1998 CEDAR Workshop

Boulder, Colorado
June 7-12, 1998

Tutorial Lecture

by Timothy Fuller-Rowell
Space Environment Center, NOAA

Polar Aeronomy: Thermosphere-Ionosphere Interactions above 100 km

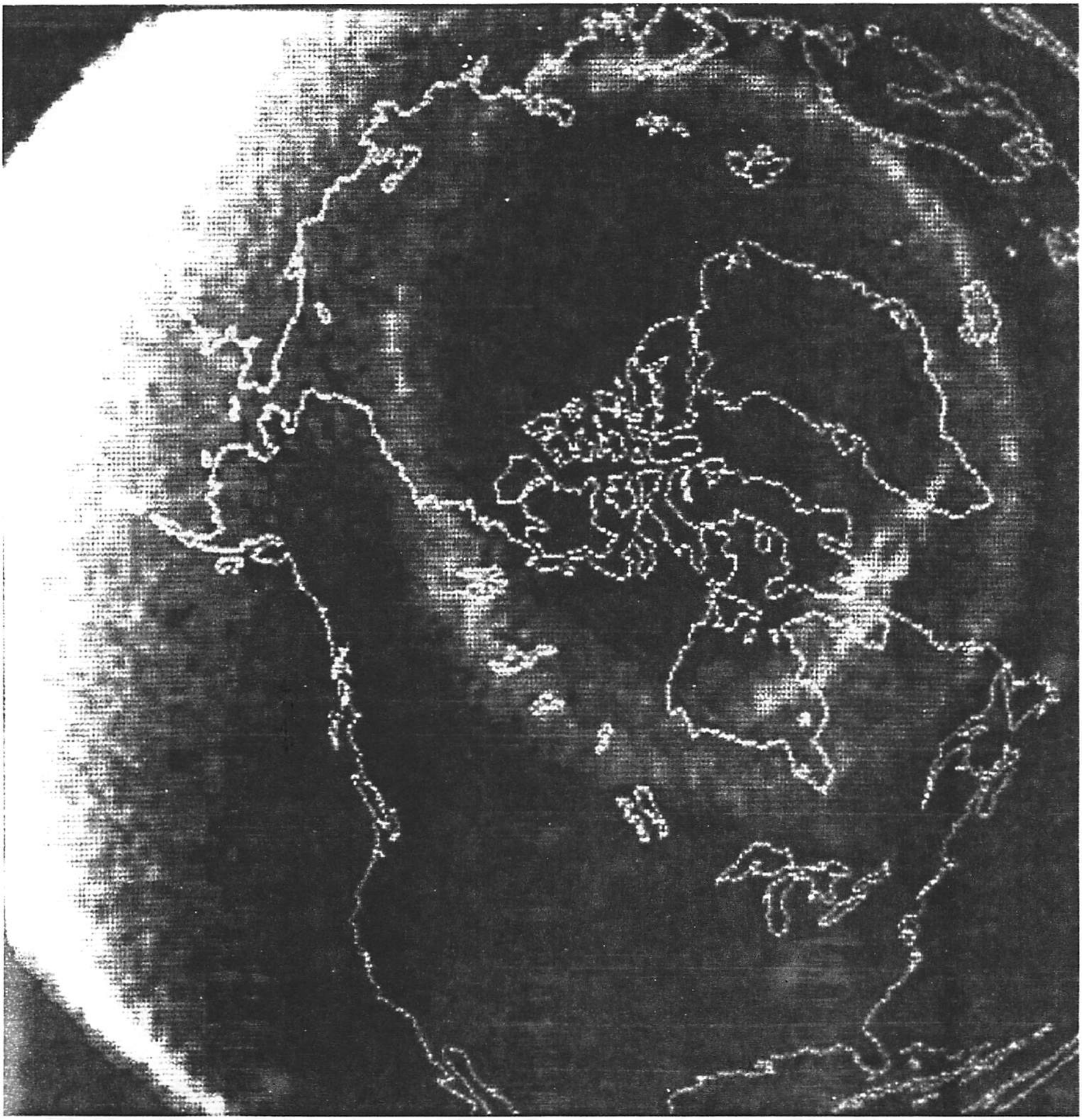
POLAR AERONOMY:

Thermosphere-Ionosphere Interactions above 100 km

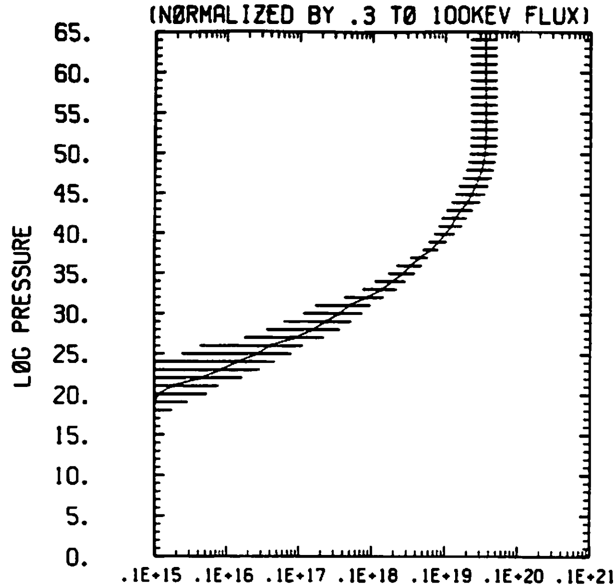
by

Tim Fuller-Rowell

CONTENTS:

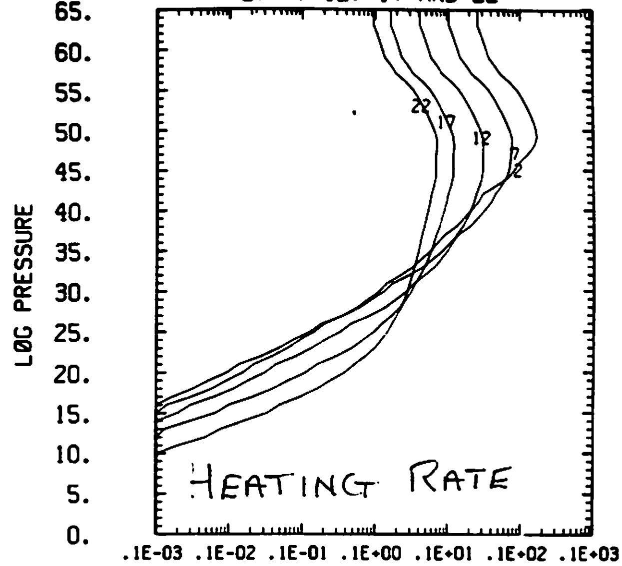


MEAN PRØFILE AND VARIANCE ØF
IØNIZATIØN RATE FØR SPECTRA
WITH PEAK IN BAND 7
(NØRMALIZED BY .3 TØ 100KEV FLUX)



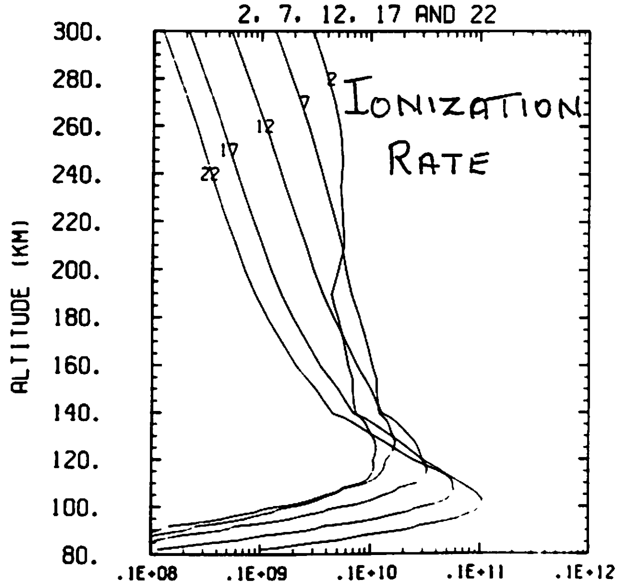
IØNIZATIØN RATE / UNIT MASS / UNIT FLUX
(/KG/S)/(MW/M2)

HEATING RATE FØR SPECTRA
WITH PEAK IN BANDS
2, 7, 12, 17 AND 22



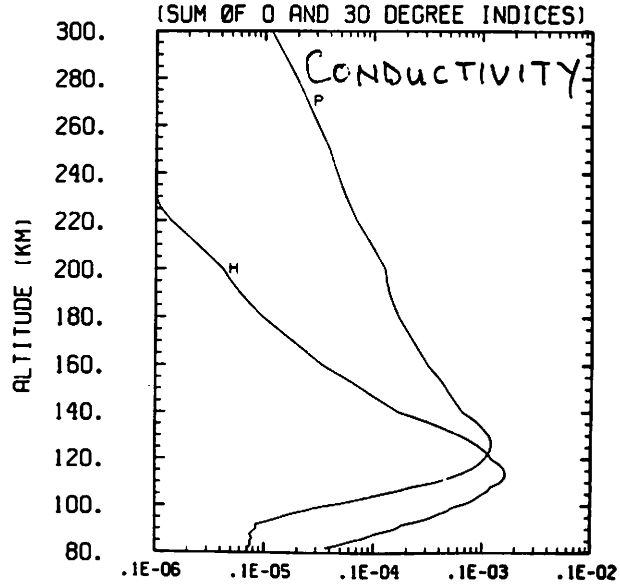
HEATING RATE / UNIT MASS / UNIT FLUX
(J/KG/S)/(MW/M2)

IØNIZATIØN RATE FØR SPECTRA
WITH PEAK IN BANDS
2, 7, 12, 17 AND 22



IØNIZATIØN RATE / UNIT FLUX
(IØN-PAIRS/M3/S)/(MW/M2)

PEDERSEN(P) AND HALL(H) CØNDUCTIVITY
PRØFILES PER UNIT FLUX FØR SPECTRA
WITH PEAK IN BAND 7
(SUM ØF 0 AND 30 DEGREE INDICES)



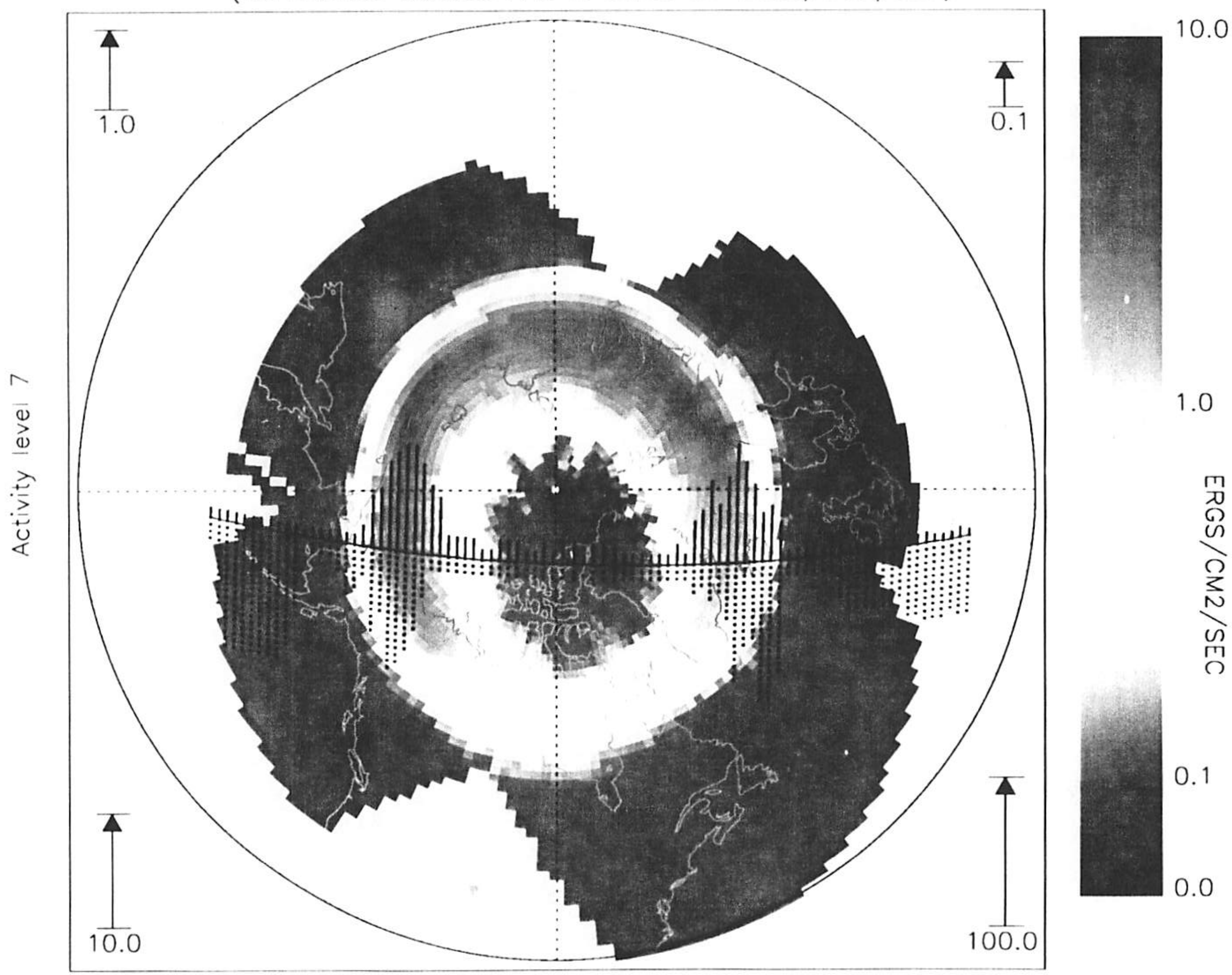
CØNDUCTIVITY (MHØS/M)

HEIGHT INTEGRATED CØNDUCTIVITIES
HALL = 4.439 MHØS
PEDERSEN = 5.094 MHØS

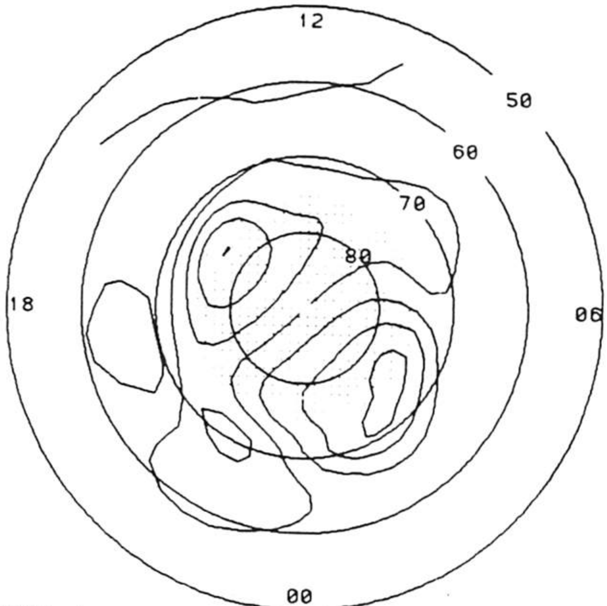
DATA :- TIROS / NOAA AURORAL PARTICLES

Evans.

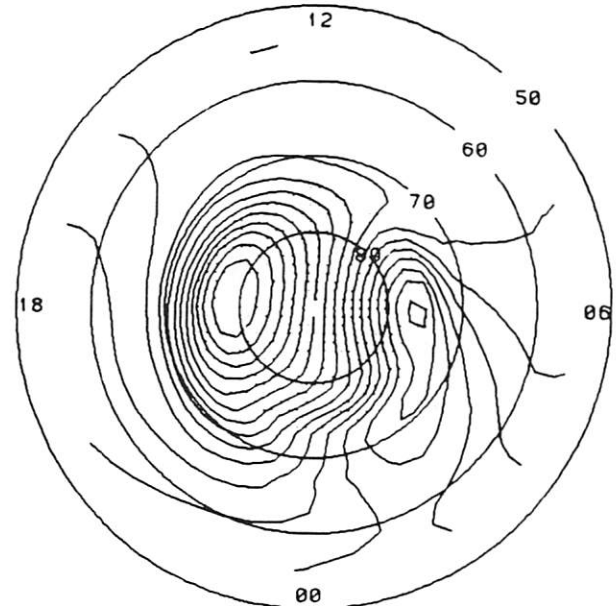
Statistical Auroral Oval Deduced
from a Single Pass of NOAA-12
at 1846 UT on 9 APR, 1996
(REFERENCE SCALES ARE IN UNITS OF ERGS/CM2/SEC)



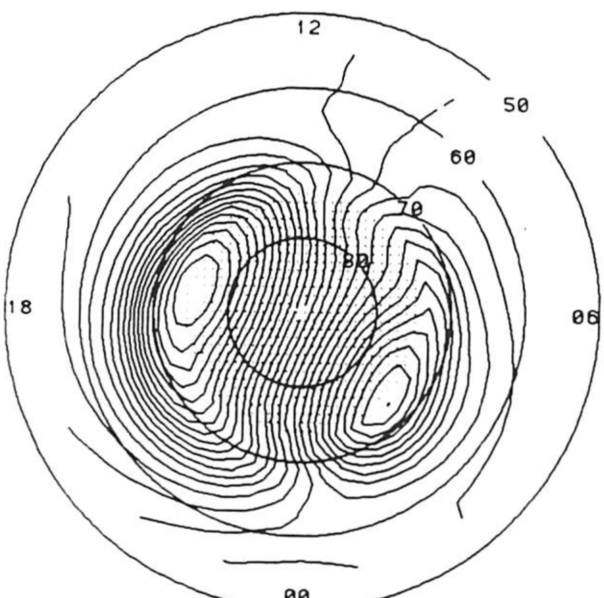
FOSTER ET AL. 1996



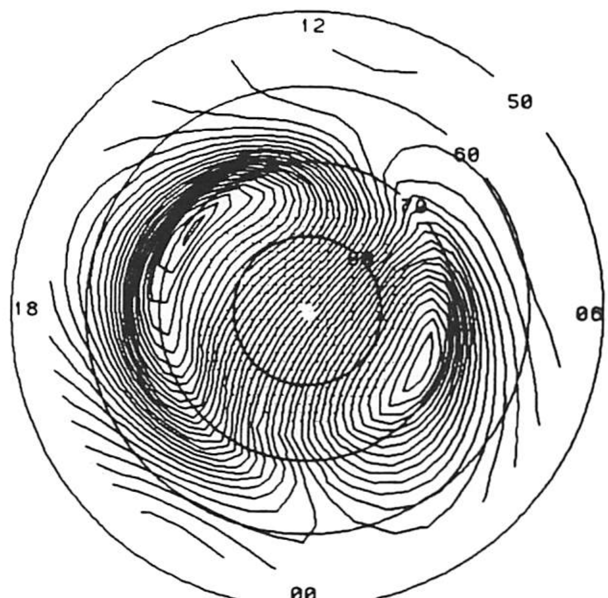
LEVEL 1



LEVEL 4

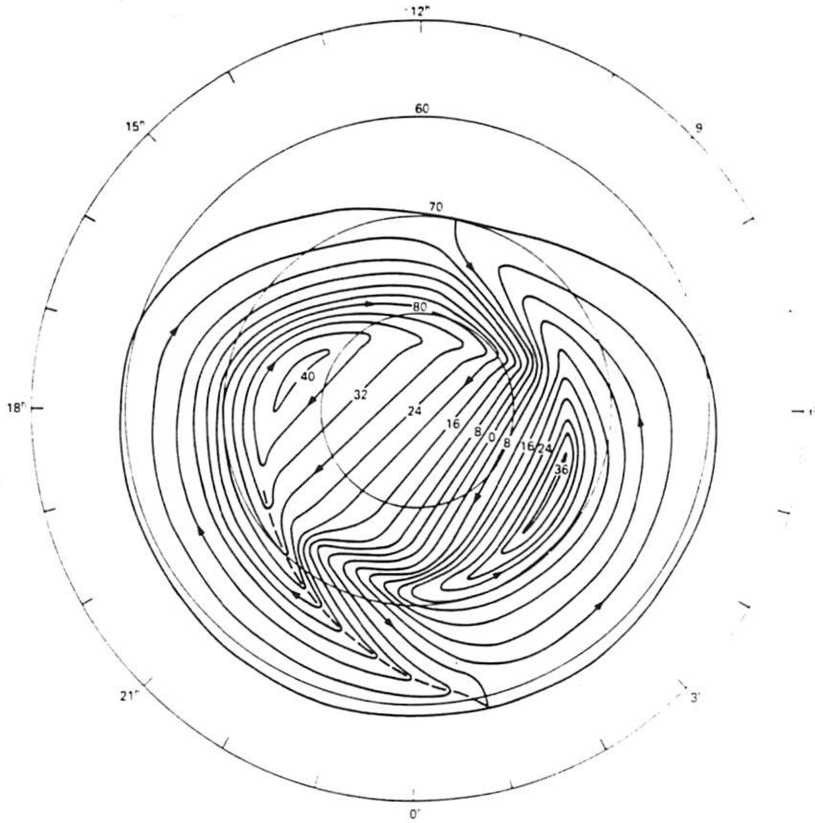


LEVEL 7



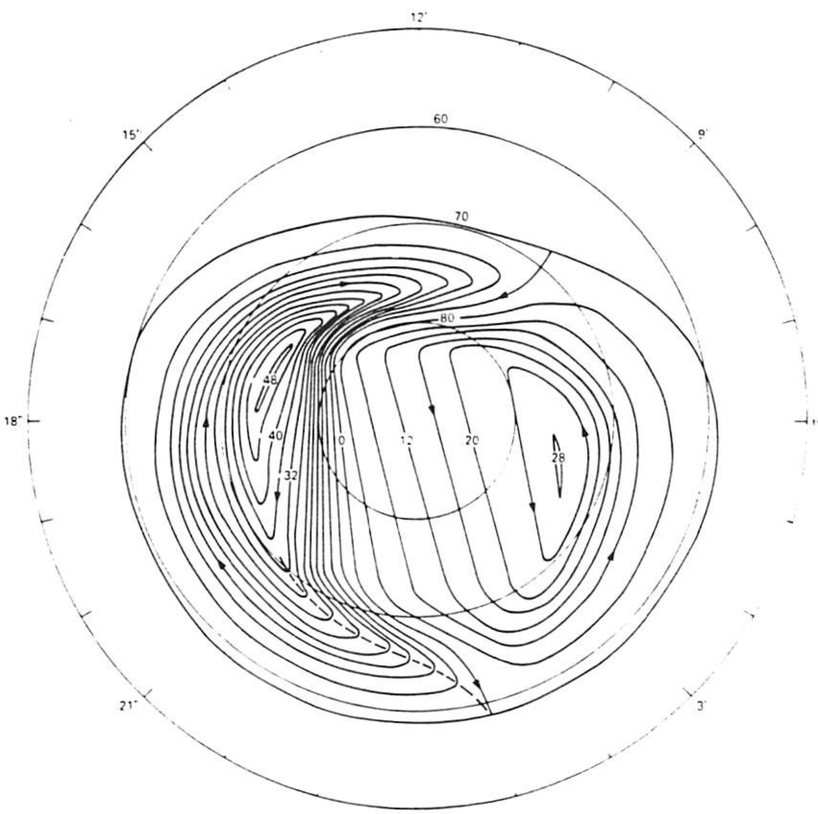
LEVEL 9

HEPPNER AND MAYNARD, 1987



By +ve

Fig. 3. Convection electric field model BC, representing the most typical pattern distribution encountered in the northern hemisphere under + Y IMF conditions and in the southern hemisphere under − Y IMF conditions (3⁻ ≤ Kp ≤ 4⁺).

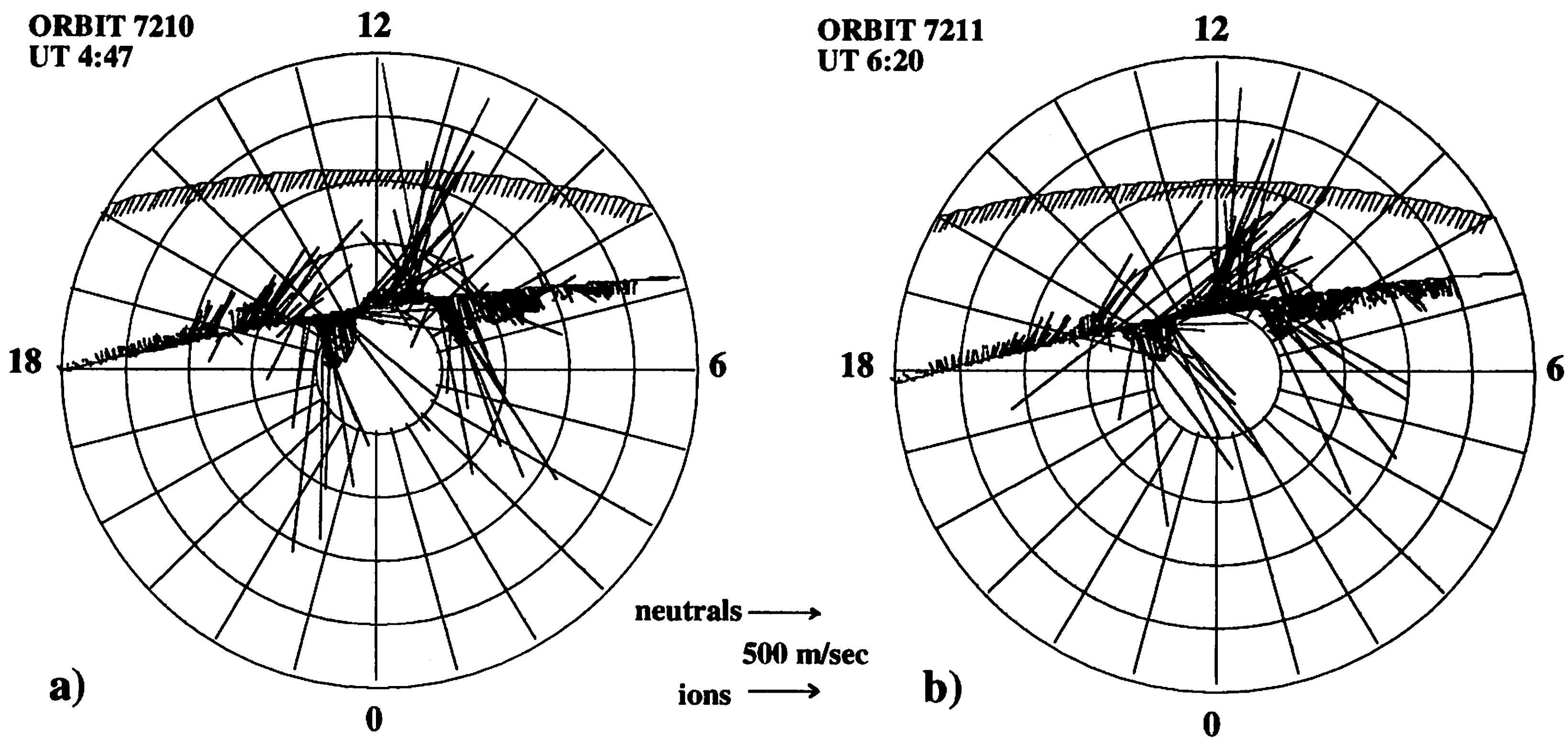


By −ve

Fig. 2. Convection electric field model DE, one of two models representing pattern distributions encountered in the northern hemisphere under − Y IMF conditions and in the southern hemisphere under + Y IMF conditions (3⁻ ≤ Kp ≤ 4⁺).

DE 2 FPI/WATS/IDM/RPA DAY 82328

B_z north.



Killeen et al., JATP 1991

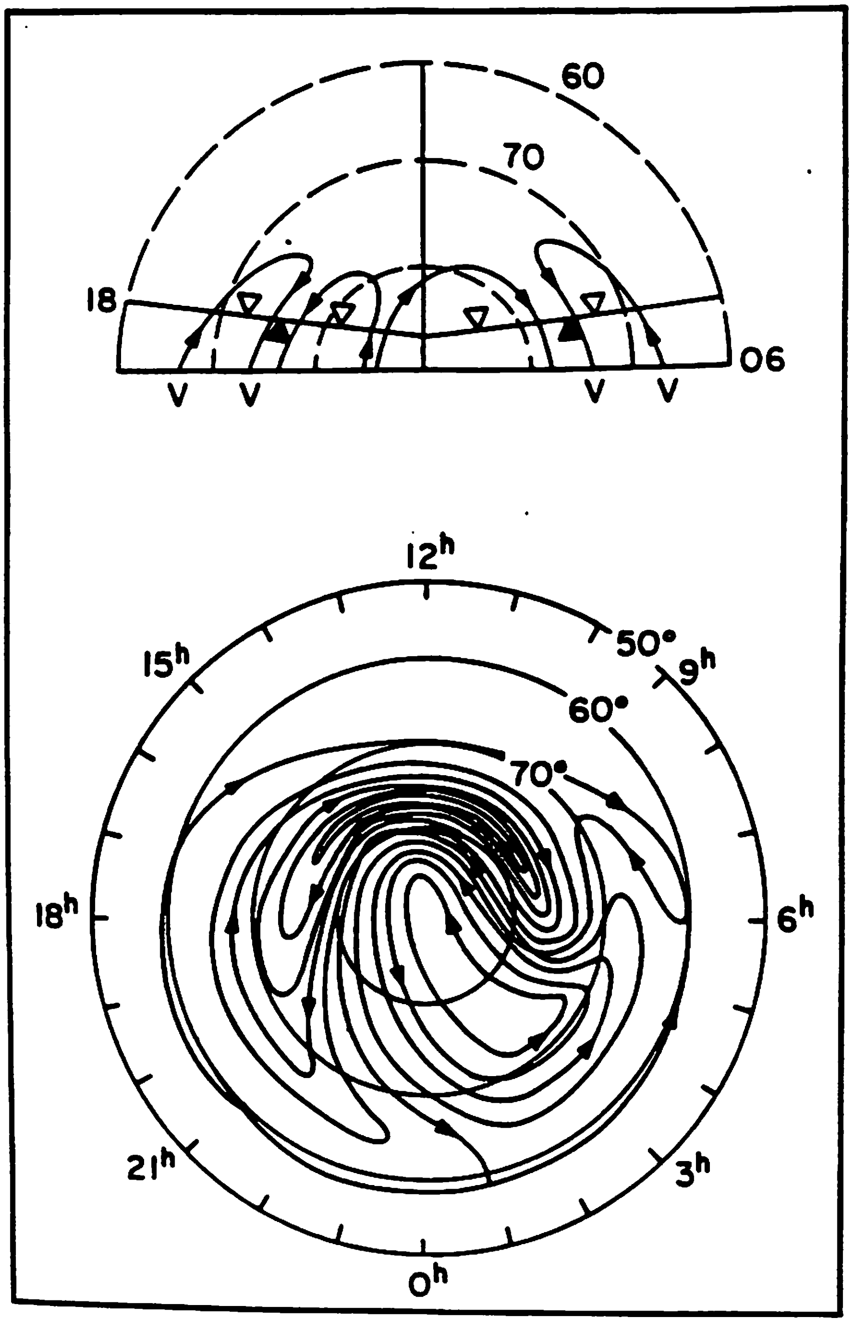


Figure 2.4.
Two different hypothetical polar cap convection patterns based on the same experimental data.

ROBINSON ET AL.

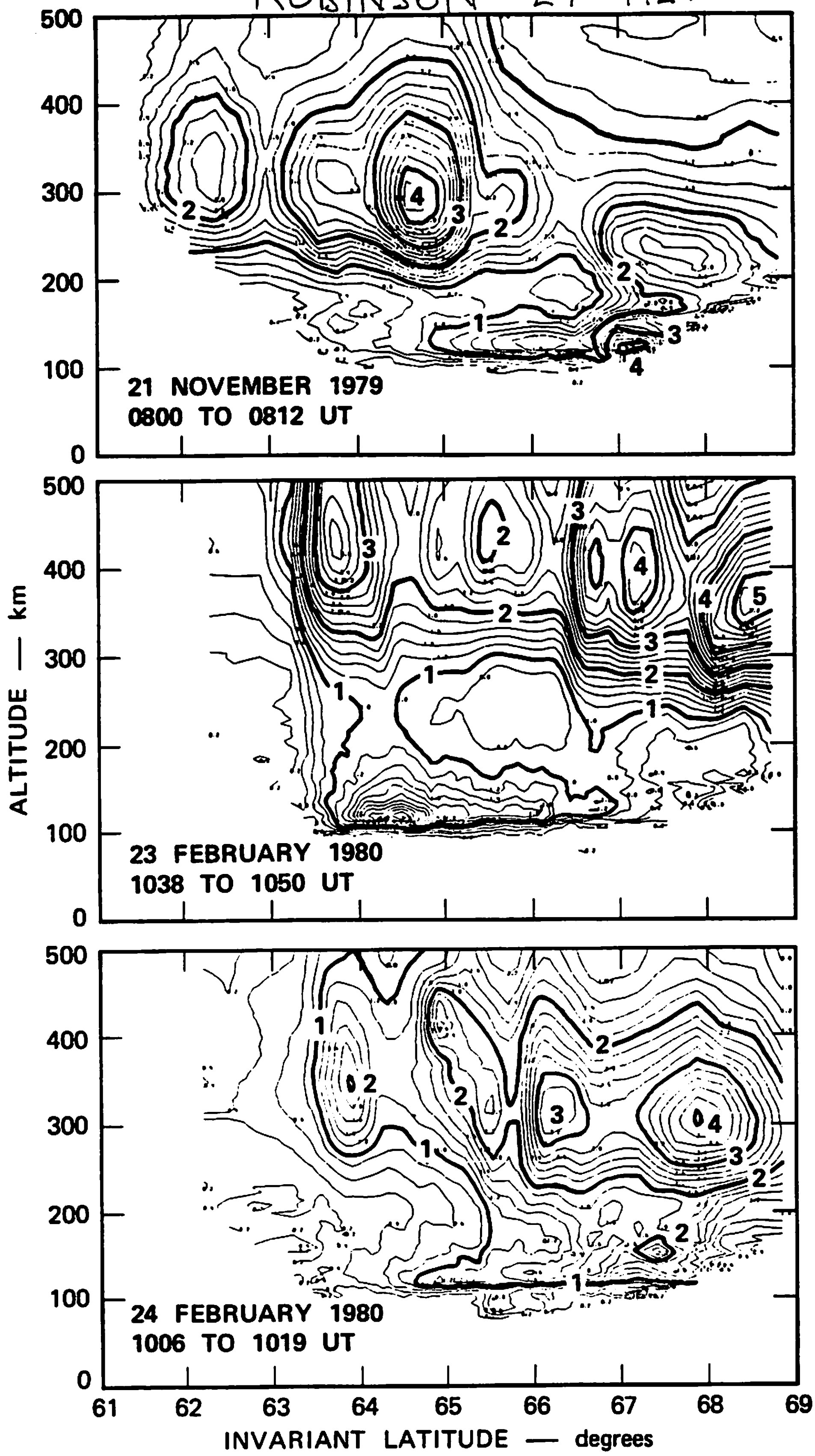
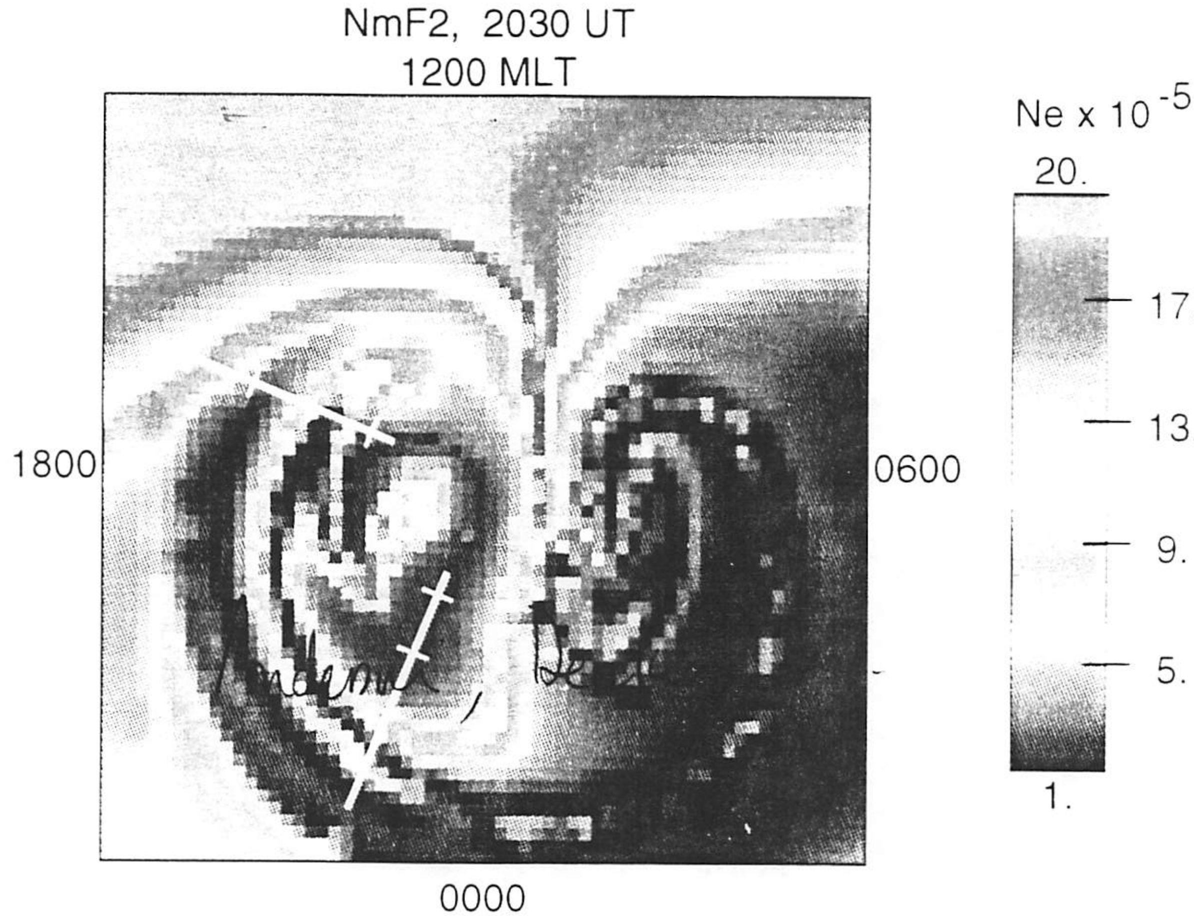
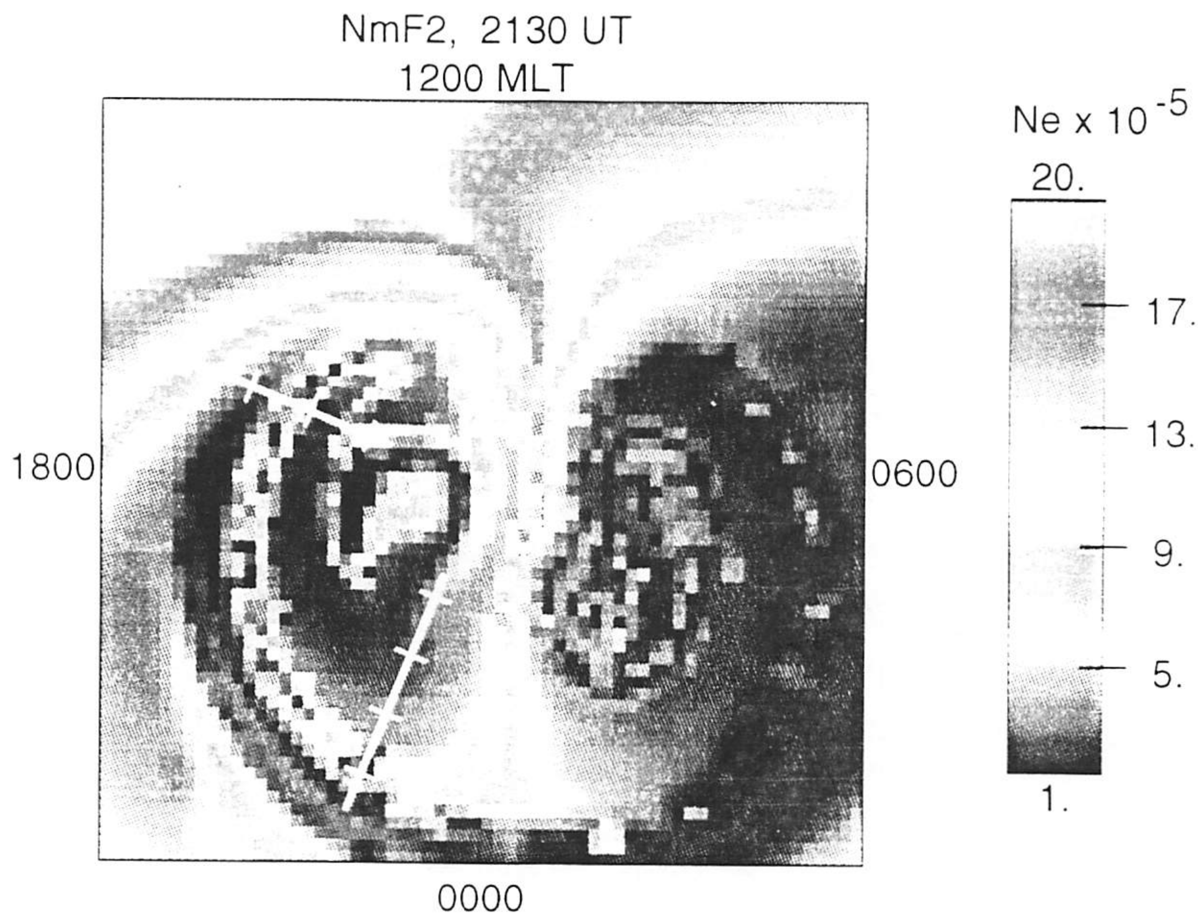
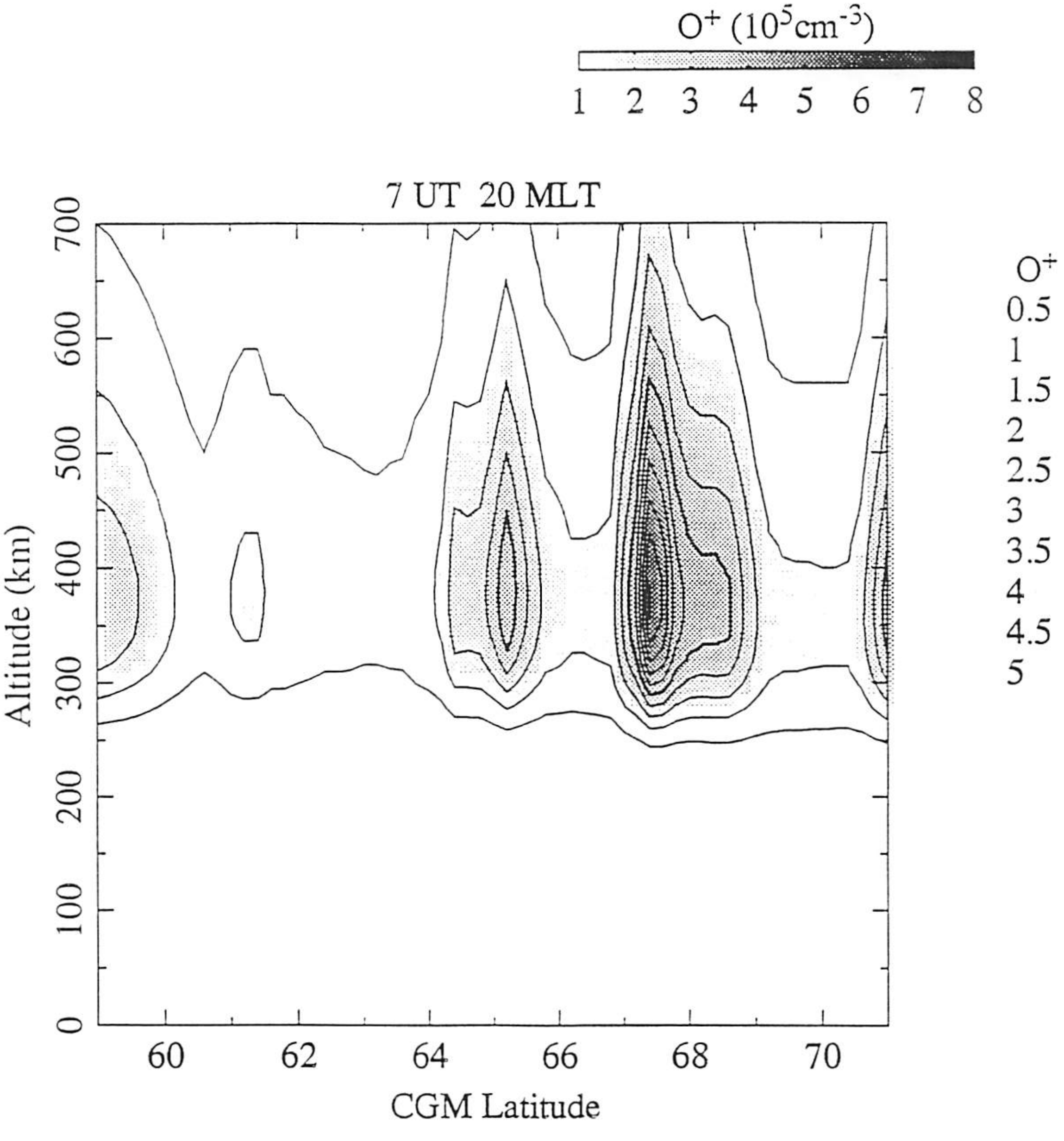


Fig. 1. Examples of elevation scan measurements of electron density obtained on three different evenings.

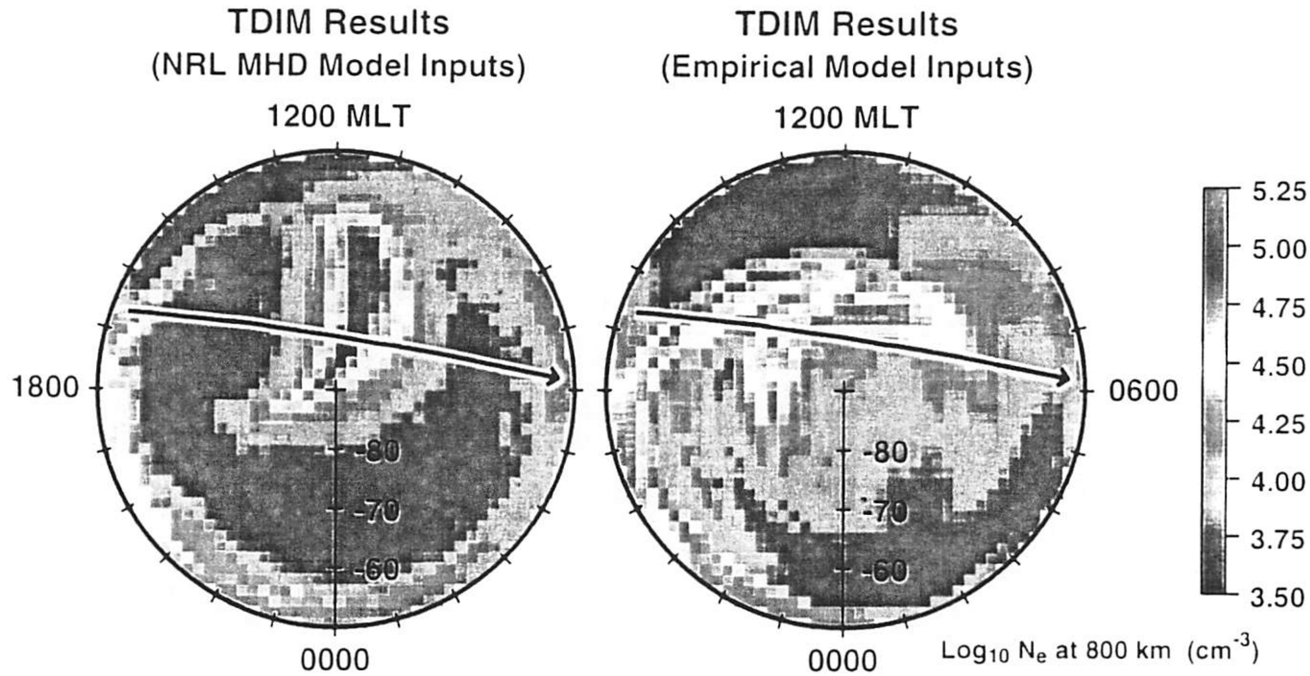

NmF2, 2030 UT
1200 MLT
Ne x 10 -5
20.
17.
13.
9.
5.
1.
1800
0600
0000


NmF2, 2130 UT
1200 MLT
Ne x 10 -5
20.
17.
13.
9.
5.
1.
1800
0600
0000



O+ (10^5cm^-3)
1 2 3 4 5 6 7 8
7 UT 20 MLT
Altitude (km)
0 100 200 300 400 500 600 700
60 62 64 66 68 70
CGM Latitude
O+
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

SOJKA, SCHUNK, ...



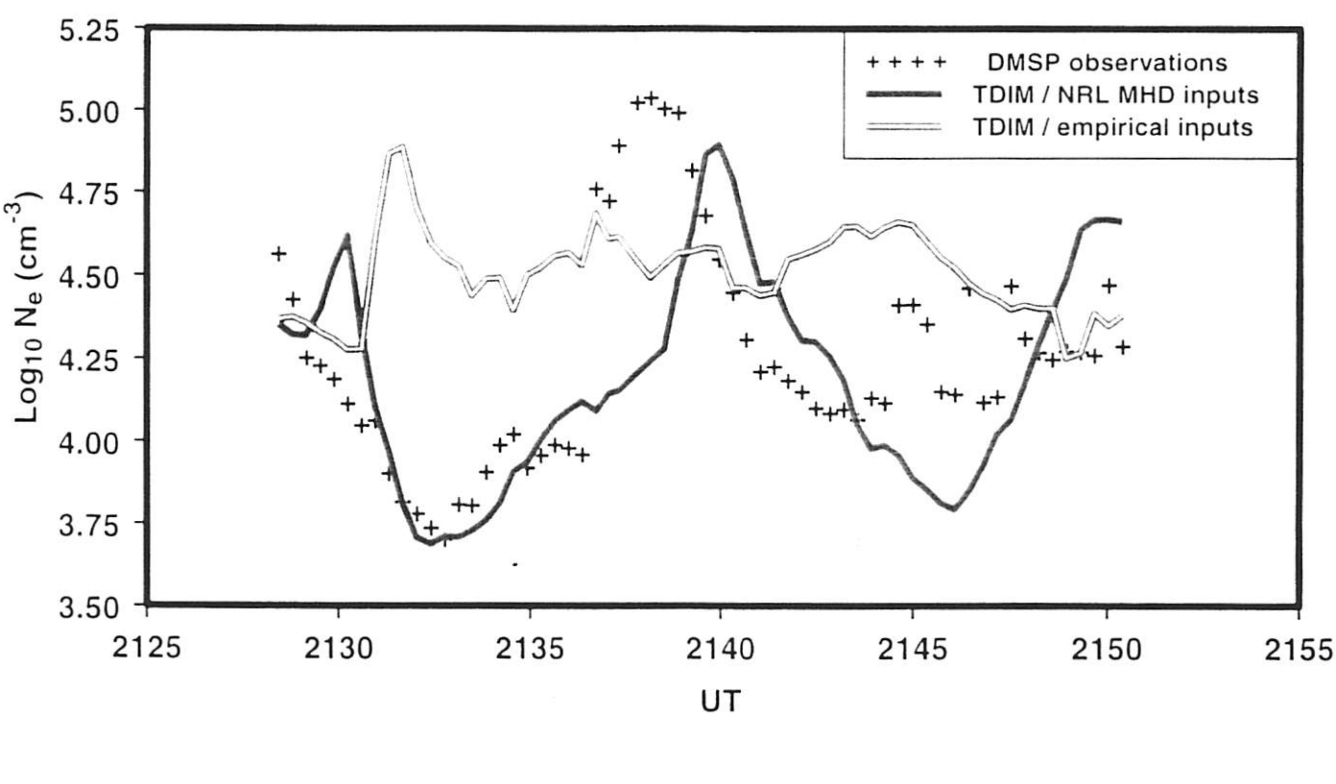
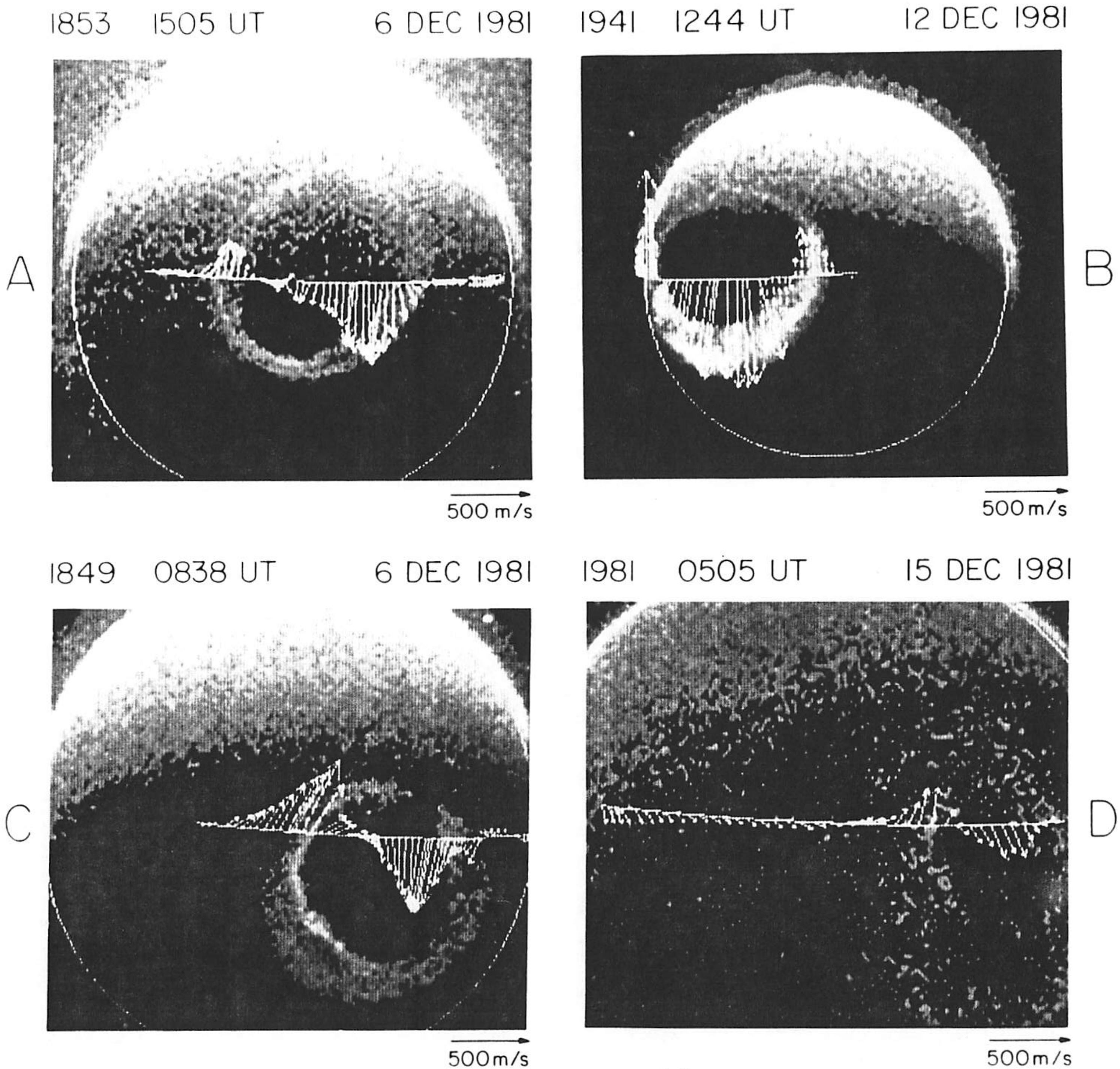
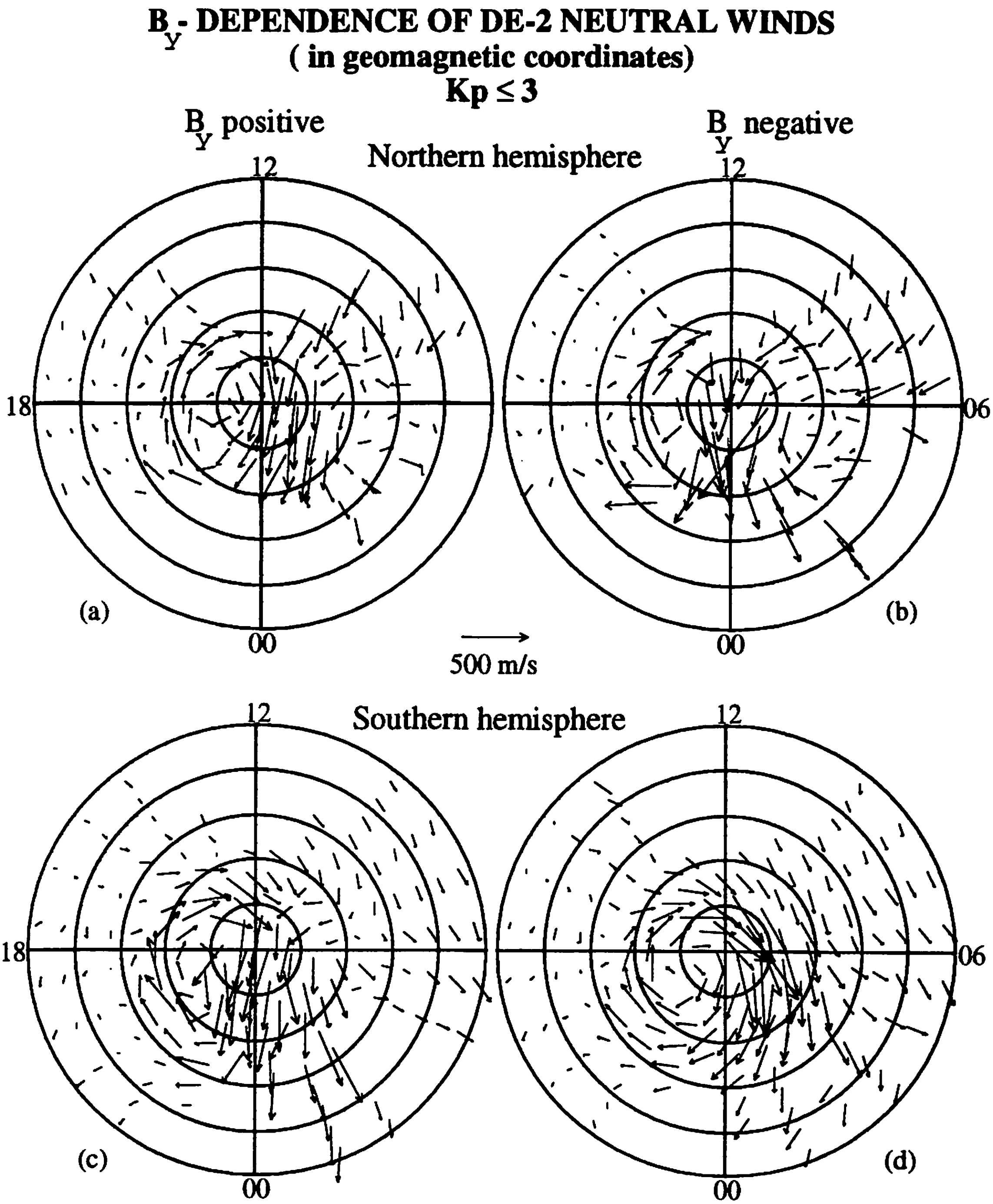


Plate 4

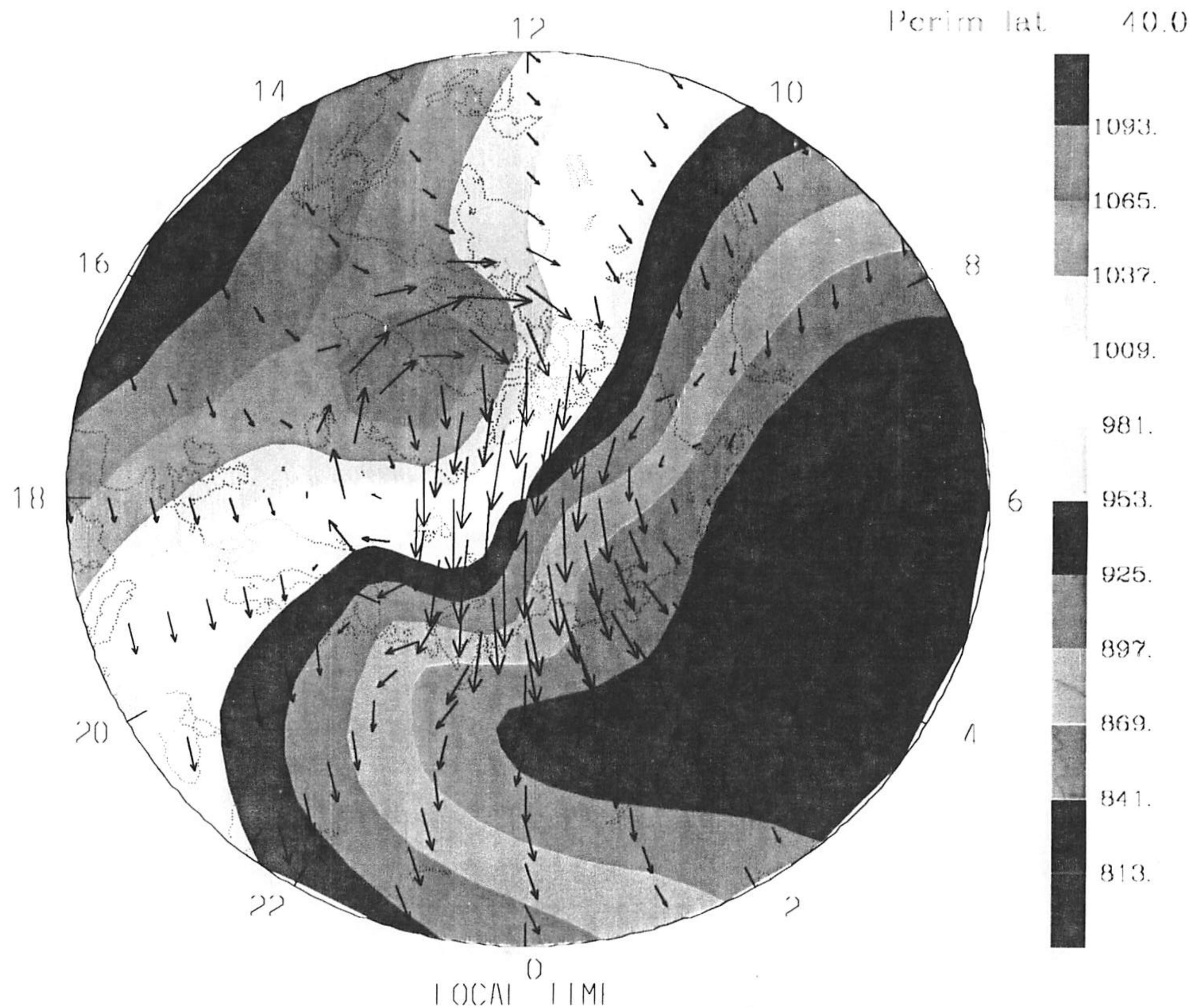


Killeen et al.

Thayer et al., JGR, 1990



CTIM NEUTRAL TEMPERATURE (DEG. K) s55



UT 18.0 Pressure level 12 405 M/S

MINIMUM 784.7, MAXIMUM 1121.2, CONTOUR INTERVAL 28.0

EQUATION OF MOTION

$$\frac{D}{Dt}\vec{V} = -\frac{1}{\rho}\nabla P - 2\vec{\Omega} \times \vec{V} - \nu_{ni}(\vec{V} - \vec{U}) + \frac{1}{\rho}\nabla(\mu\nabla\vec{V}) + \vec{g}$$

Pressure gradient | Coriolis | Ion drag | Viscosity | Gravity

$$\frac{D}{Dt}X = \frac{\partial}{\partial t}X + (\vec{V} \cdot \nabla)X$$

$$\frac{\partial}{\partial t}V_\theta = -\frac{V_\theta}{r}\frac{\partial}{\partial\theta}V_\theta - \frac{V_\phi}{r\sin\theta}\frac{\partial}{\partial\phi}V_\theta - \omega\frac{\partial}{\partial p}V_\theta - \frac{g}{r}\frac{\partial}{\partial\theta}h$$

$$+(2\Omega+\frac{V_\phi}{r\sin\theta})V_\phi\cos\theta+g\frac{\partial}{\partial p}[(\mu_m+\mu_T)\frac{p}{H}\frac{\partial}{\partial p}V_\theta]-\nu_{ni}(V_\theta-U_\theta)$$

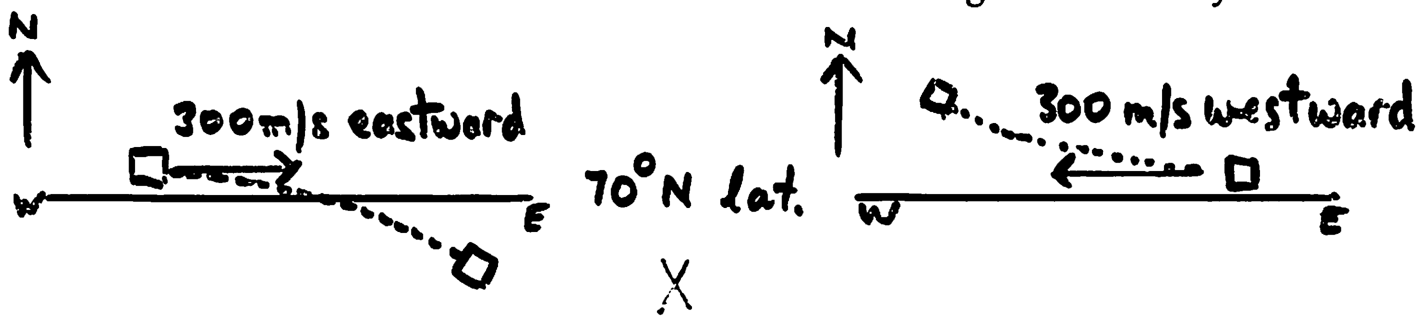
$$\frac{\partial}{\partial t}V_\phi = -\frac{V_\theta}{r}\frac{\partial}{\partial\theta}V_\phi - \frac{V_\phi}{r\sin\theta}\frac{\partial}{\partial\phi}V_\phi - \omega\frac{\partial}{\partial p}V_\phi - \frac{g}{r\sin\theta}\frac{\partial}{\partial\phi}h$$

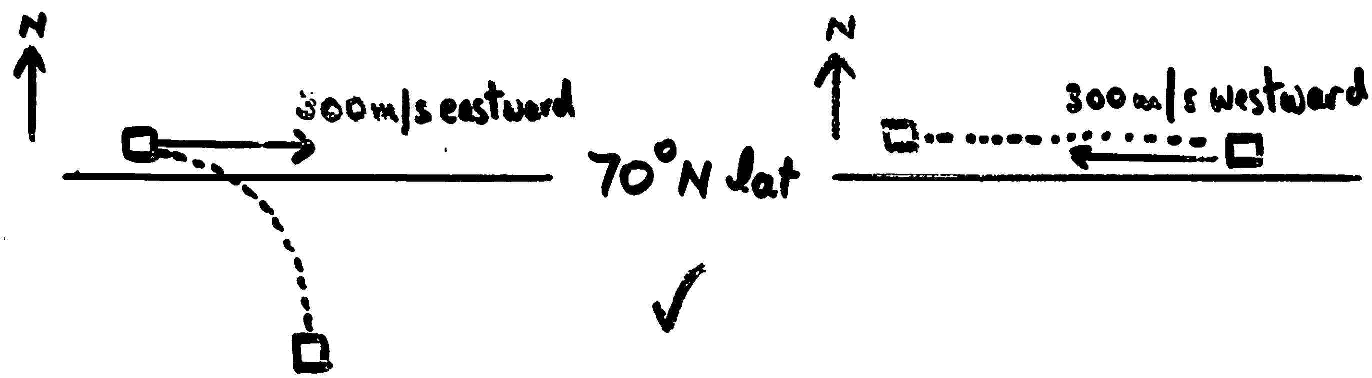
$$+(2\Omega+\frac{V_\phi}{r\sin\theta})V_\theta\cos\theta+g\frac{\partial}{\partial p}[(\mu_m+\mu_T)\frac{p}{H}\frac{\partial}{\partial p}V_\phi]-\nu_{ni}(V_\theta-U_\theta)$$

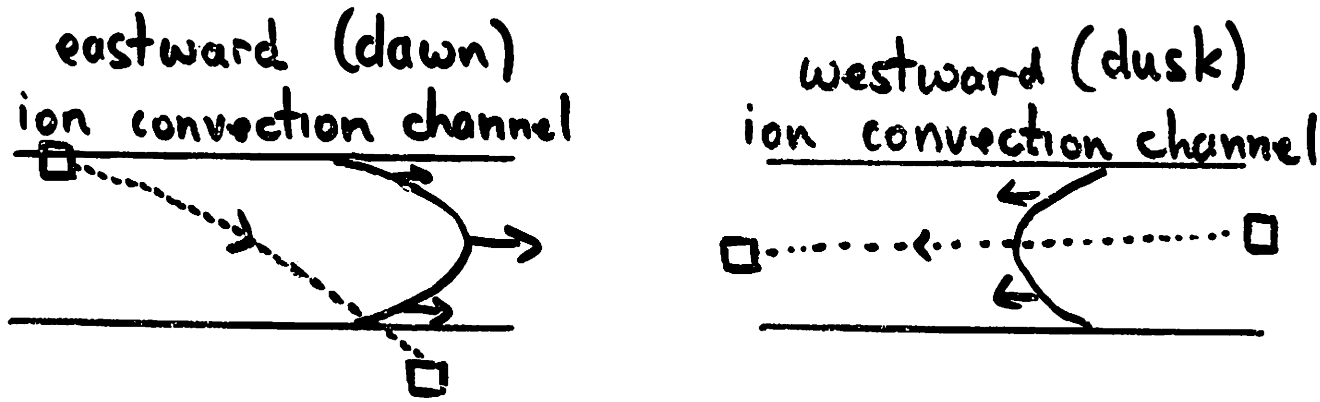
EQUATION OF MOTION

$$\frac{D}{Dt}V = -\frac{1}{\rho}\nabla p - 2\Omega \wedge V - \nu_{ni}(V-U) + \frac{1}{\rho}\nabla(\mu\nabla V)$$

Pressure Coriolis Ion Drag Viscosity







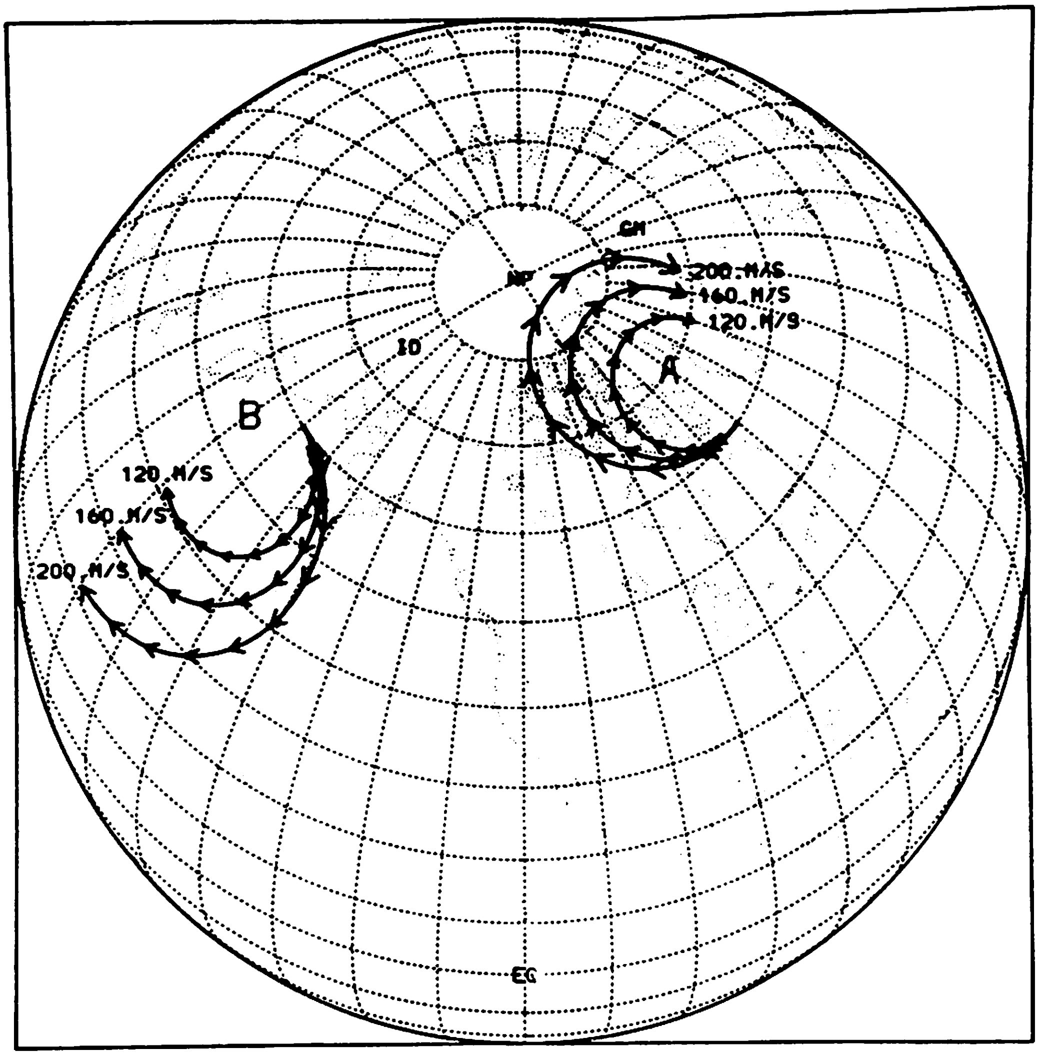


FIG. 2. THE PROGRESS OF PARCELS OF AIR OVER A 9 h PERIOD INITIALLY DIRECTED A—WESTWARD, B—EASTWARD. (NP = North Pole, GM = Greenwich Meridian, ID = International Date Line.)

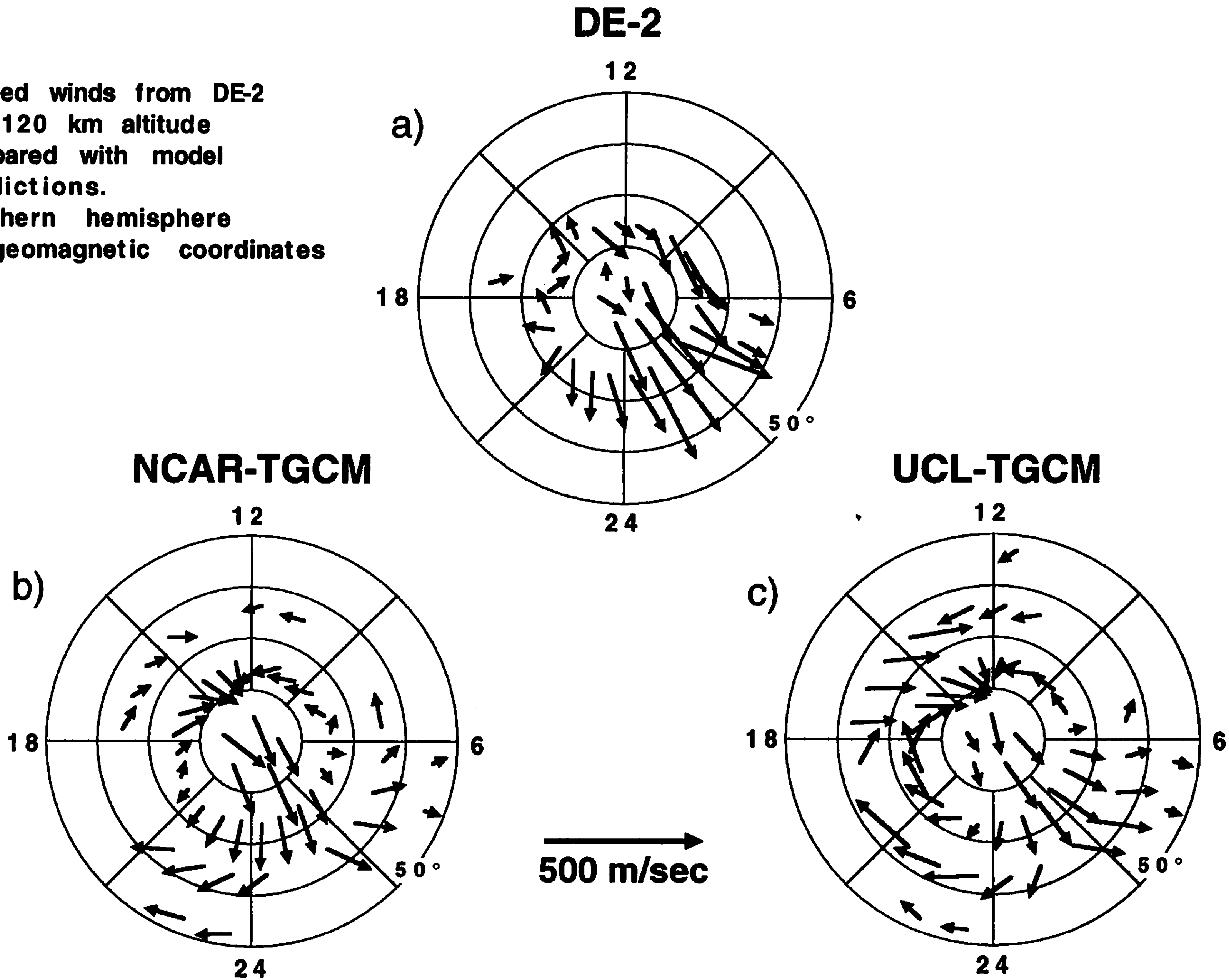
Inertial Oscillation: natural motion of parcels of air

$$\frac{V^2}{r} = fV$$

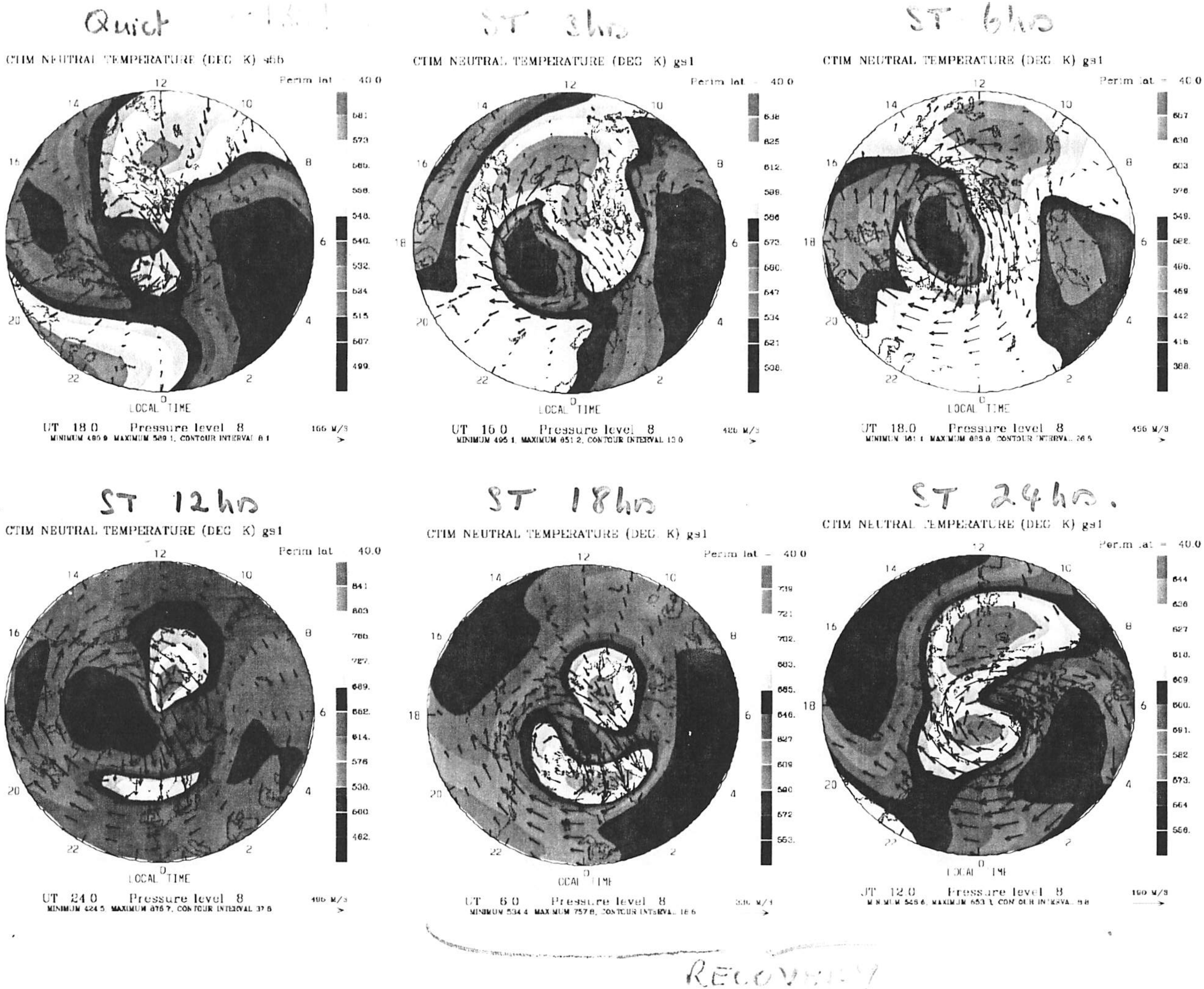
$$\frac{V}{r} \approx \text{const}$$

clockwise vortex in N. H.

Bunned winds from DE-2
at ~120 km altitude
compared with model
predictions.
Southern hemisphere
in geomagnetic coordinates



Killeen et al., GRL, 1992


Quick
ST 3hrs
ST 6hrs
ST 12hrs
ST 18hrs
ST 24hrs.
CTIM NEUTRAL TEMPERATURE (DEG K) gs1
Perim lat 40.0
LOCAL TIME
UT 18.0 Pressure level 8
UT 15.0 Pressure level 8
UT 18.0 Pressure level 8
UT 24.0 Pressure level 8
UT 6.0 Pressure level 8
UT 12.0 Pressure level 8
RECOVERY

CROWLEY, SCHOENDORF, ..

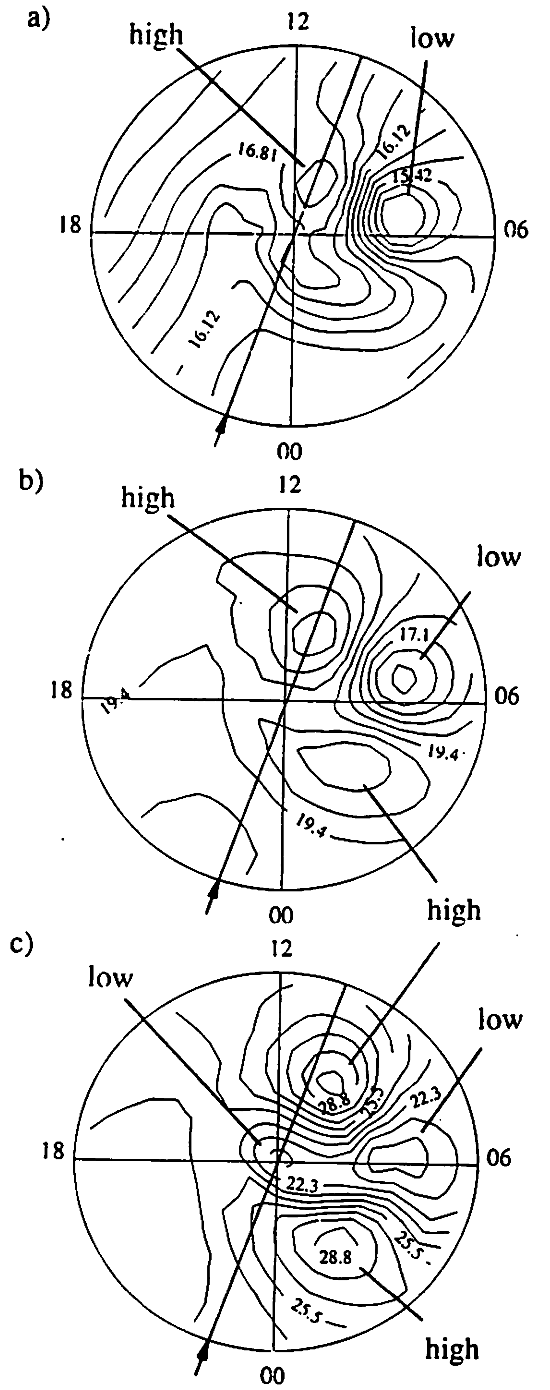
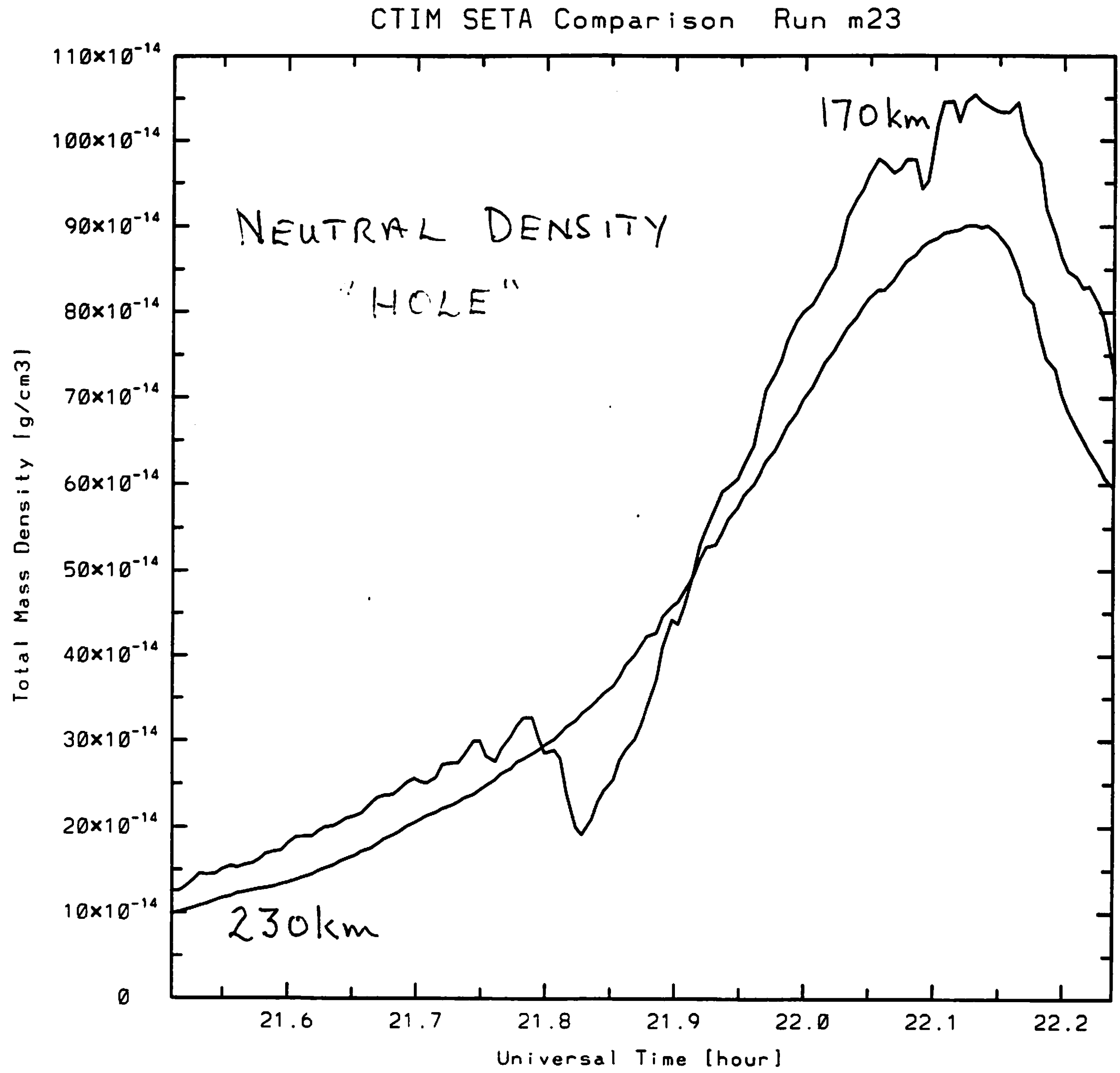
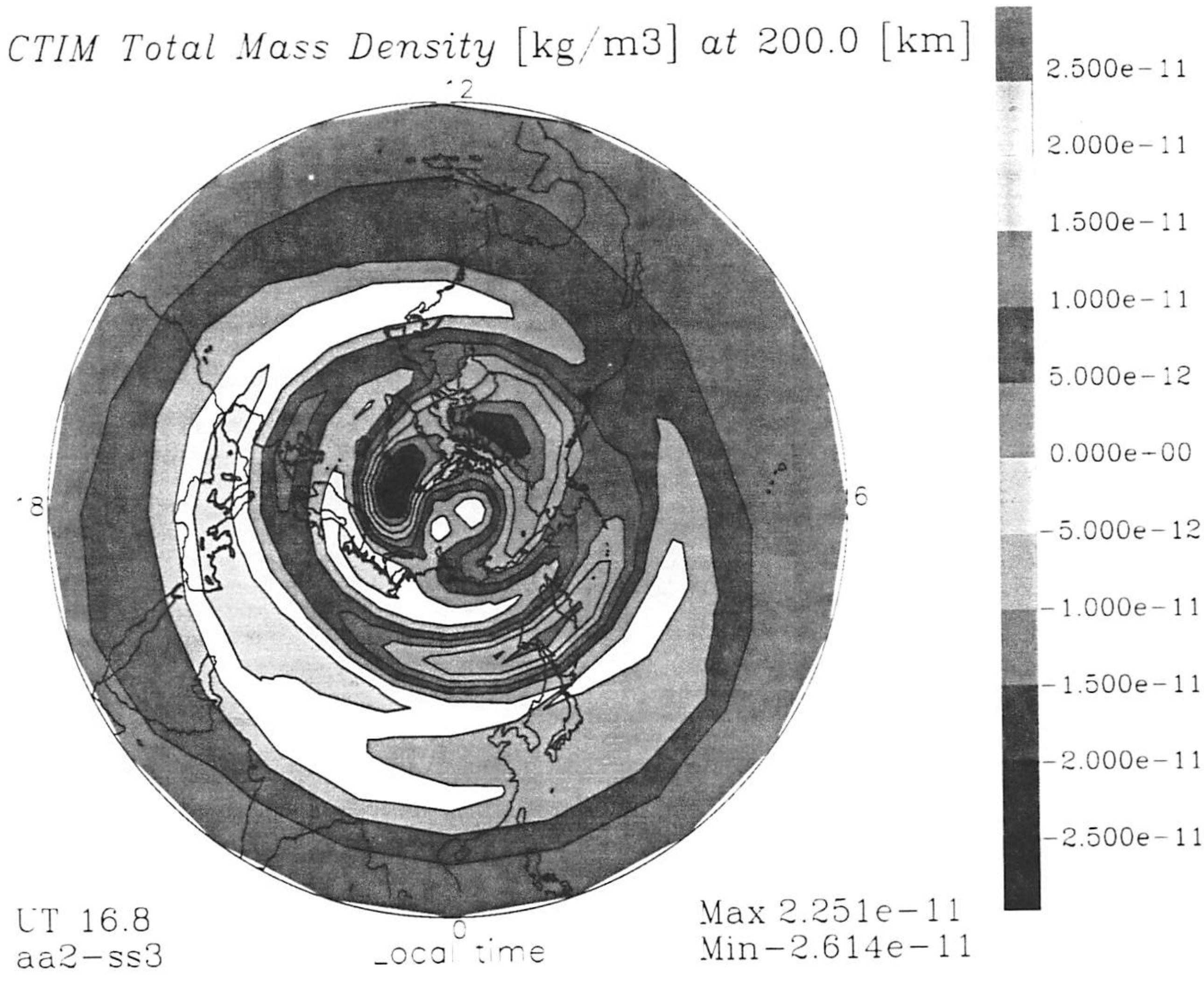


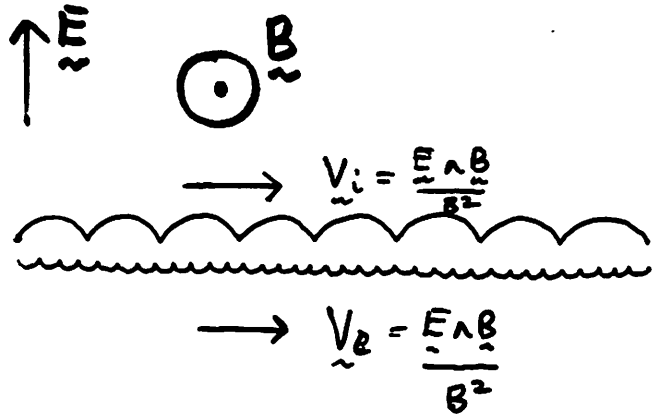
Fig. 1. TIGCM predictions of neutral mass density showing 2-, 3-, and 4-cell patterns in geographic coordinates at 200-km altitude and 12 UT from (a) quiet time (30 kV), (b) moderate (60 kV), and (c) active (90 kV) conditions, respectively. A satellite trajectory in the 2240–1040 Local Time plane is superimposed on each figure. The outer latitude circle corresponds to 45°N. Intermediate latitude circles are omitted for clarity.

MARCOS,


CTIM SETA Comparison Run m23
NEUTRAL DENSITY
"HOLE"
170km
230km
Total Mass Density [g/cm3]
110x10^-14
100x10^-14
90x10^-14
80x10^-14
70x10^-14
60x10^-14
50x10^-14
40x10^-14
30x10^-14
20x10^-14
10x10^-14
0
21.6
21.7
21.8
21.9
22.0
22.1
22.2
Universal Time [hour]

MATSUO ET. AL.


CTIM Total Mass Density [kg/m3] at 200.0 [km]
12
18
6
0
Local time
UT 16.8
aa2-ss3
Max 2.251e-11
Min-2.614e-11
2.500e-11
2.000e-11
1.500e-11
1.000e-11
5.000e-12
0.000e-00
-5.000e-12
-1.000e-11
-1.500e-11
-2.000e-11
-2.500e-11



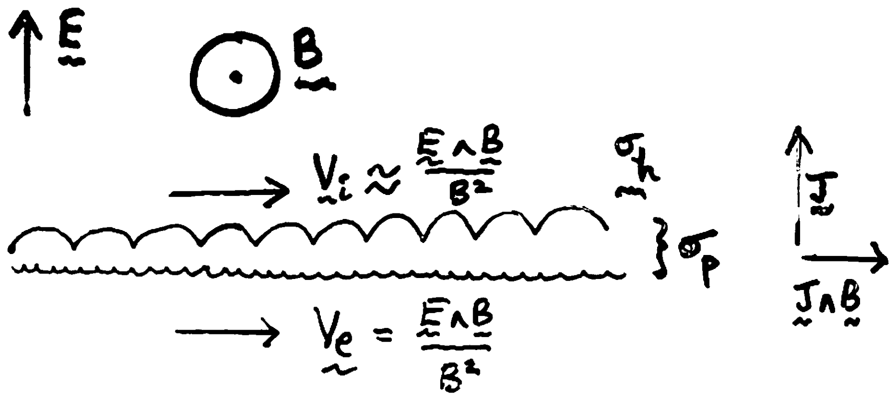
$\nu_{in} = 0$

$V_i = V_e$

$J = 0$

$J \wedge B = 0$

$J \cdot E = 0$

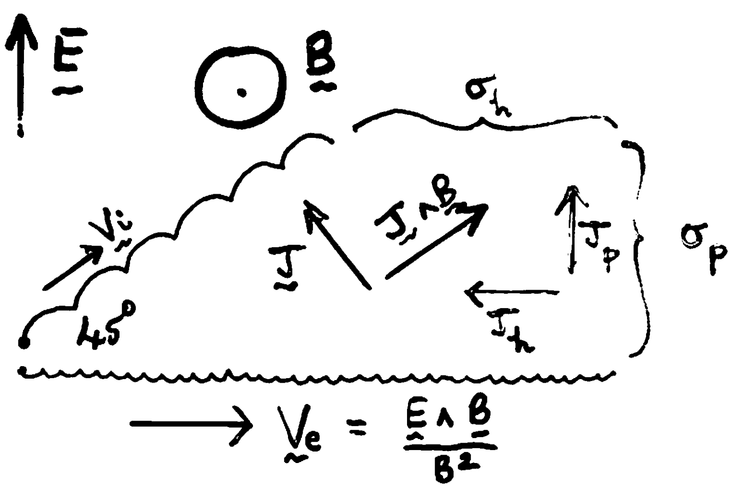


300 km (>150km)

$\nu_{in} << \omega_i$

$V_i < V_e$

$\sigma_p > \sigma_h$

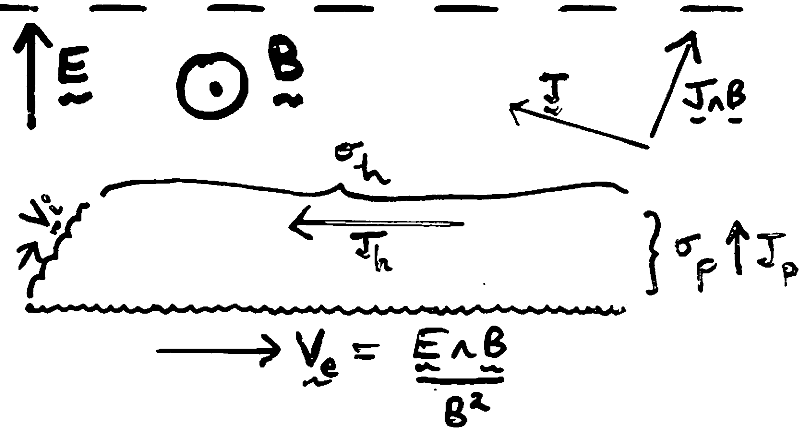


125 km

$\nu_{in} = \omega_i$

$V_i < V_e$

$\sigma_p = \sigma_h$

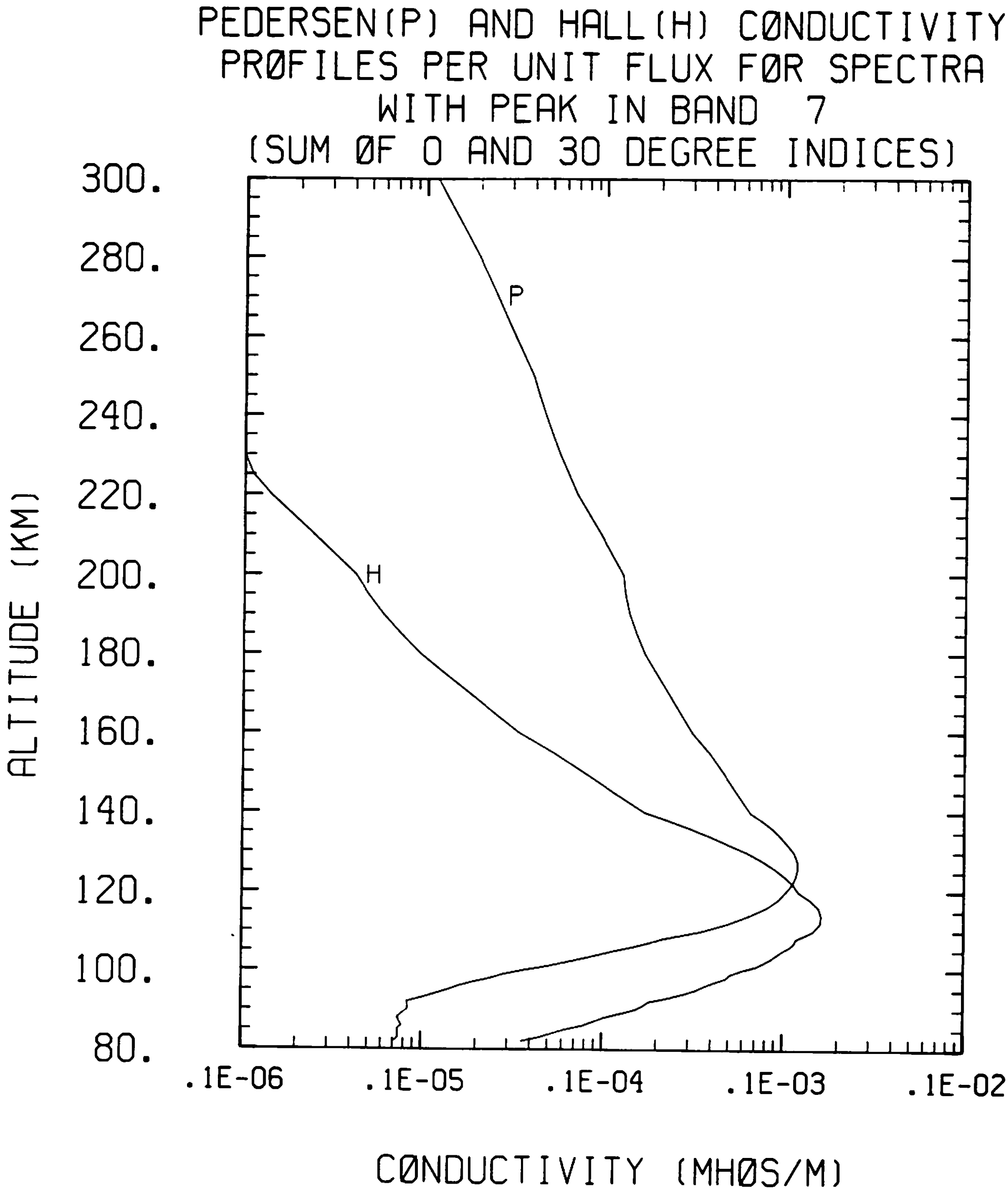


110 km

$\nu_{in} > \omega_i$

$V_i << V_e$

$\sigma_p < \sigma_h$



HEIGHT INTEGRATED CØNDUCTIVITIES
HALL = 4.439 MHØS
PEDERSEN = 5.094 MHØS

$$\underset{\sim}{J} = \underset{\sim}{\sigma} \cdot (\underset{\sim}{E} + \underset{\sim}{V_n} \wedge \underset{\sim}{B})$$

$$= \underset{\sim}{\sigma} \cdot (\underset{\sim}{E}')$$

Joule Heating and Mechanical Energy Transfer Rates

$$\mathbf{j}(z) \bullet \mathbf{E} = \mathbf{j}(z) \bullet \mathbf{E}' + \mathbf{u}_n(z) \bullet [\mathbf{j}(z) \times \mathbf{B}]$$

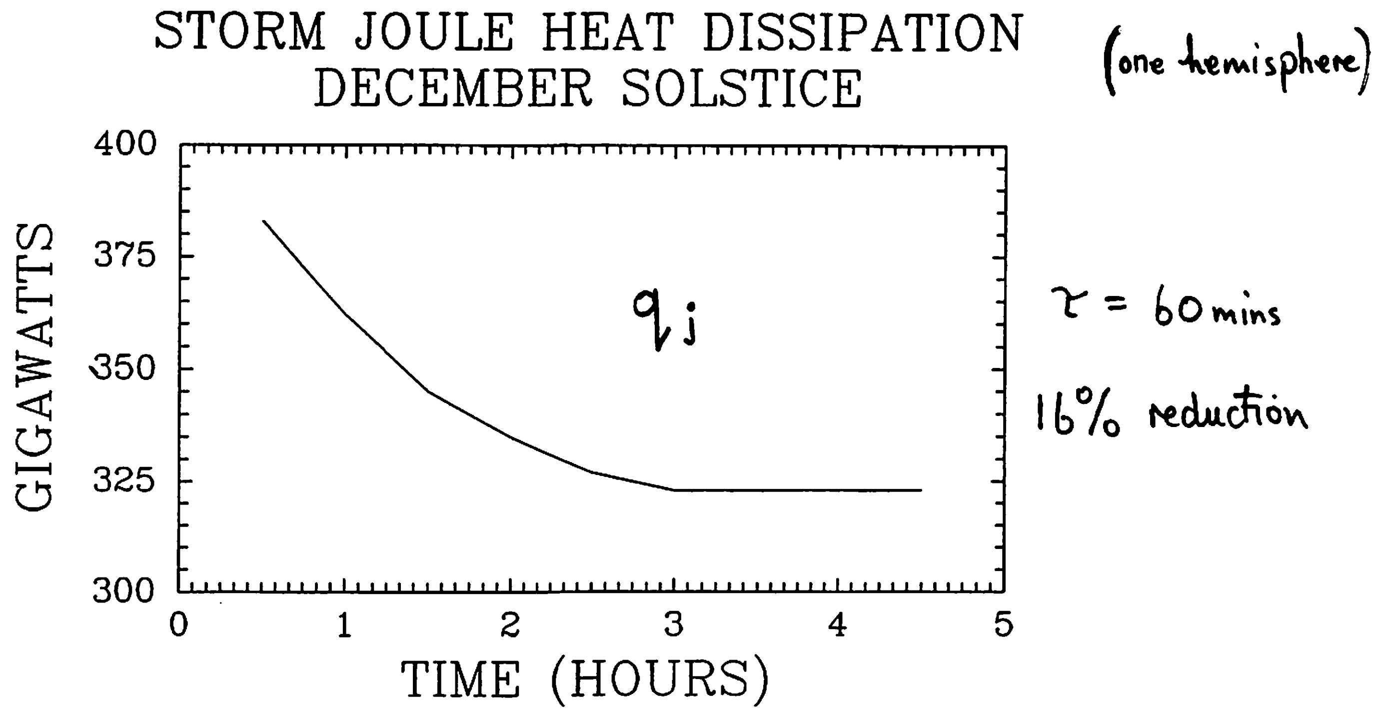
$$\{ \quad q(z) = q_j(z) + q_m(z) \quad \}$$

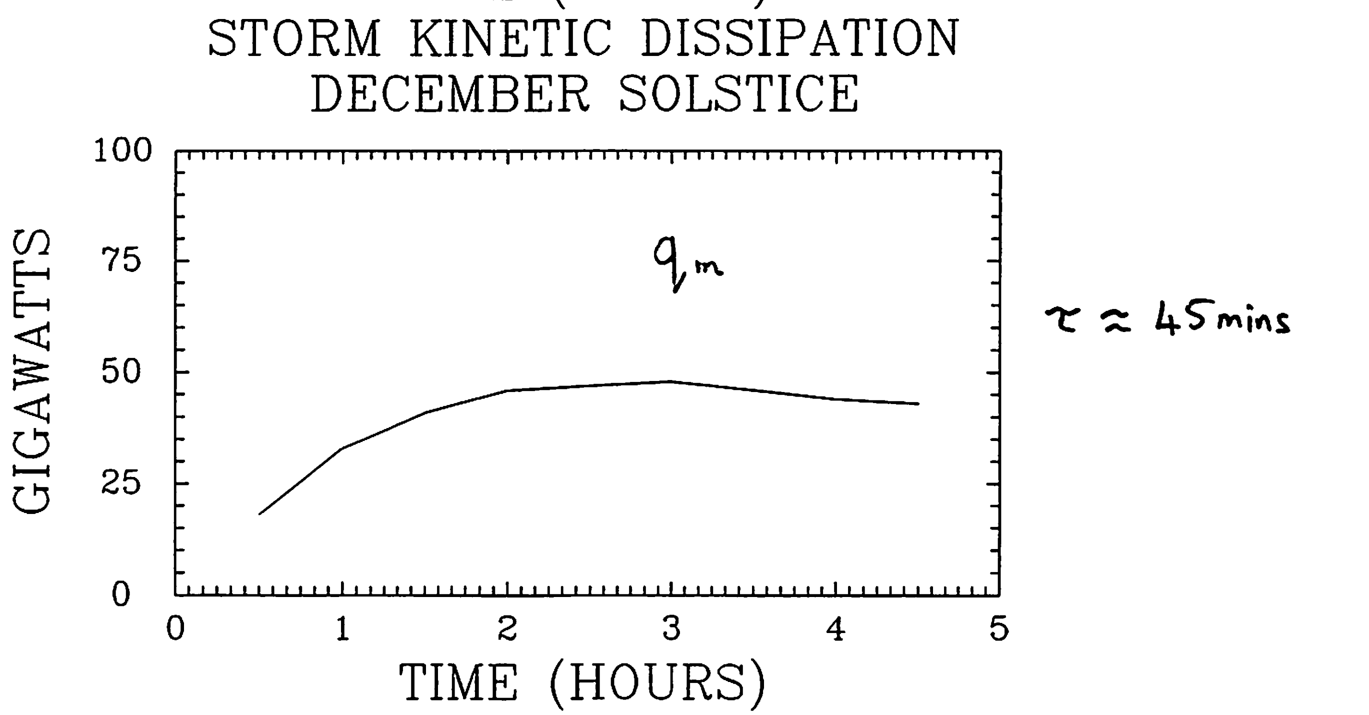
$q_j(z) = \mathbf{j}(z) \bullet \mathbf{E}'$ => **Joule heating rate** $\quad \underset{\sim}{J} \cdot (\underset{\sim}{E} + \underset{\sim}{u}_n \wedge \underset{\sim}{B})$

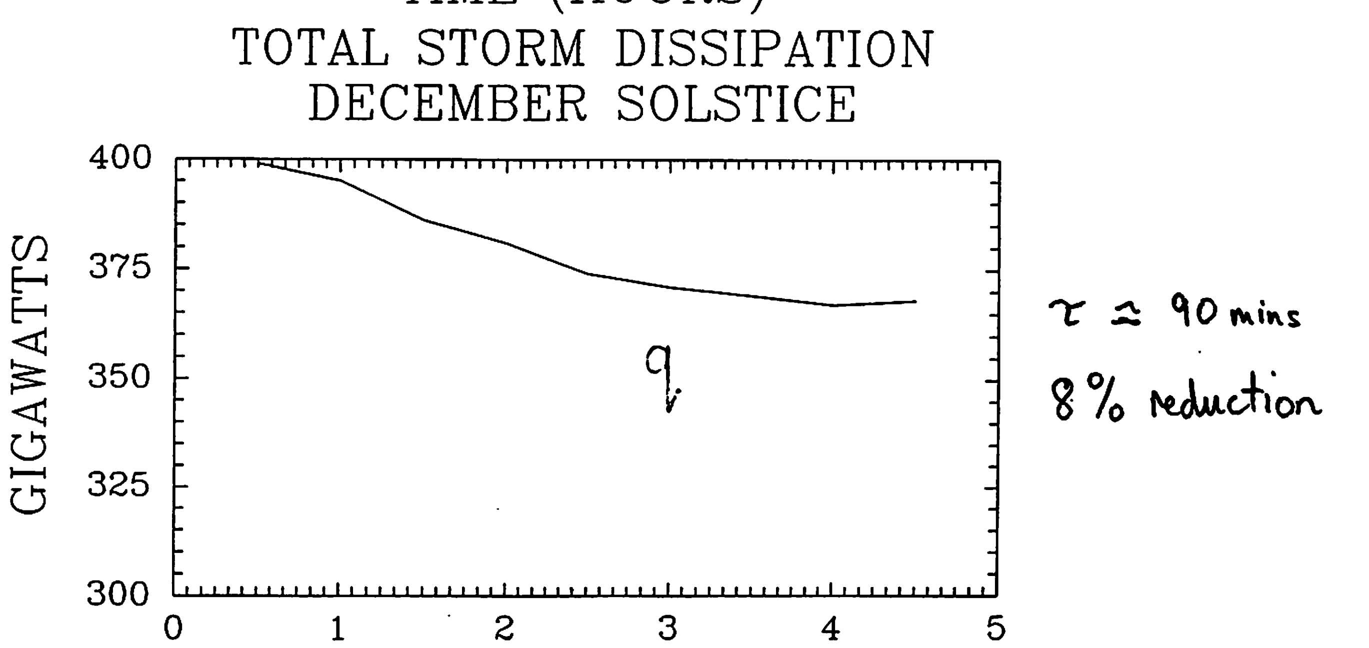
Always positive, q_j serves as a sink of electromagnetic energy

$q_m(z) = \mathbf{u}_n(z) \bullet [\mathbf{j}(z) \times \mathbf{B}]$ => **Mechanical energy transfer rate**

If negative, q_m serves as a source of electromagnetic energy


STORM JOULE HEAT DISSIPATION
DECEMBER SOLSTICE
(one hemisphere)
GIGAWATTS
400
375
350
325
300
0
1
2
3
4
5
TIME (HOURS)
q_j
τ = 60 mins
16% reduction

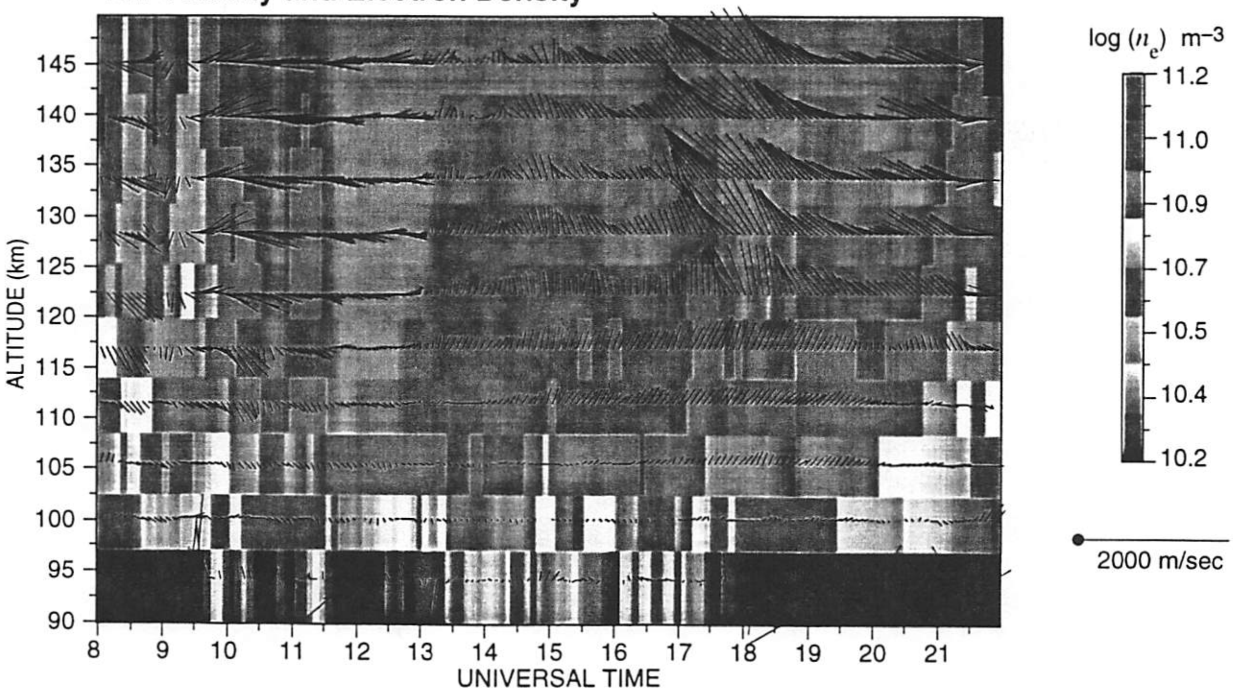

STORM KINETIC DISSIPATION
DECEMBER SOLSTICE
GIGAWATTS
100
75
50
25
0
0
1
2
3
4
5
TIME (HOURS)
q_m
$\tau \simeq$ 45 mins


TOTAL STORM DISSIPATION
DECEMBER SOLSTICE
GIGAWATTS
400
375
350
325
300
0
1
2
3
4
5
q
$\tau \simeq$ 90 mins
8% reduction

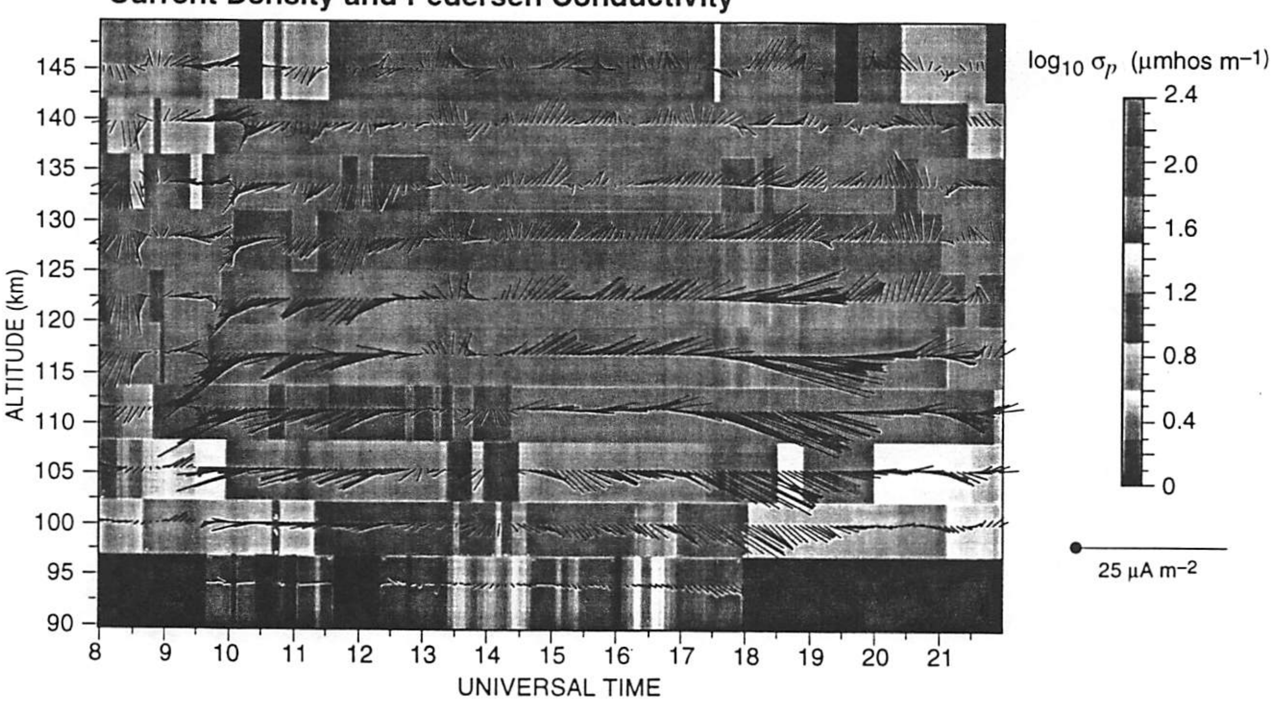
Thayer and Heelis

E-REGION ELECTRODYNAMIC PARAMETERS FOR AUGUST 5, 1993

Ion Velocity and Electron Density



Current Density and Pedersen Conductivity

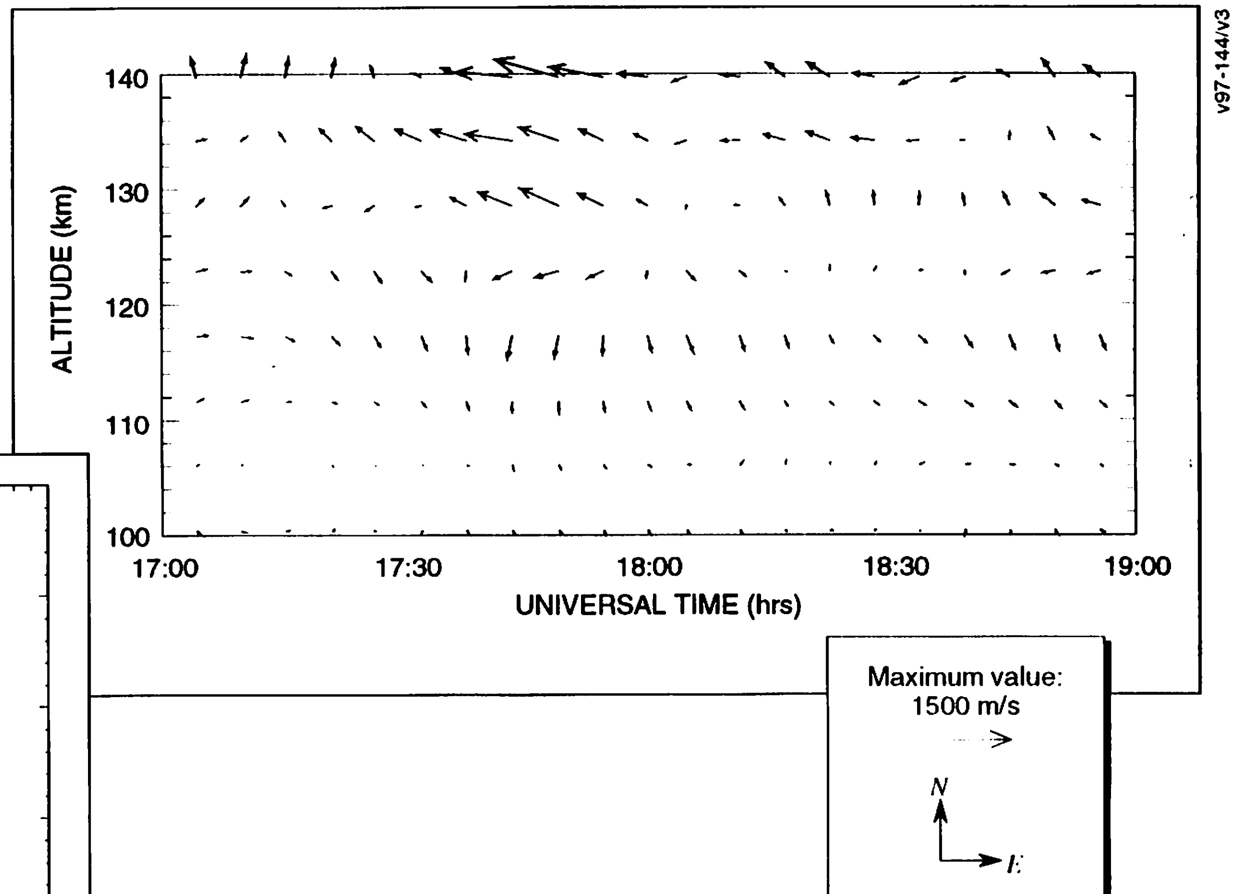


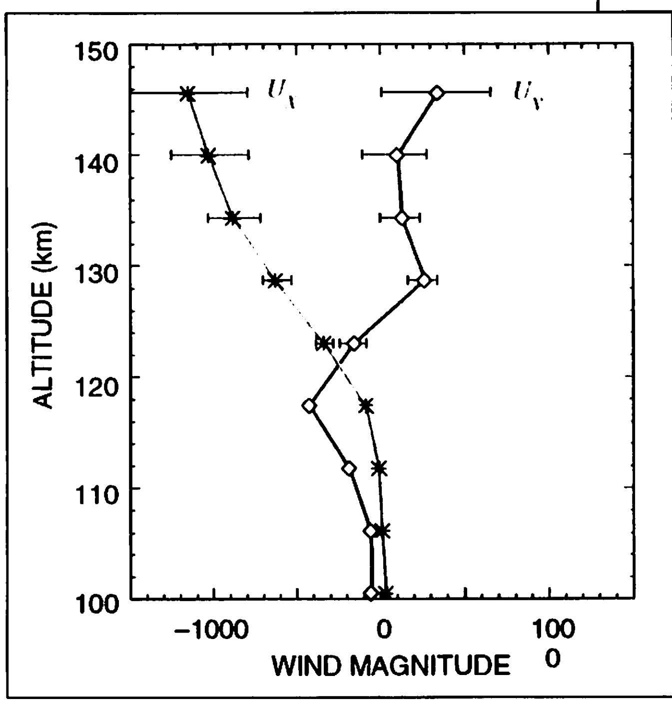
$$\sigma_p = \frac{en_e}{|B|}\left[\frac{\Omega_i \nu_{in}}{\Omega_i^2 + \nu_{in}^2}\right]$$

$$j_\perp = en_e\left[V_{i\perp} - V_{e\perp}\right]$$

Thayer & Heelis

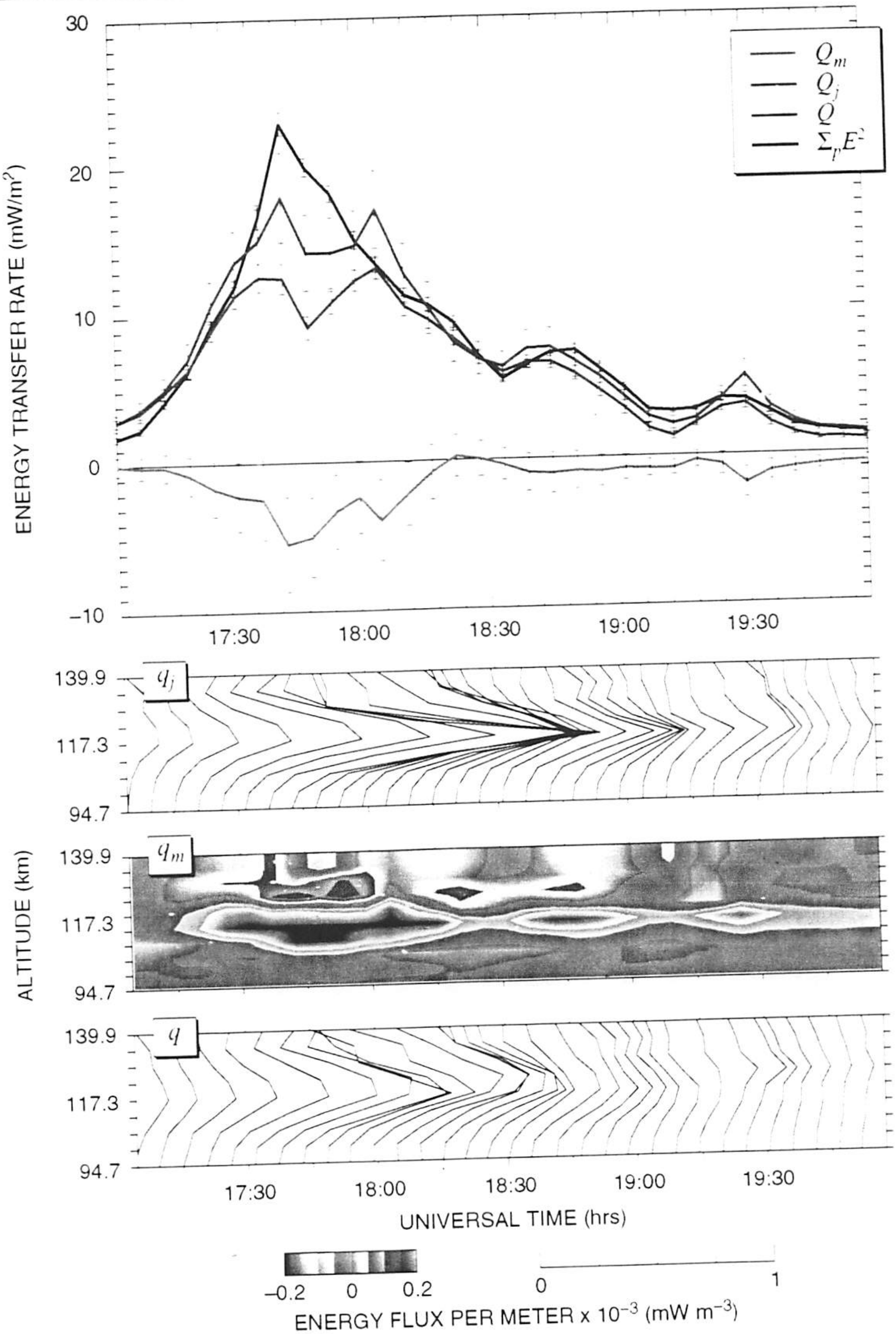
Radar-Derived Neutral Winds
(August 5, 1993)

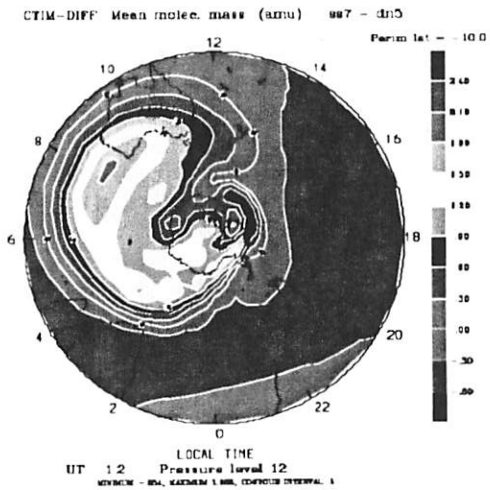


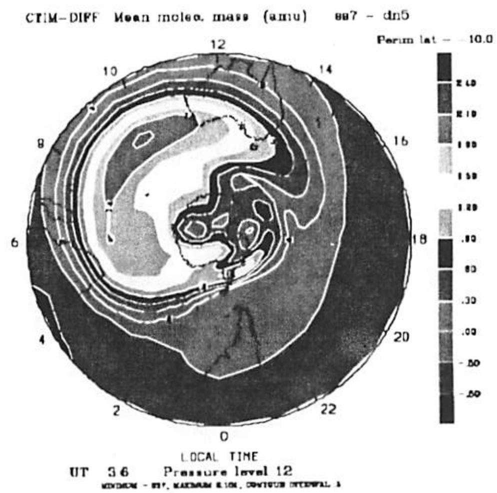


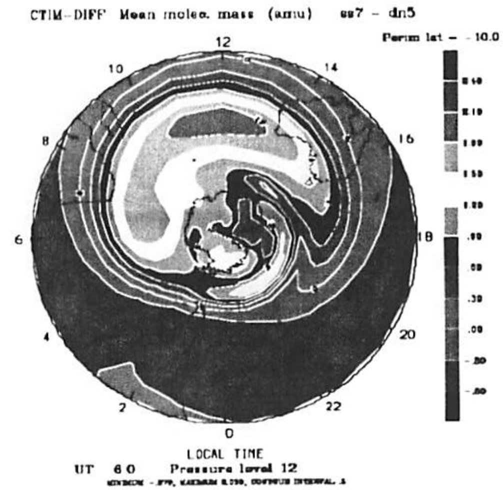
Thayer & Heelis

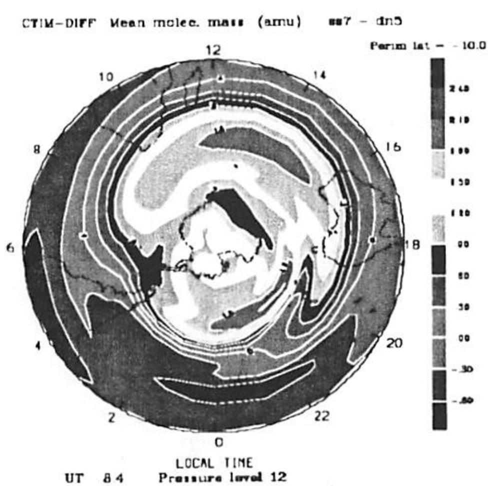
E-REGION ELECTRODYNAMICS FOR AUGUST 5, 1993

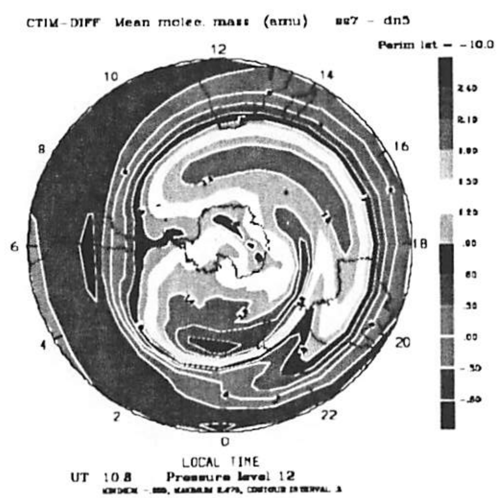


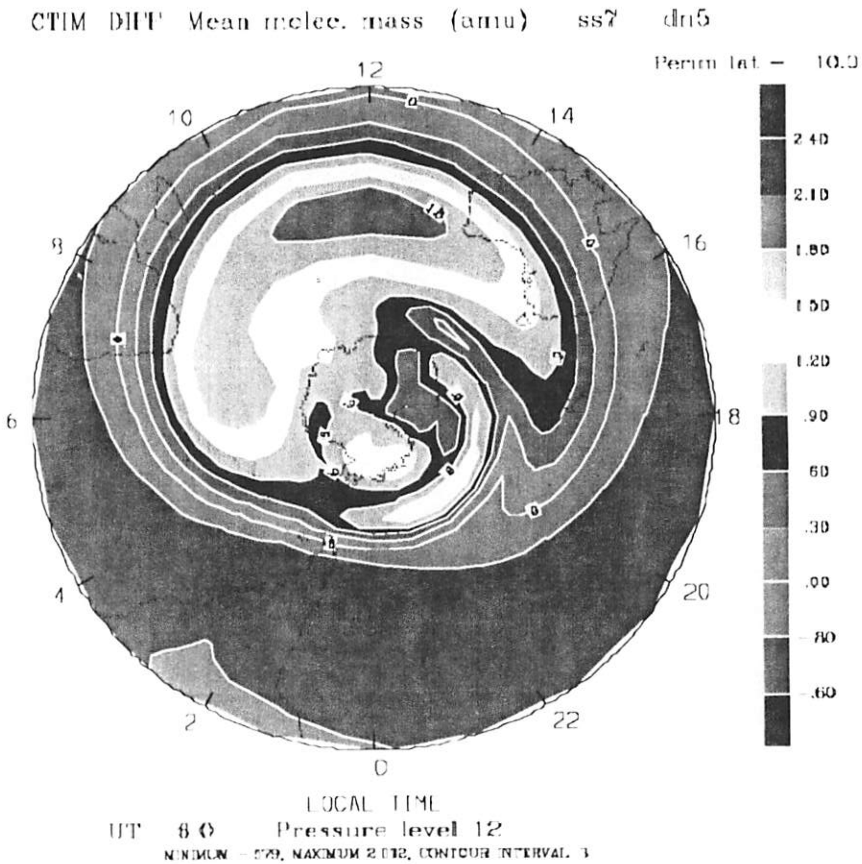

CTIM-DIFF Mean molec. mass (amu) ss7 - dn5
Perim lat = -10.0
12
10
14
8
16
6
18
4
20
2
22
0
LOCAL TIME
UT 1.2 Pressure level 12

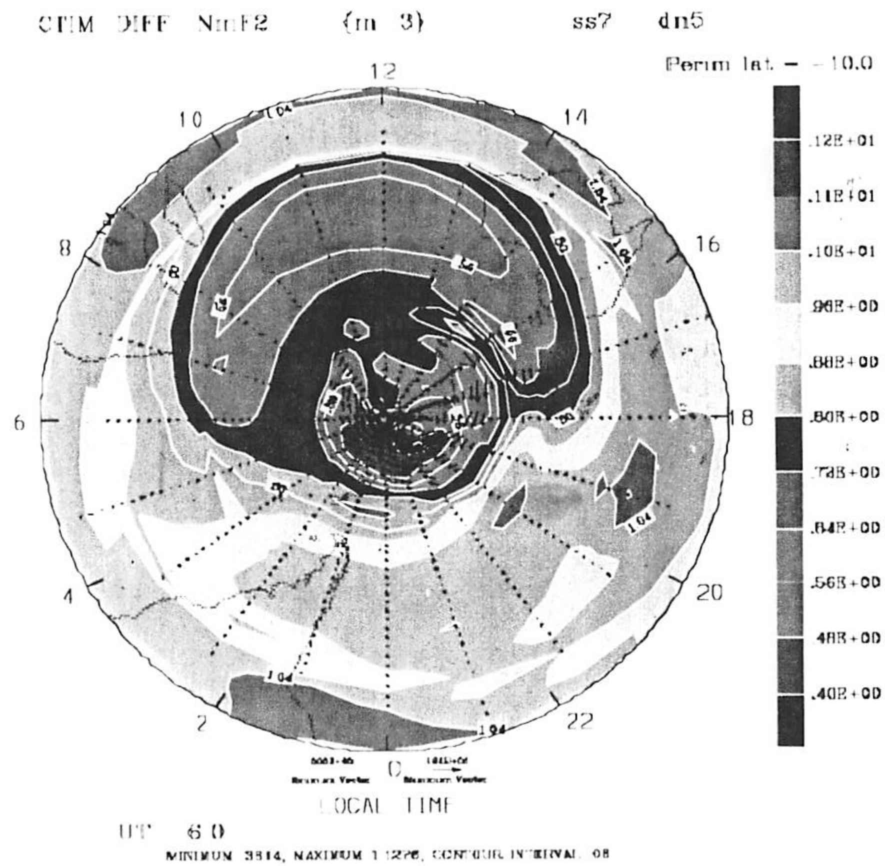

CTIM-DIFF Mean molec. mass (amu) ss7 - dn5
Perim lat = -10.0
12
10
14
8
16
6
18
4
20
2
22
0
LOCAL TIME
UT 3.6 Pressure level 12


CTIM-DIFF Mean molec. mass (amu) ss7 - dn5
Perim lat = -10.0
12
10
14
8
16
6
18
4
20
2
22
0
LOCAL TIME
UT 6.0 Pressure level 12


CTIM-DIFF Mean molec. mass (amu) ss7 - dn5
Perim lat = -10.0
12
10
14
8
16
6
18
4
20
2
22
0
LOCAL TIME
UT 8.4 Pressure level 12


CTIM-DIFF Mean molec. mass (amu) ss7 - dn5
Perim lat = -10.0
12
10
14
8
16
6
18
4
20
2
22
0
LOCAL TIME
UT 10.8 Pressure level 12


CTIM DIFF Mean molec. mass (amu) ss7 dn5
Perim lat. = 10.0
12
10
14
8
16
6
18
4
20
2
22
0
2.40
2.10
1.80
1.50
1.20
.90
.60
.30
.00
-.30
-.60
LOCAL TIME
UT 6.0 Pressure level 12
MINIMUM -.579, MAXIMUM 2.612, CONTOUR INTERVAL .3


CTIM DIFF NmF2 (m-3) ss7 dn5
Perim lat. = -10.0
12
10
14
8
16
6
18
4
20
2
22
0
.12E+01
.11E+01
.10E+01
.96E+00
.88E+00
.80E+00
.72E+00
.64E+00
.56E+00
.48E+00
.40E+00
LOCAL TIME
UT 6.0
MINIMUM .3814, MAXIMUM 1.1226, CONTOUR INTERVAL .08