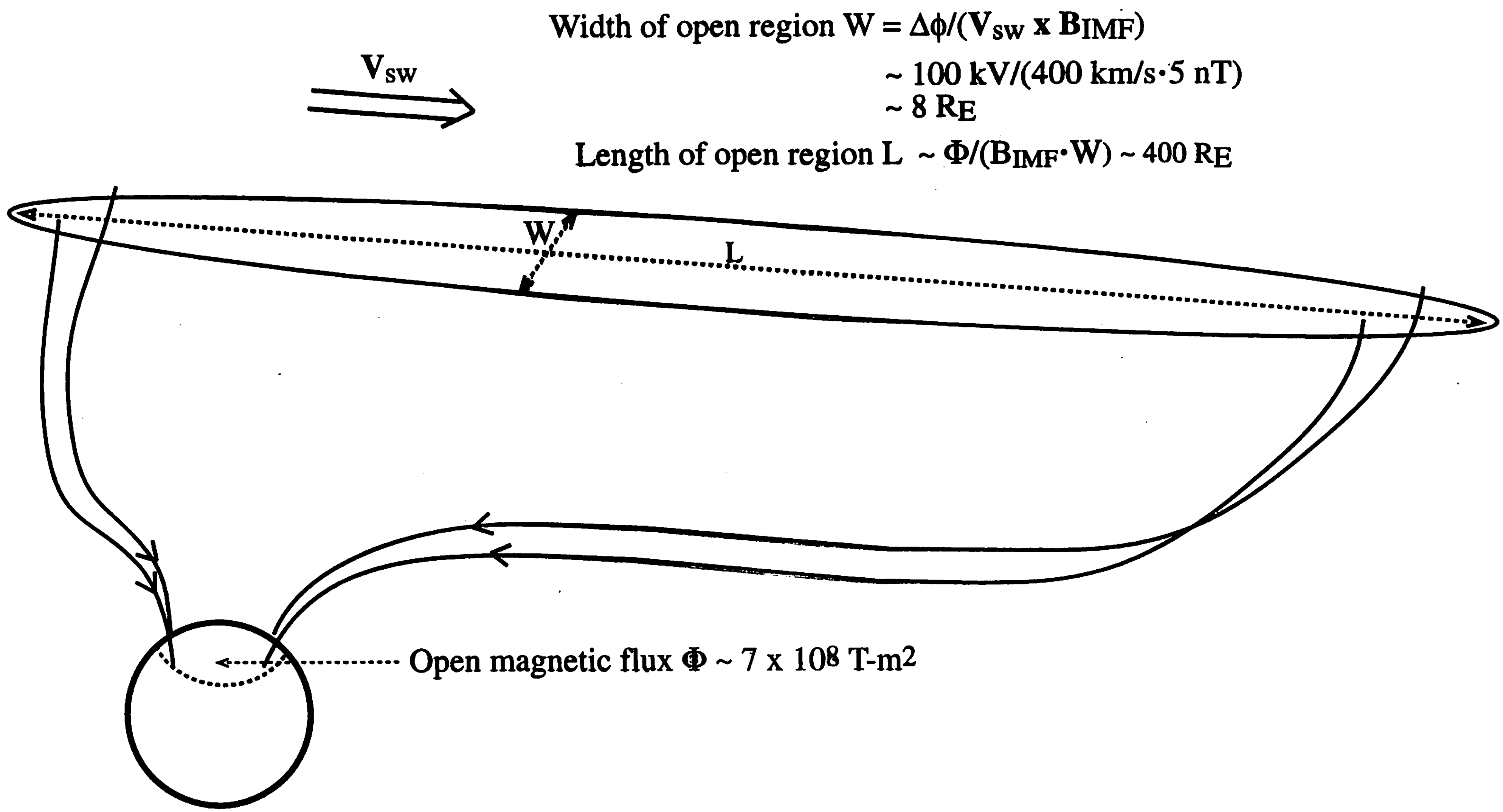
Convection Strength

Increases as IMF B_z becomes increasingly negative (well know)

Also increases significantly as IMF $|B_y|$ increases (not as well studied)

AMIE results for GEM stable IMF periods [G. Lu]

B_x (nT)	B_y(nT)	B_z (nT)	N. hem. $\Delta\Phi$	S. hem. $\Delta\Phi$
7.6	-1.9	6.8	30 kV	20 kV
5.1	-19.7	6.5	50 kV	80 kV
1.9	13.1	1.1	81 kV	74 kV
7	0	0	15 kV	25 kV



Width of open region W = Δϕ/(Vsw x BIMF)
~ 100 kV/(400 km/s·5 nT)
~ 8 RE
Length of open region L ~ Φ/(BIMF·W) ~ 400 RE
Vsw
W
L
Open magnetic flux Φ ~ 7 x 10^8 T-m^2

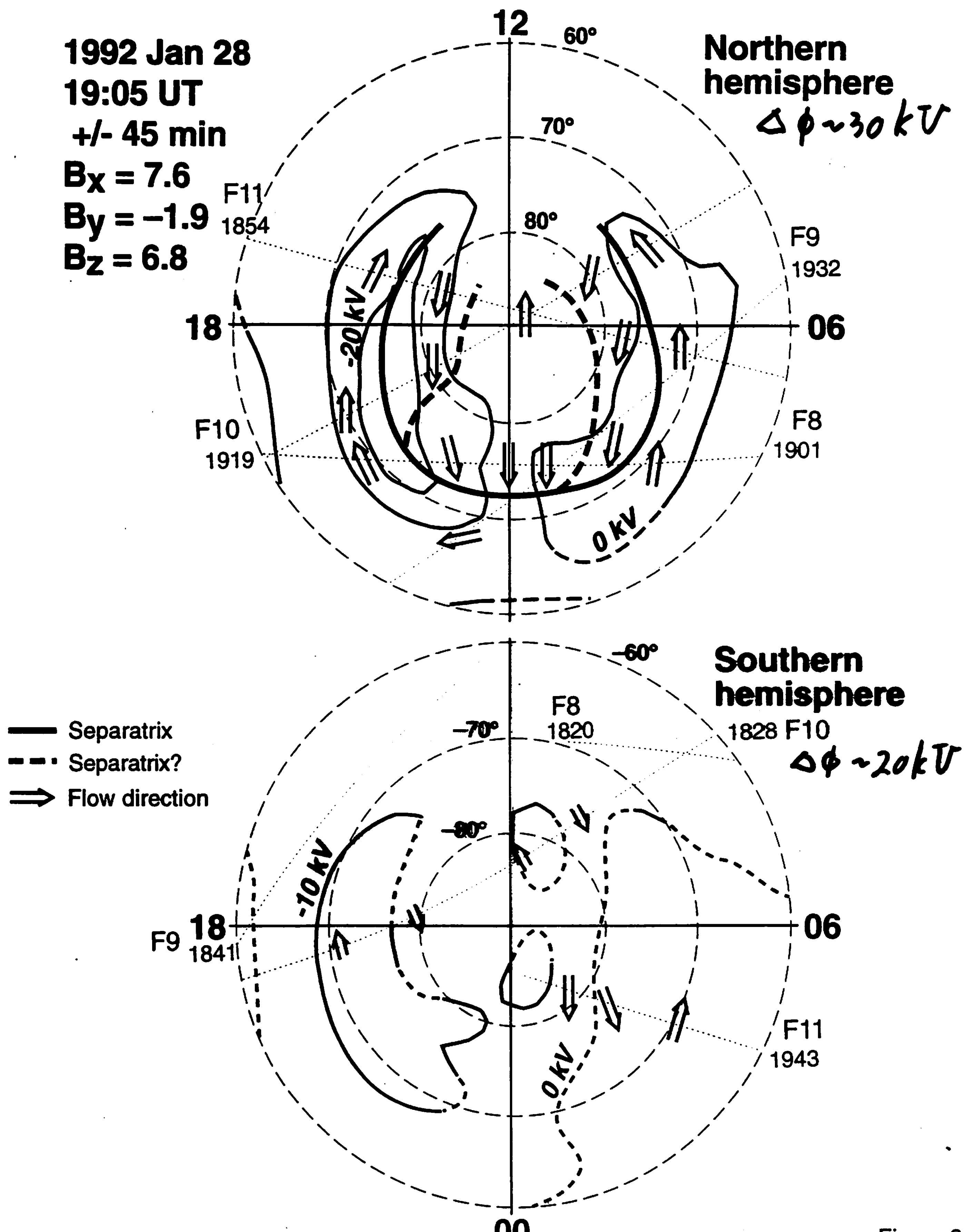
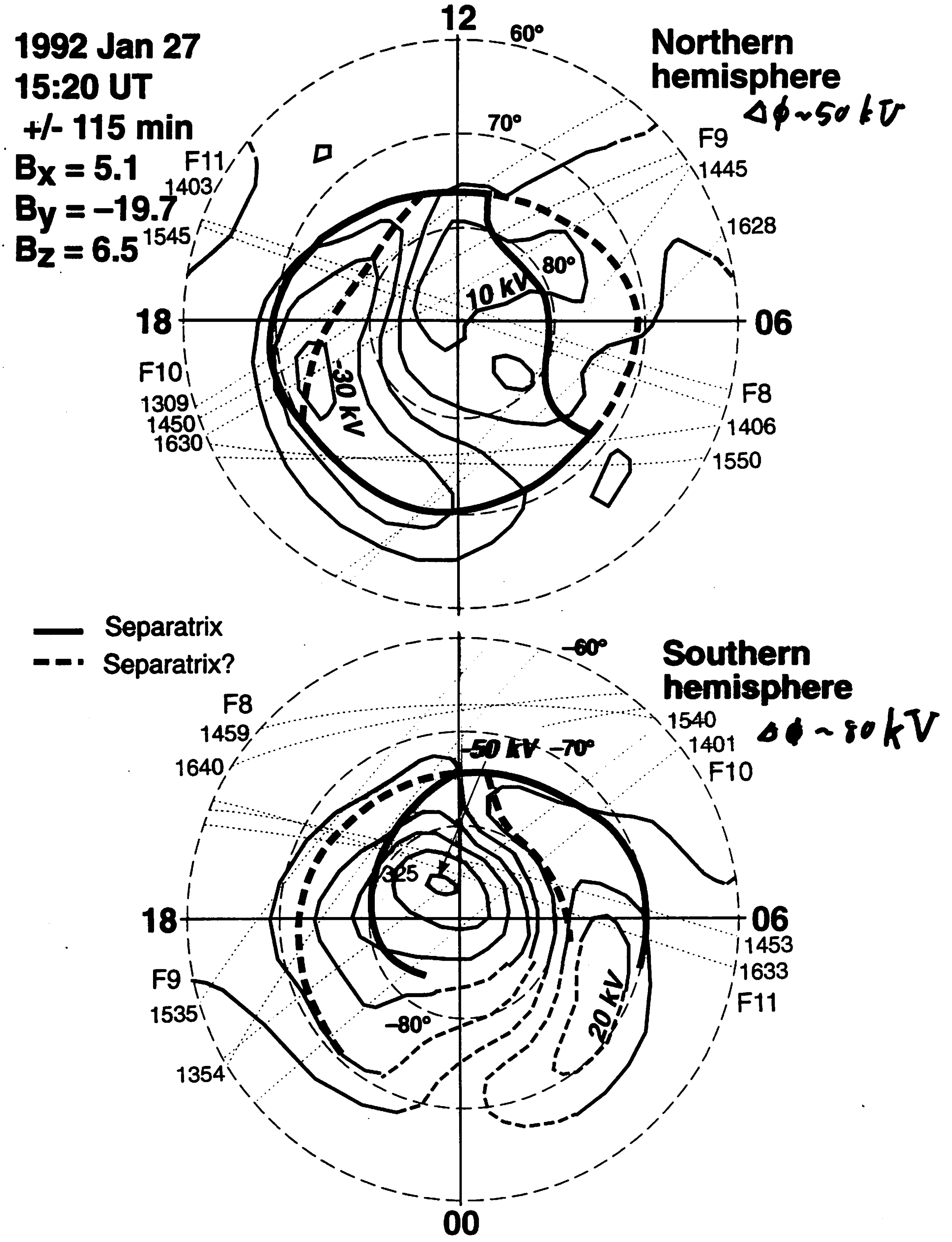
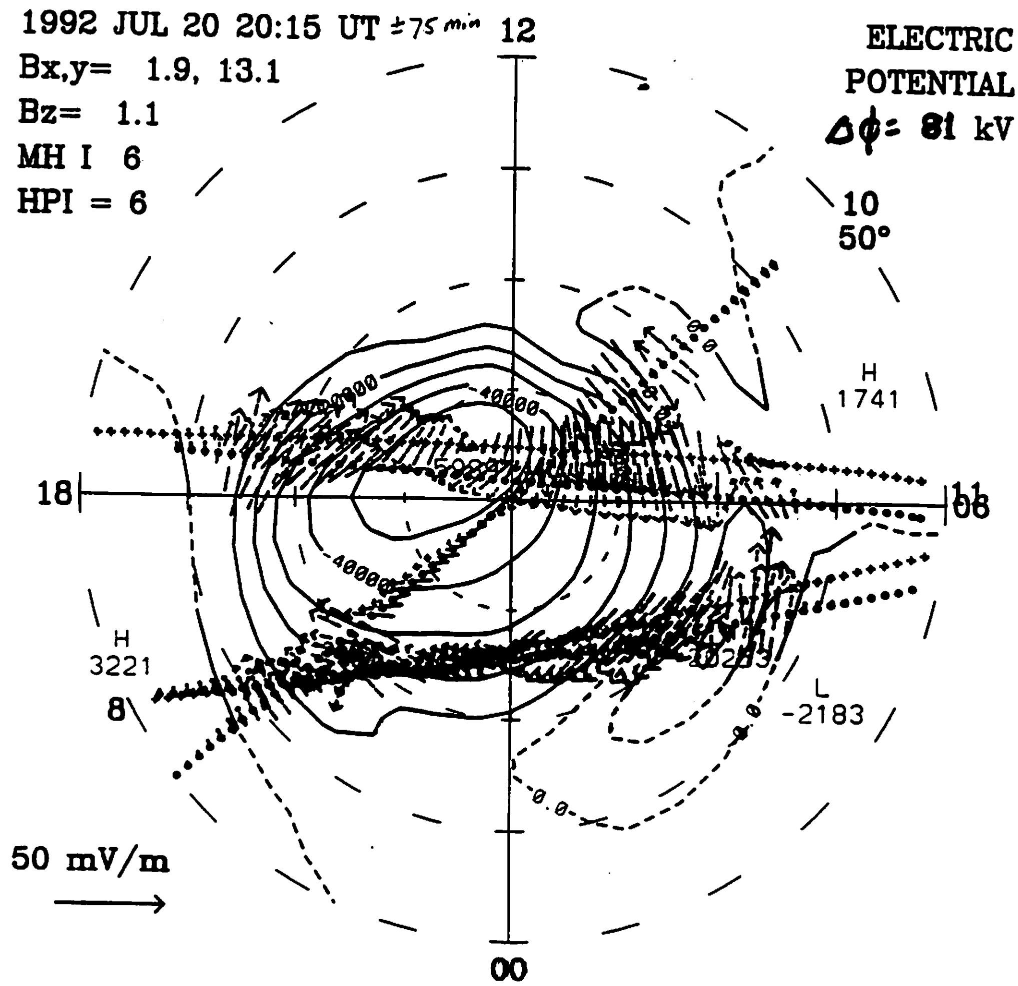
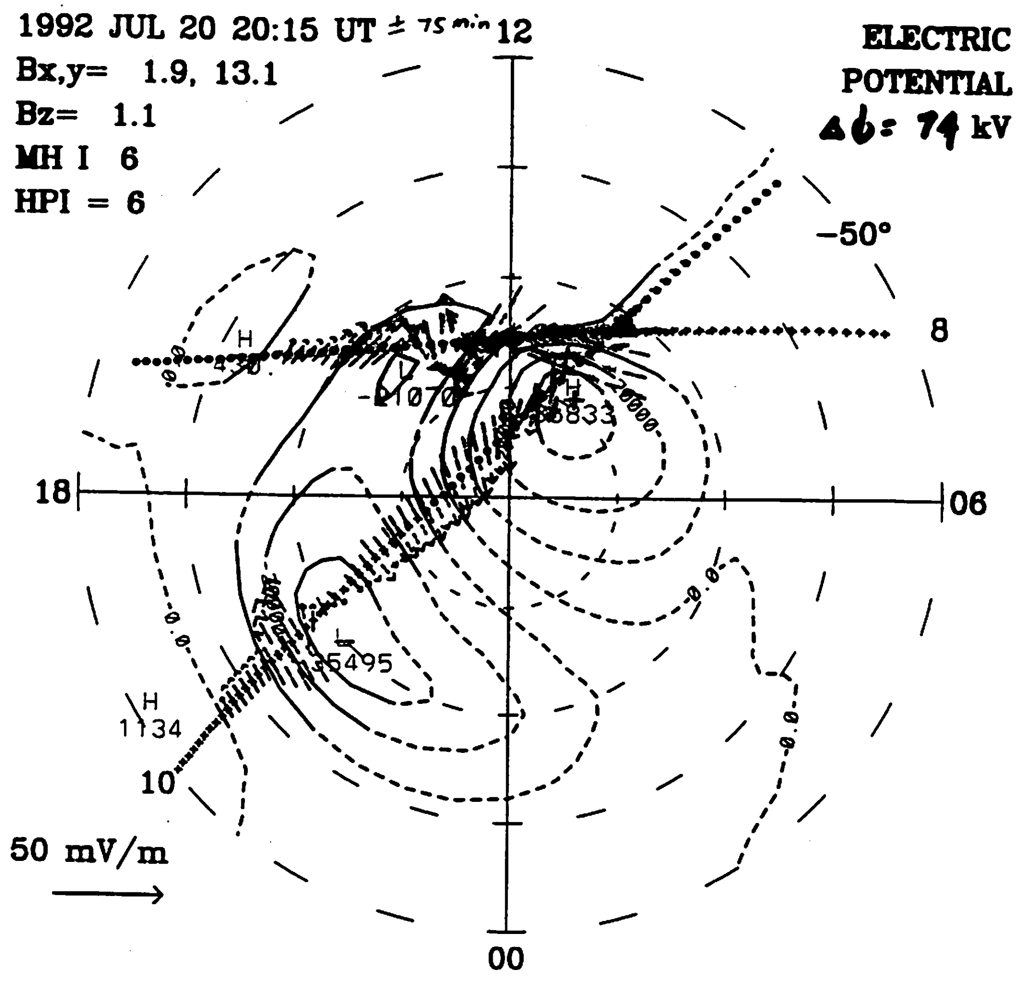

1992 Jan 28
19:05 UT
+/- 45 min
Bx = 7.6
By = −1.9
Bz = 6.8
Northern hemisphere
Δφ~30kV
12
60°
70°
80°
18
06
F11
1854
F9
1932
F10
1919
F8
1901
-20 kV
0 kV
Southern hemisphere
Δφ ~20kV
−60°
−70°
−80°
F8
1820
1828 F10
F9
1841
F11
1943
-10 kV
0 kV
00
Separatrix
Separatrix?
Flow direction

Figure 8

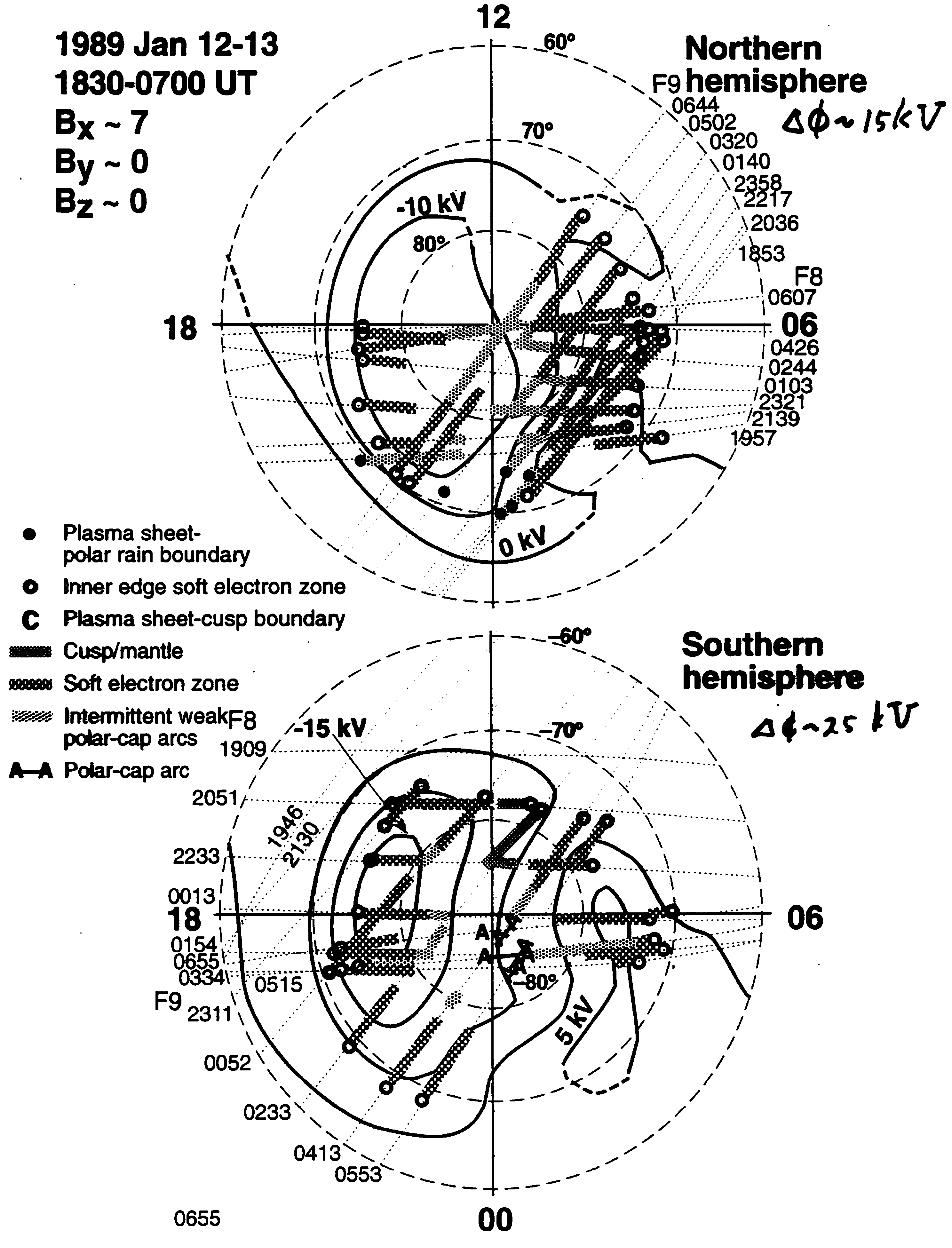


1992 Jan 27
15:20 UT
+/- 115 min
Bx = 5.1
By = −19.7
Bz = 6.5
Northern hemisphere
Δφ~50 kV
12
60°
70°
80°
18
06
00
10 kV
-30 kV
F11
1403
1545
F9
1445
1628
F10
1309
1450
1630
F8
1406
1550
Separatrix
Separatrix?
Southern hemisphere
Δφ~80 kV
−60°
−70°
−80°
-50 kV
-325
20 kV
F8
1459
1640
1540
1401
F10
F9
1535
1354
1453
1633
F11



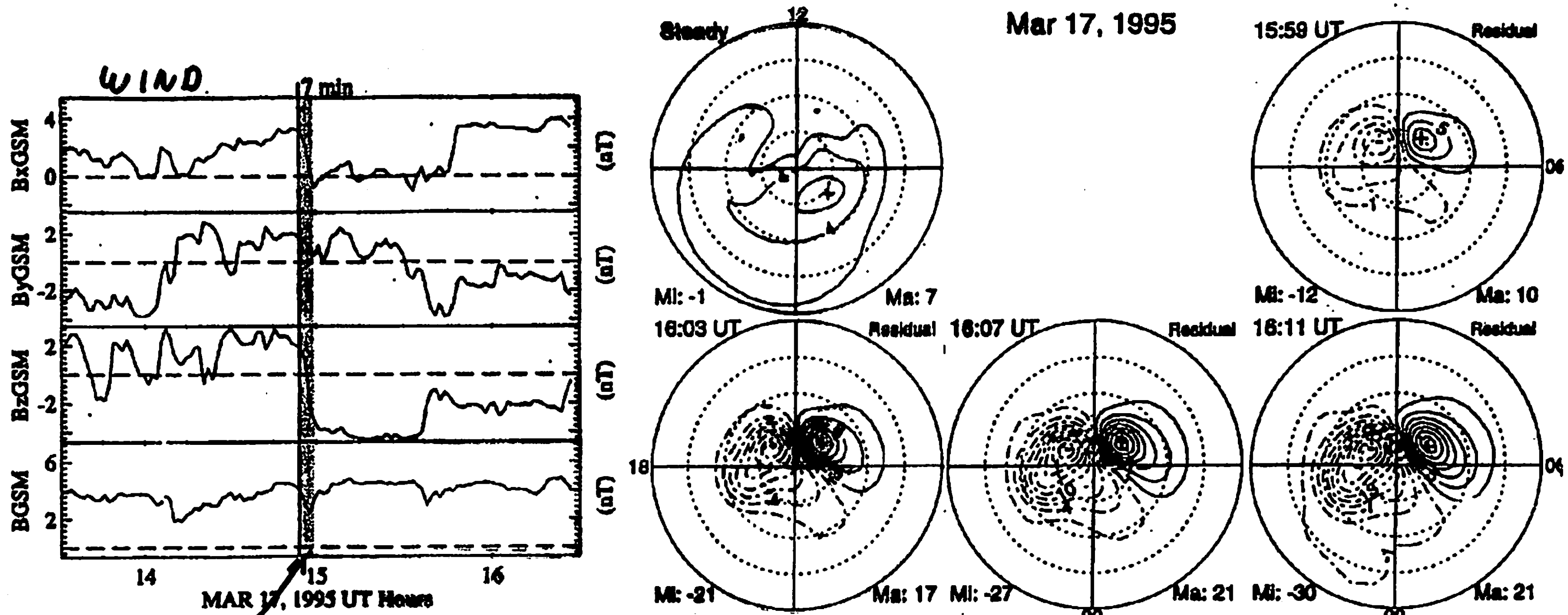


08/16/94 (FITTED)
CONTOUR FROM -30000. TO 30000. CONTOUR INTERVAL OF 10000. PT(3,3)= 9889.9

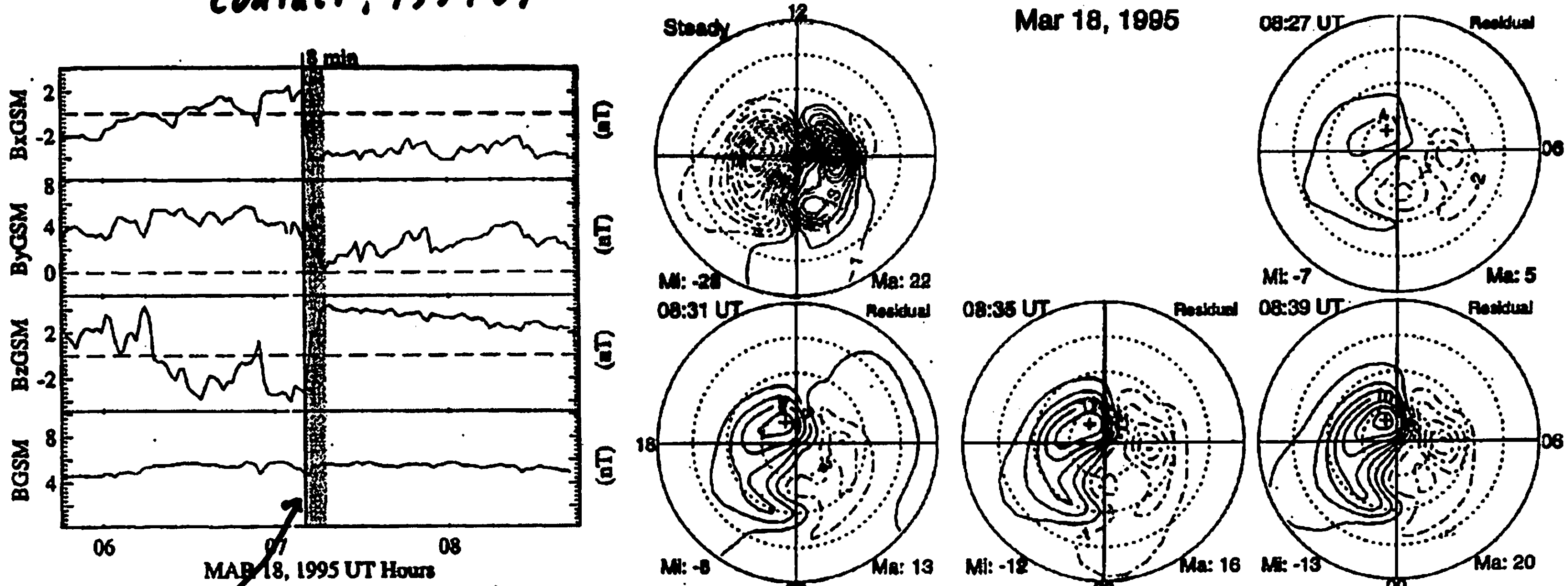


1989 Jan 12-13
1830-0700 UT
Bx ~ 7
By ~ 0
Bz ~ 0
Northern hemisphere
Δφ ~ 15kV
12
18
06
00
60°
70°
80°
-10 kV
0 kV
F9
0644
0502
0320
0140
2358
2217
2036
1853
F8
0607
0426
0244
0103
2321
2139
1957
Plasma sheet-polar rain boundary
Inner edge soft electron zone
C Plasma sheet-cusp boundary
Cusp/mantle
Soft electron zone
Intermittent weak polar-cap arcs
A—A Polar-cap arc
Southern hemisphere
Δφ ~ 25 kV
-60°
-70°
-80°
-15 kV
5 kV
F8
1909
2051
1946
2130
2233
0013
0154
0655
0334
0515
F9
2311
0052
0233
0413
0553
0655
A

Ridley et al. [1998]



Estimated magnetopause contact; 1554 UT



Estimated magnetopause contact 0820 UT

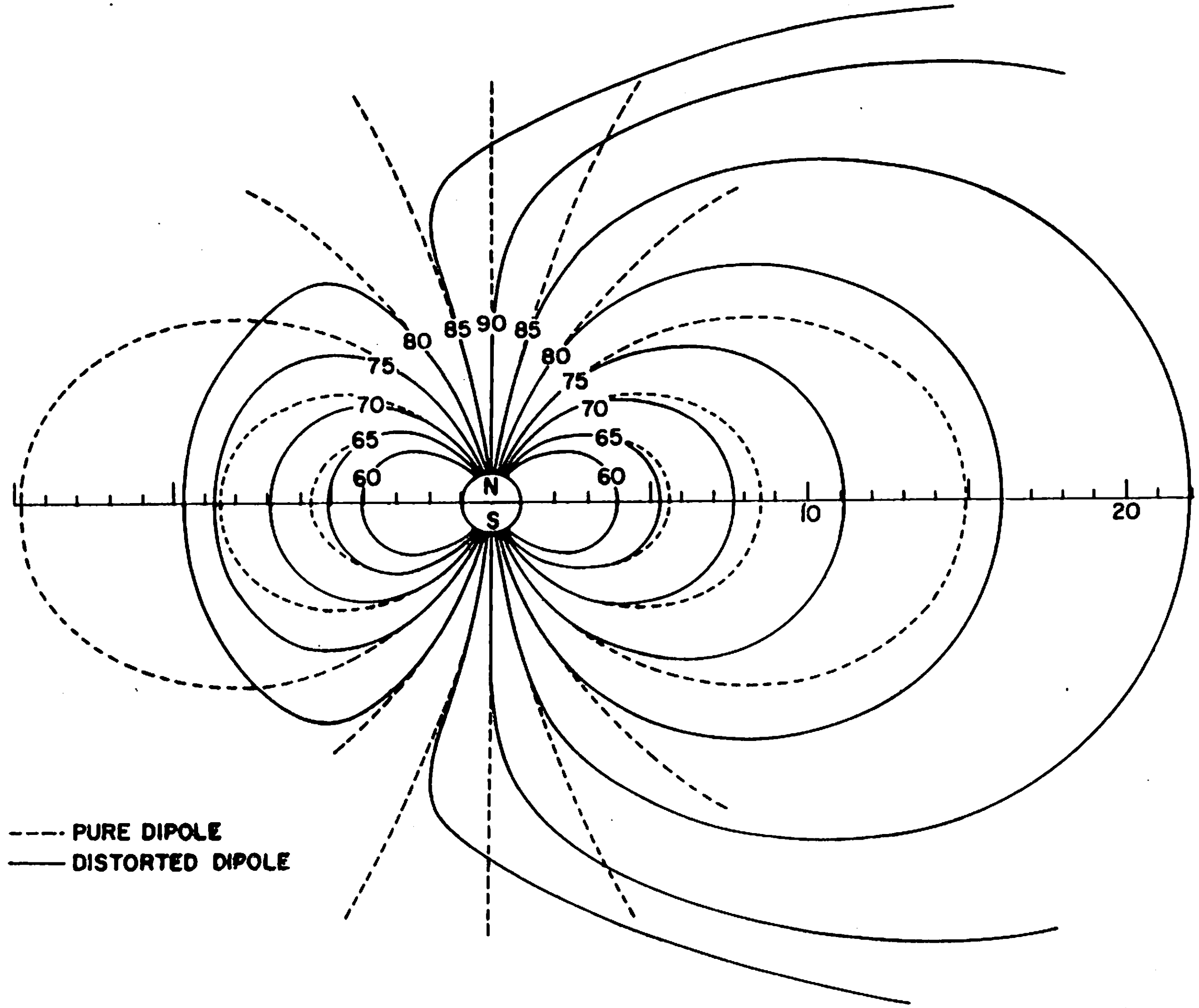


Fig. 4. Field line configuration in the noon-midnight meridian plane. With r_b = 10 earth radii, the critical latitude is about 83°. The dipole lines are compressed on both the daytime and nighttime side.

Pilipp and Morfill [1978]

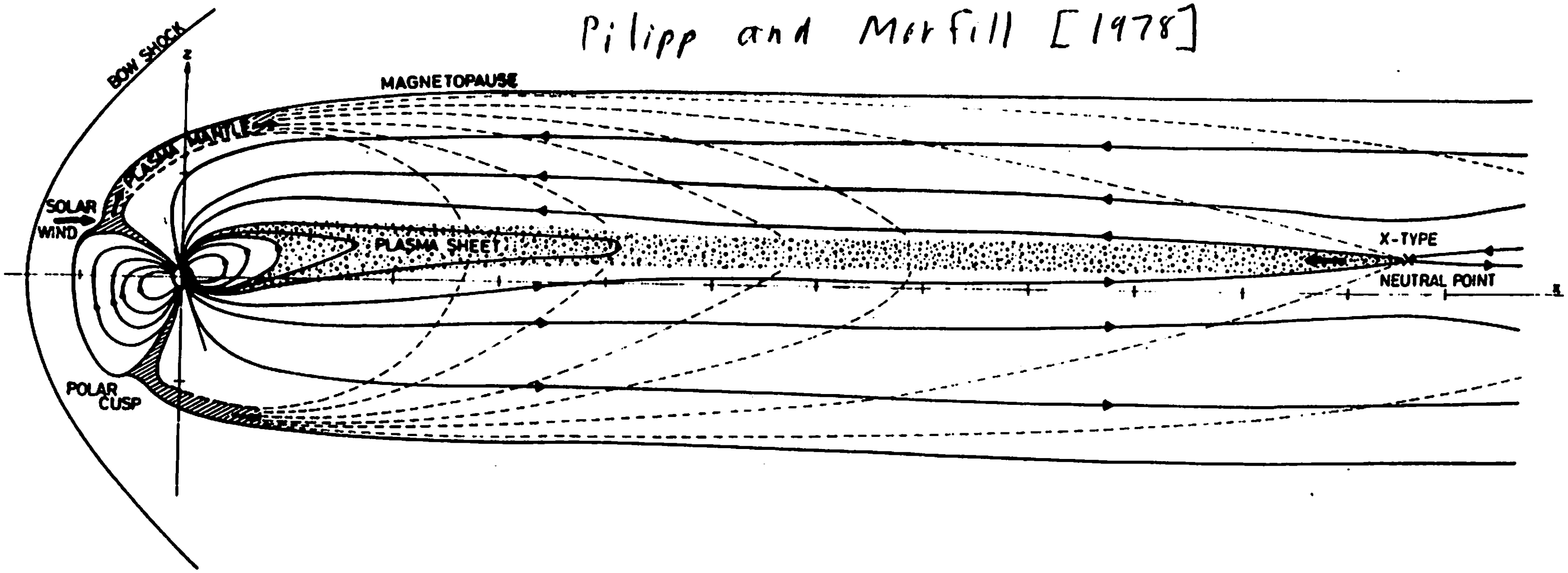


Fig. 1. Schematic diagram of the transport of mantle plasma onto the plasma sheet under the influence of the large-scale convection electric field. The mantle particles disperse and move along the dashed lines. Mantle plasma entering the field reversal region within the 'neutral point' becomes trapped and forms the plasma sheet. The magnetic field (solid lines) is depicted as an instantaneous snapshot of the quiet time configuration.

For average $\Delta\phi_{tail}$ ~ 50 kV

~ 2.7 hrs to move ~15 R_E from mantle to current sheet (tail width = 50 R_E, B_{lobe} = 15 nT)

Only particles with $V_{||}$ < 67 km/s reach current sheet earthward of X-line (x = -100 R_E)

Small fraction of mantle particles, since V_{mantle} ~ 150 km/s

For $\Delta\phi_{tail}$ ~ 120 kV

~ 1.1 hrs to reach curent sheet; particles with $V_{||}$ < 160 km/s enter earthward of X-line

Much larger fraction of mantle particles have access

Potential for greatly enhanced cross-tail current when have strong convection for >~1hrs (storm conditions)

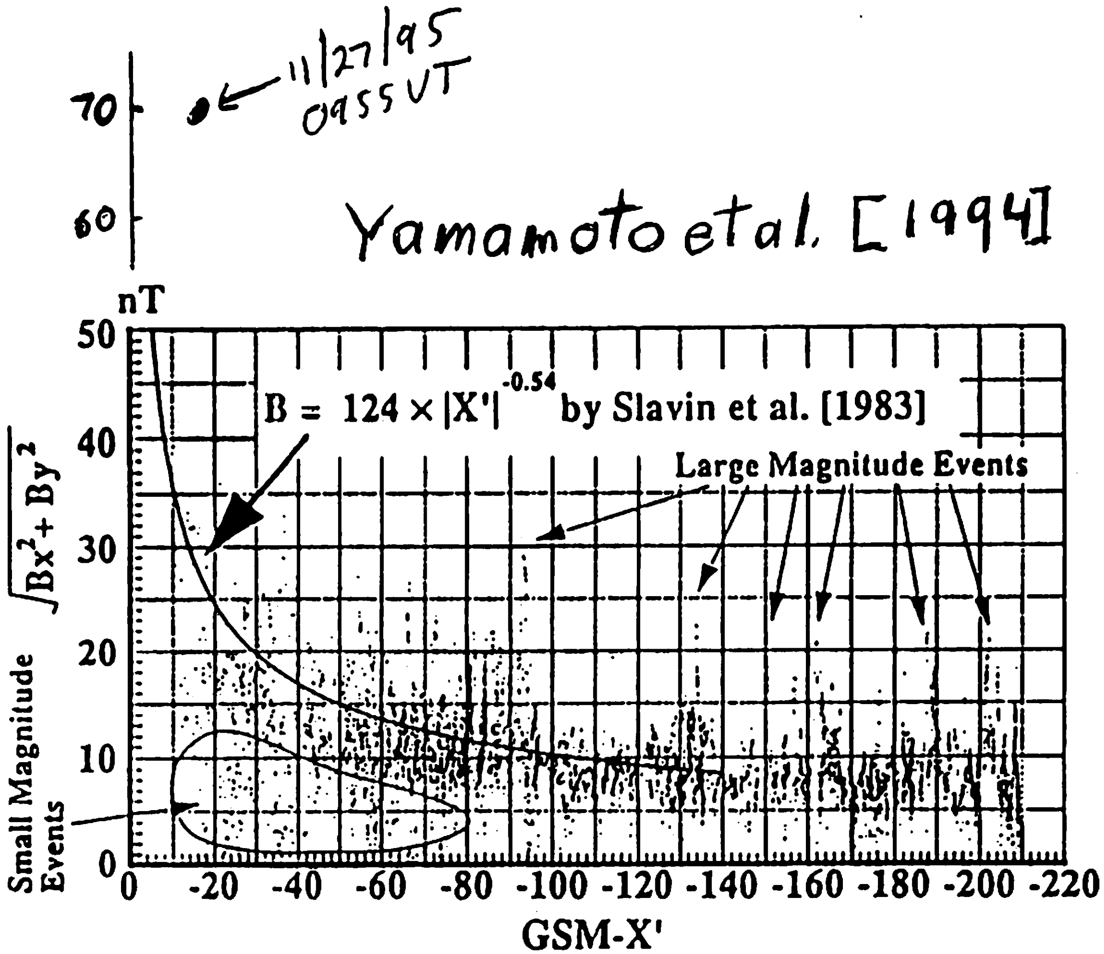
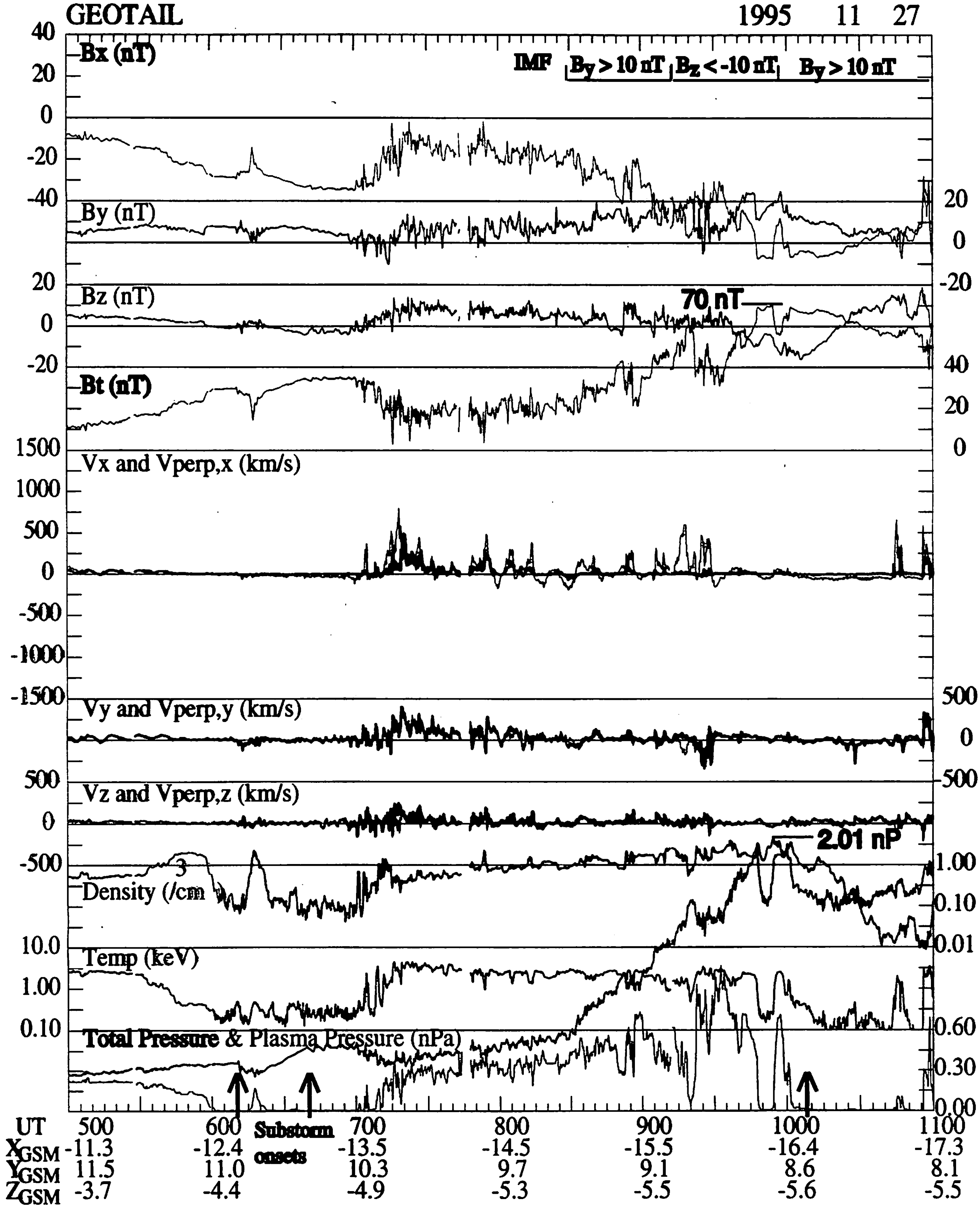
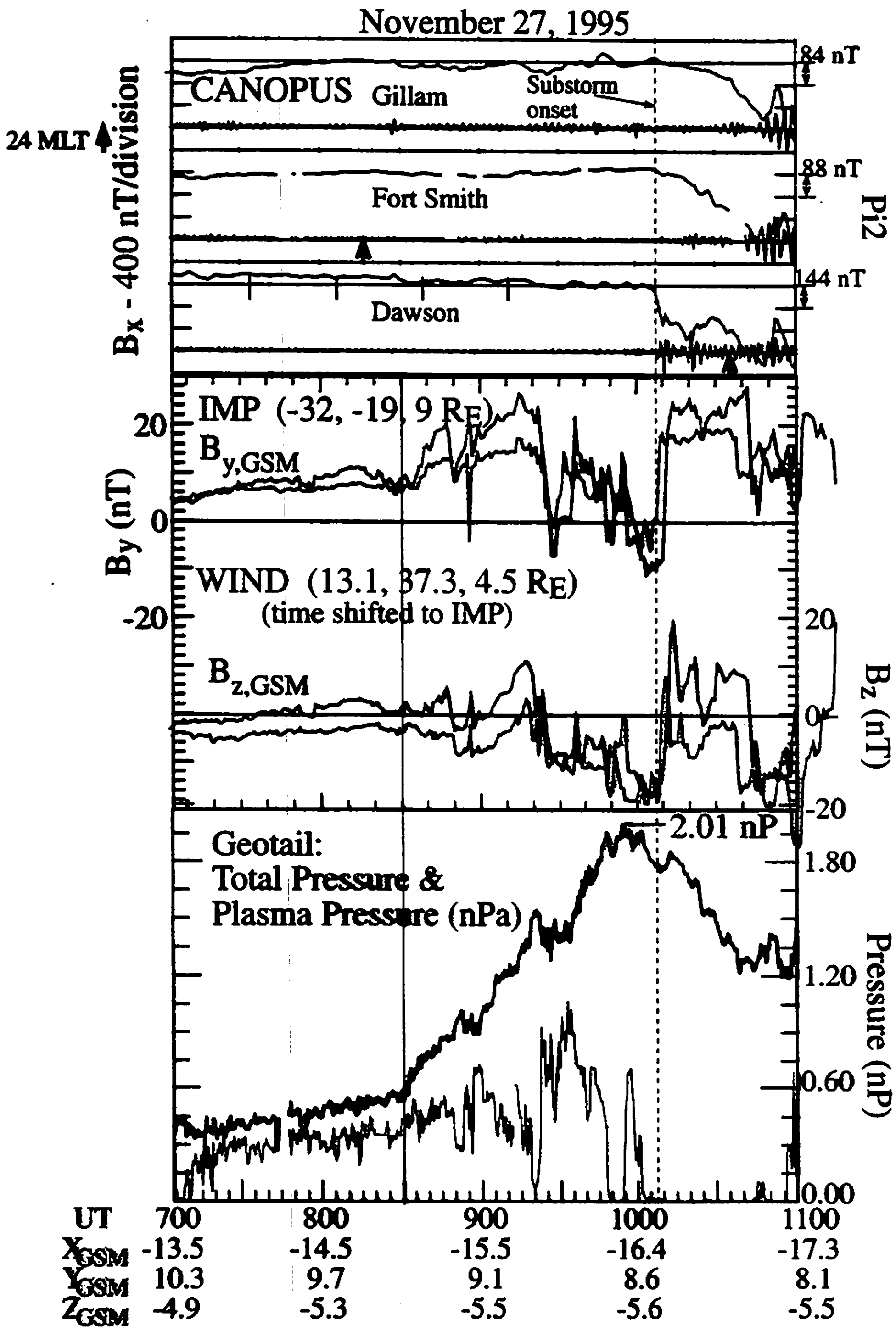
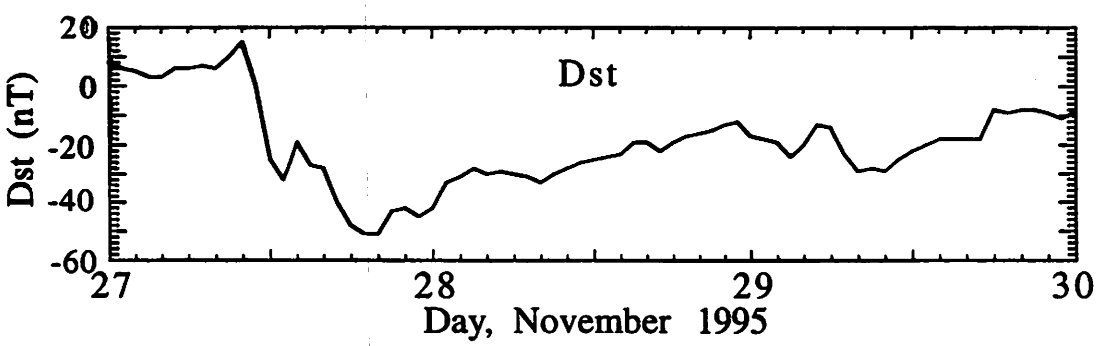


Figure 3. Magnitude of magnetic field in the *XY* plane as a function of *X'*. The empirical curve by *Slavin et al.* [1983] is drawn as a reference.


GEOTAIL
1995 11 27
Bx (nT)
IMF By > 10 nT Bz < -10 nT By > 10 nT
By (nT)
Bz (nT)
70 nT
Bt (nT)
Vx and Vperp,x (km/s)
Vy and Vperp,y (km/s)
Vz and Vperp,z (km/s)
2.01 nP
Density (/cm3
Temp (keV)
Total Pressure & Plasma Pressure (nPa)
Substorm onsets
UT 500 600 700 800 900 1000 1100
XGSM -11.3 -12.4 -13.5 -14.5 -15.5 -16.4 -17.3
YGSM 11.5 11.0 10.3 9.7 9.1 8.6 8.1
ZGSM -3.7 -4.4 -4.9 -5.3 -5.5 -5.6 -5.5


November 27, 1995
CANOPUS
Gillam
Substorm onset
24 MLT
84 nT
Fort Smith
88 nT
Pi2
Dawson
144 nT
B_x - 400 nT/division
IMP (-32, -19, 9 R_E)
$B_{y,GSM}$
B_y (nT)
20
0
-20
WIND (13.1, 37.3, 4.5 R_E)
(time shifted to IMP)
$B_{z,GSM}$
B_z (nT)
20
0
-20
Geotail:
Total Pressure &
Plasma Pressure (nPa)
2.01 nP
1.80
1.20
0.60
0.00
Pressure (nP)
UT 700 800 900 1000 1100
X_{GSM} -13.5 -14.5 -15.5 -16.4 -17.3
Y_{GSM} 10.3 9.7 9.1 8.6 8.1
Z_{GSM} -4.9 -5.3 -5.5 -5.6 -5.5


Dst
Dst (nT)
20
0
-20
-40
-60
27
28
29
30
Day, November 1995

IMF effects strength of convection and probably solar wind plasma access

How does this lead to geomagnetic activity?

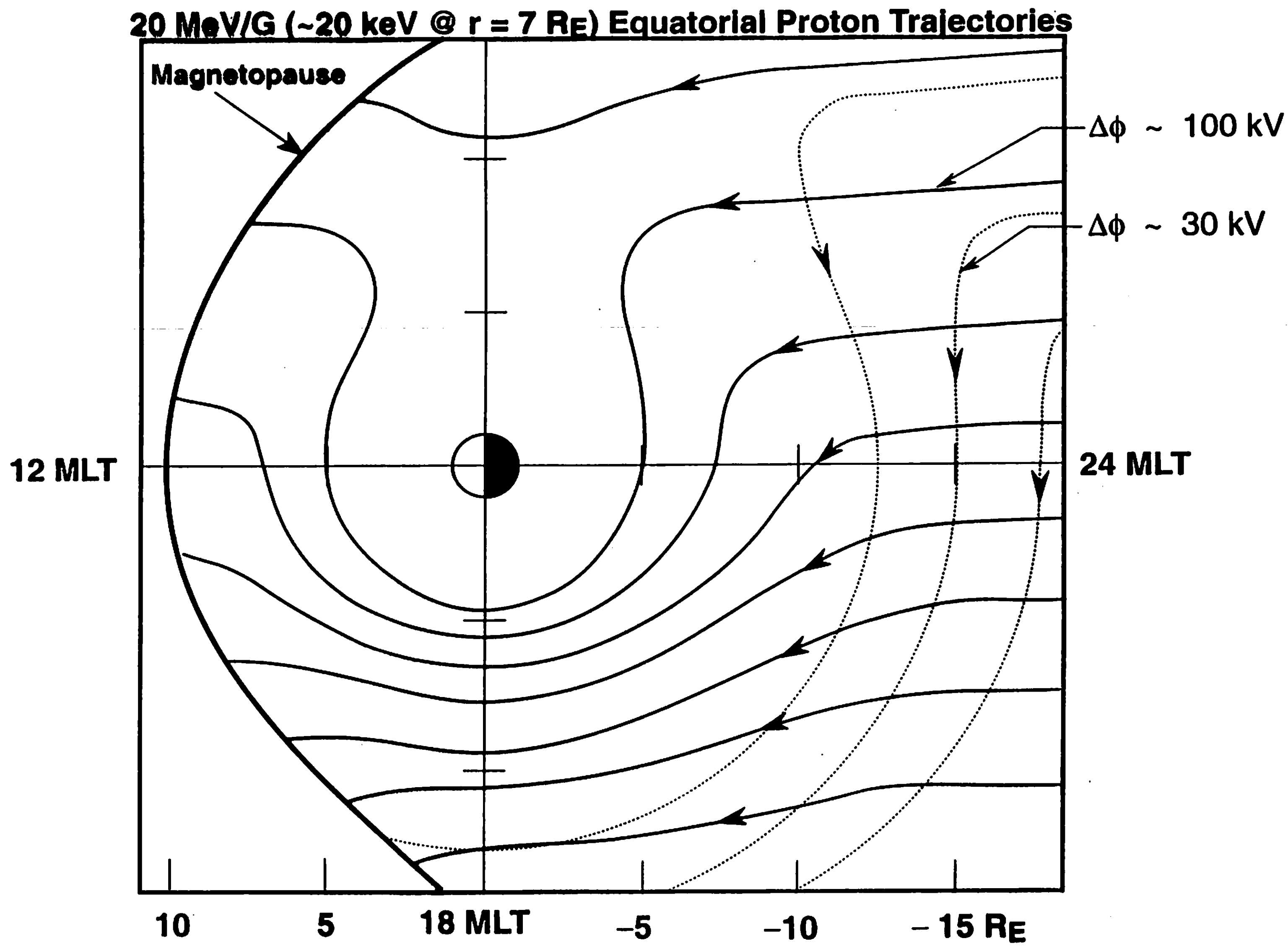
— Get enhanced **J•E** within tail and ionosphere

— High β of plasma sheet greatly modifies **B**

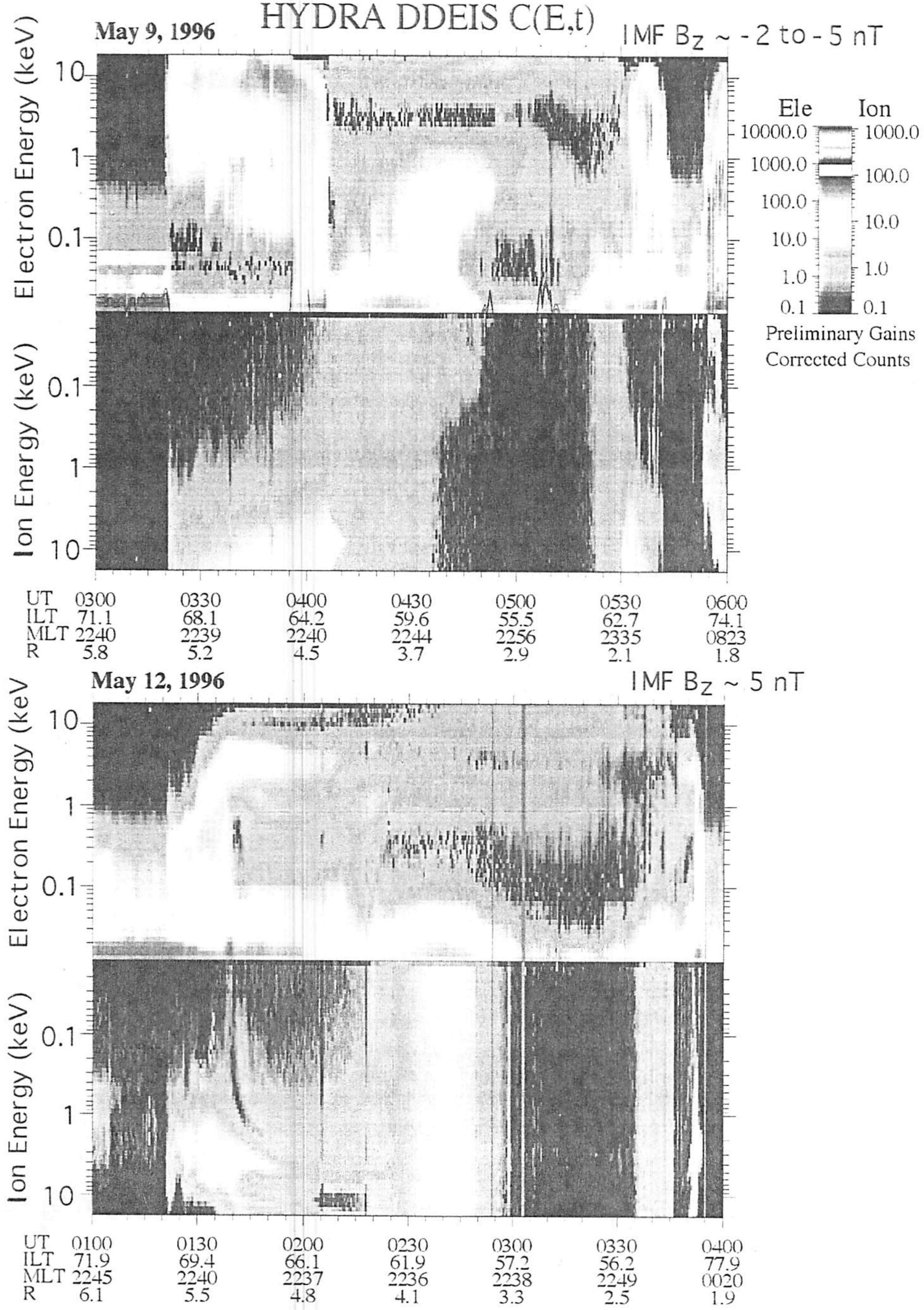
— Get enhanced plasma and magnetic energies

Largest plasma pressure and B changes at r ~ 6-10 R_E

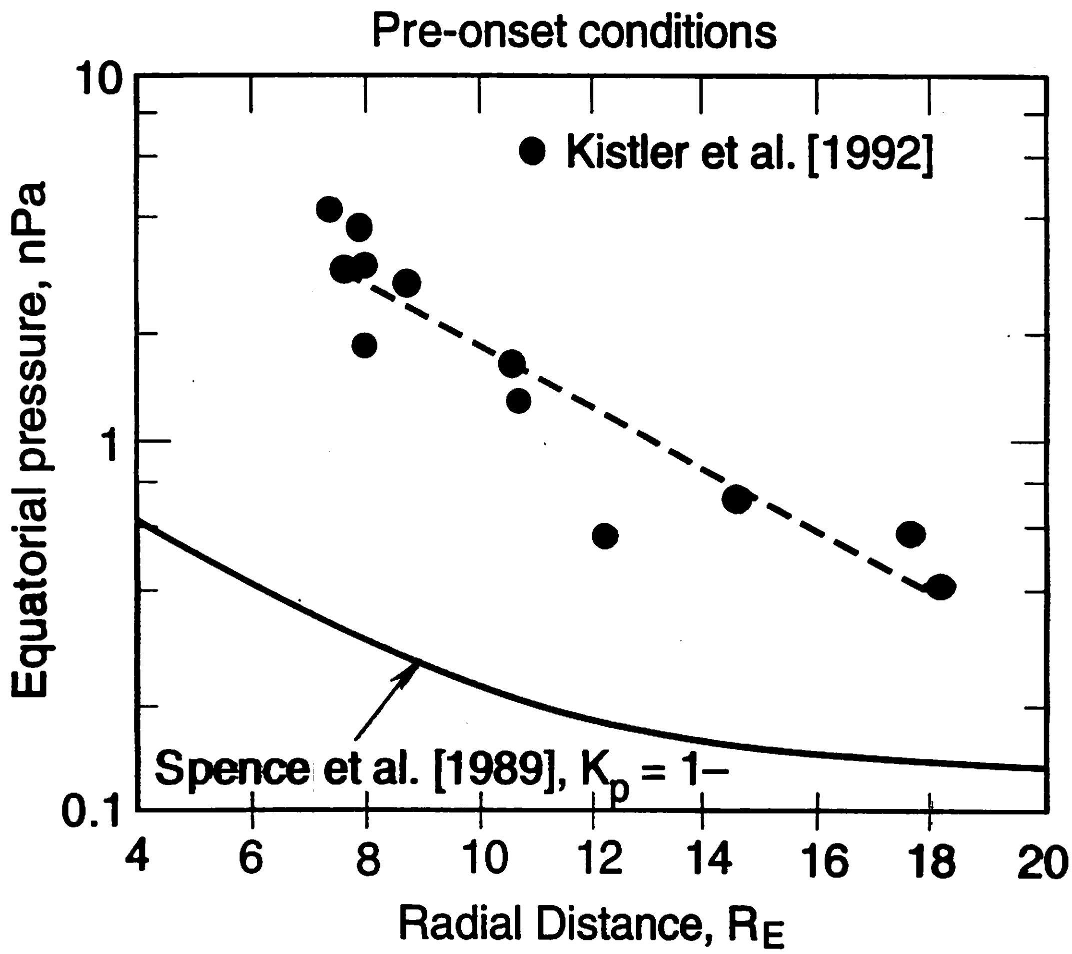
— Due to earthward motion of plasma sheet driven by enhanced **E**



20 MeV/G (~20 keV @ r = 7 RE) Equatorial Proton Trajectories
Magnetopause
Δφ ~ 100 kV
Δφ ~ 30 kV
12 MLT
24 MLT
10
5
18 MLT
−5
−10
− 15 RE



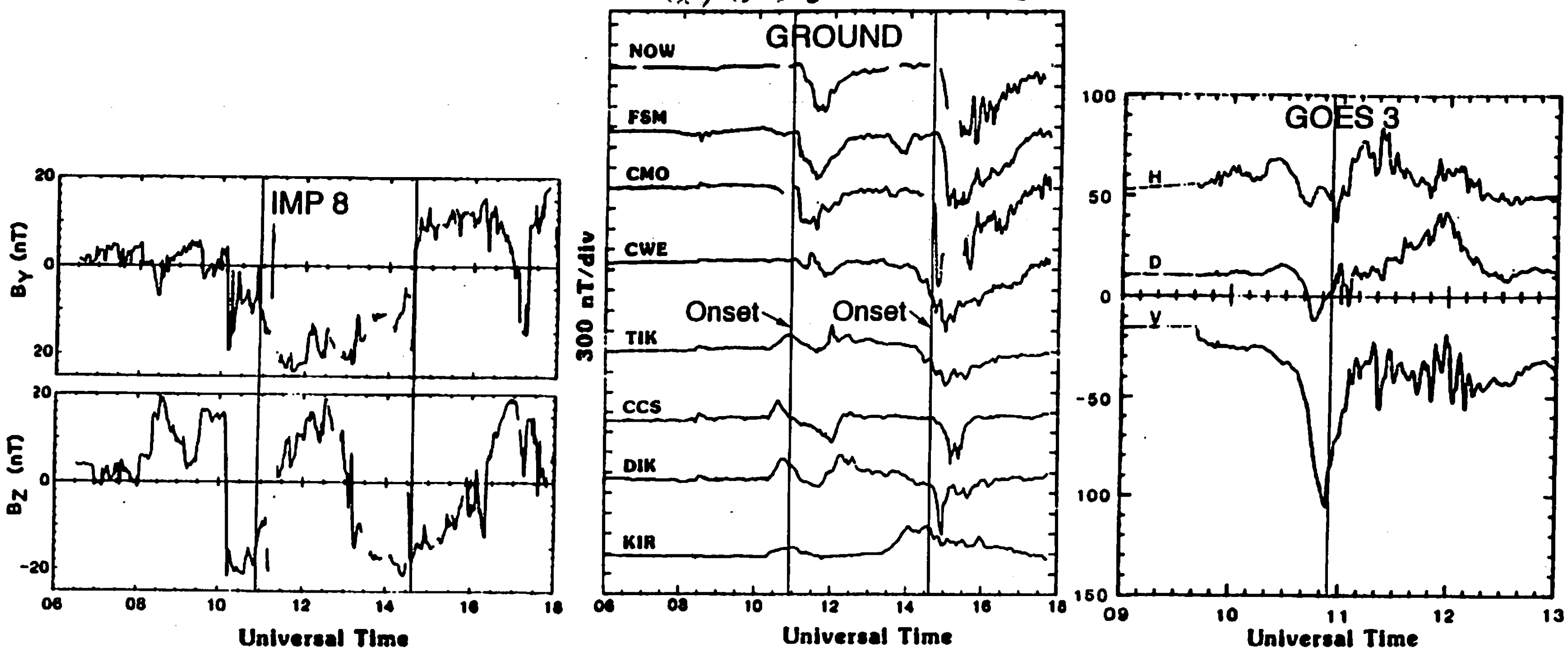
HYDRA DDEIS C(E,t)
May 9, 1996
IMF B_Z ~ -2 to -5 nT
Electron Energy (keV)
Ion Energy (keV)
Ele
Ion
10000.0
1000.0
100.0
10.0
1.0
0.1
Preliminary Gains
Corrected Counts
UT 0300 0330 0400 0430 0500 0530 0600
ILT 71.1 68.1 64.2 59.6 55.5 62.7 74.1
MLT 2240 2239 2240 2244 2256 2335 0823
R 5.8 5.2 4.5 3.7 2.9 2.1 1.8
May 12, 1996
IMF B_Z ~ 5 nT
Electron Energy (keV
Ion Energy (keV)
UT 0100 0130 0200 0230 0300 0330 0400
ILT 71.9 69.4 66.1 61.9 57.2 56.2 77.9
MLT 2245 2240 2237 2236 2238 2249 0020
R 6.1 5.5 4.8 4.1 3.3 2.5 1.9



Pre-onset conditions
10
1
0.1
Equatorial pressure, nPa
● Kistler et al. [1992]
Spence et al. [1989], K$_p$ = 1–
4
6
8
10
12
14
16
18
20
Radial Distance, R$_E$

McPherron and Manka [1985]

March 22, 1979



Geomagnetic Disturbances: Identification; relation to plasma sheet

Plasma sheet ions, electrons pitch-angle scattered and precipitate

- Resulting auroral emissions excellent for identifying geomagnetic disturbances & determining relation to time evolution of plasma sheet

Will use data from CANOPUS meridian scanning photometers.

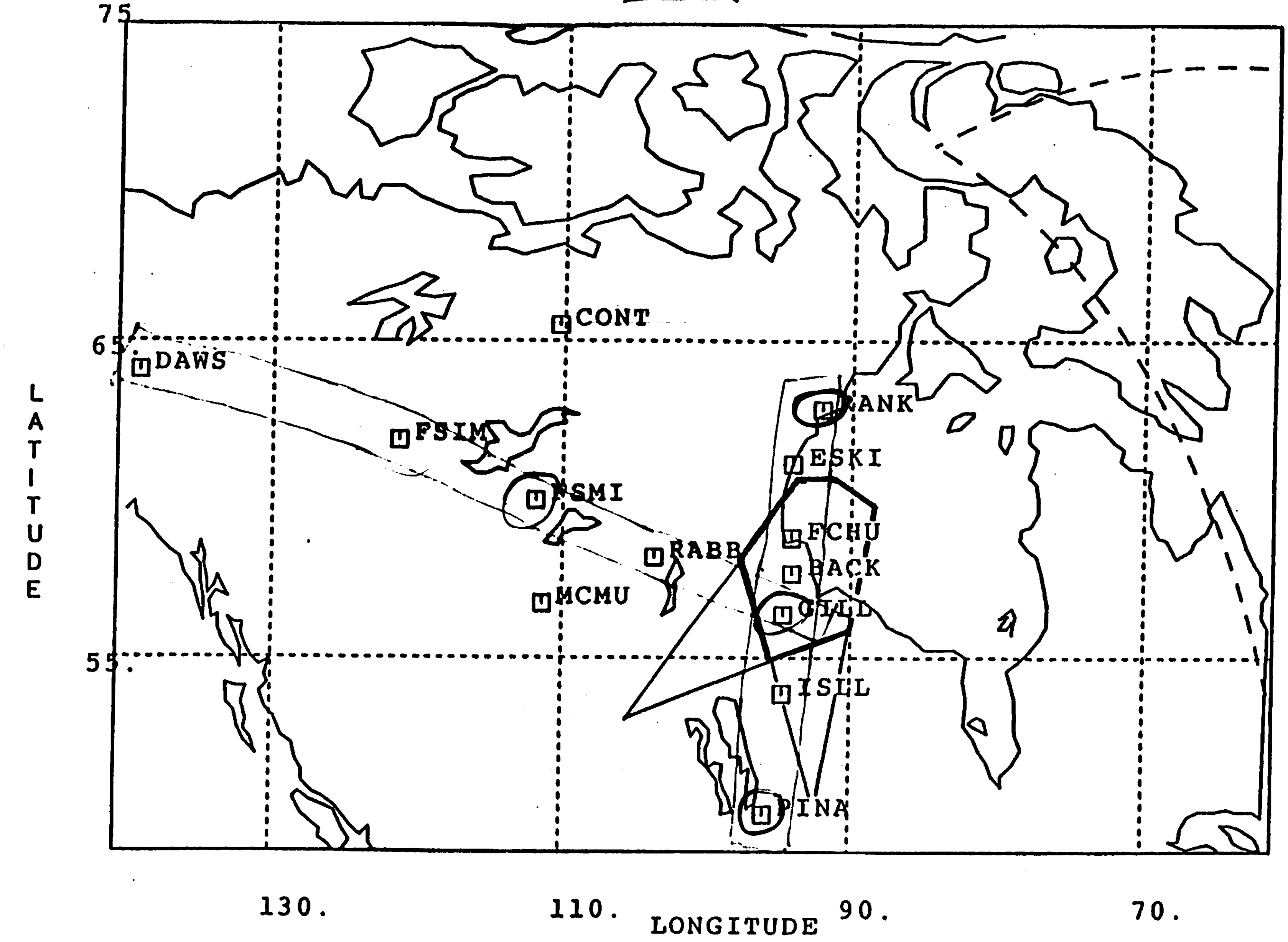
- **Hβ emissions** (proton precip.)
  - Identifies & locates ionospheric mapping of inner plasma sheet
- **6300 Å emissions** (< ~1 keV elec. precip.)
  - Identifies & locates latitude range of plasma sheet electrons
  - Poleward edge locates ionospheric mapping of separatrix (+/-1°, Blanchard et al. [1996])
- **5577 Å emissions** (> ~1 keV elec. precip.)
  - Identifies & locates auroral disturbances associated with geomagnetic activity

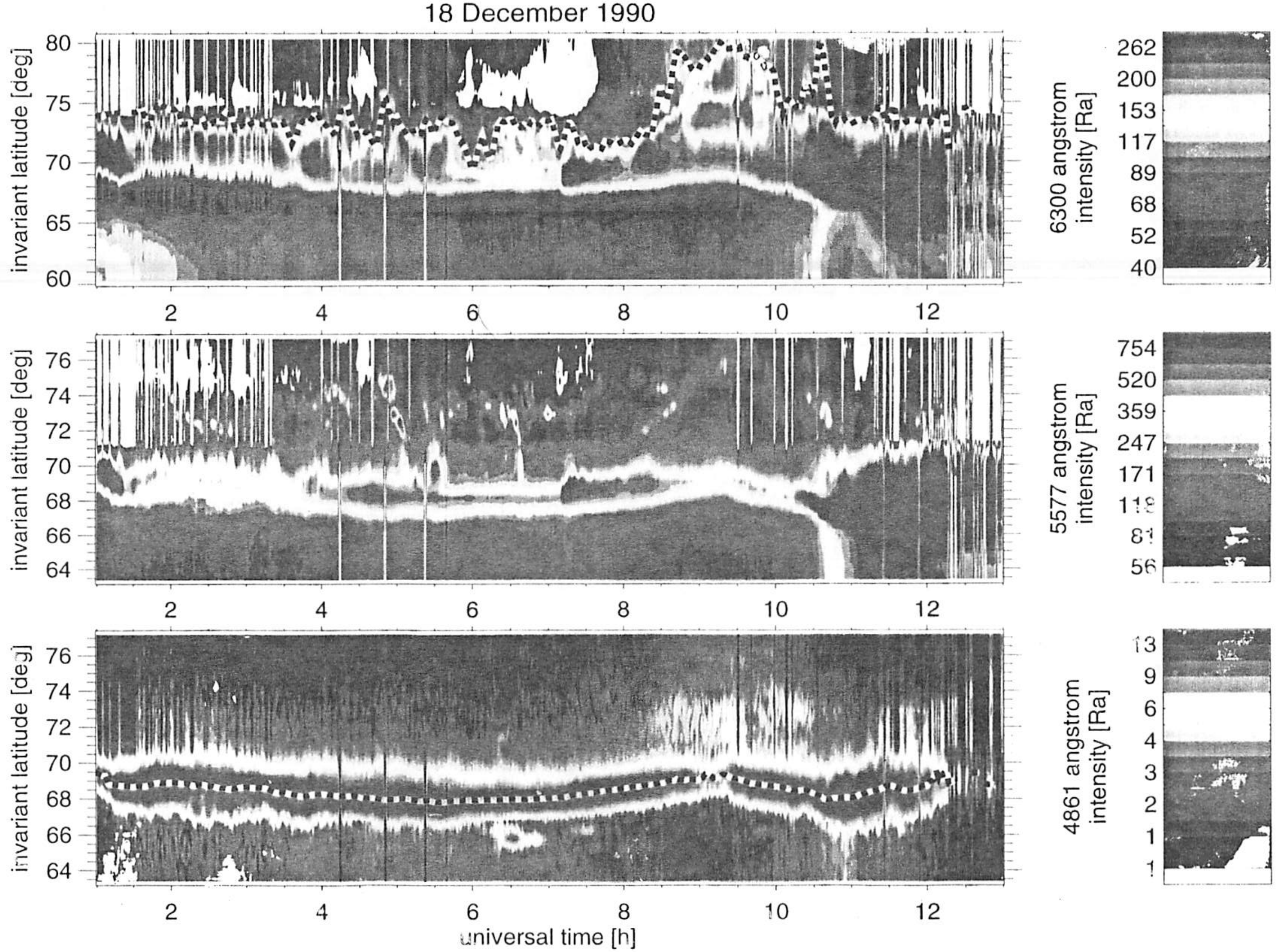
CANOPUS SITES

○ Meridian Scanning Photometers

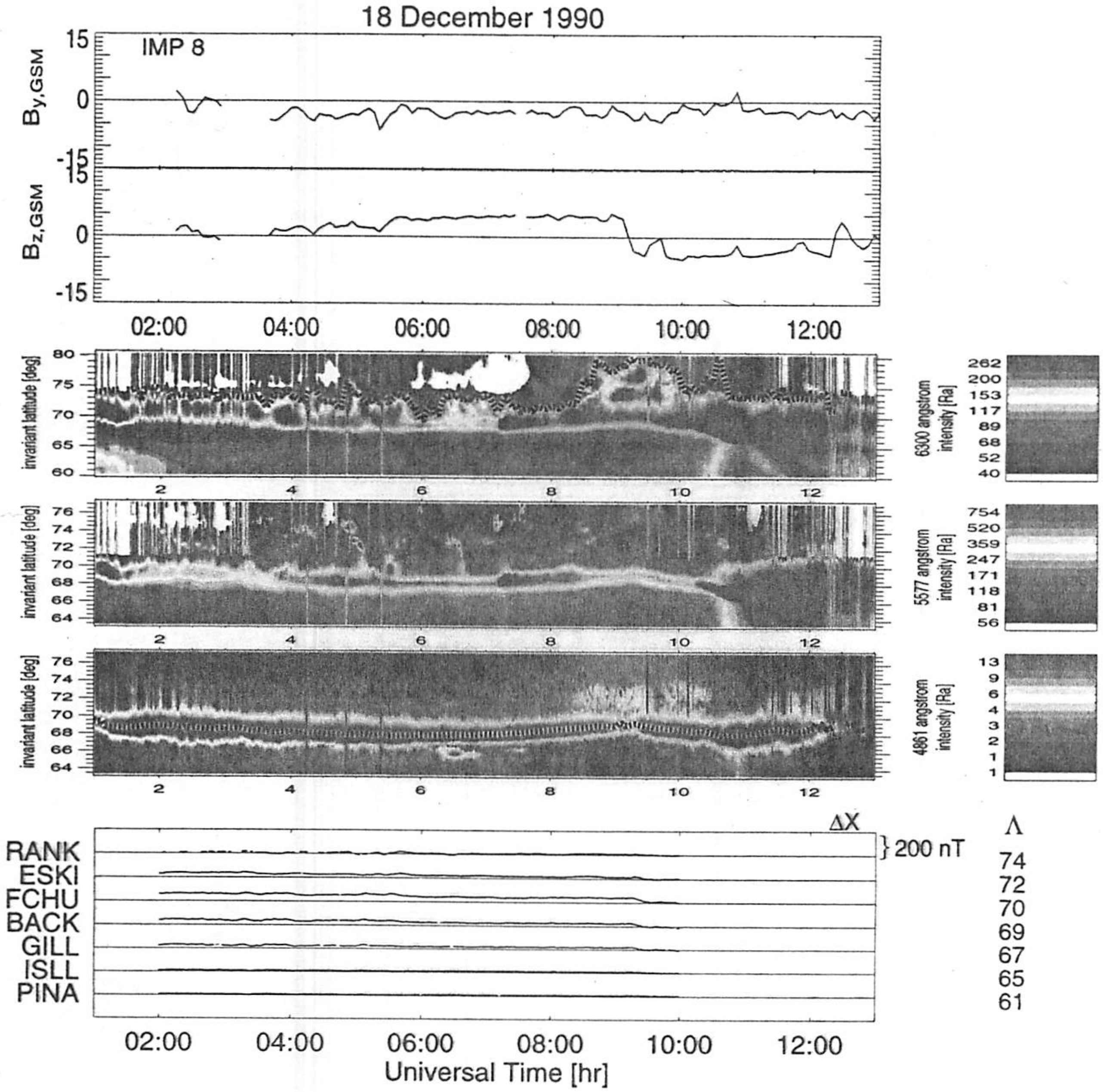
▯ N-S Magnetometer Chain

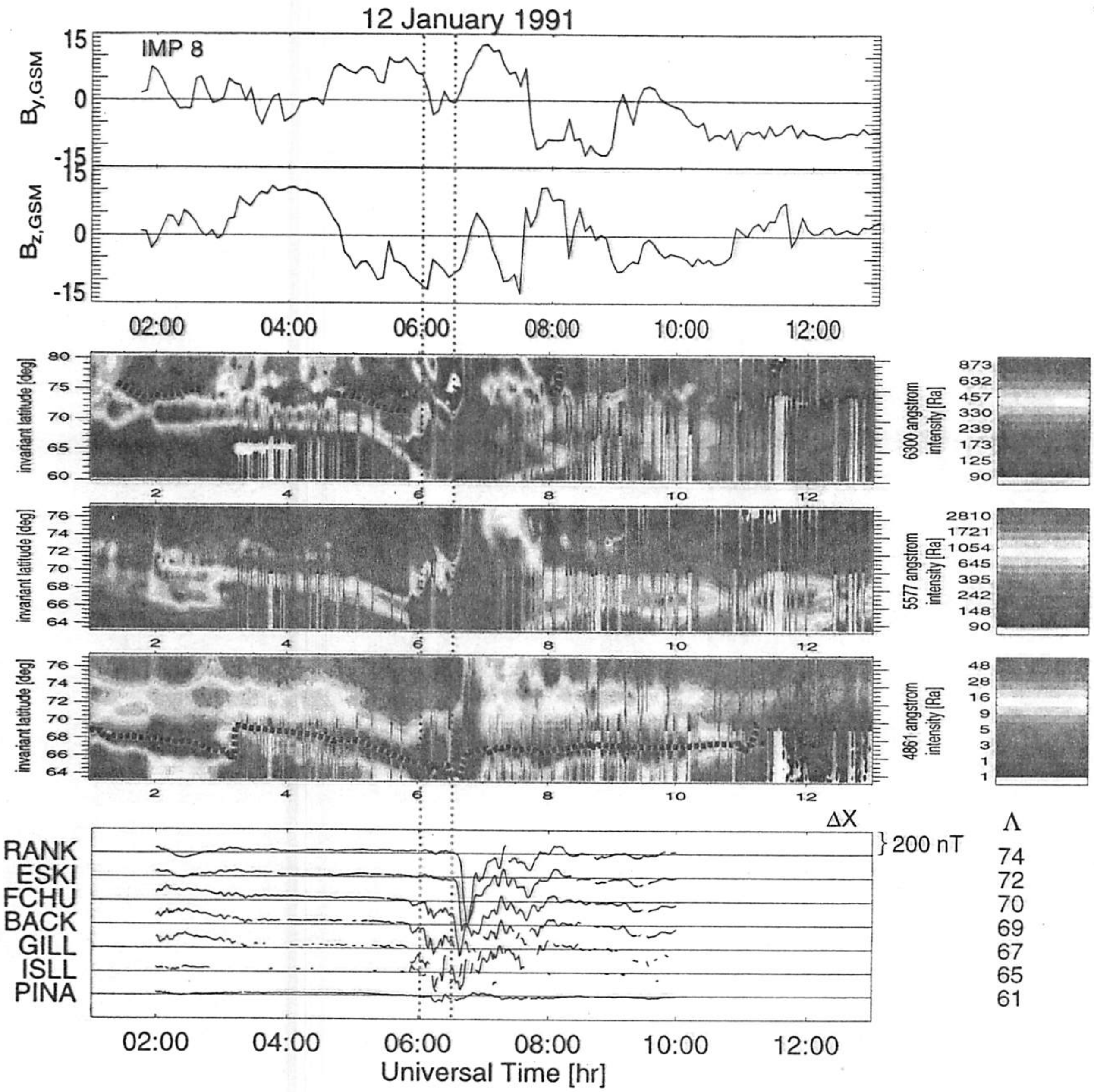
▭ E-W " "



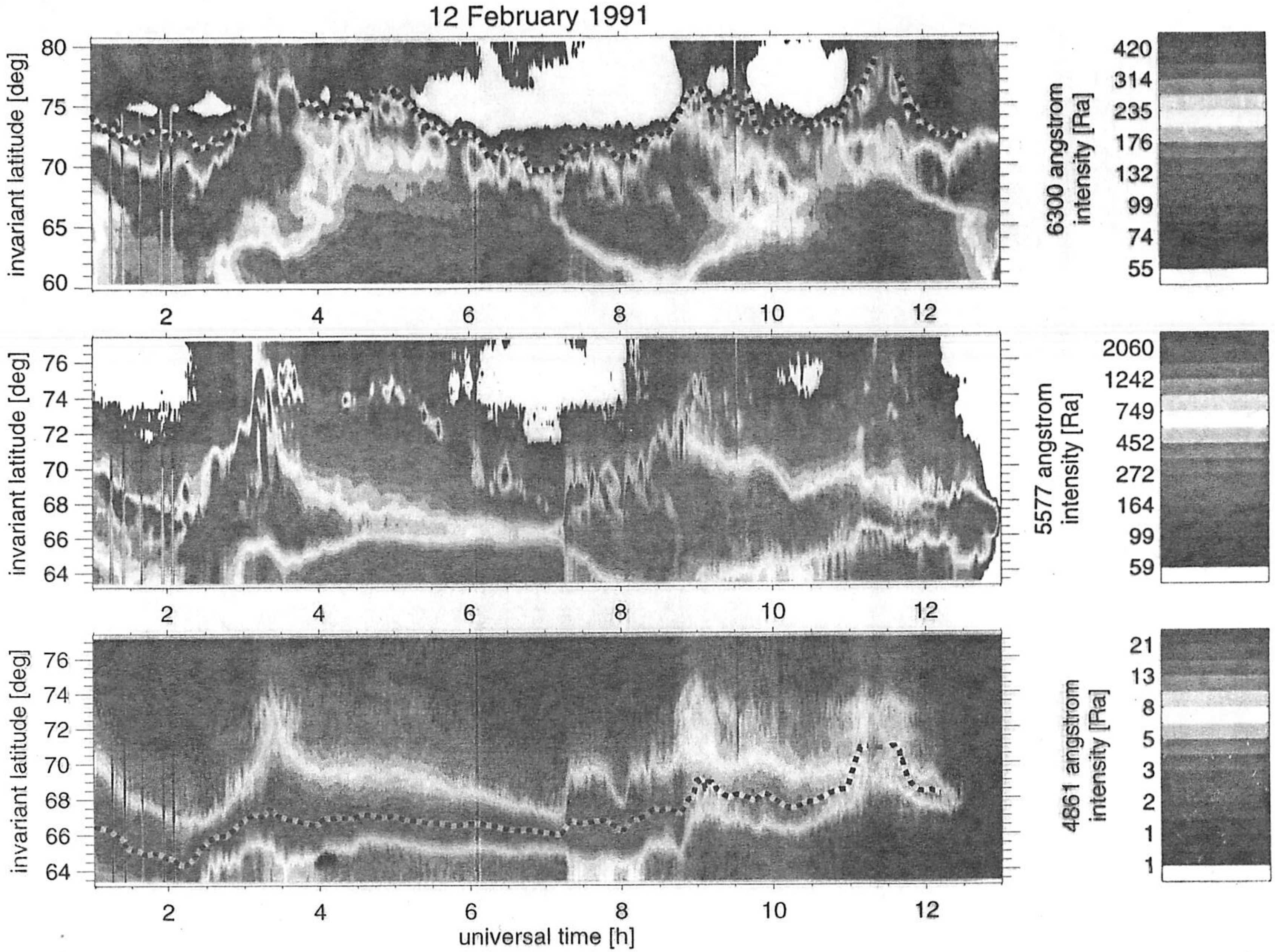


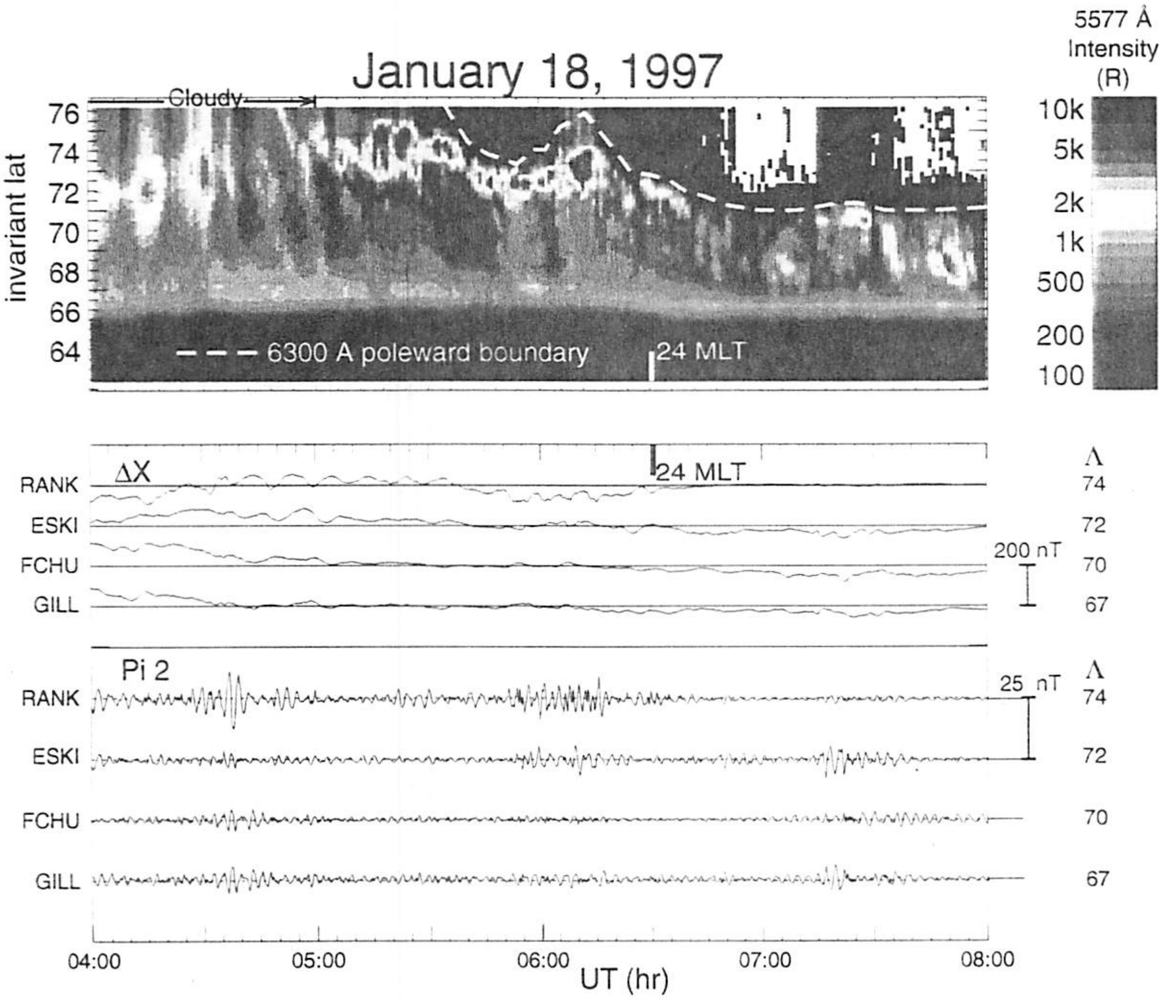
18 December 1990
invariant latitude [deg]
universal time [h]
6300 angstrom intensity [Ra]
5577 angstrom intensity [Ra]
4861 angstrom intensity [Ra]


18 December 1990
IMP 8
$B_{y,GSM}$
$B_{z,GSM}$
15
0
-15
02:00
04:00
06:00
08:00
10:00
12:00
invariant latitude [deg]
6300 angstrom intensity [Ra]
262
200
153
117
89
68
52
40
5577 angstrom intensity [Ra]
754
520
359
247
171
118
81
56
4861 angstrom intensity [Ra]
13
9
6
4
3
2
1
1
ΔX
} 200 nT
Λ
RANK 74
ESKI 72
FCHU 70
BACK 69
GILL 67
ISLL 65
PINA 61
Universal Time [hr]



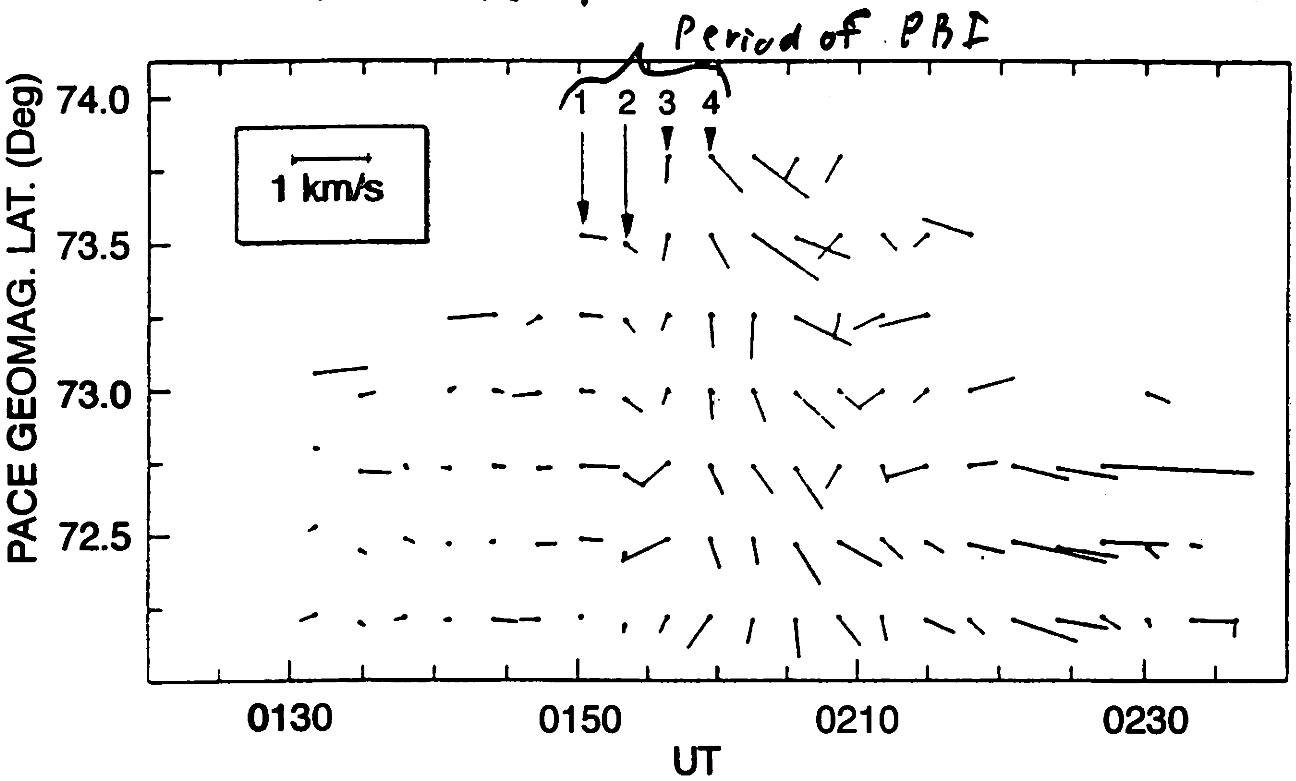
12 January 1991
IMP 8
$B_{y,GSM}$
15
0
-15
$B_{z,GSM}$
-15
02:00
04:00
06:00
08:00
10:00
12:00
invariant latitude [deg]
6300 angstrom intensity [Ra]
873
632
457
330
239
173
125
90
5577 angstrom intensity [Ra]
2810
1721
1054
645
395
242
148
90
4861 angstrom intensity [Ra]
48
28
16
9
5
3
1
1
ΔX
} 200 nT
Λ
RANK 74
ESKI 72
FCHU 70
BACK 69
GILL 67
ISLL 65
PINA 61
Universal Time [hr]


12 February 1991
invariant latitude [deg]
6300 angstrom intensity [Ra]
420
314
235
176
132
99
74
55
5577 angstrom intensity [Ra]
2060
1242
749
452
272
164
99
59
4861 angstrom intensity [Ra]
21
13
8
5
3
2
1
1
universal time [h]



January 18, 1997
Cloudy
invariant lat
76
74
72
70
68
66
64
6300 A poleward boundary
24 MLT
5577 Å
Intensity
(R)
10k
5k
2k
1k
500
200
100
ΔX
RANK
ESKI
FCHU
GILL
200 nT
Λ
74
72
70
67
Pi 2
RANK
ESKI
FCHU
GILL
25 nT
Λ
74
72
70
67
04:00
05:00
06:00
07:00
08:00
UT (hr)

de la Beaujardière et al. [1994]



Poleward Boundary Intensifications (PBIs)

Active aurora initiates near separatrix, can then move equatorward.

Very common, individual events often $\lesssim$10 min apart.

Occur during **all levels of geomagnetic activity**.

Generally brightest feature in auroral zone

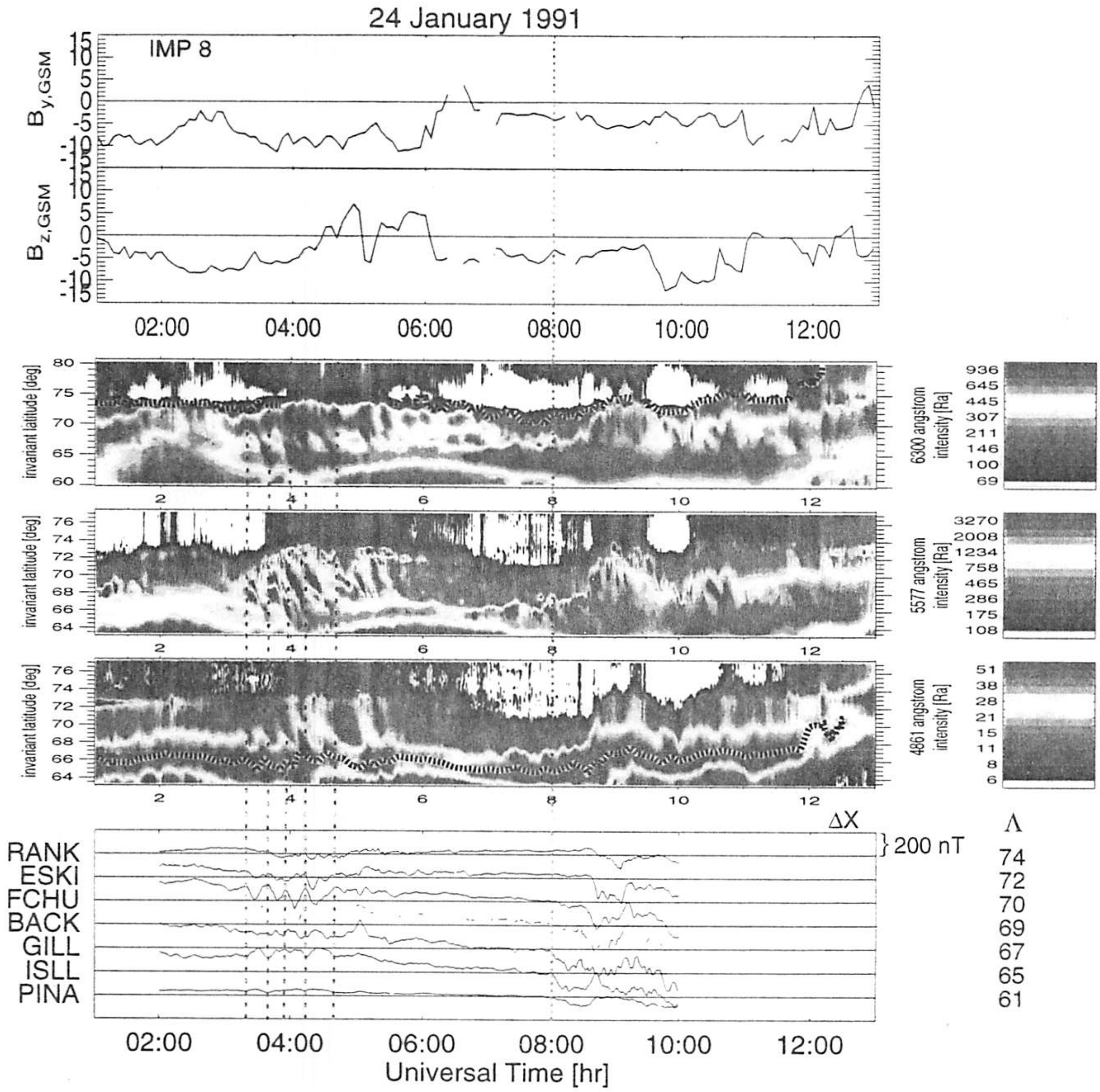
Associated few min flow bursts

— Equatorward in ionosphere [Sergeev et al., 1990; de la Beaujardière et al. 1994]

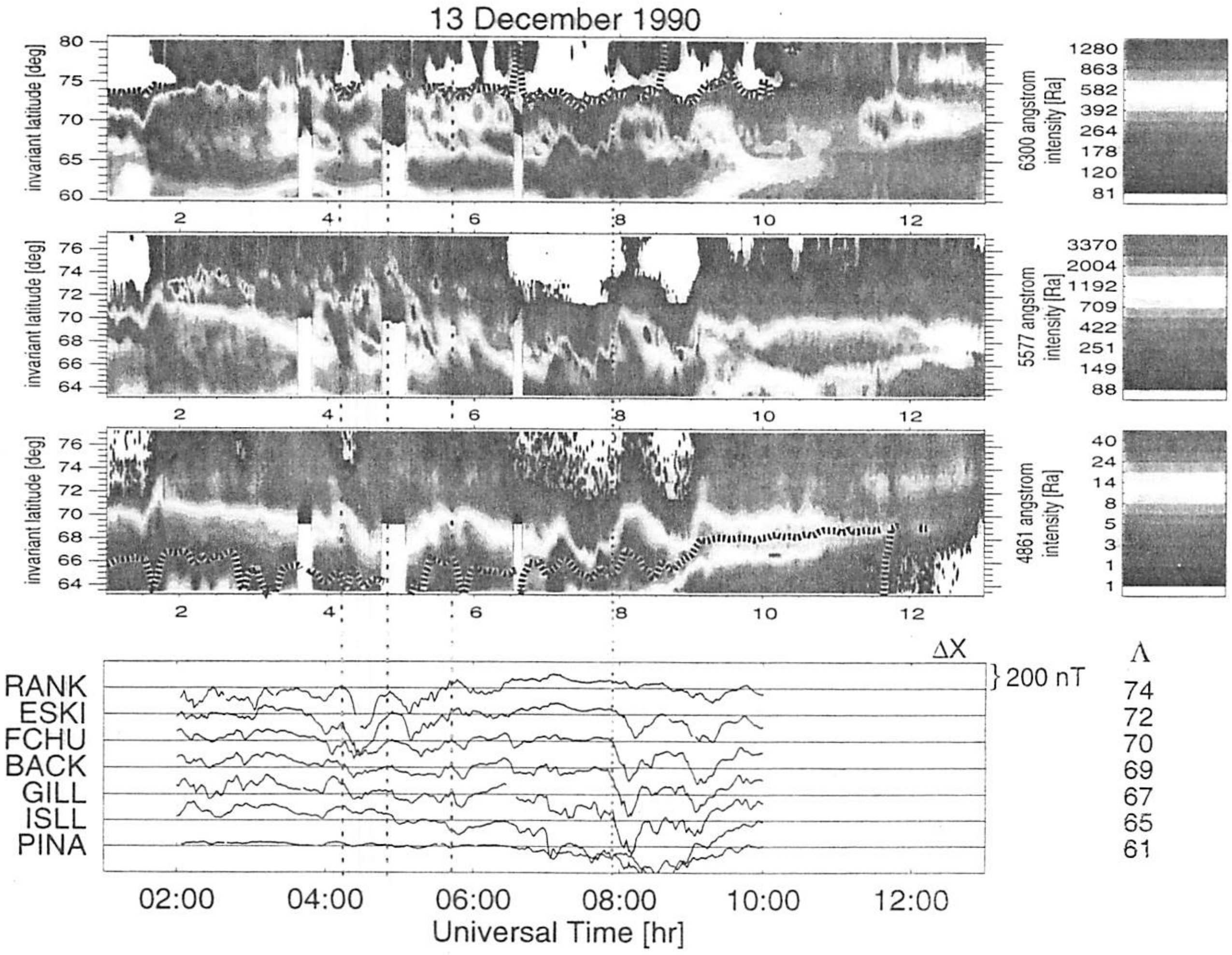
— Earthward in tail (i.e., BBF's) [Lyons et a., 1999]

PBIs not associated with substorms have **clear preference for radial IMF** [Zesta et al., 1998]

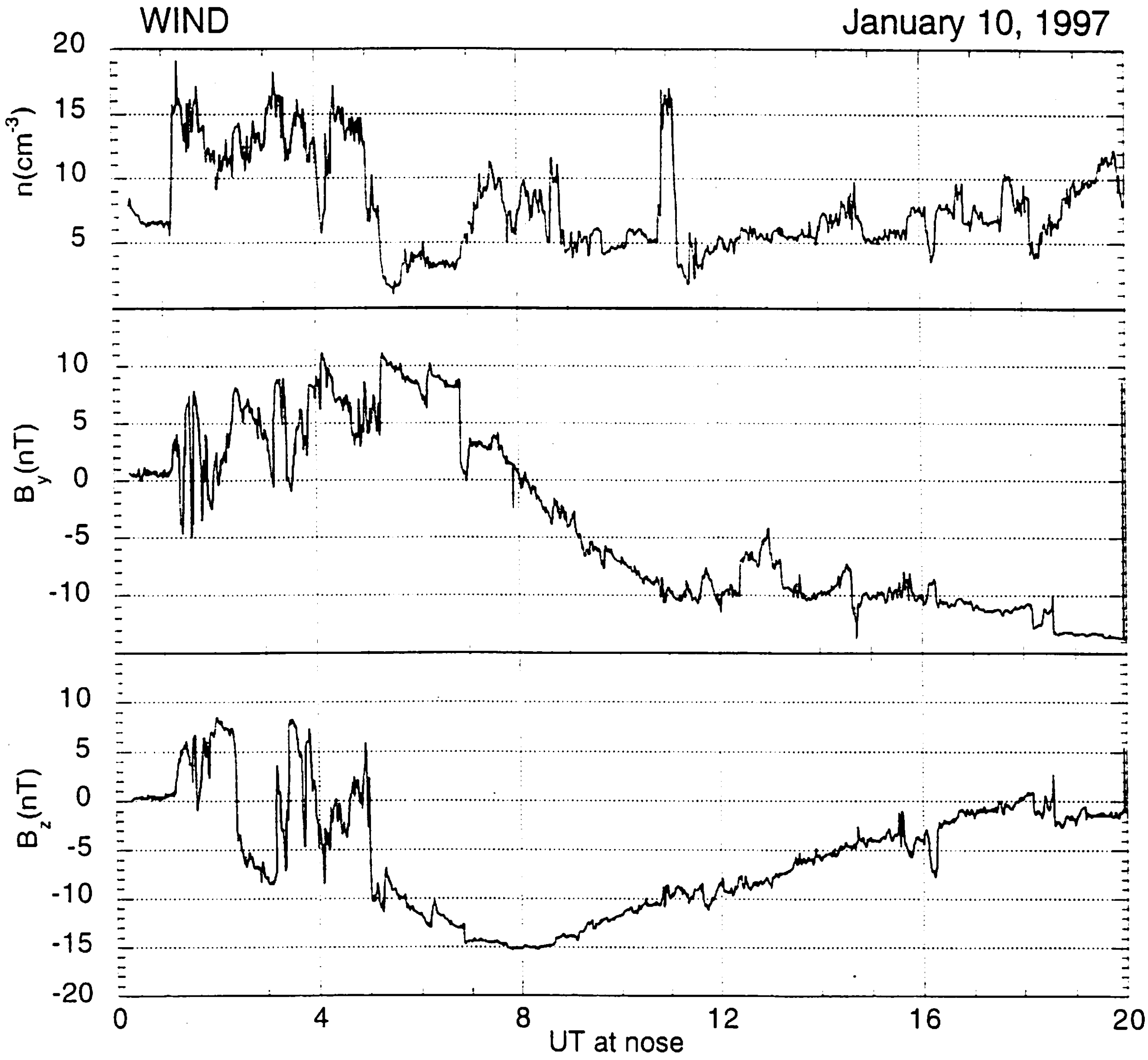
— Related to enhanced magnetosheath turbulence from quasi-parallel bow shock?

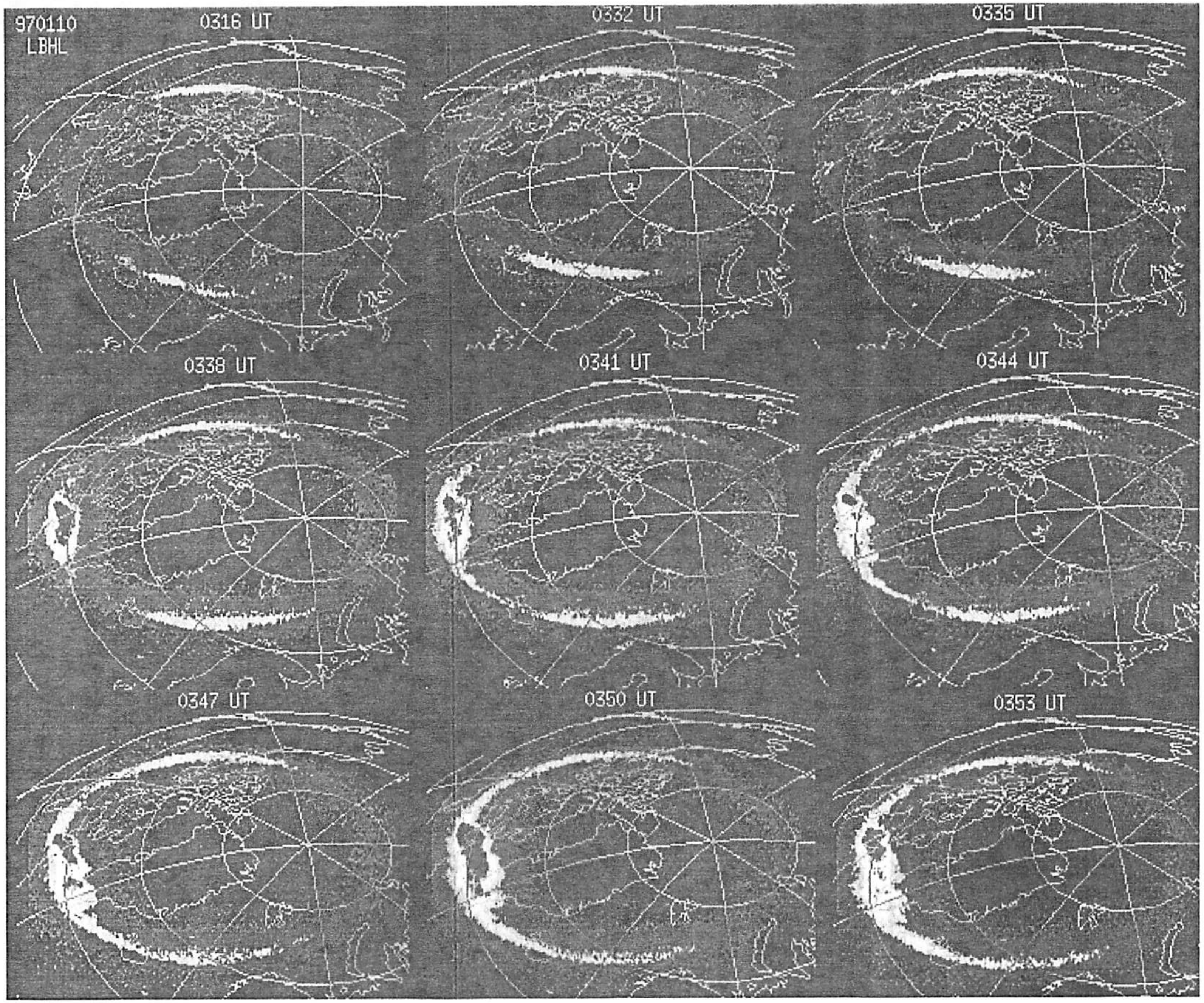


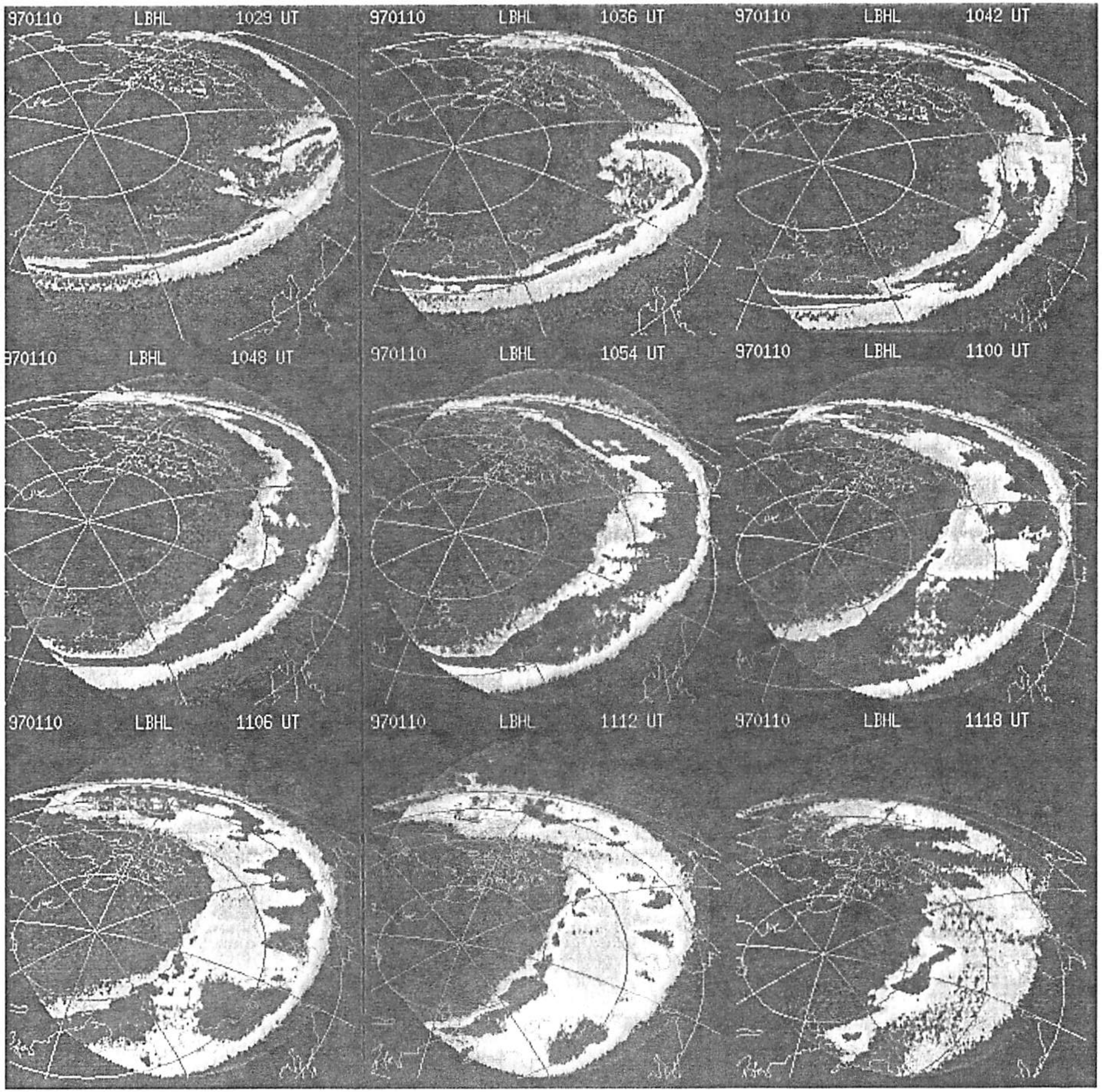
24 January 1991
IMP 8
$B_{y,GSM}$
$B_{z,GSM}$
02:00
04:00
06:00
08:00
10:00
12:00
invariant latitude [deg]
6300 angstrom intensity [Ra]
936
645
445
307
211
146
100
69
5577 angstrom intensity [Ra]
3270
2008
1234
758
465
286
175
108
4861 angstrom intensity [Ra]
51
38
28
21
15
11
8
6
ΔX
} 200 nT
Λ
RANK 74
ESKI 72
FCHU 70
BACK 69
GILL 67
ISLL 65
PINA 61
Universal Time [hr]



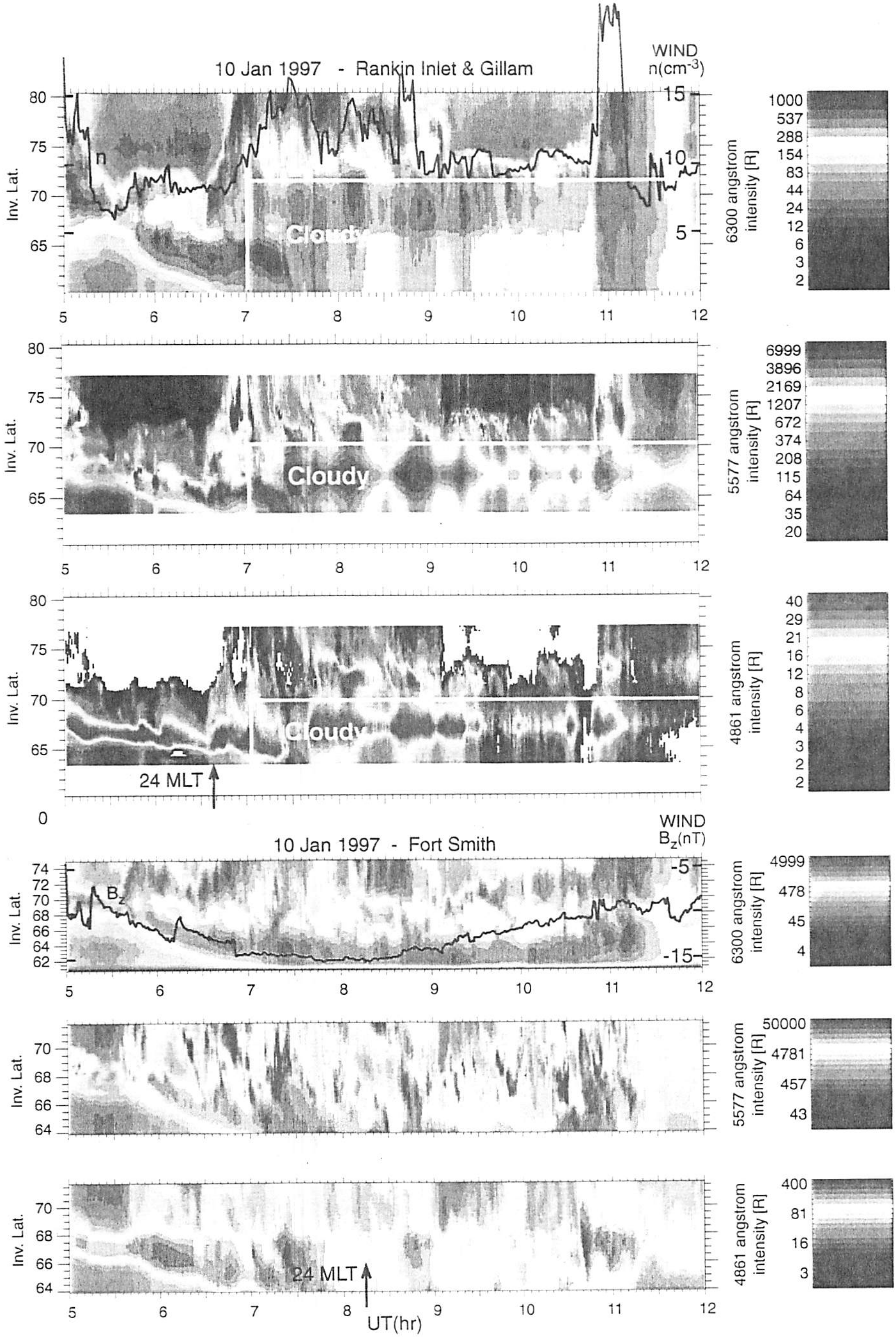
13 December 1990
invariant latitude [deg]
6300 angstrom intensity [Ra]
1280
863
582
392
264
178
120
81
5577 angstrom intensity [Ra]
3370
2004
1192
709
422
251
149
88
4861 angstrom intensity [Ra]
40
24
14
8
5
3
1
1
ΔX
} 200 nT
Λ
RANK 74
ESKI 72
FCHU 70
BACK 69
GILL 67
ISLL 65
PINA 61
02:00
04:00
06:00
08:00
10:00
12:00
Universal Time [hr]


WIND
January 10, 1997
n(cm^-3)
20
15
10
5
B_y (nT)
10
5
0
-5
-10
B_z (nT)
10
5
0
-5
-10
-15
-20
0
4
8
12
16
20
UT at nose


970110
LBHL
0316 UT
0332 UT
0335 UT
0338 UT
0341 UT
0344 UT
0347 UT
0350 UT
0353 UT

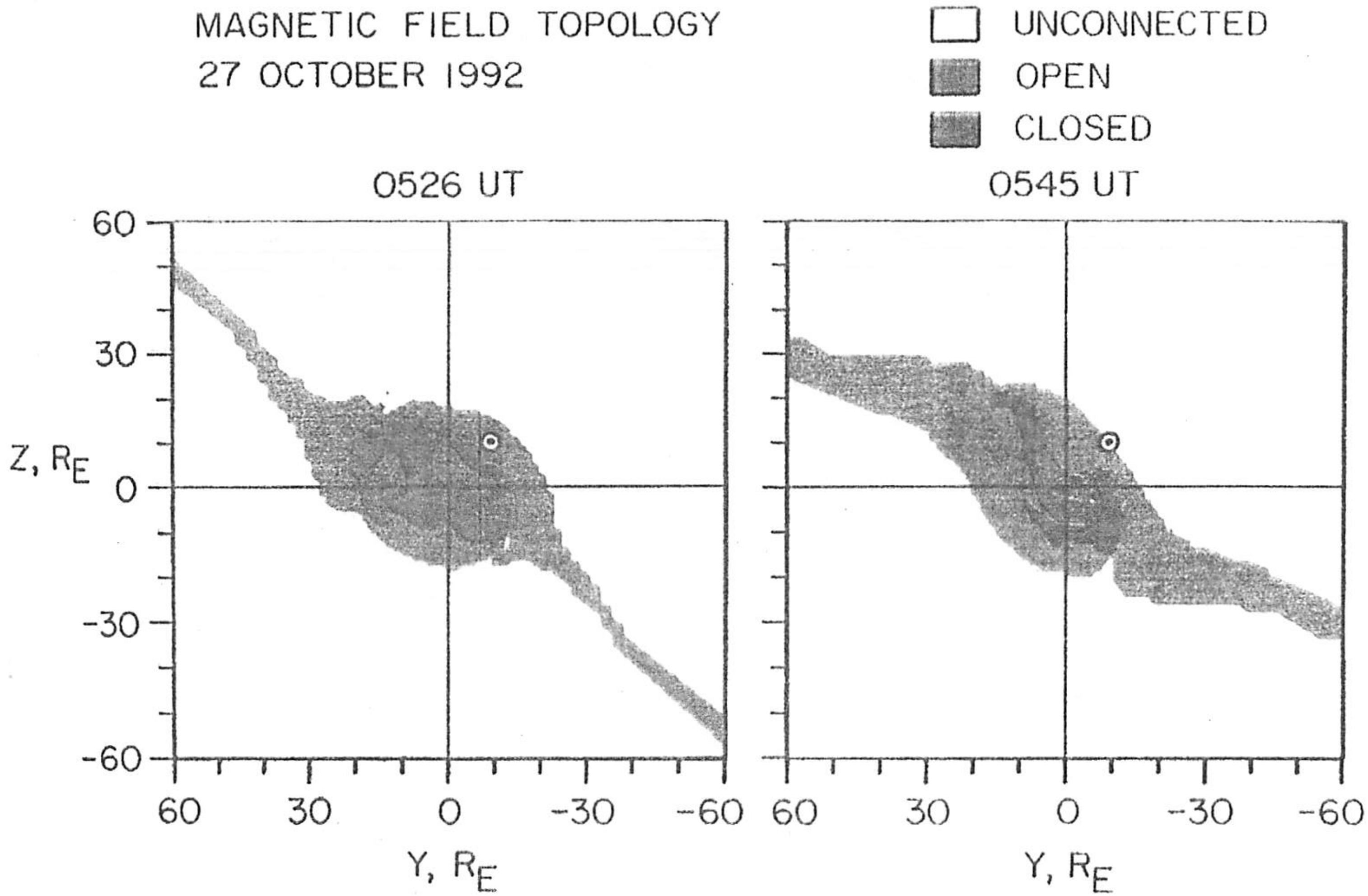


970110 LBHL 1029 UT
970110 LBHL 1036 UT
970110 LBHL 1042 UT
970110 LBHL 1048 UT
970110 LBHL 1054 UT
970110 LBHL 1100 UT
970110 LBHL 1106 UT
970110 LBHL 1112 UT
970110 LBHL 1118 UT

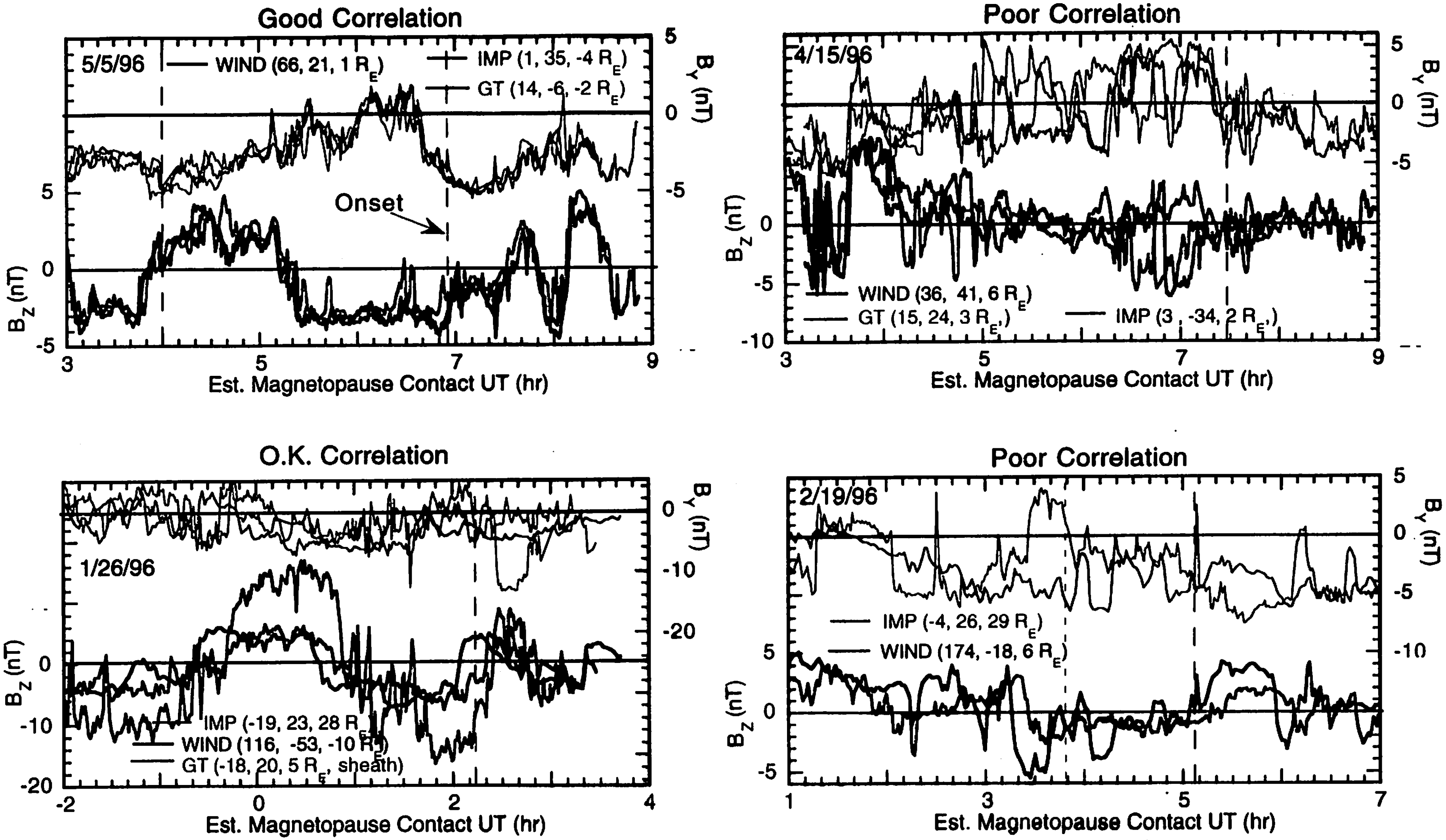


10 Jan 1997 - Rankin Inlet & Gillam
WIND
n(cm-3)
Inv. Lat.
Cloudy
6300 angstrom intensity [R]
5577 angstrom intensity [R]
4861 angstrom intensity [R]
24 MLT
10 Jan 1997 - Fort Smith
WIND
Bz(nT)
UT(hr)

Frank et al. [1995]



IMF Measurements with Multiple Monitors



SUMMARY

General

- **Convection**
  - — IMF B_z and B_y control strength
  - — Response to IMF changes rapid throughout polar cap
- **Tail plasma source**
  - — Significant dependence on convection strength strongly affects tail?
- **Strong convection**
  - — Gives earthward penetration of plasma sheet and associated large distortion of **B**
  - — Of major importance to substorms, convection bays, storms
- **Important consideration** for studying interplanetary sources for activity
  - — IMF structure in plane perpendicular to $\mathbf{V}_{SW}$

Geomagnetic disturbances:

- **Poleward boundary intensifications (PBIs):** All levels of activity
  - — Associated few min flow bursts (equatorward ionosphere, earthward tail)
  - — PBIs not associated with substorms have preference for radial IMF
- **Substorms:** Follow > 0.5 hr of enhanced convection (negative IMF B_z)
  - — Growth: earthward plasma sheet penetration, tail energy enhancement
  - — Onsets often (at least?) assoc. with IMF changes that reduce convection
  - — Initial predictions using such IMF changes successful [Blanchard et al., 1999]
- **Convection bays:** Prolonged periods of steady enhanced convection
  - — Plasma sheet, tail **B** like end of substorm growth phase, but ~steady state
  - — Activity dominated by large PBIs, substorms (if any) much less significant
- **Storms:** Prolonged periods of strongly enhanced convection
  - — Plasma sheet and geomagnetic activity like during convection bays
  - — Also global auroral, current enhancements from interplanetary dynamic pressure enhancements?