Ionospheric/Thermospheric Space Weather Issues

R. W. Schunk and J. J. Sojka

Center for Atmospheric and Space Sciences
Utah State University
Logan, Utah 84322-4405

CEDAR Tutorial
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Outline

- Applications
- Weather Features
- Causes of Weather
- Status of Weather Modeling
- Requirements for Forecasting

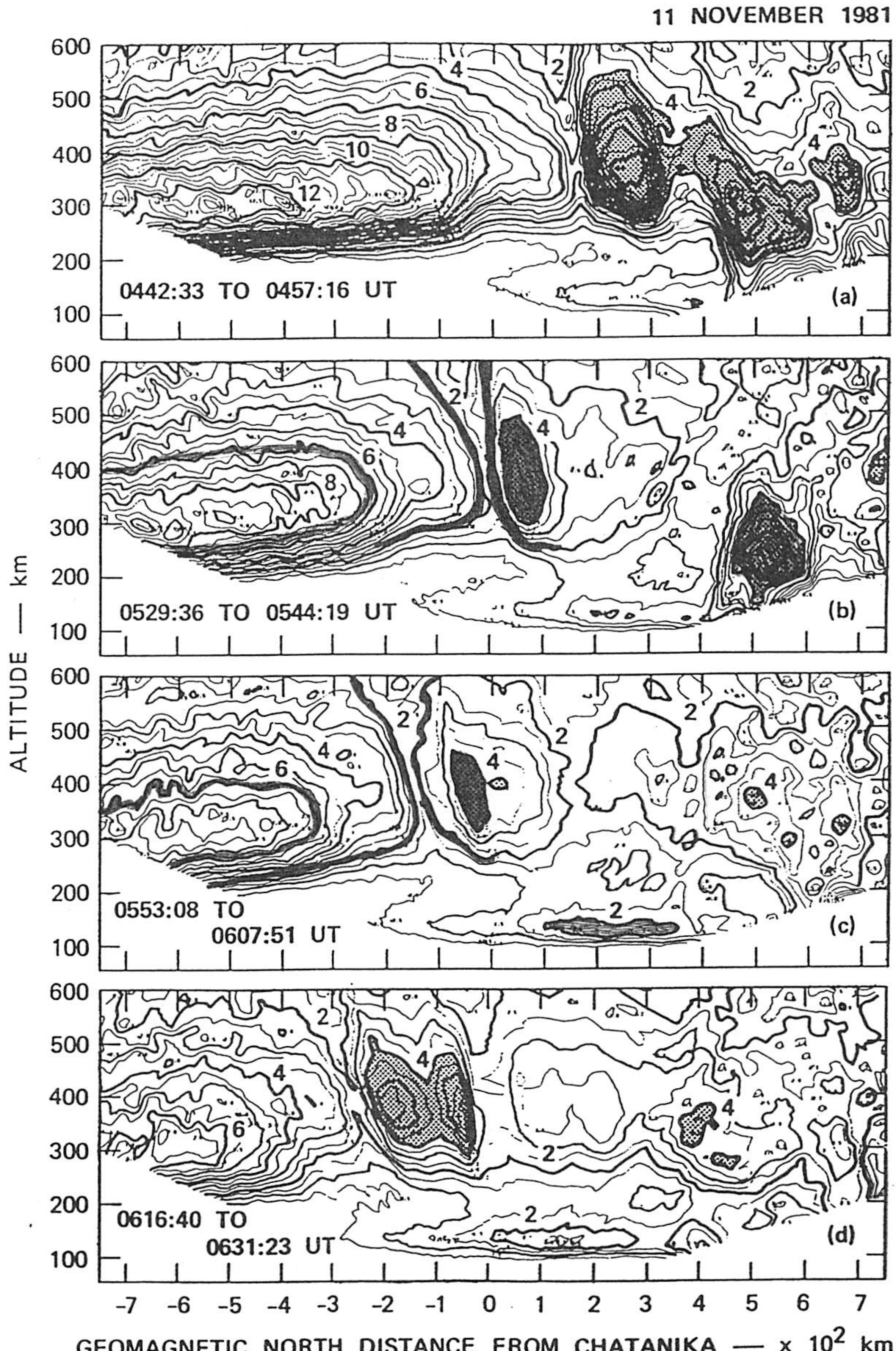
Applications

Weather disturbances in the ionosphere-thermosphere system affect the following:

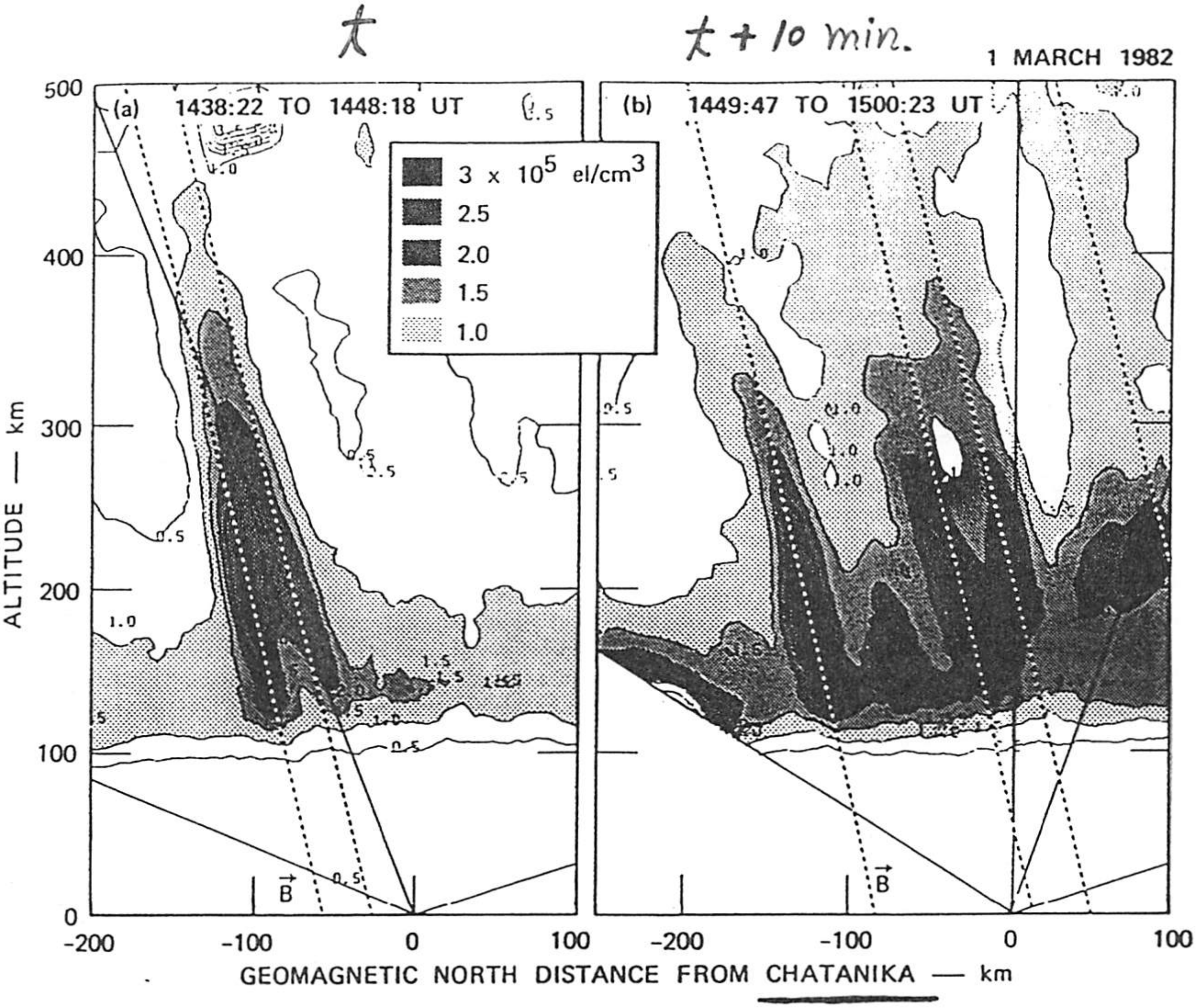
- Over-The-Horizon (OTH) Radars
- Communications
- GPS Surveying
- Navigation Systems (GPS and VLF)
- Satellite Drag
- Spacecraft Charging (in Trough)
- Surveillance
    - Optical Emissions
    - Radar Altimetry
- Induced EMF at Ground
    - Pipelines
    - Power Grids
    - Long Telecommunications Cables

Weather Features

- Sun-Aligned Arcs
- Auroral Arcs
- Plasma Patches
- Boundary Blobs
- Flux Transfer Events
- Traveling Convection Vortices
- SAID Events
- SAR-arcs
- Anomalous T_e in E-region
- Sporadic E
- Spread F
- Equatorial Bubbles
- Descending Layers
- Magnetic Storms
- Substorms
- Gravity and Tidal Waves
- Scintillations



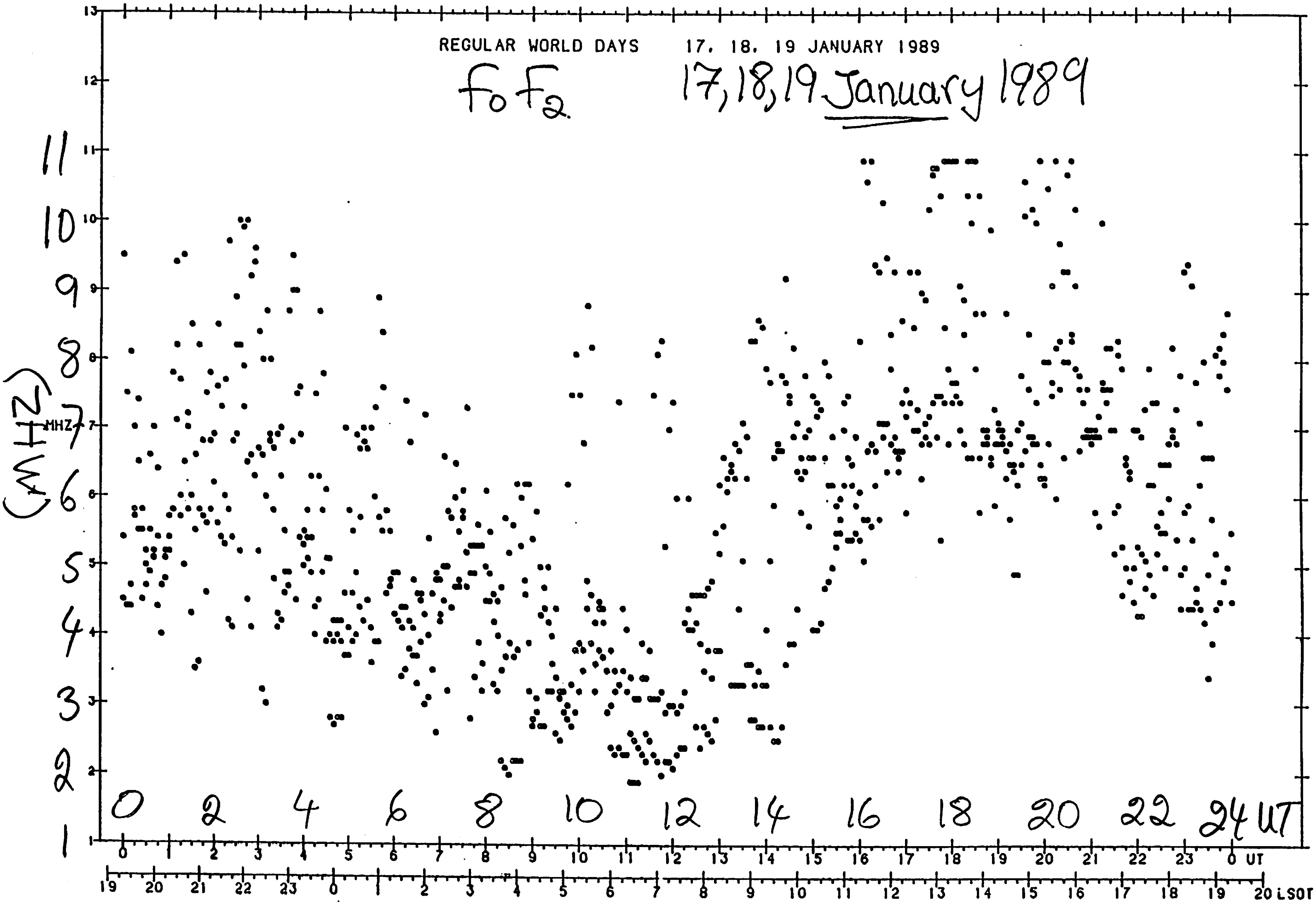
Rino et al (1983)



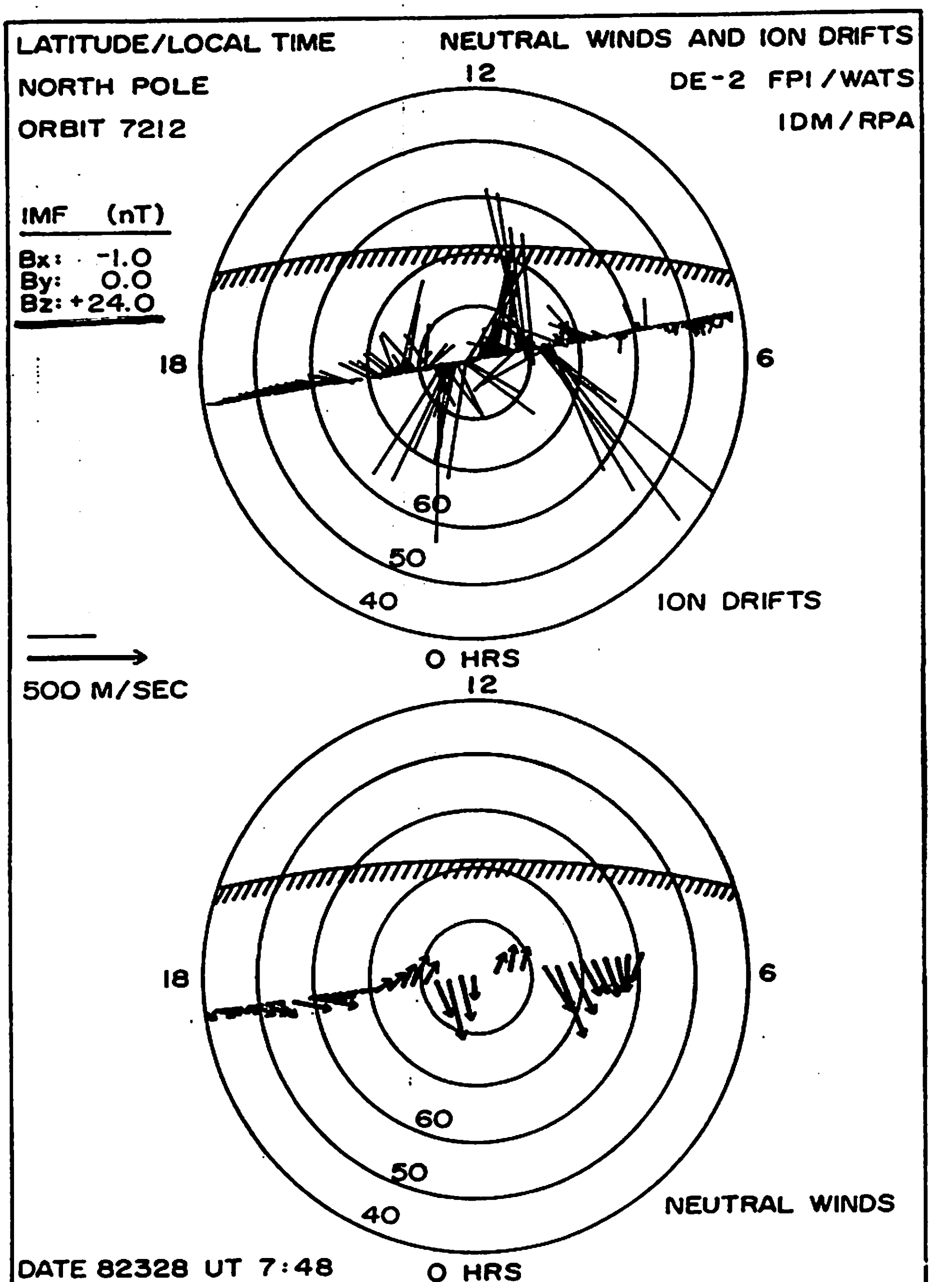
Tsunoda (1988)

- Chatanika radar scan
- On-going precipitation
- Evidence for rapid ionization in F-region

MASSPLOT OF foF2 MEASUREMENTS (Δt=5 min) QAANAAQ, GREENLAND



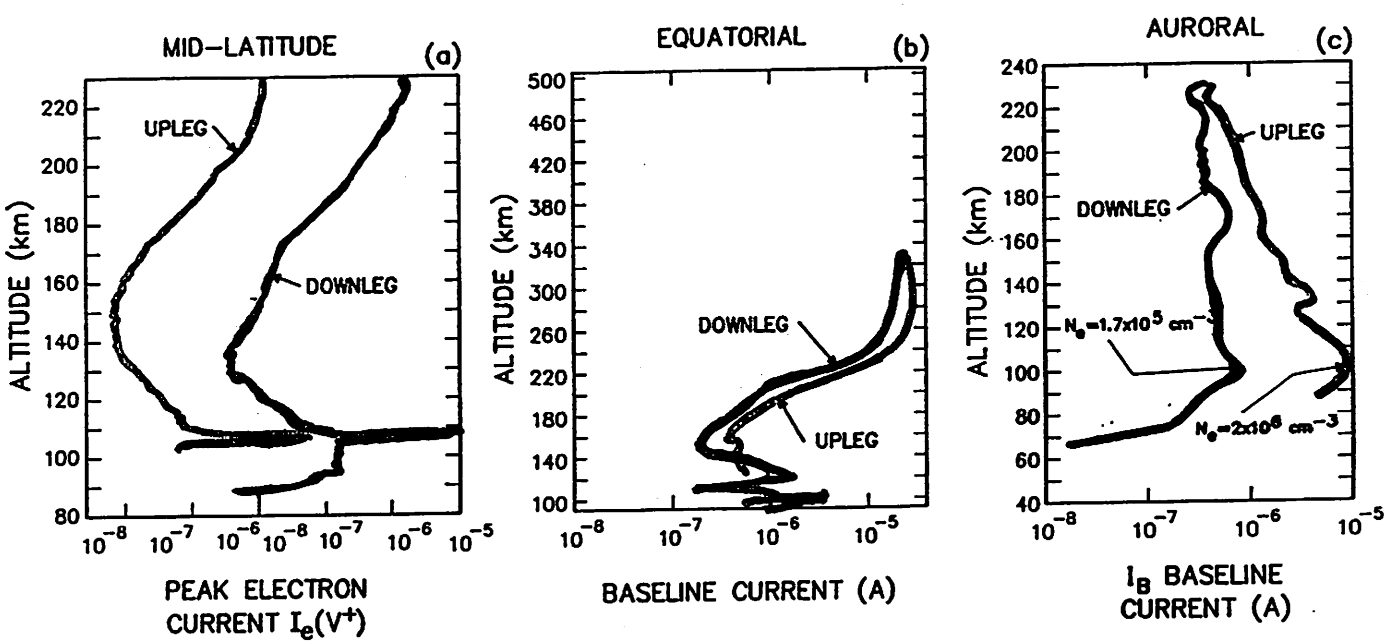
DE-2 Satellite
Northern Hemisphere
Winter



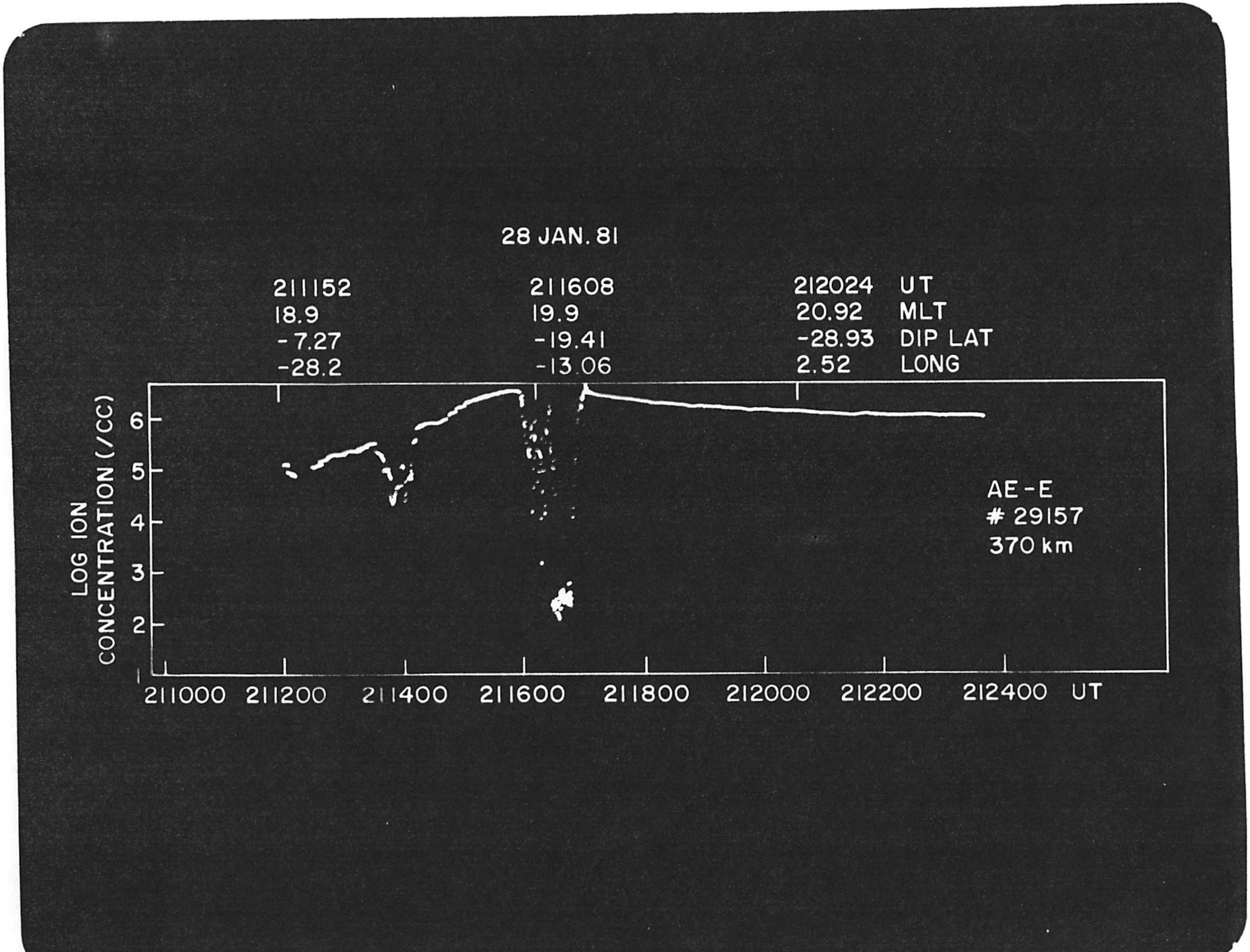
Northward IMF
Multicell Pattern

Killeen et al (1985)

Sporadic - E



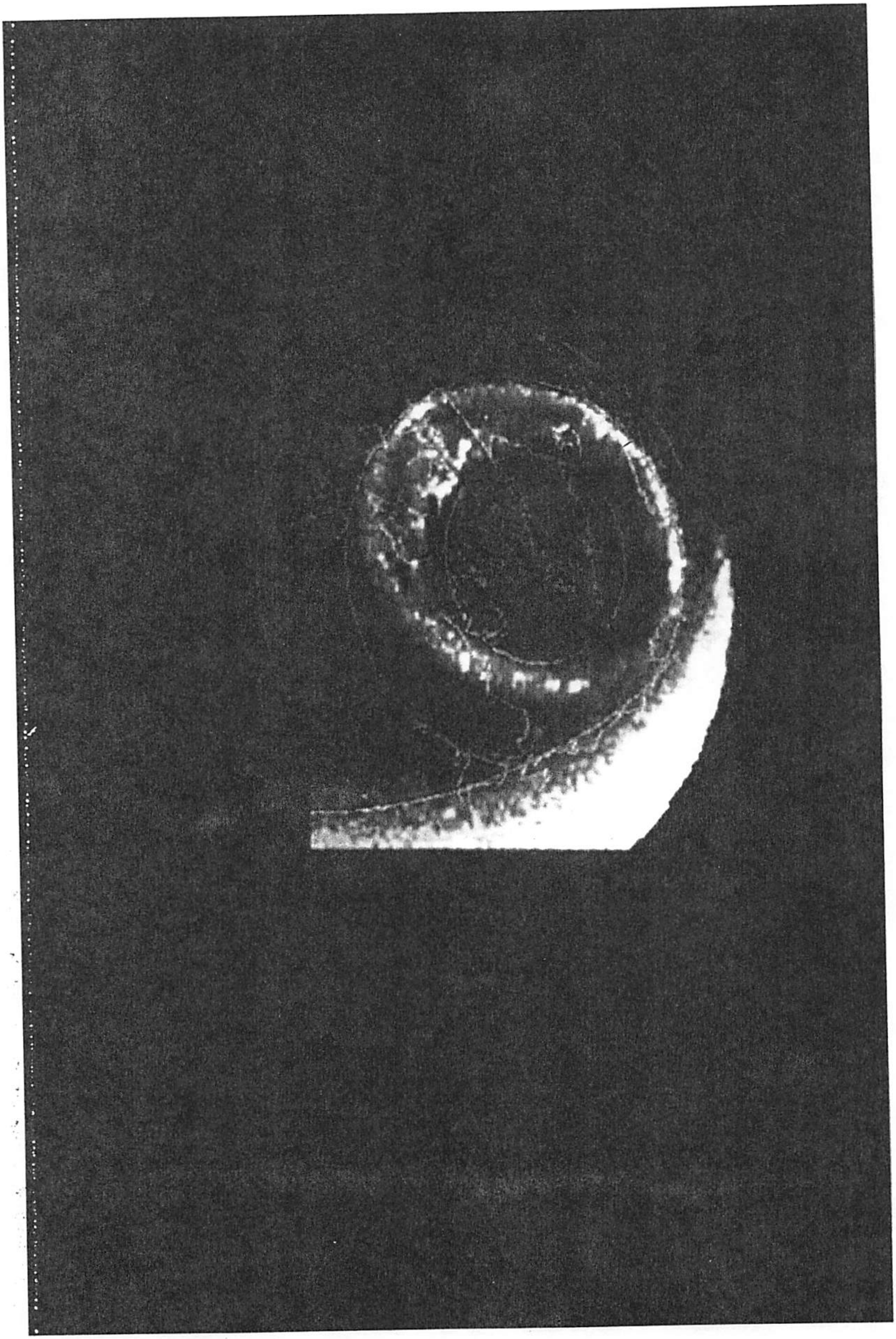
Szuszczewicz

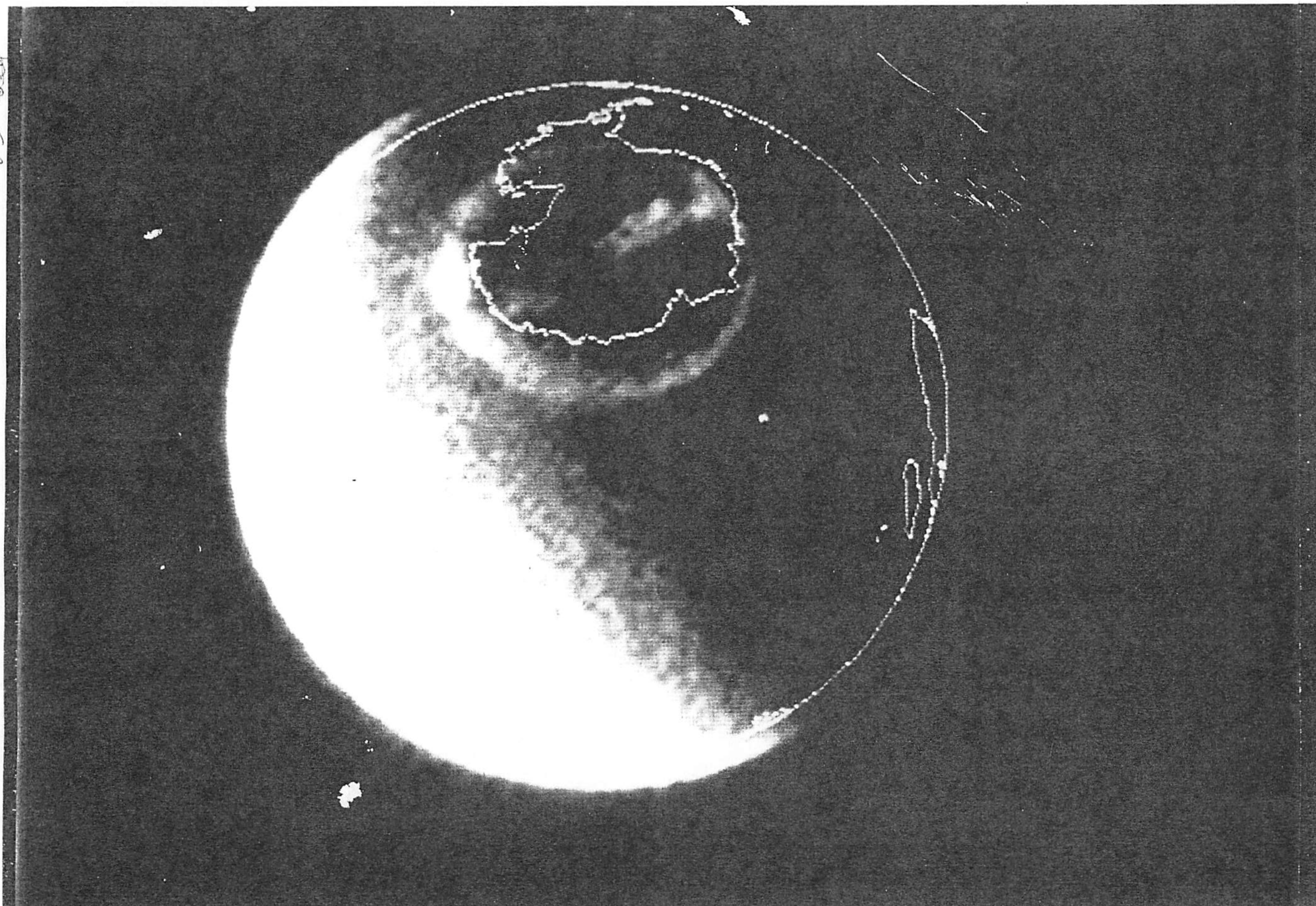


28 JAN. 81
211152
18.9
-7.27
-28.2
211608
19.9
-19.41
-13.06
212024 UT
20.92 MLT
-28.93 DIP LAT
2.52 LONG
LOG ION CONCENTRATION (/CC)
6
5
4
3
2
AE-E
29157
370 km
211000 211200 211400 211600 211800 212000 212200 212400 UT

Causes of Weather

- Structured Precipitation
- Structured Electric Fields
- Structured Downward Heat Fluxes
- Time Varying Electric Fields
- Time Varying Precipitation
- Plasma Instabilities
- Upward Propagating Gravity and Tidal Waves





Θ - aurora Northward IMF L.A. Frank

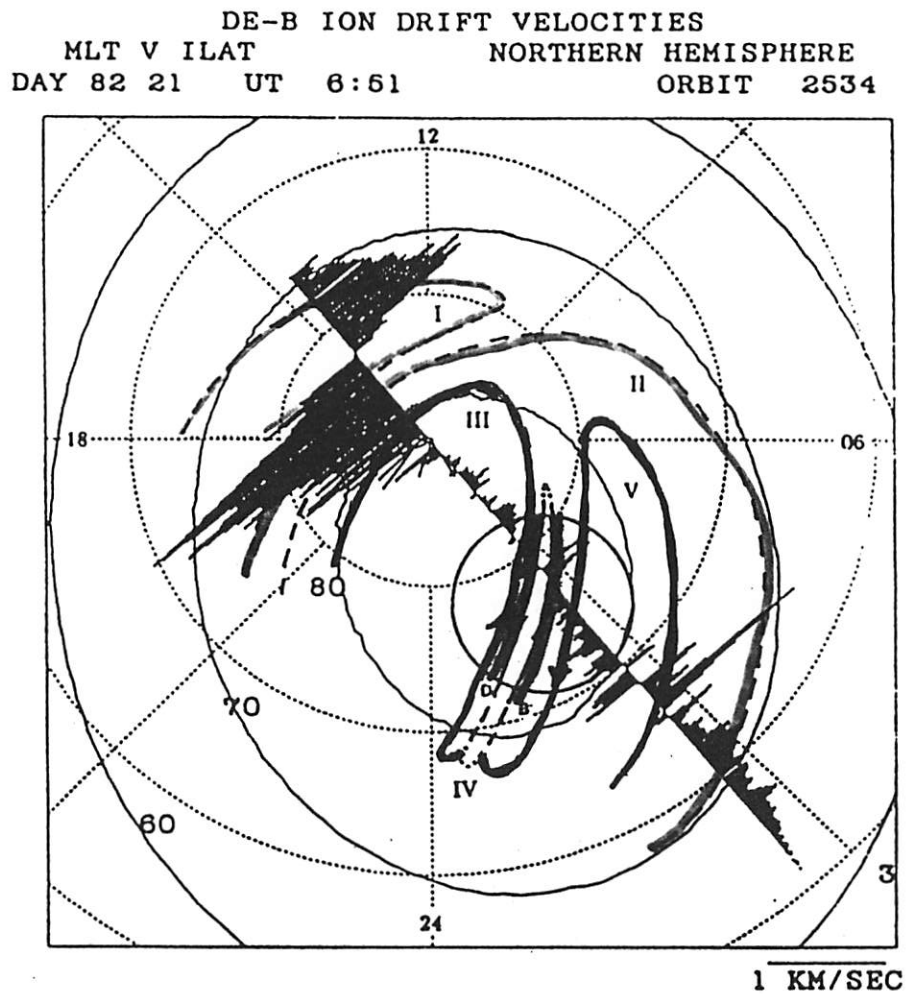
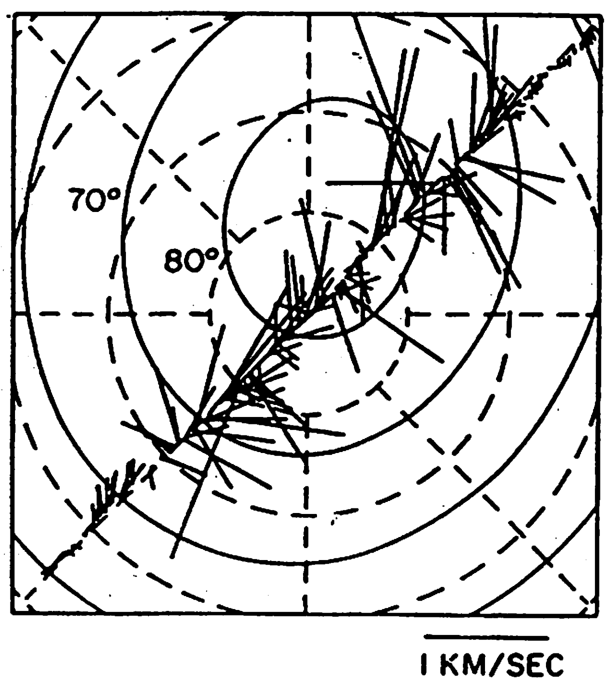


Figure 18. An implied convection pattern consistent with observed optical emissions and plasma convection velocities measured by DE 2. The flow lines describing cells III, IV, and V are at the same potential and may be connected 'fingers' or separate convection cells. From Carlson et al. [1988].

Electric Field Structure

ION DRIFT METER, DE-2
UNIVERSITY OF TEXAS AT DALLAS
OCTOBER 17, 1981
1634 - 1646 UT



Frank et al (1986)

Magnetospheric Parameters

Parameters

- Convection
- Precipitation
- Birkeland Currents
- Heat Flows

Dependence

- IMF (B_x, B_y, B_z)
- Kp

Issues

- Statistical Patterns
- Instantaneous Patterns
- Spatial Structure
- Temporal Variations
- Transition Time-Scales

Statistical Patterns

Southward IMF

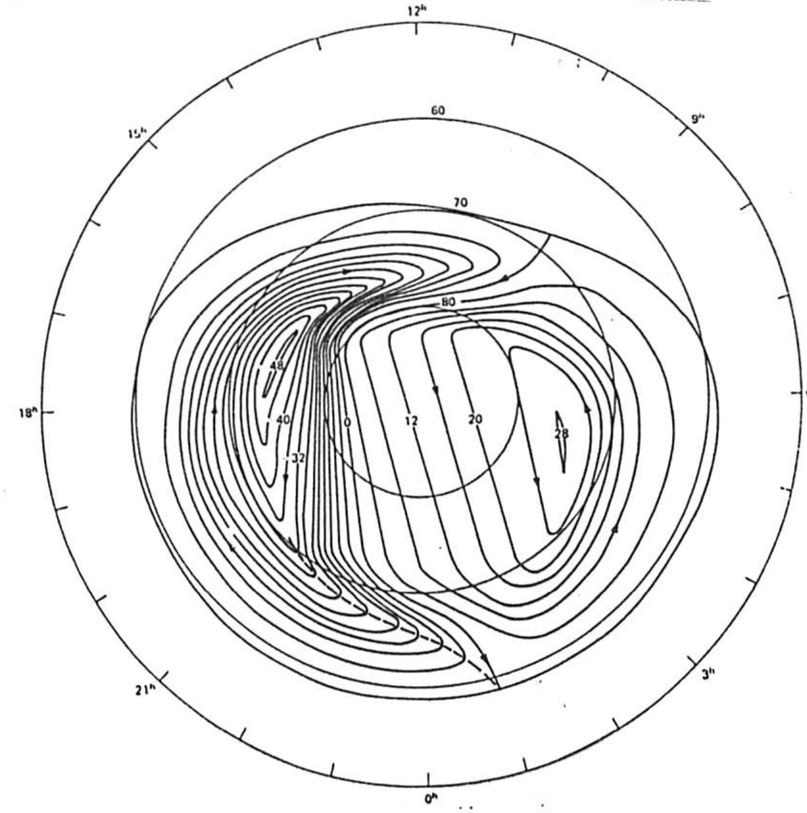
- 2-Cell Convection
- Precipitation

Northward IMF

- 4 ~~2~~-Cell Convection
- 3-Cell Convection
- Distorted 2-Cell Convection
- Turbulent
- Sun-Aligned Arcs
- θ-Aurora
- Uniform Precipitation (in polar cap)
- Precipitation in Classical Oval

Heppner-Maynard Convection

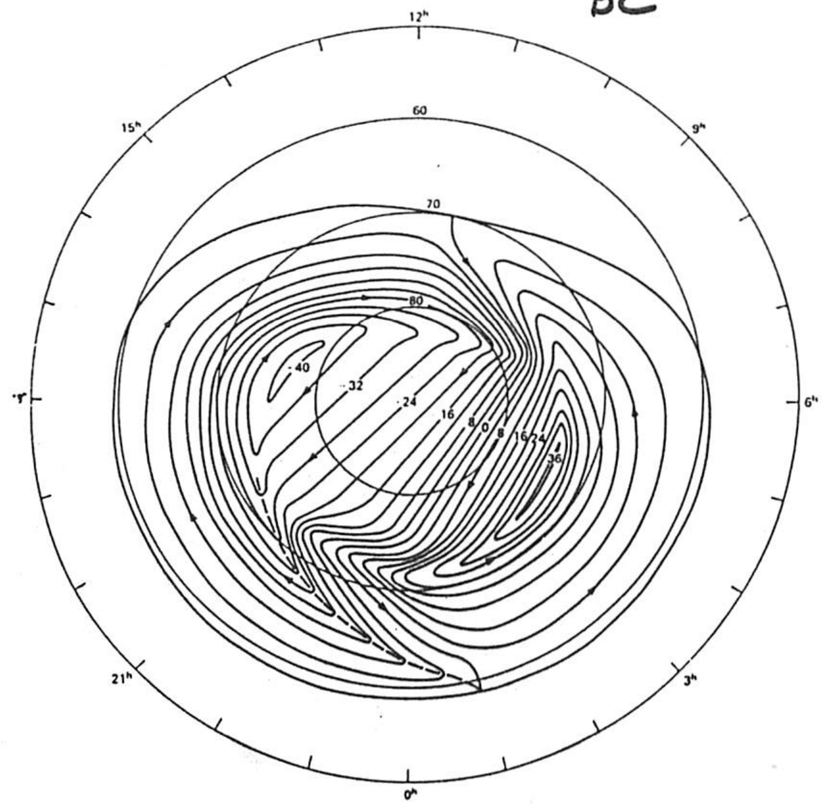
DE



$B_y < 0$

Northern Hemisphere

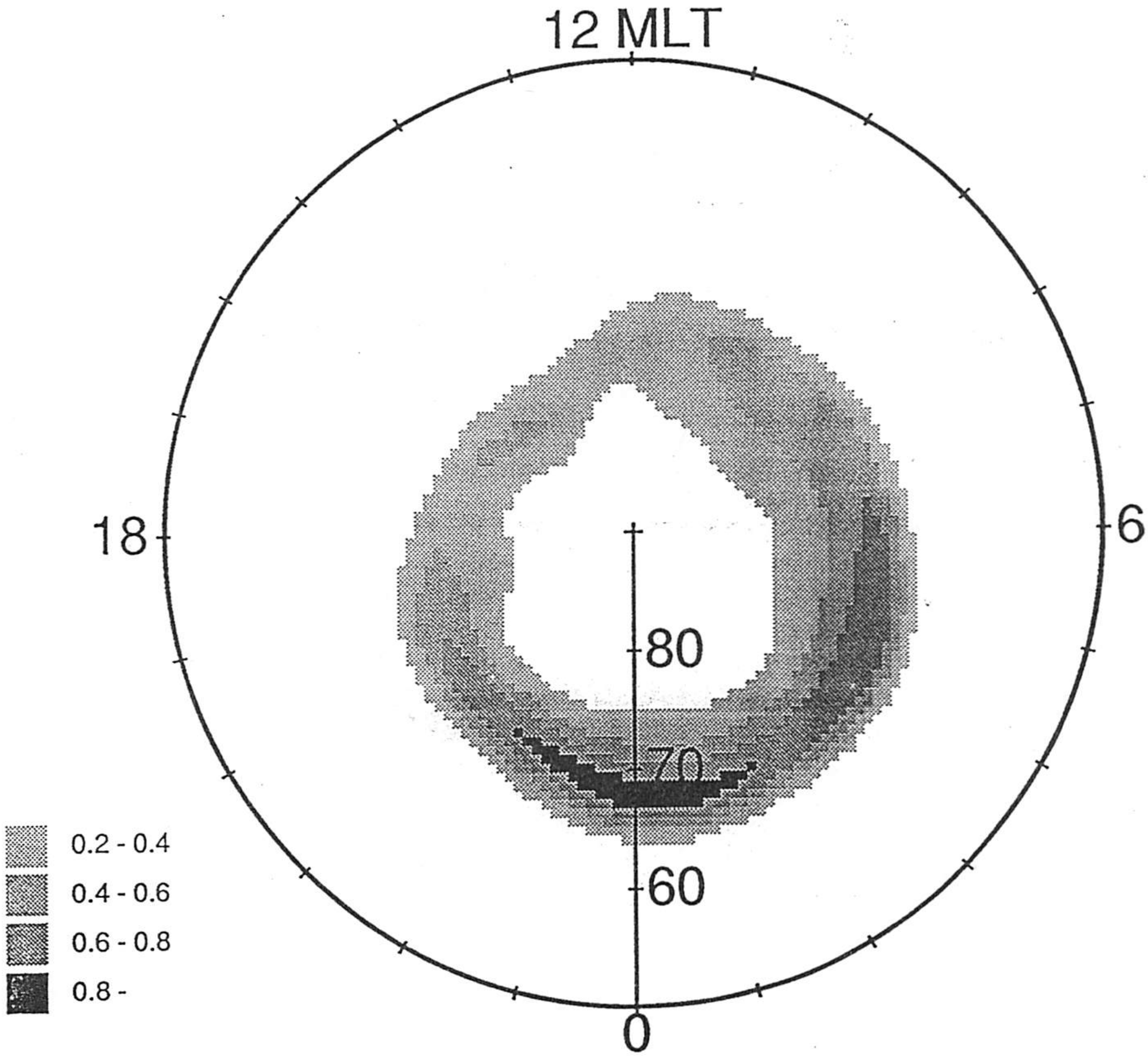
BC



$B_y > 0$

Northern Hemisphere

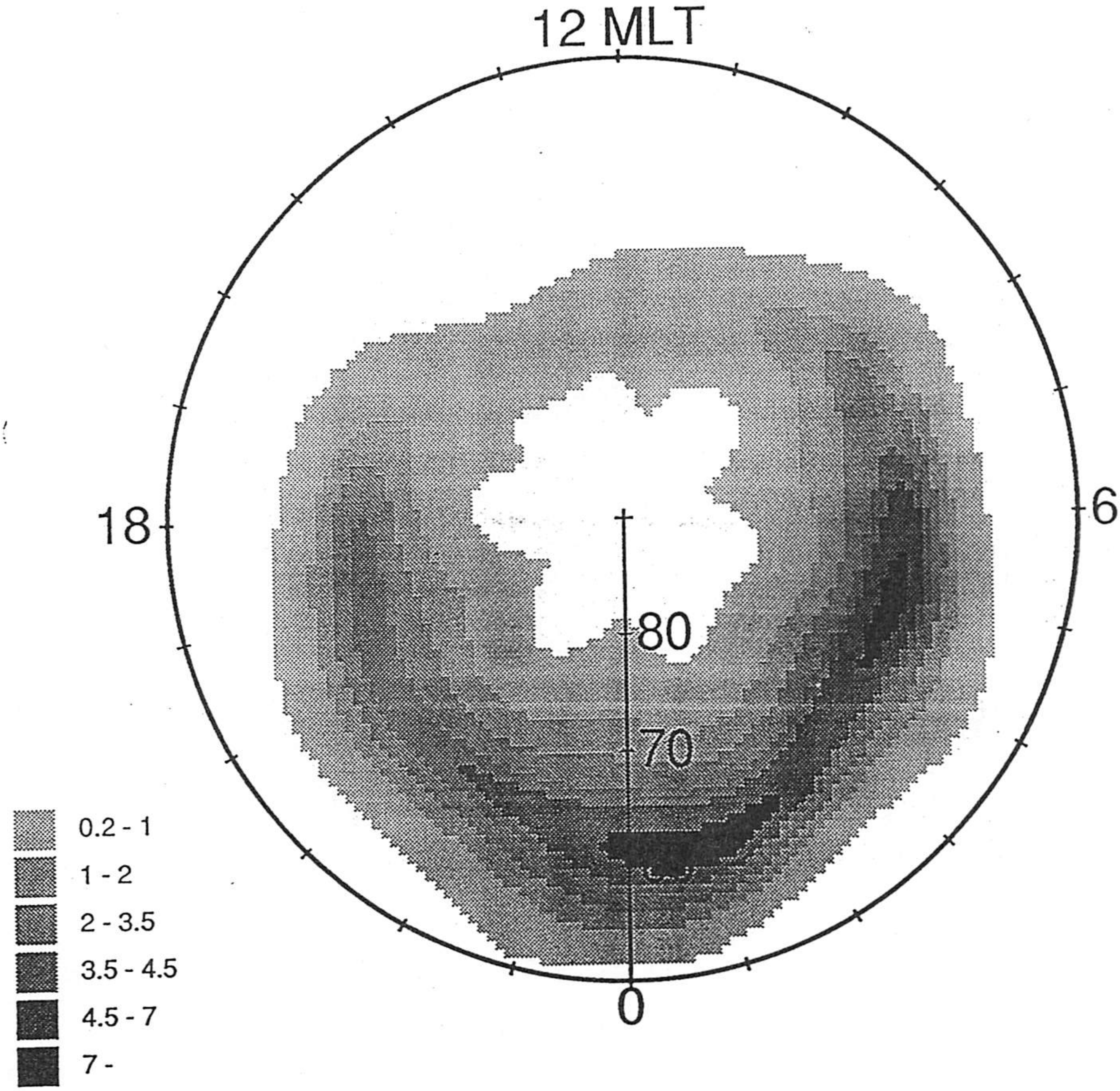
Kp = 1



Hardy et al

24-AUG-90 14:14:01 SQANY101.FOR input OVALAFGLKP10.101

Kp = 6



Hardy et al

24-AUG-90 14:22:49 SQANY101.FOR input OVALAFGLKP60.101

Northward IMF

Potemra et al (1984)

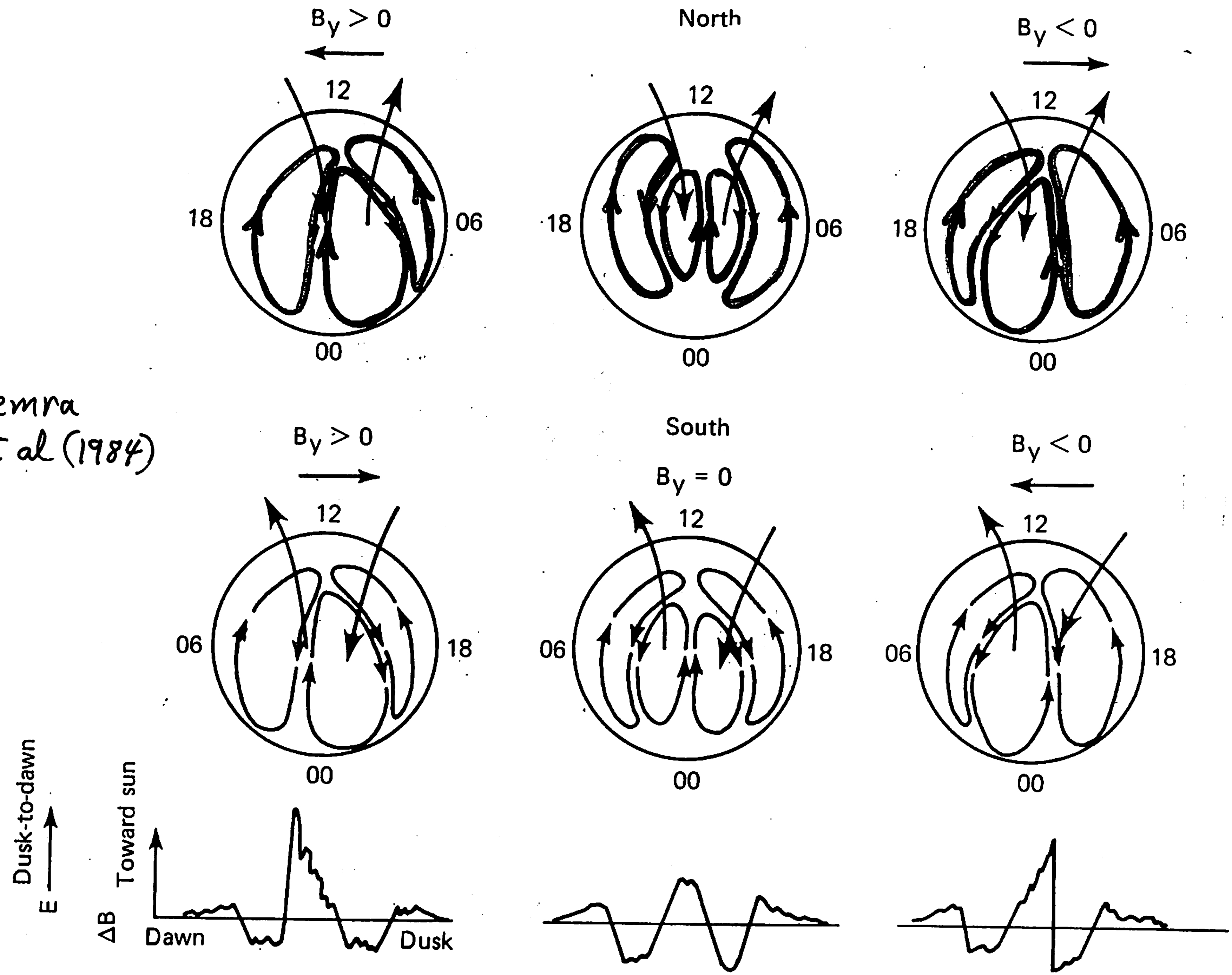


FIGURE 5

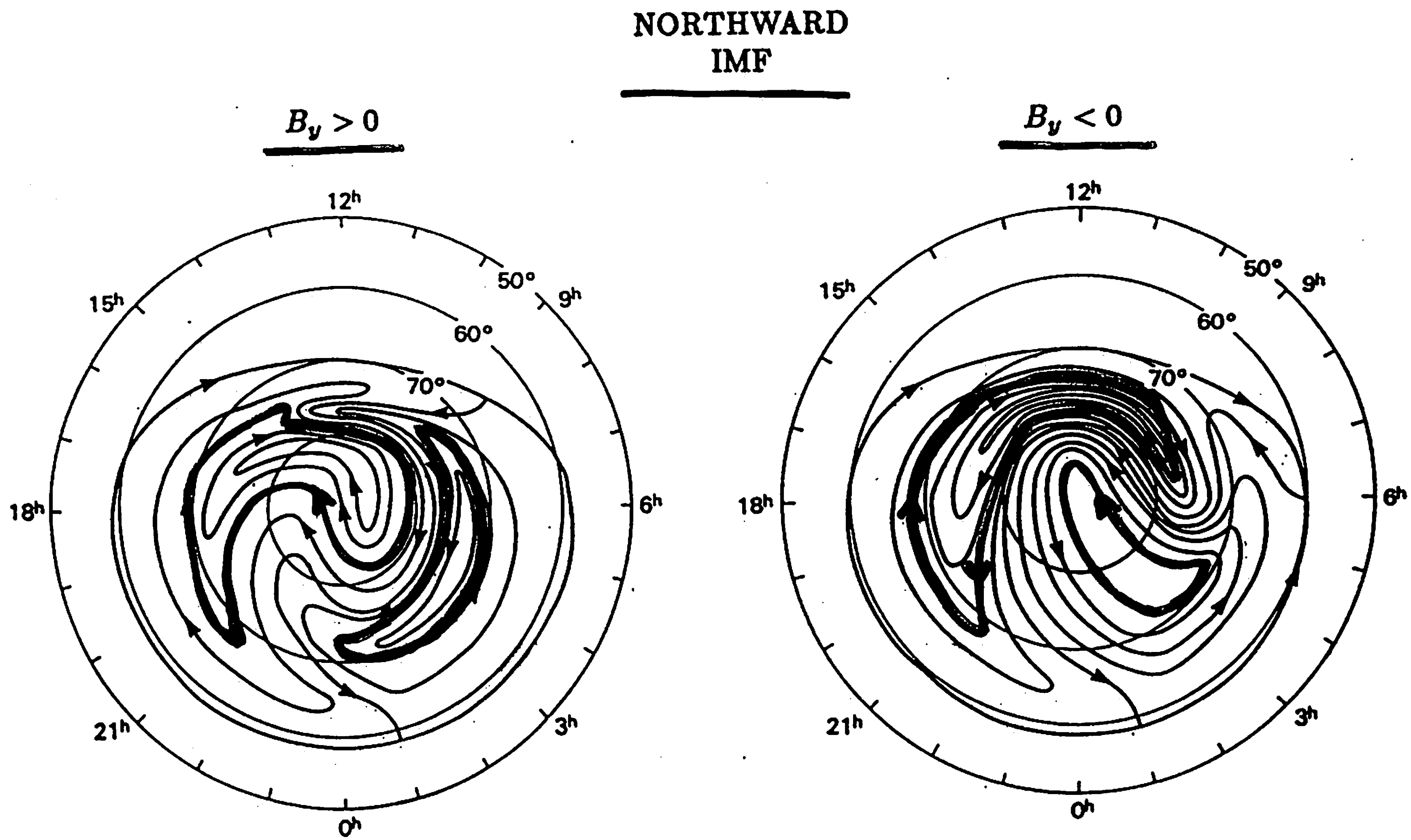


Figure 10. Distorted two-cell convection patterns for a strongly northward IMF and for $B_y > 0$ (left dial) and $B_y < 0$ (right dial) in the northern hemisphere. From Heppner and Maynard [1987].

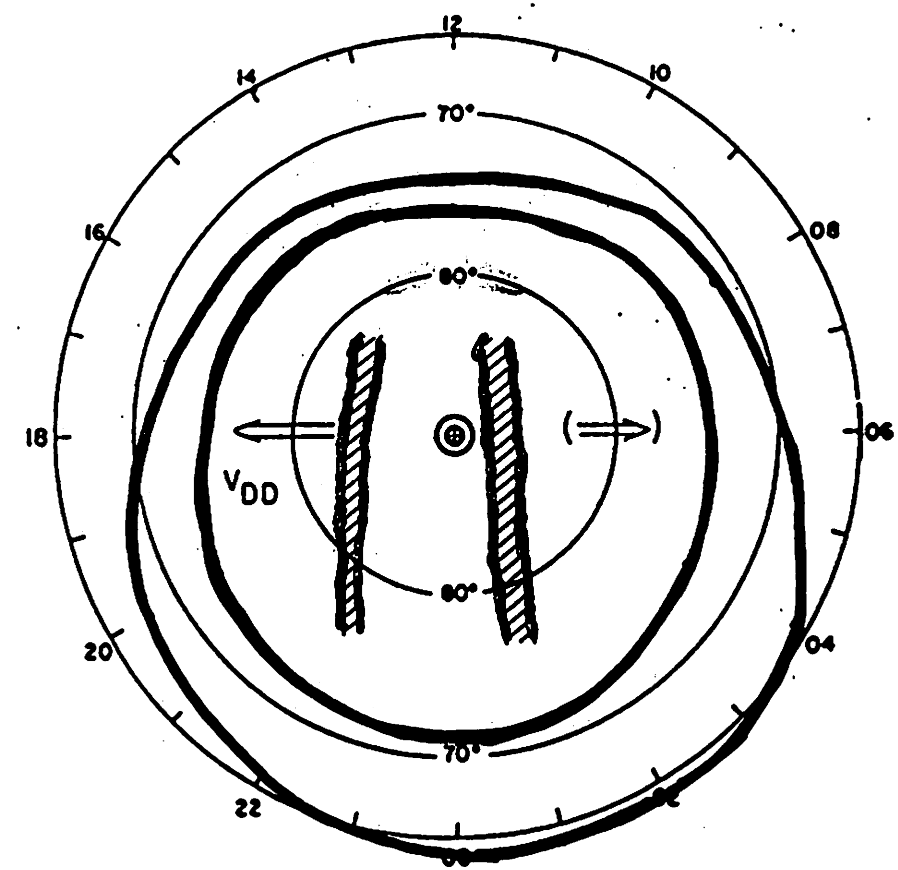


Figure 11. Schematic illustration of sun-aligned arcs in the polar cap for a northward IMF. From Buchau et al. [1983].

Status of Northward IMF Convection

Rich and Hairston (1994)

- Comprehensive Study Using DMSP F8 and F9 Satellites

- The development of more than 2 convection cells for northward IMF is either uncommon or nonexistent. A distorted 2-cell pattern occurs, not a 4-cell pattern.

Weimer (1995)

- Comprehensive Study Using DE 2 Satellite Data

- For northward IMF, evidently there are 4 convection cells, rather than a distortion of the 2-cell pattern.

Temporal Variation

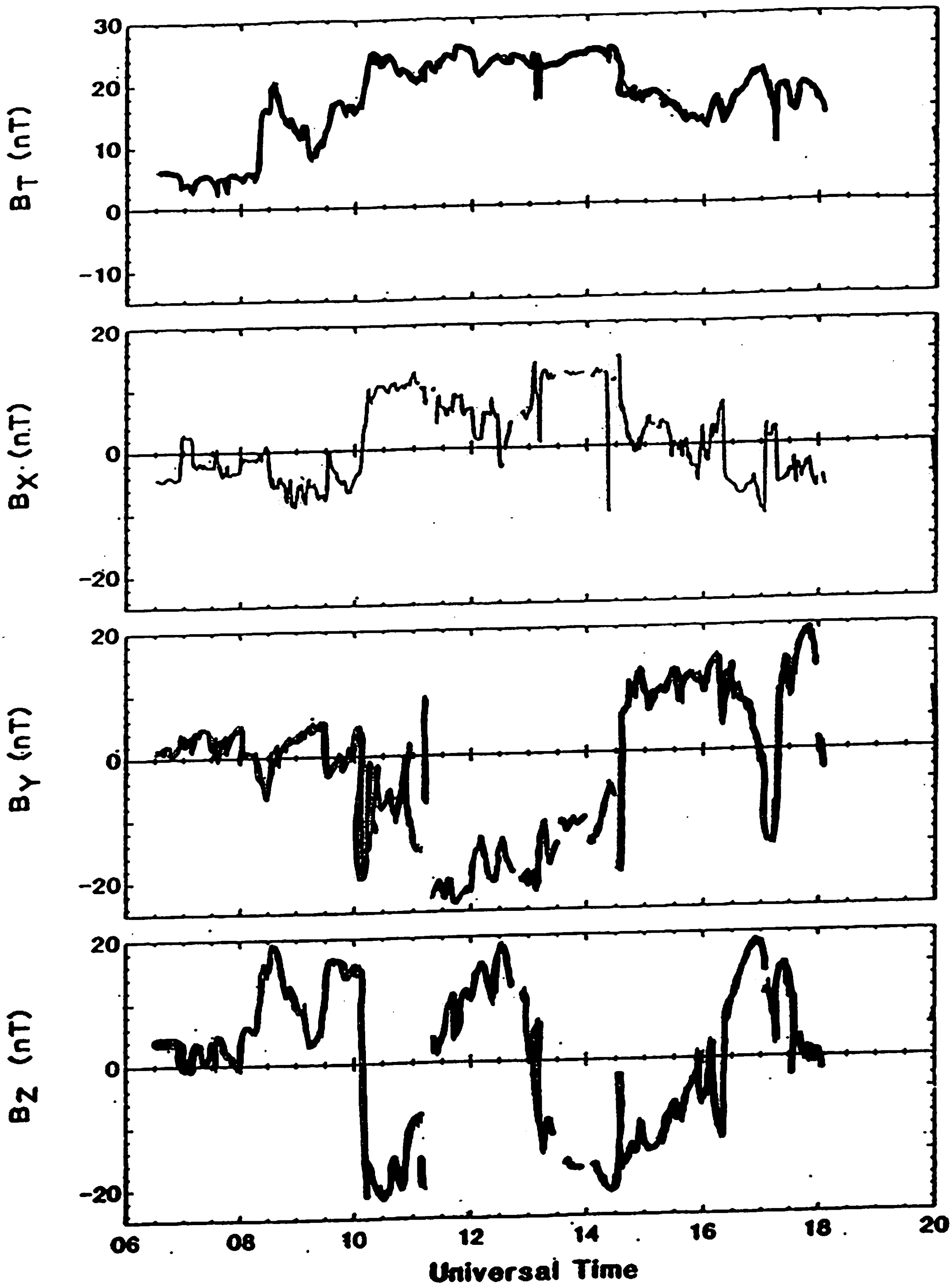


Figure 21. Variation of the interplanetary magnetic field (B_x, B_y, B_z, B_T) versus universal time for a representative 14-hour period. From Roble et al. [1987].

Status of Weather Modeling

- Climatology
- Sun-Aligned Polar Cap Arcs
- Traveling Convection Vortices
- Plasma Patches
- Tides and Gravity Waves
- SAID Events
- Storms and Substorms

GLOBAL IONOSPHERE MODEL

- 3-dimensional, time-dependent
- 100-1000 km altitude range
- Densities & velocities for electrons and NO^+, O_2^+, N_2^+, O^+, N^+, He^+
- Ion and electron temperatures

<u>Inputs Needed</u>

- Magnetospheric electric field
- Auroral oval
- Neutral atmosphere
- Neutral wind
- Magnetospheric Heat Flow

108 RUNS OF USU IONOSPHERIC MODEL

- Season - Equinox
  - June Solstice
  - December Solstice

- Solar Activity
  - High $F_{10.7} = 210$
  - Mid $F_{10.7} = 130$
  - Low $F_{10.7} = 70$

- Geomagnetic Activity
  - High $Kp = 6.0$
  - Mid $Kp = 3.5$
  - Low $Kp = 1.0$

- Heppner-Maynard Convection ($Bz < 0$)
  - $By > 0$
  - $By < 0$

- Northern and Southern Hemispheres

Sojka and Schunk (1994)

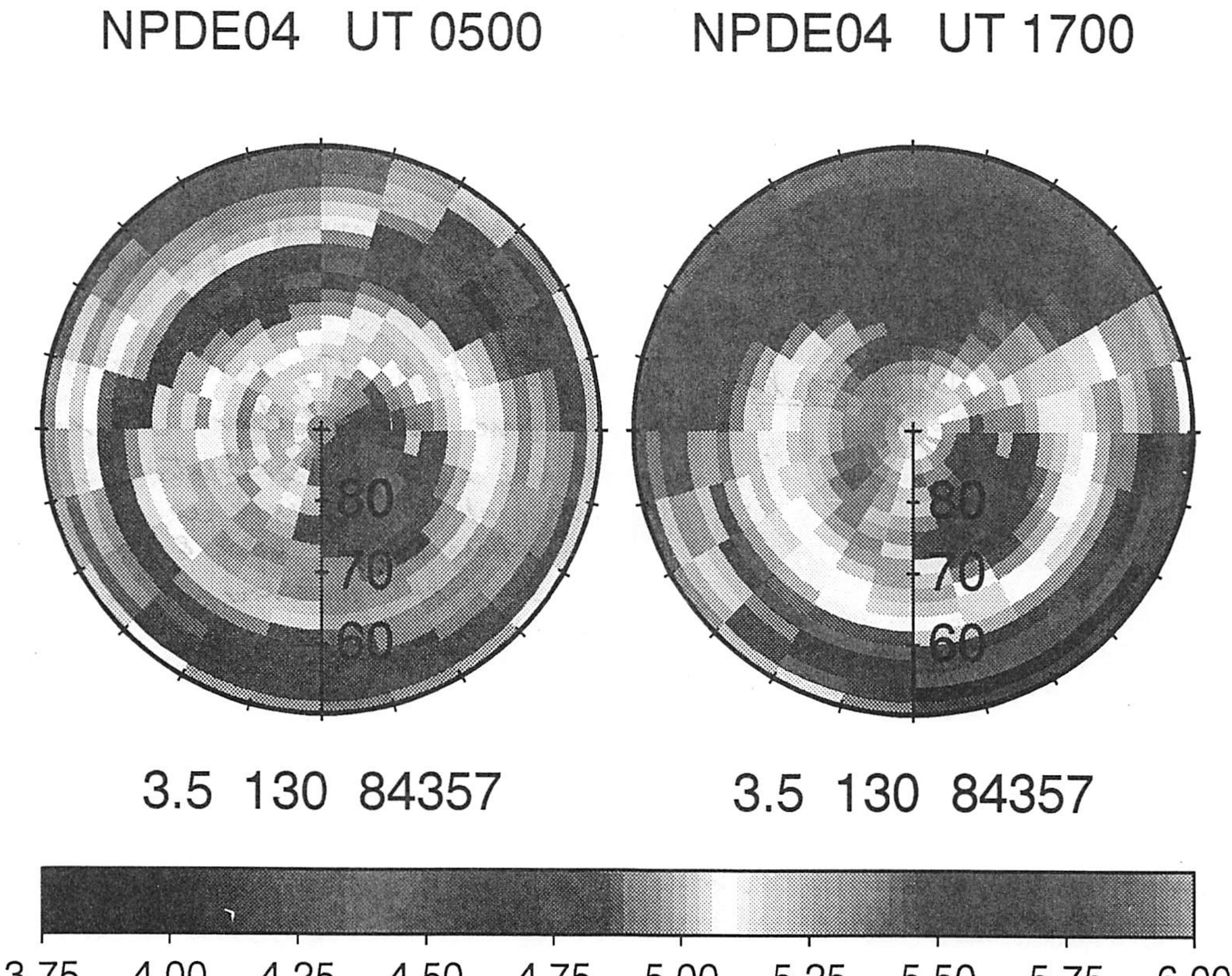
Model Inputs

- Heppner-Maynard Convection
- Hardy Auroral Oval
- MSIS Atmosphere
- Hedin Winds
- Displaced Poles

Diurnally Reproducible Results

"Climatology"

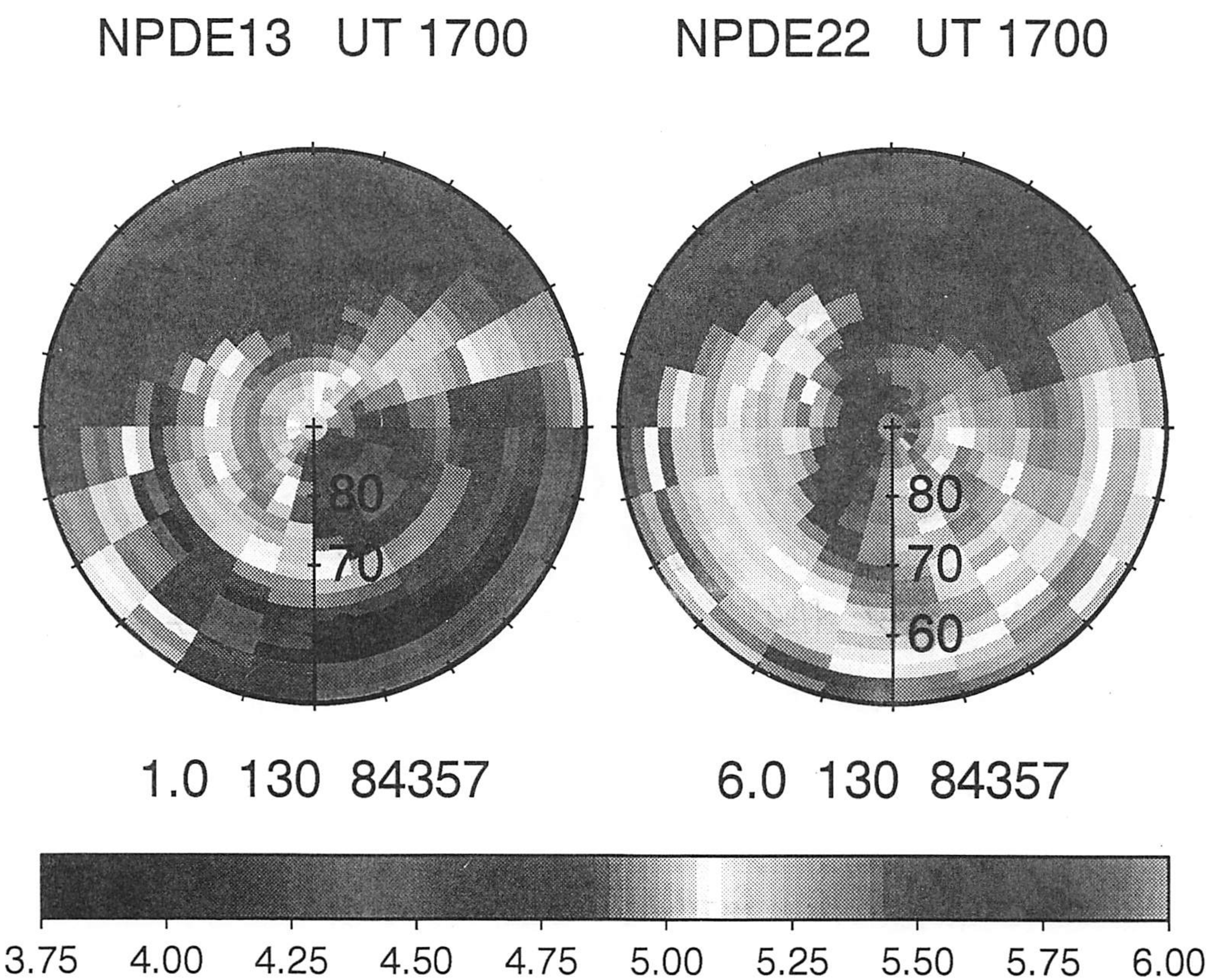
O+ 300 km



20-Jan-91 18:23:24 pl2aseslas.f npde04.asc npde04.asc

UT Variation

O+ 300 km

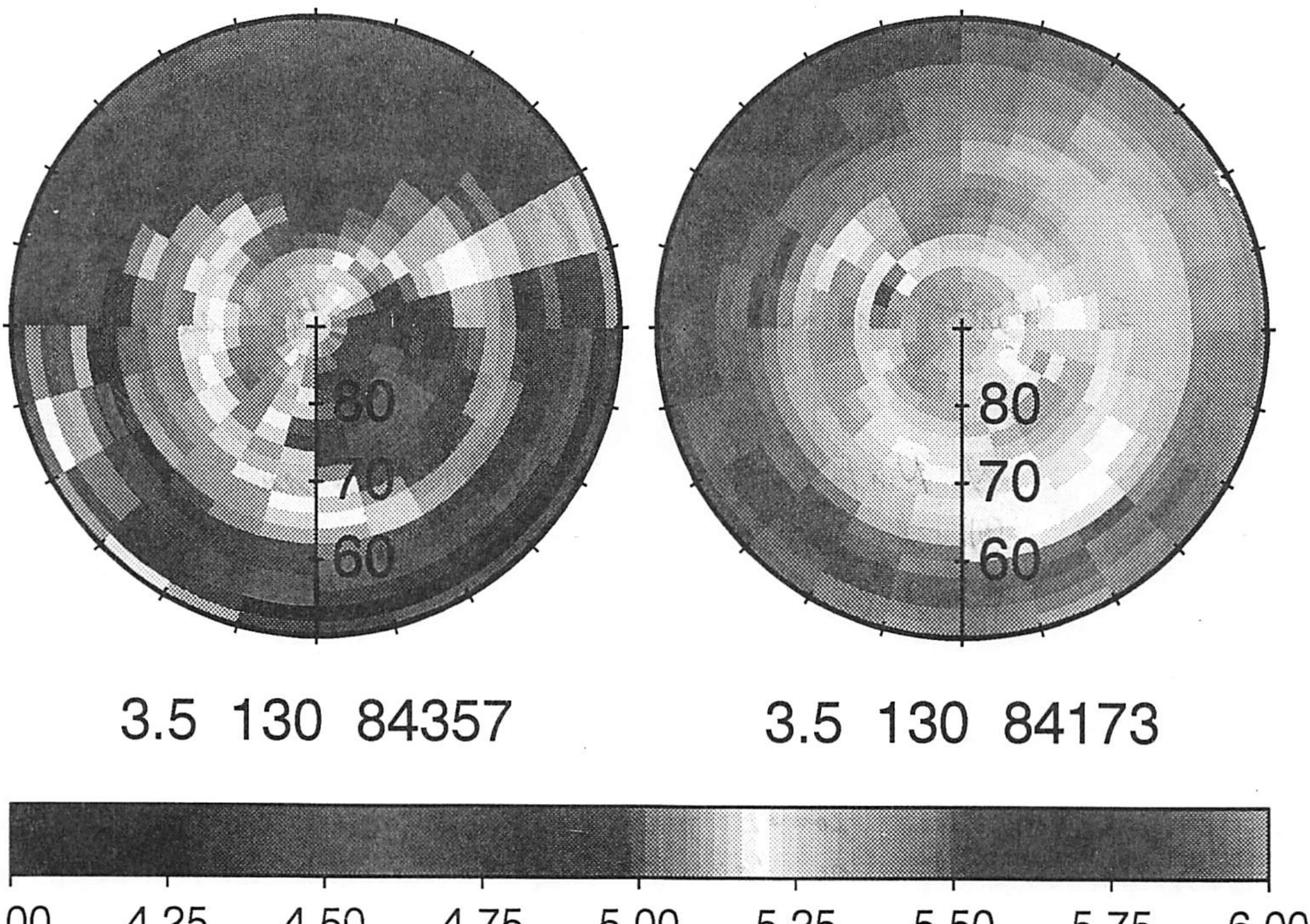


28-Jan-91 21:32:57 pl2ascslas.f npde13.asc npde22.asc

Kp = 1 Kp Variation Kp = 6

O+ 300 km

NPDE04 UT 1700 NPDE05 UT 1700



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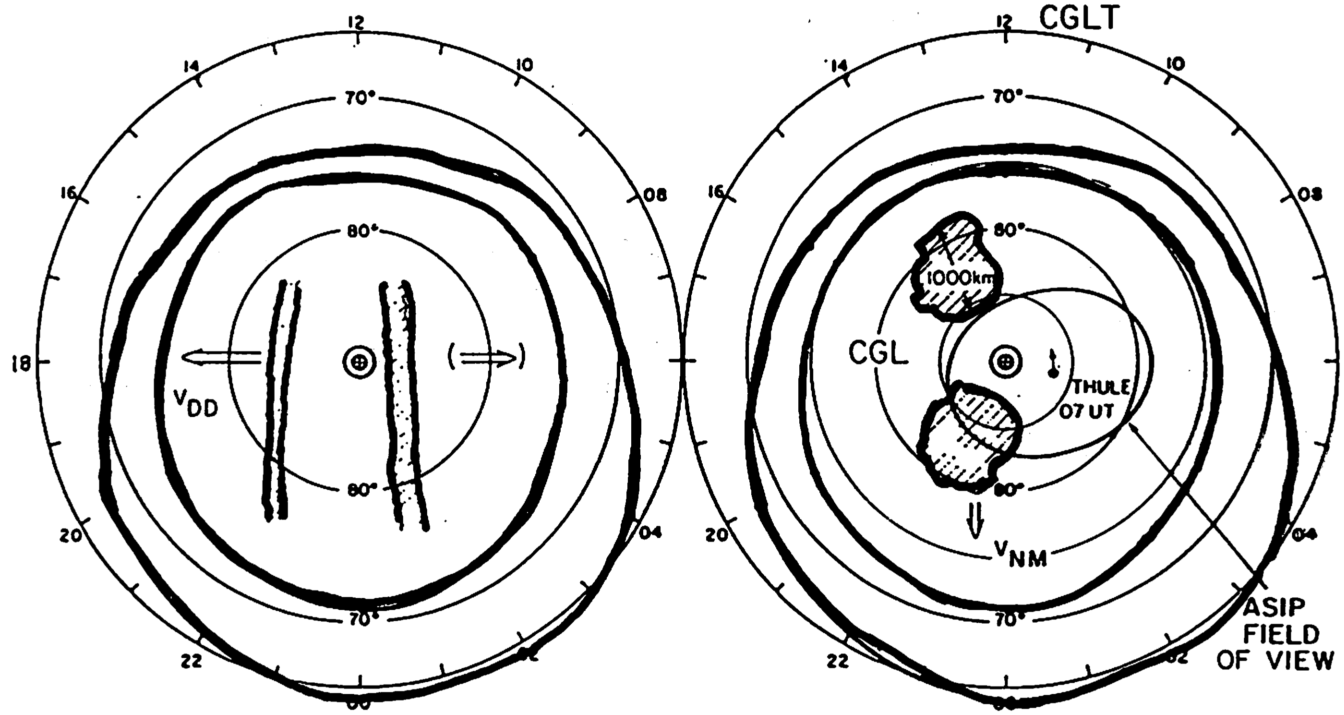
W W Seasonal Variation AS

Ionospheric Structure

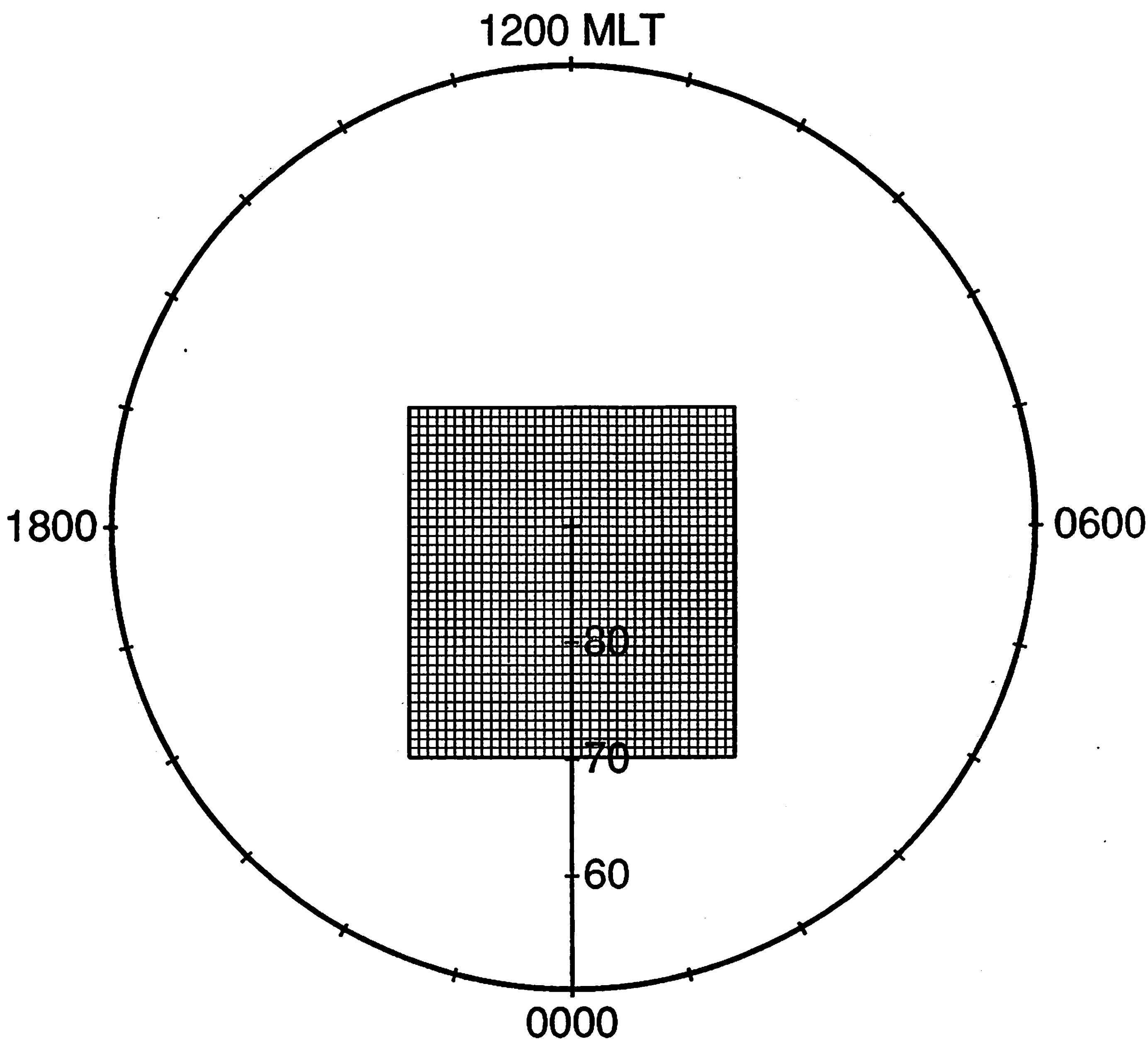


TYPE 1 SUNALIGNED ARCS
DAWN-DUSK DRIFT (PREDOMINANT)
100 - 250 m/s

TYPE 2 PATCHES
ANTI-SUNWARD DRIFT
0.1 - 1 Km/s

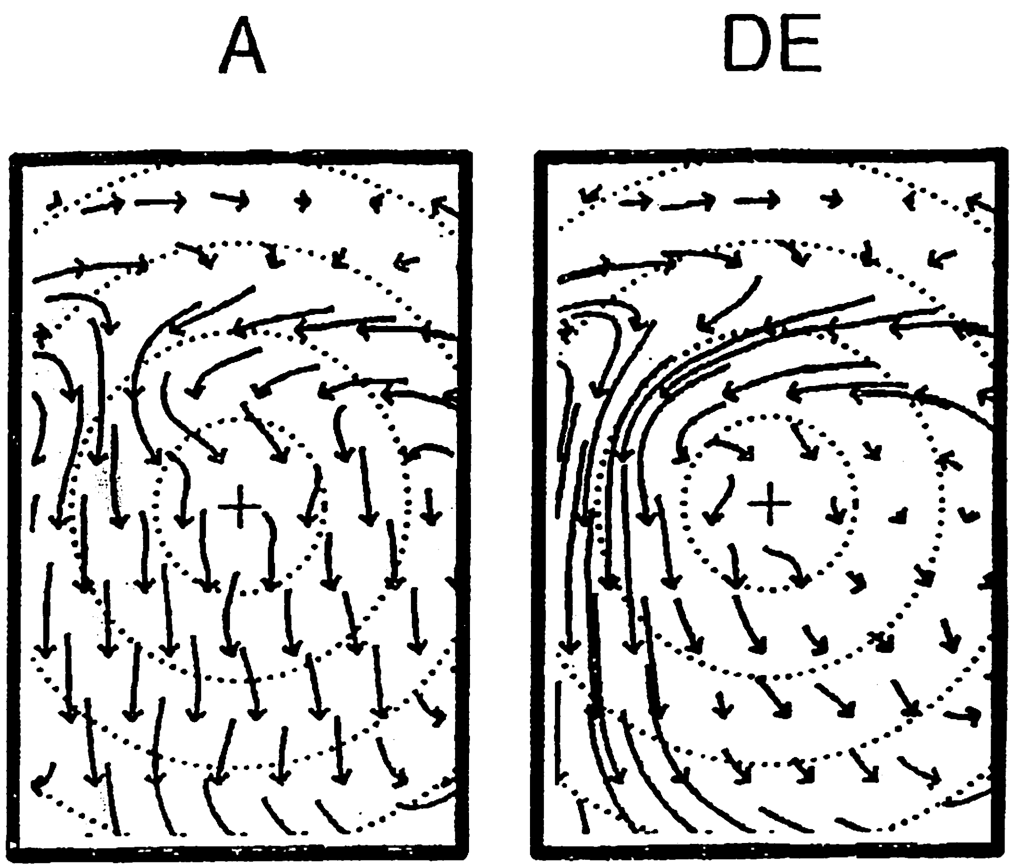
Buchau et al (1983)

Plasma Patch Formation

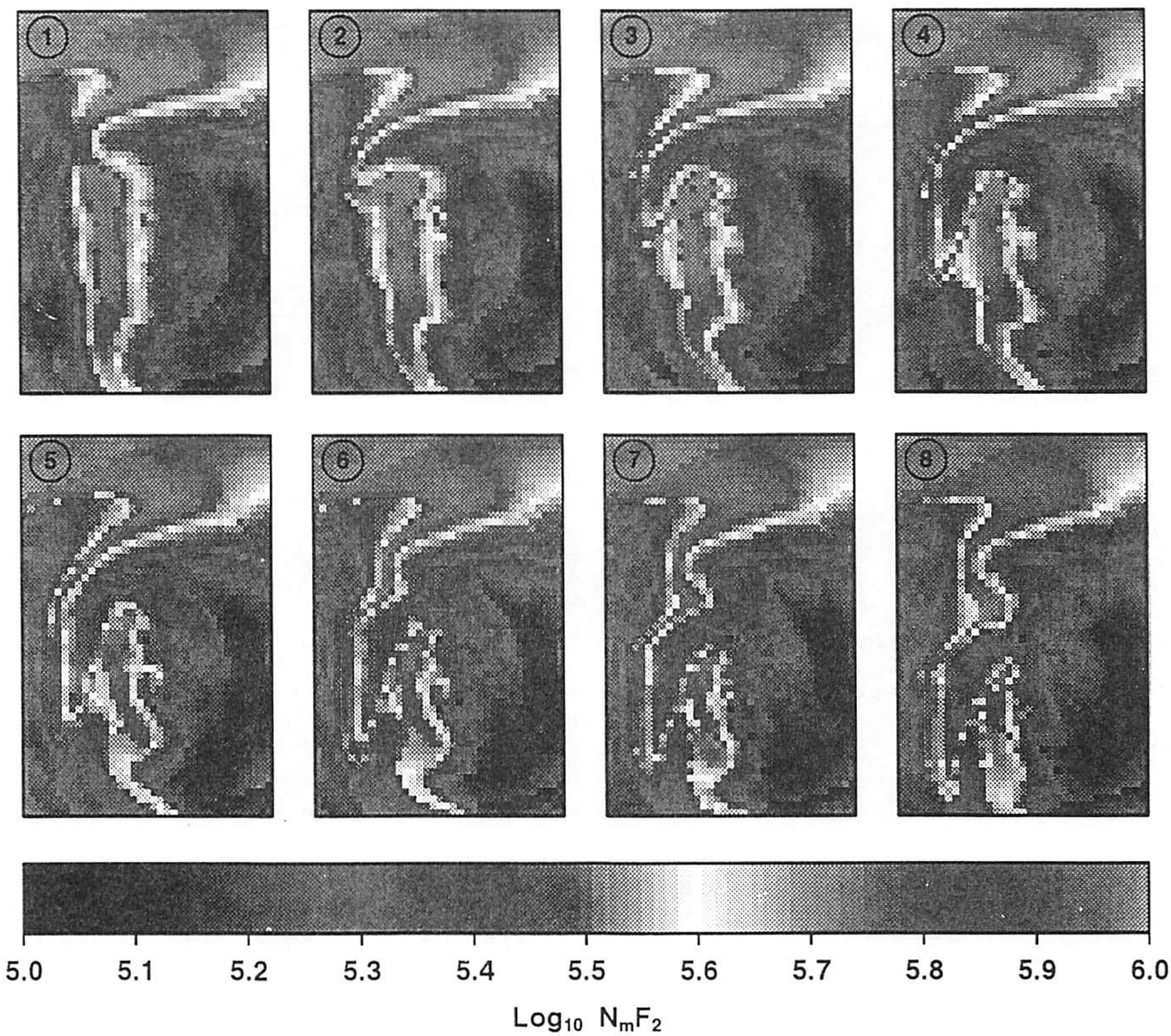


Sojka et al (1993)

Heppner-Maynard Convection



- Southward IMF
- "A" yields uniform flow at 500 m/s
- "DE" yields strong flow in dusk sector at 1 Km/s
- change every ½ hour


1
2
3
4
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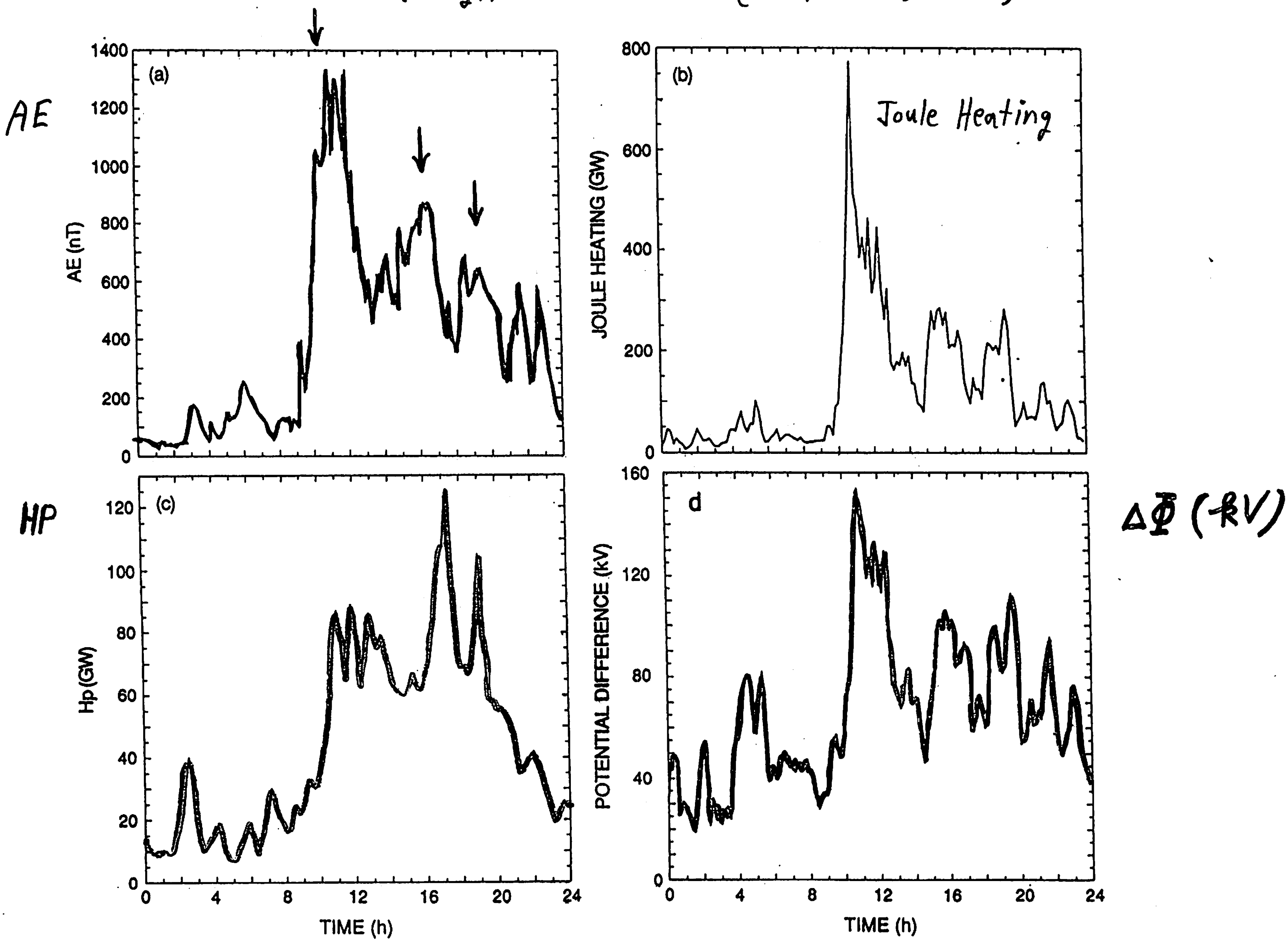
6
7
8
5.0
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
6.0
Log10 NmF2

NCAR-TGCM Simulation

- Equinox Transition Study
  - September 18-19, 1984
- Parameterized Convection and Precipitation Models for Entire Period
  - NOAA & DMSP Particle Data
  - AMIE Technique for Convection
  - Semi-diurnal Tides
- Several Quiet Days Followed by Storm

Crowley et al. (1989)

Magnetic Storm (Sept. 19, 1984)



Neutral Winds and Temperatures

9 UT

(Prestorm)

Active Day
300 km

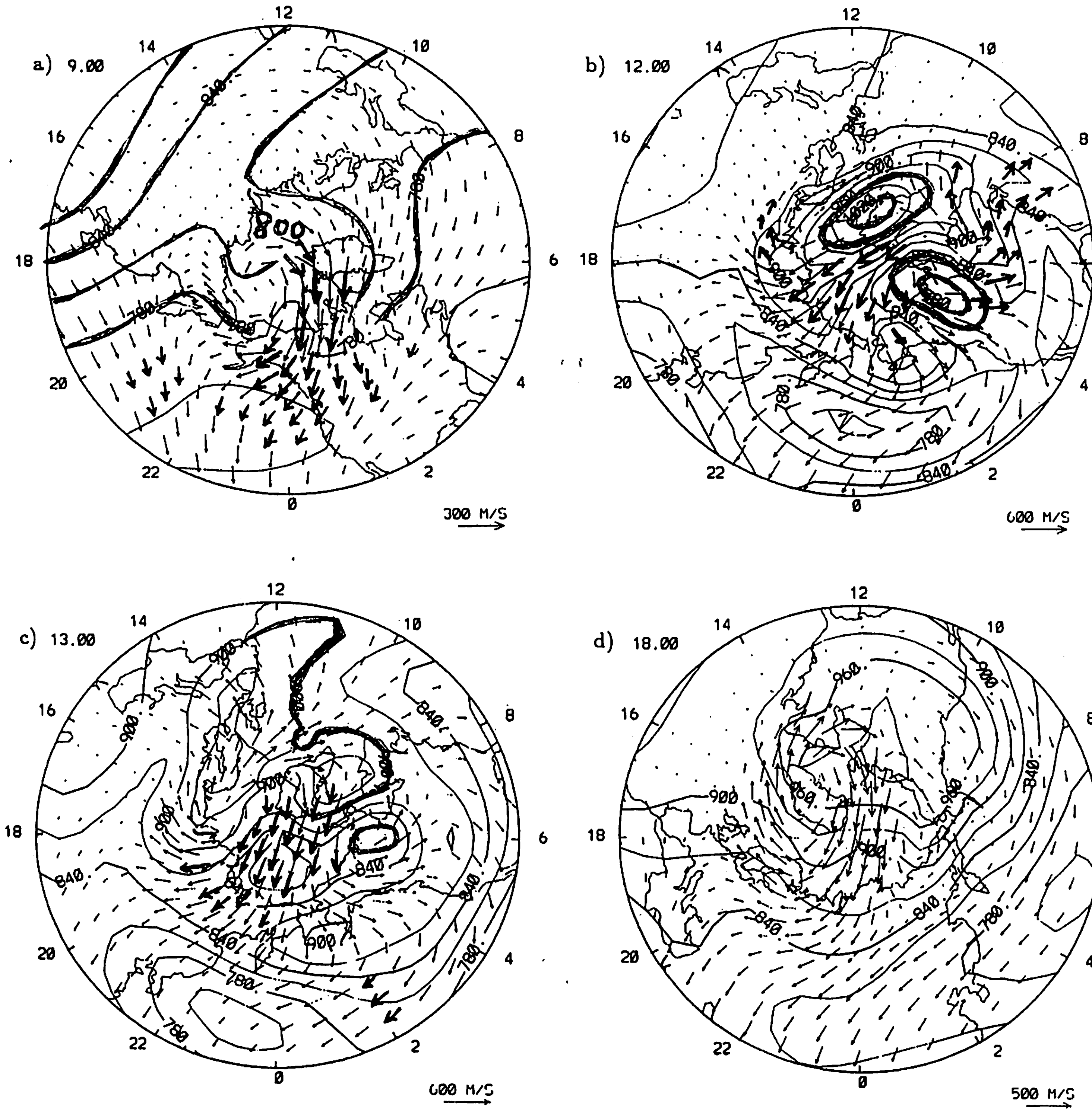
12 UT

1000°

780°

13 UT

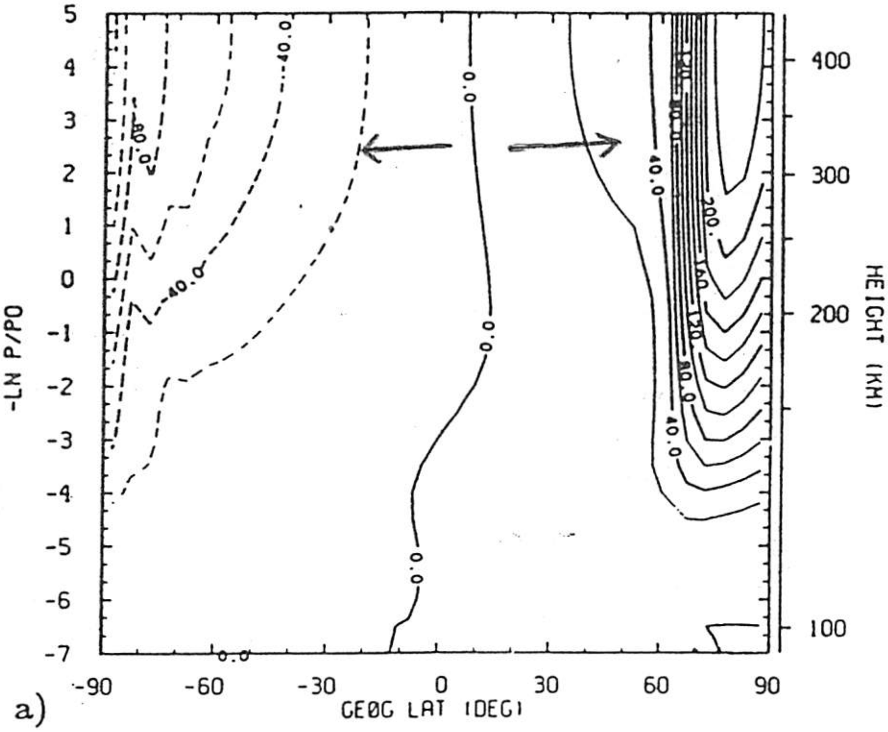
18 UT



Meridional Neutral Wind

1800 UT ; 70° West Longitude

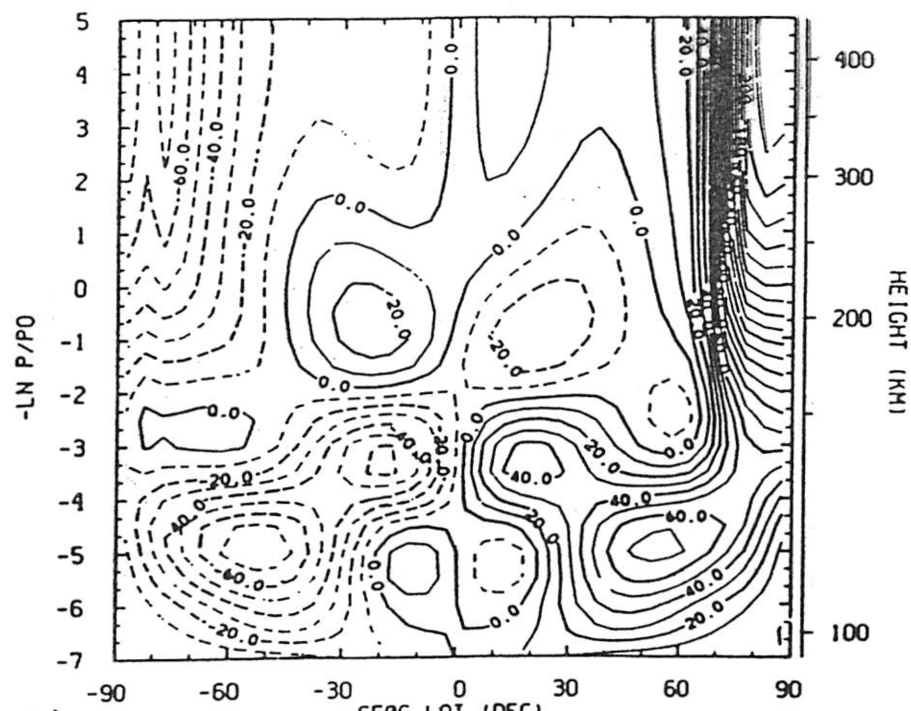
No Tides



Height

a)

Tides



Height

b)

Geographic Latitude

Forecasting: What's Needed?

- Requirements range from hours to 30 or 90 days forecast of the ITM system.

- The latter arise from the need to define optimal usable communication links.

- Typically, 12 hours to a day is a good forecast for severe weather related problems, i.e., satellite drag, spacecraft damage, etc.

- How can we do this?

  An example on 14 April 1994, from Murray Dryer, SEL, NOAA, shows forecasters had no evidence of a CME ejection. However, soft x-ray images from YOHKOH (Japanese satellite) were FAXed to SEL. They showed a very extended short-lived filament. Forecast was made ~ 2-3 days to reach Earth and 7 days to reach Ulysses.

Forecasting: Science Issues

- When a CME arrives at the Earth, how do you convert this knowledge into convection and precipitation patterns? How long will the storm last?

- For non-storm conditions, how do you forecast K_p and *Dst* variations? That is, how do you forecast convection and precipitation pattern variations?

- Models of convection and precipitation do not exist for severe storms. A cross-tail potential of 216 kV was observed, but this corresponds to a K_p = 14.

- The 'average' convection pattern for northward IMF has not been clearly identified.

- The spatial structure seen in the ionosphere-thermosphere system needs to be incorporated into the forecast models. Multi-grids or nested models are required.

- More work needs to be done on establishing how the convection and precipitation patterns vary with time.

    - AMIE approach is the state-of-the-art, but needs validation.

    - PCO is important.

- Need to predict substorm onset.

- Real-time monitoring is important to update forecast models.

- Need a specification of upward propagating gravity and tidal waves.