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Boulder, Colorado
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Solar-Terrestrial Coupling Processes
Tutorial Lecture III

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Ionosphere/Thermosphere:
Response to Disturbances

Ionosphere/Thermosphere: Response to Disturbances

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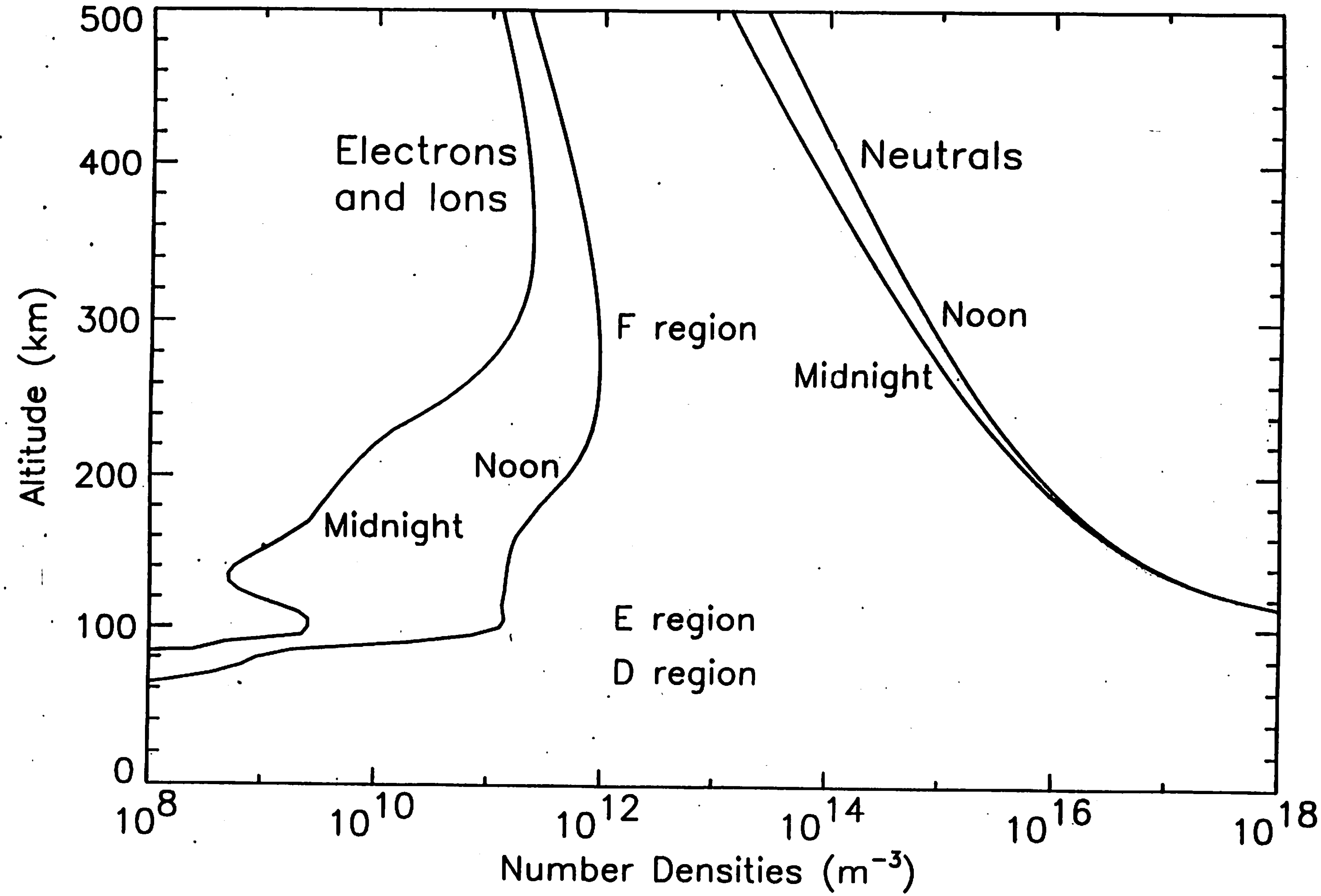
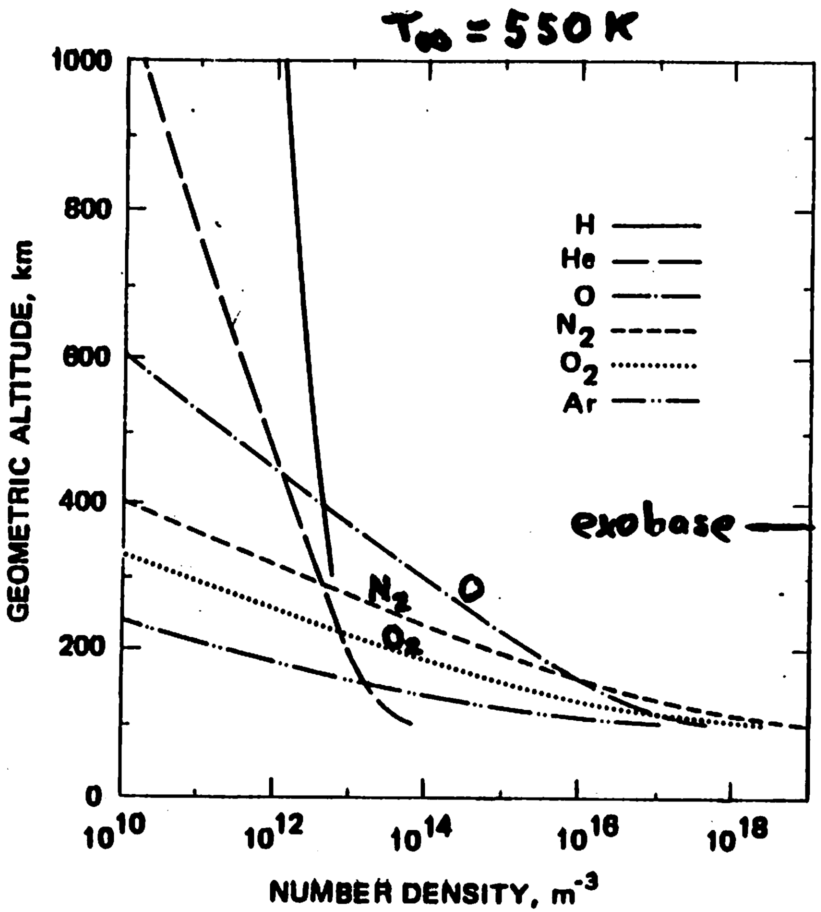
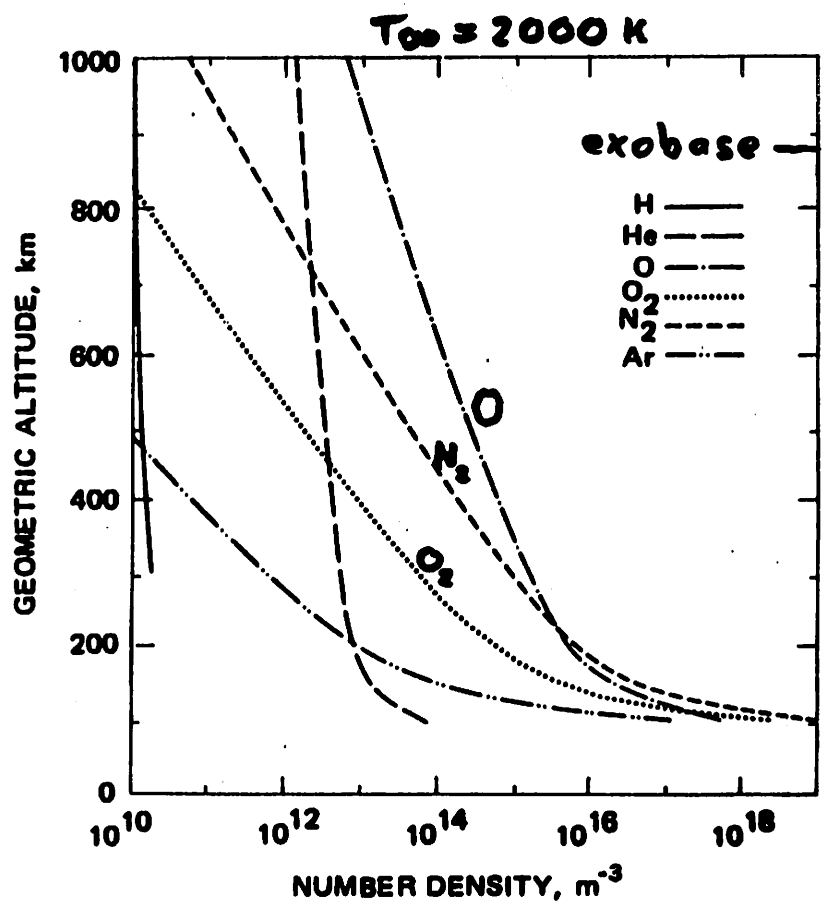
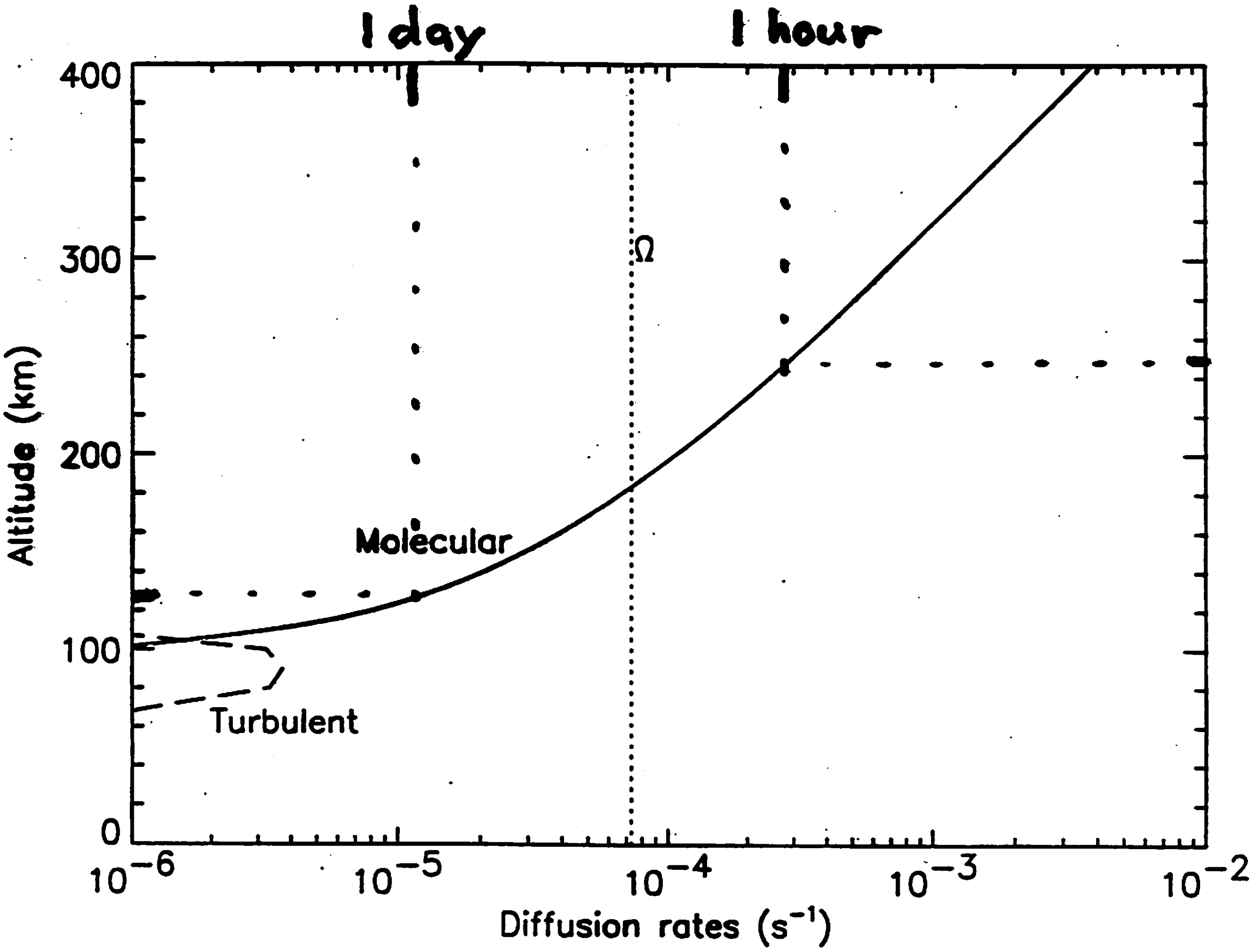
National Center for Atmospheric Research



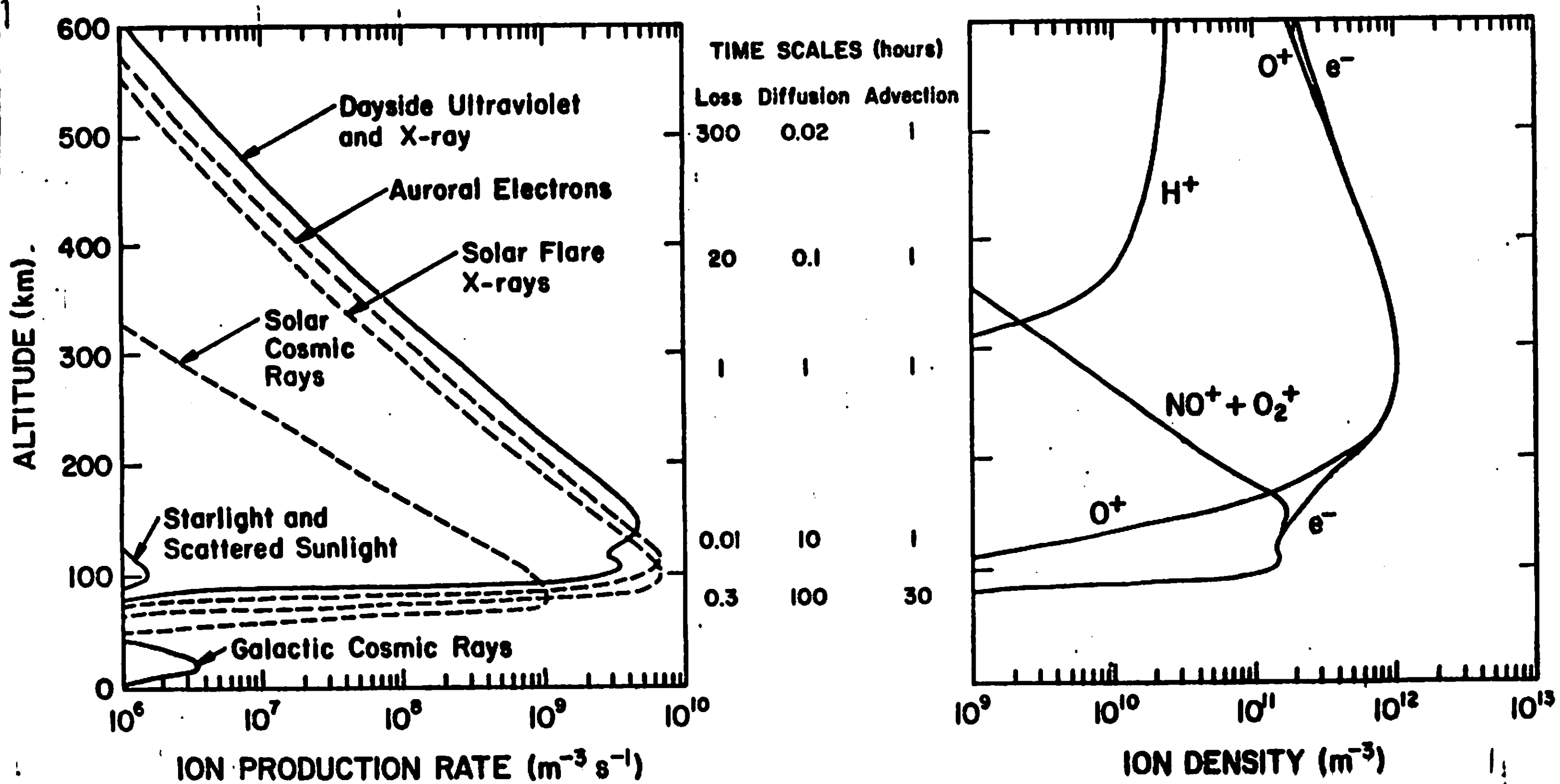
500
400
300
200
100
0
Altitude (km)
Electrons
and Ions
Neutrals
F region
Noon
Midnight
Noon
Midnight
E region
D region
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
Number Densities (m^{-3})


T∞ = 550 K
GEOMETRIC ALTITUDE, km
NUMBER DENSITY, m⁻³
H
He
O
N_2
O_2
Ar
exobase
N_2
O
O_2


T∞ = 2000 K
GEOMETRIC ALTITUDE, km
NUMBER DENSITY, m⁻³
exobase
H
He
O
O_2
N_2
Ar
O
N_2
O_2

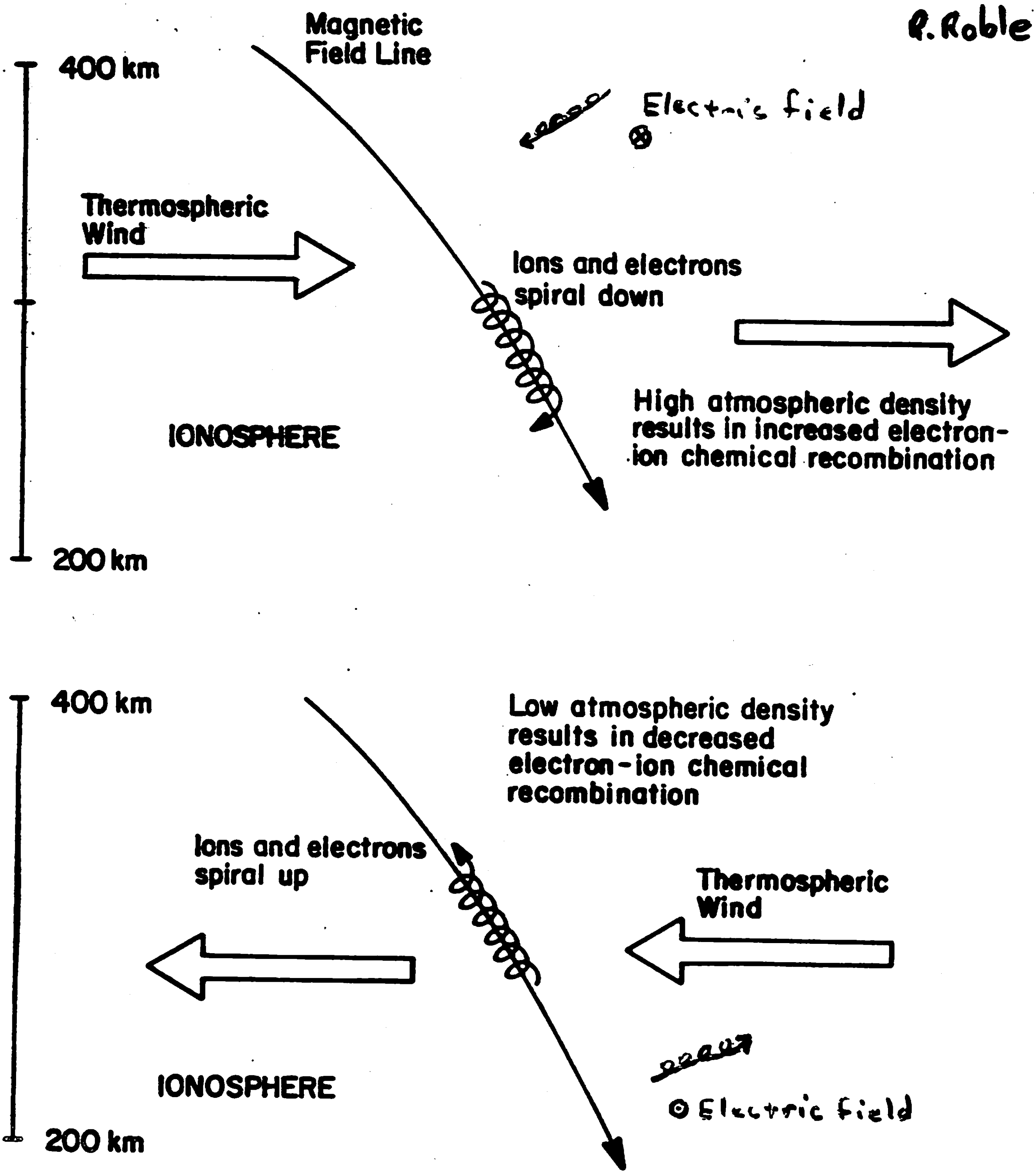


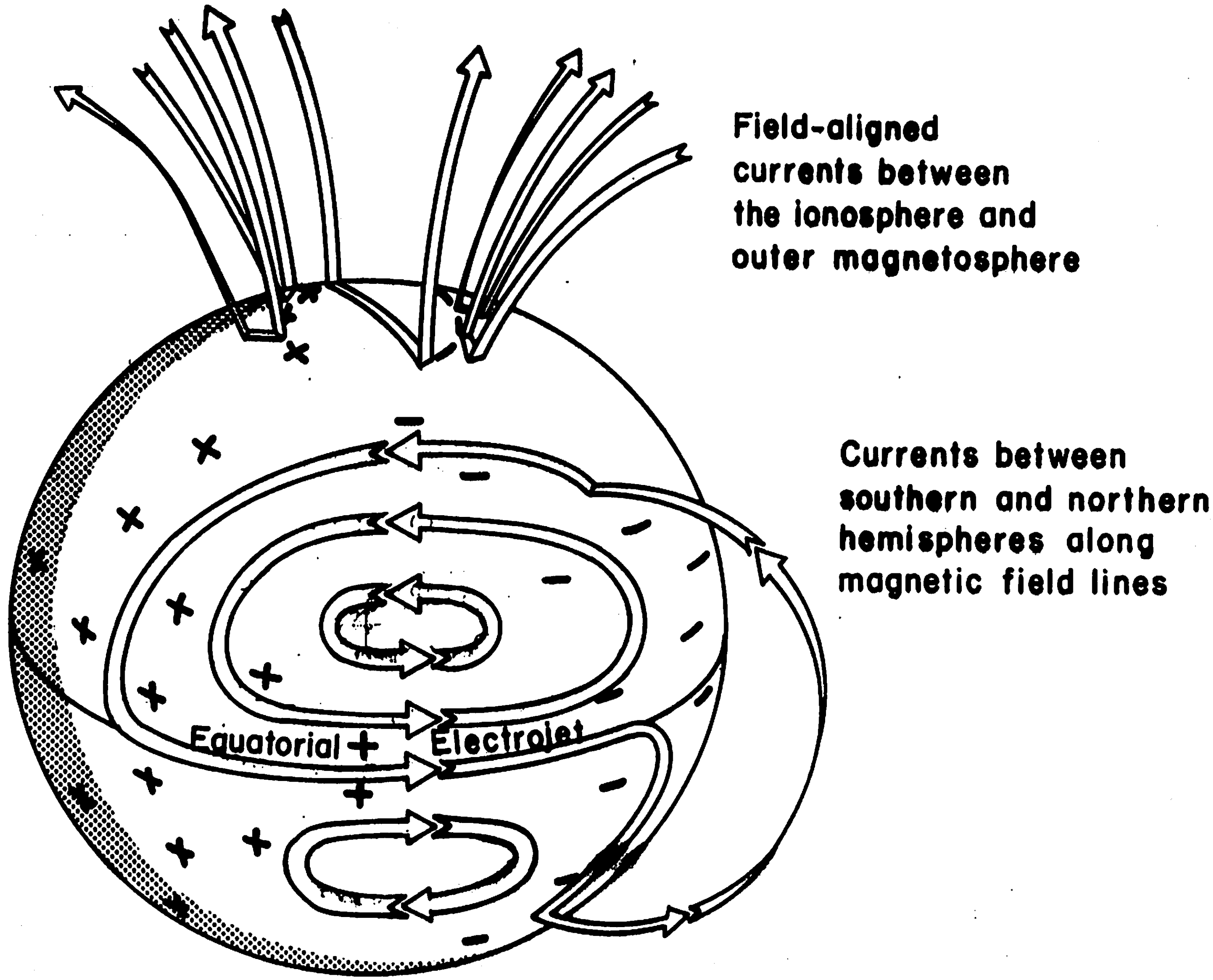
1 day
1 hour
400
300
200
100
0
Ω
Molecular
Turbulent
Altitude (km)
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Diffusion rates (s^{-1})

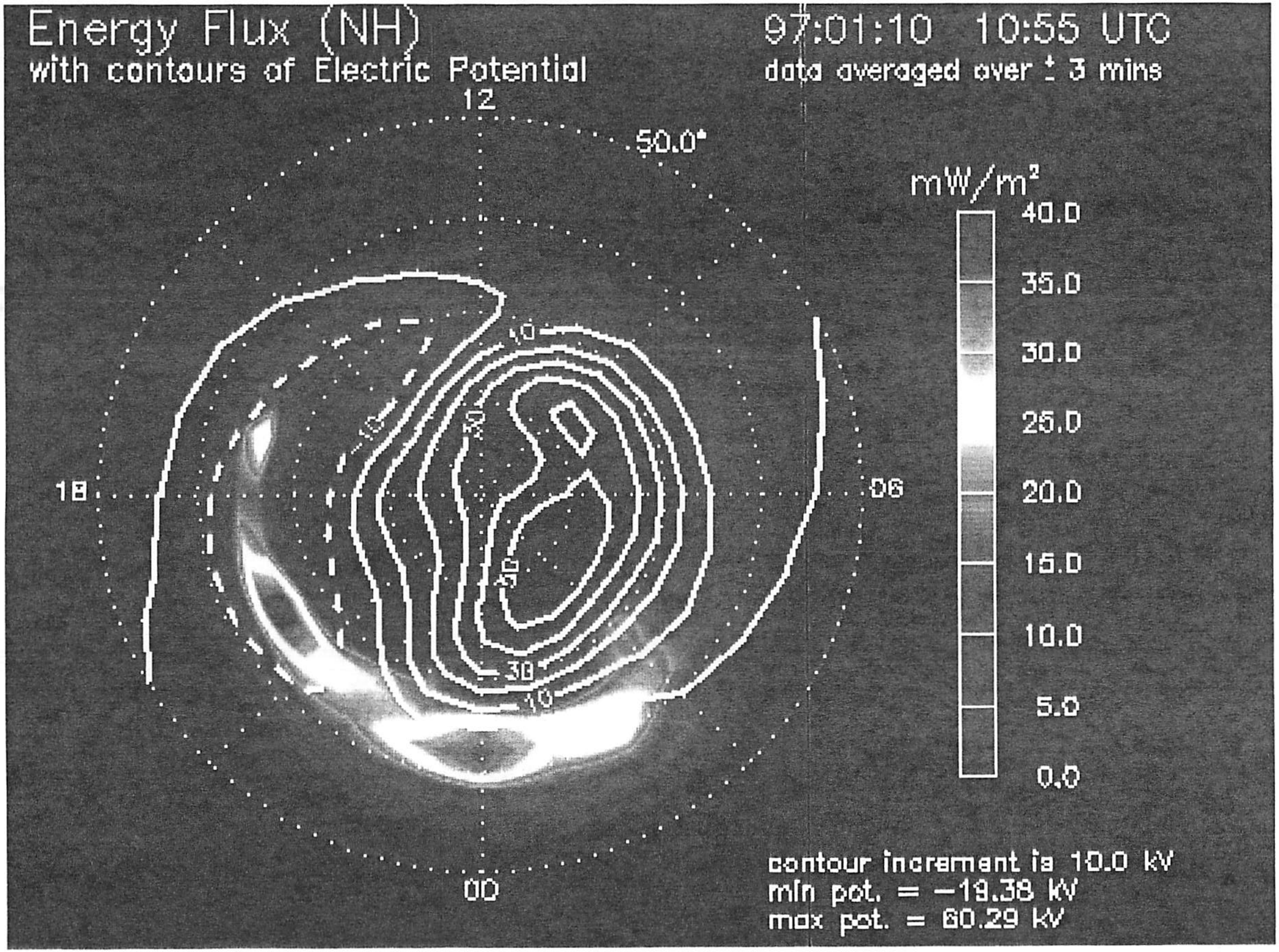


ALTITUDE (km)
600
500
400
300
200
100
0
Dayside Ultraviolet and X-ray
Auroral Electrons
Solar Flare X-rays
Solar Cosmic Rays
Starlight and Scattered Sunlight
Galactic Cosmic Rays
10^6 10^7 10^8 10^9 10^{10}
ION PRODUCTION RATE (m^{-3} s^{-1})
TIME SCALES (hours)
Loss Diffusion Advection
300 0.02 1
20 0.1 1
1 1 1
0.01 10 1
0.3 100 30
O^+
e^-
H^+
$NO^+ + O_2^+$
O^+
e^-
10^9 10^{10} 10^{11} 10^{12} 10^{13}
ION DENSITY (m^{-3})

5


R. Roble
Magnetic Field Line
400 km
Electric field
Thermospheric Wind
Ions and electrons spiral down
High atmospheric density results in increased electron-ion chemical recombination
IONOSPHERE
200 km
400 km
Low atmospheric density results in decreased electron-ion chemical recombination
Ions and electrons spiral up
Thermospheric Wind
IONOSPHERE
Electric field
200 km

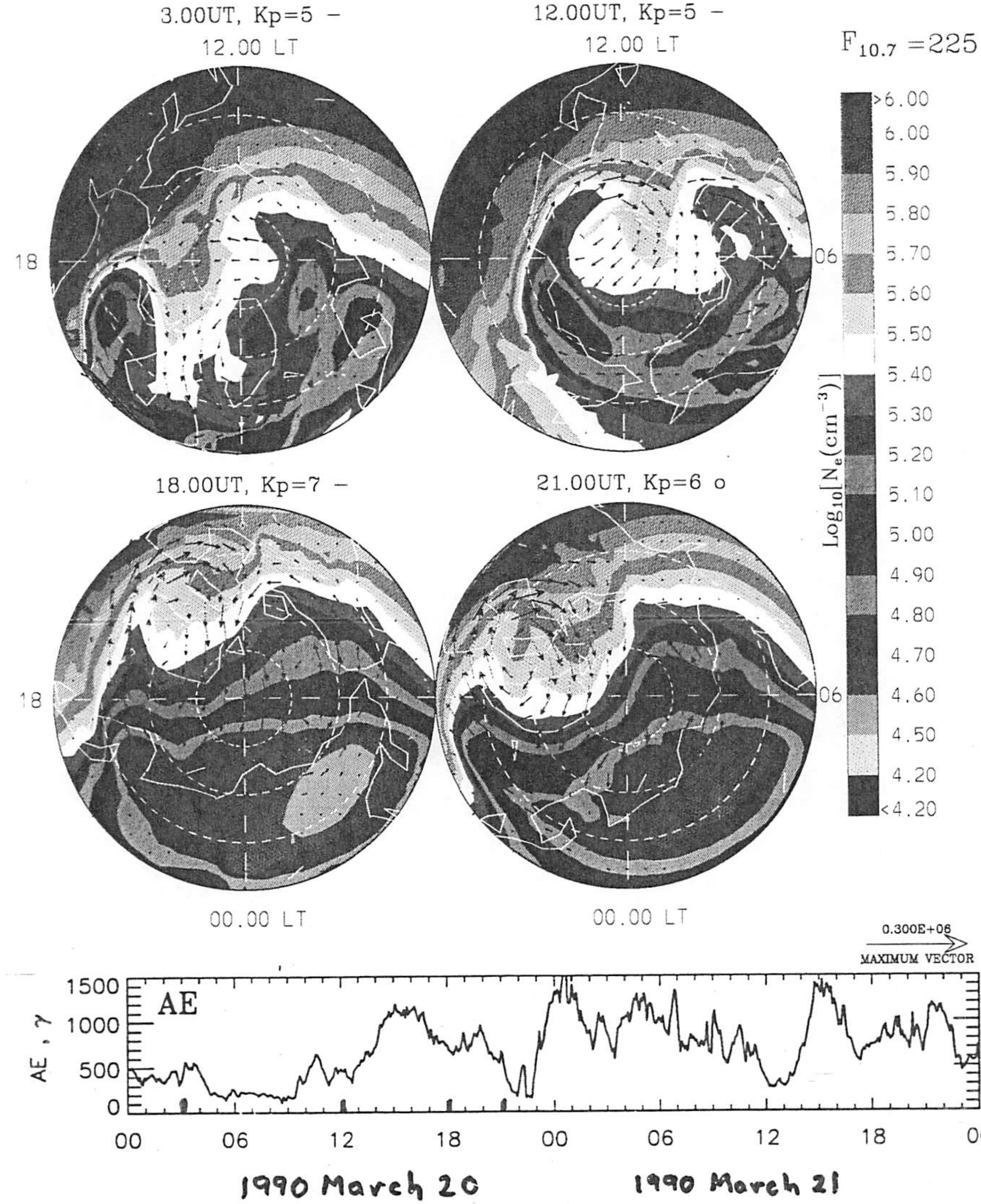

Field-aligned
currents between
the ionosphere and
outer magnetosphere
Currents between
southern and northern
hemispheres along
magnetic field lines
Equatorial
Electrojet



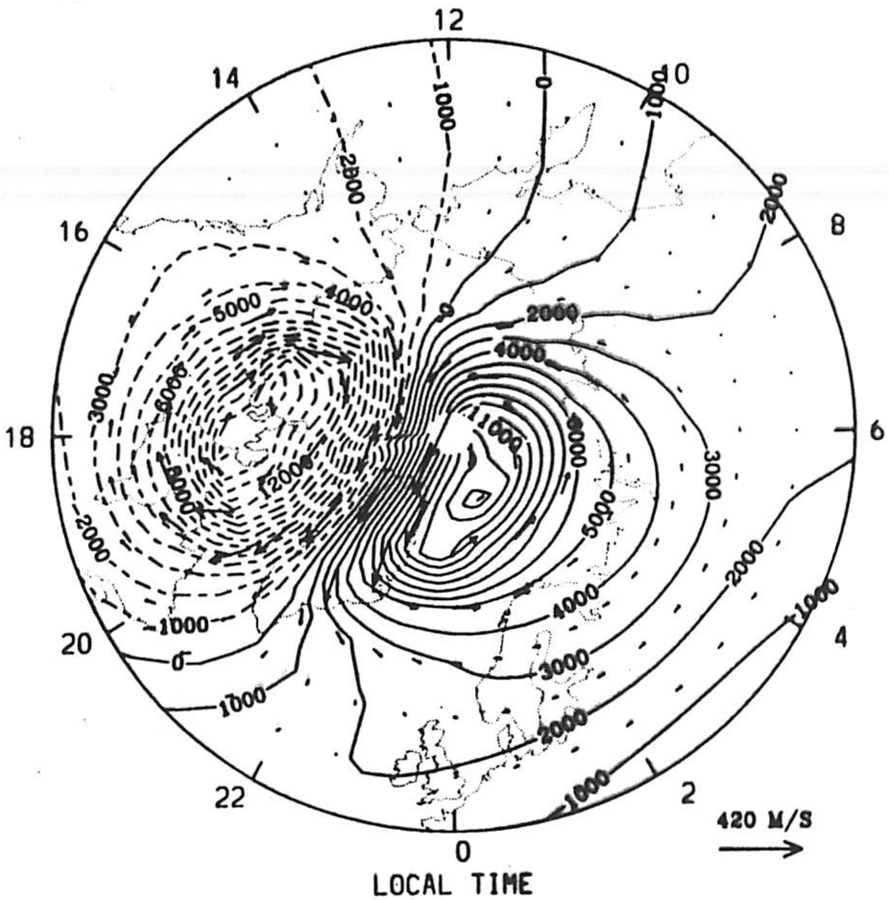
Energy Flux (NH)
with contours of Electric Potential
97:01:10 10:55 UTC
data averaged over ± 3 mins
12
50.0°
18
06
00
10
-10
30
30
30
10
mW/m²
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
contour increment is 10.0 kV
min pot. = −19.38 kV
max pot. = 60.29 kV

S. Maurits

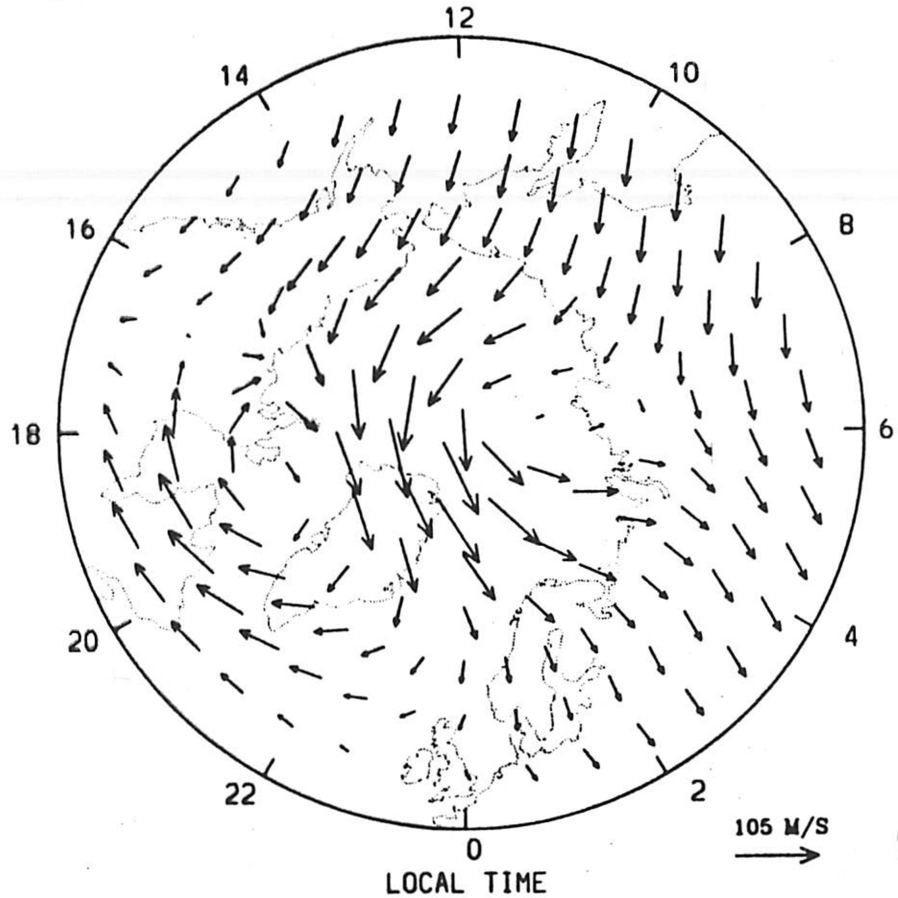
UAF Eulerian Ionosphere Model, $\mathrm{Log}_{10}[N_e(\mathrm{cm}^{-3})]$ at 350 km



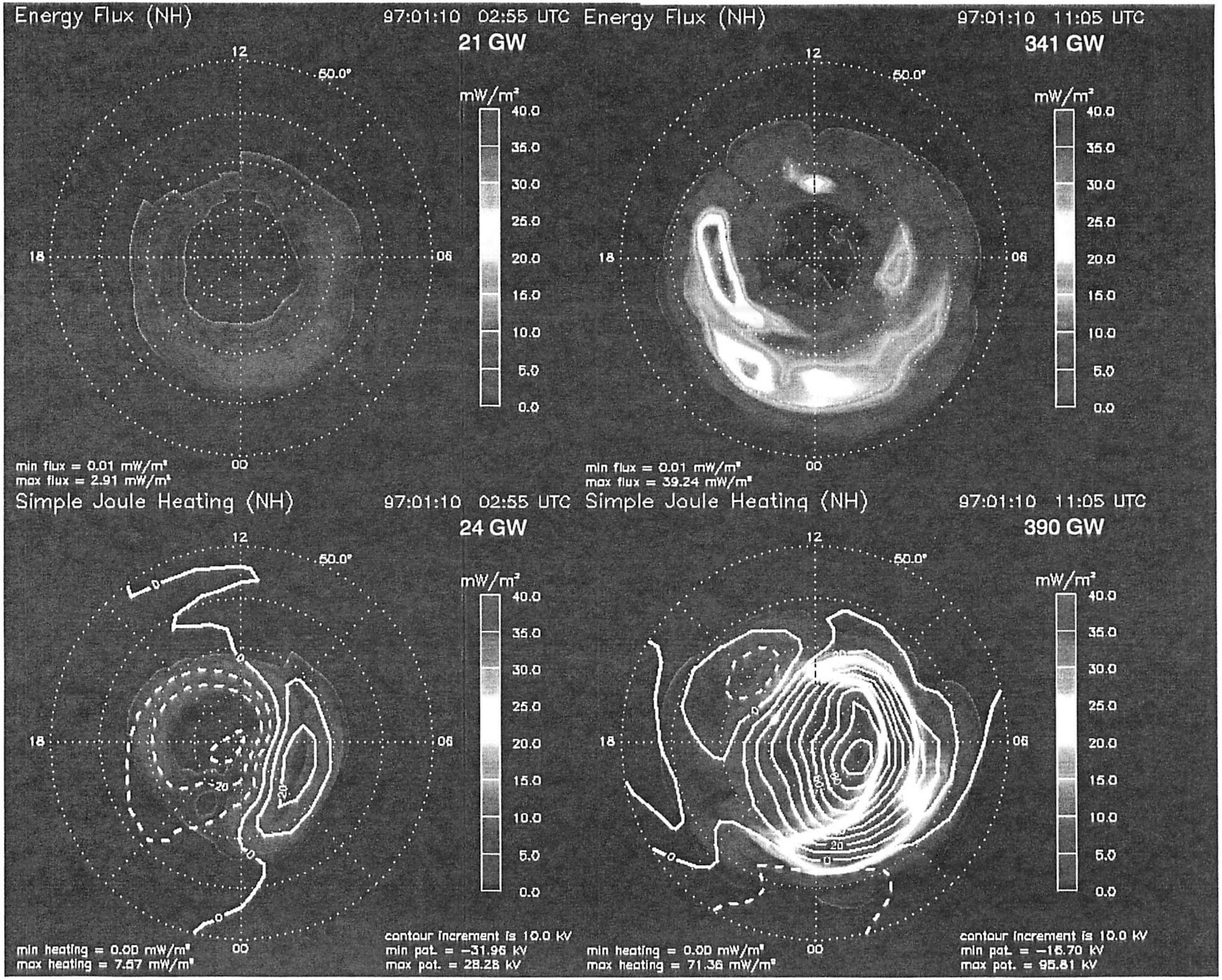
TIEGCM ELECTRIC POTENTIAL (volts)
UT = 0.00

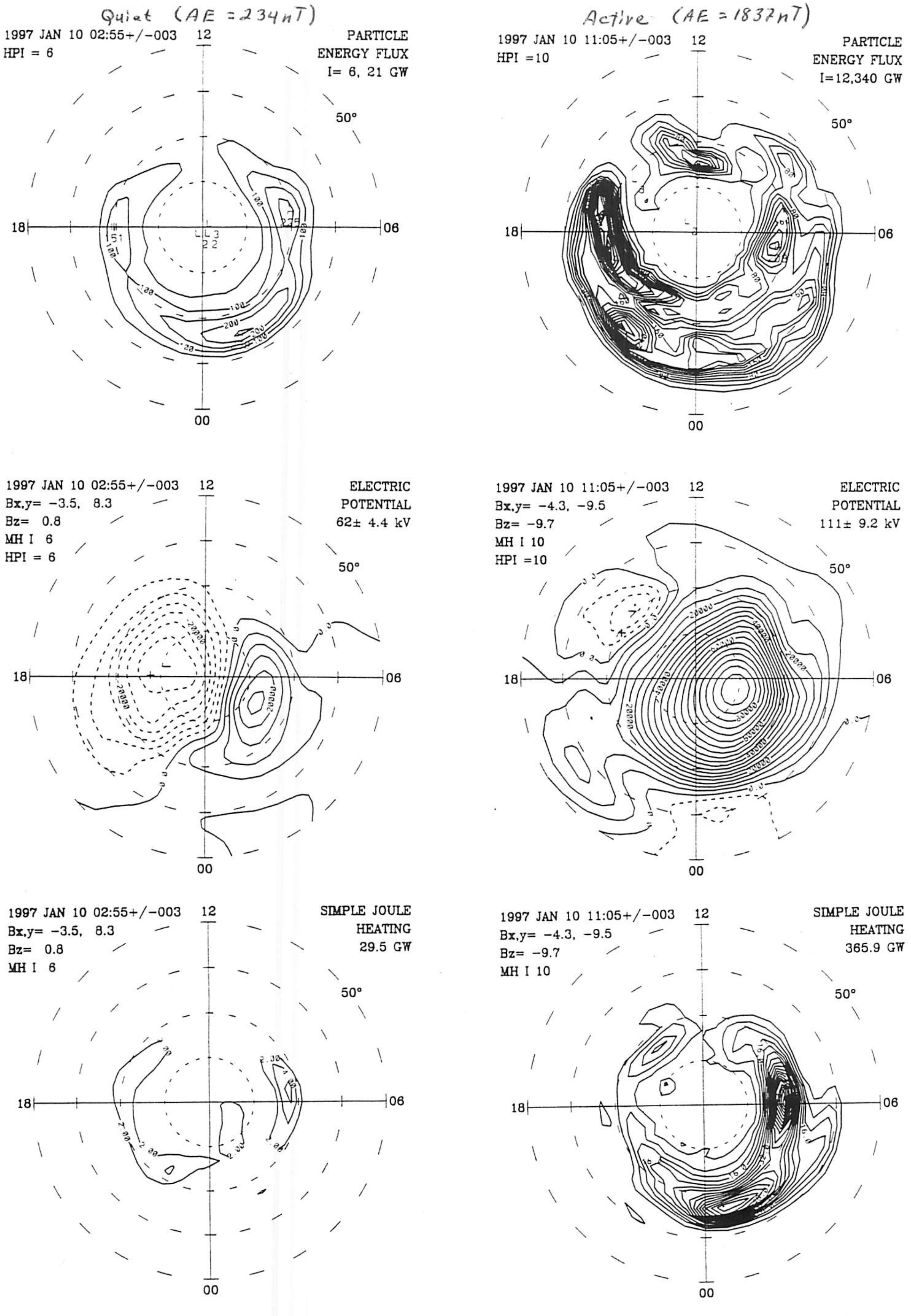


TIEGCM NEUTRAL WINDS (U+V) (M/S)
UT = 0.00 145 km



AE = 234 nT, Quiet AE = 1837 nT, Active

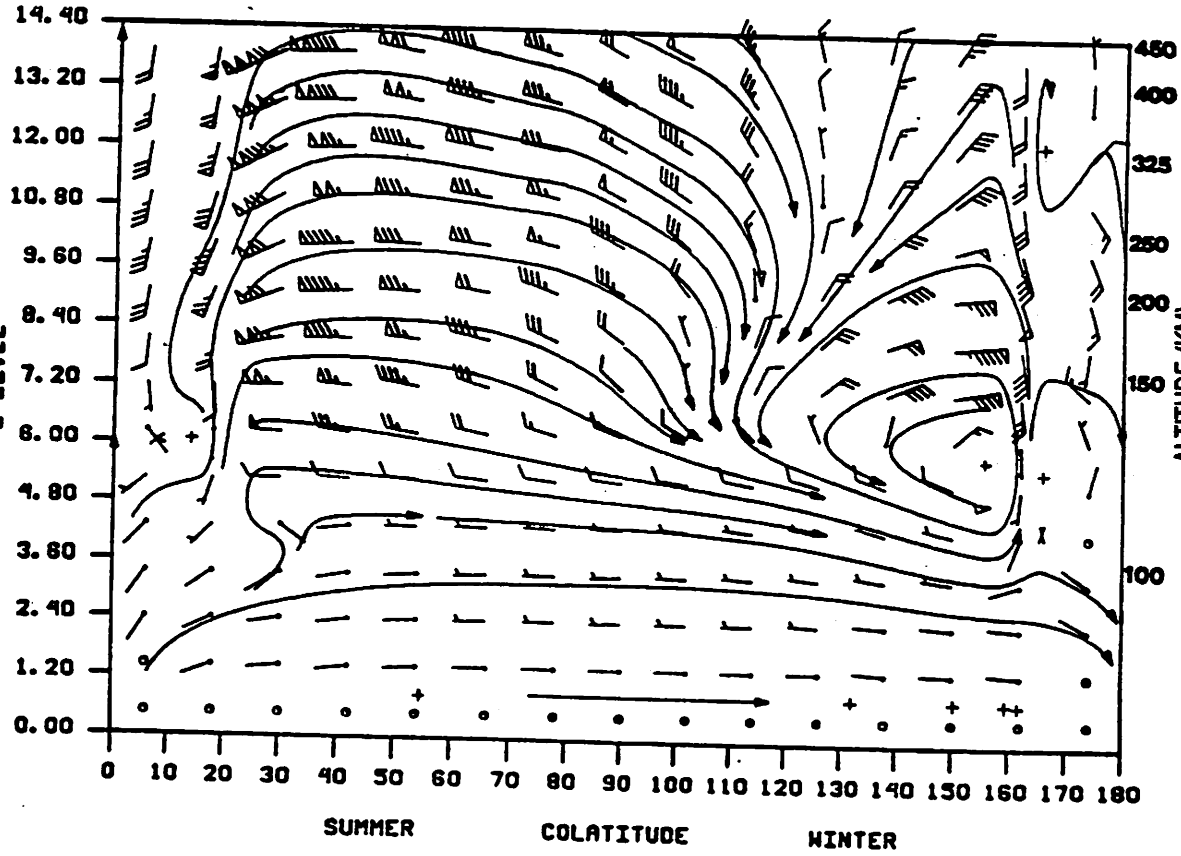




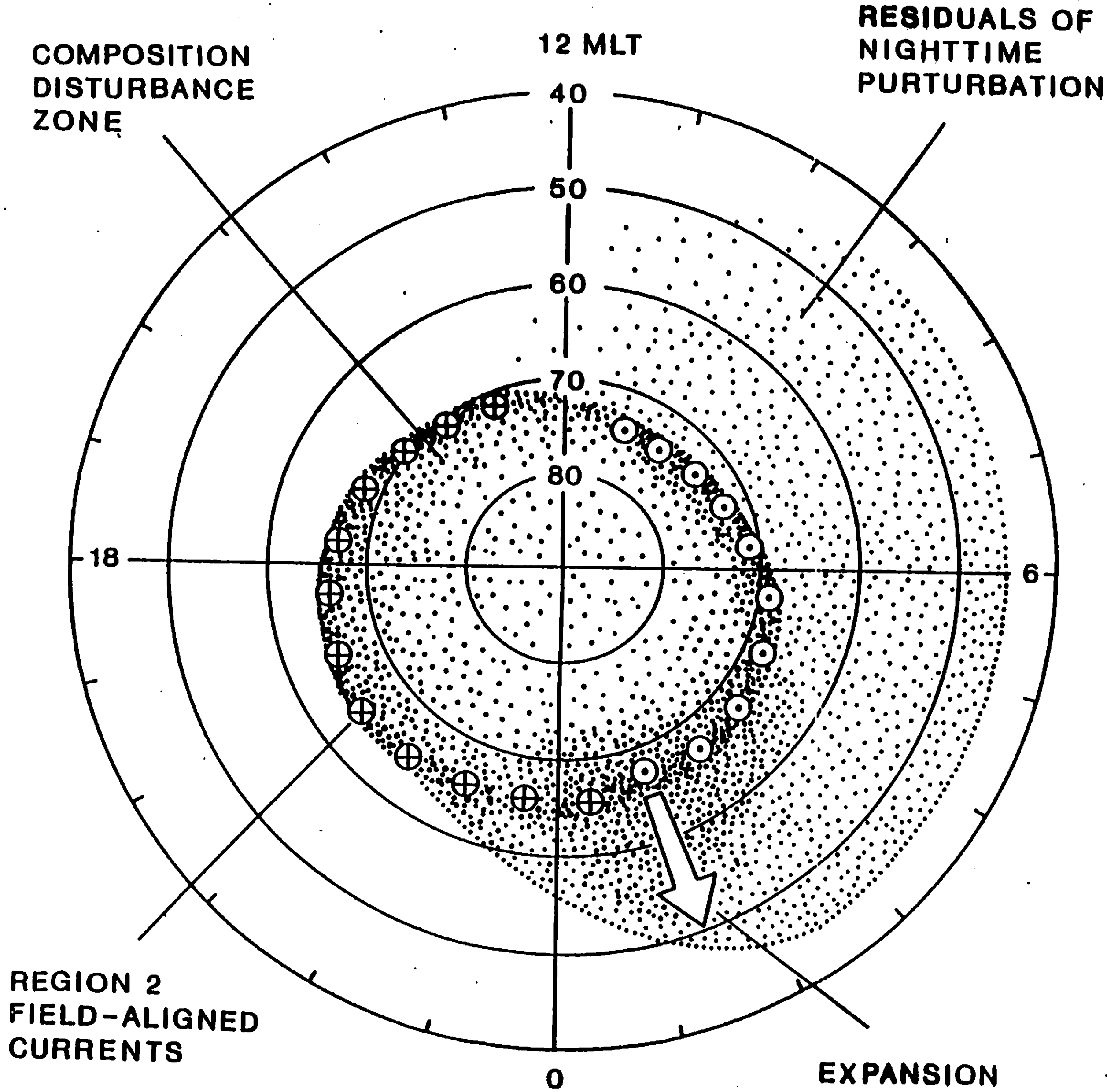
Quiet (AE = 234nT)
Active (AE = 1837nT)
1997 JAN 10 02:55+/-003
HPI = 6
PARTICLE
ENERGY FLUX
I= 6, 21 GW
1997 JAN 10 11:05+/-003
HPI =10
PARTICLE
ENERGY FLUX
I=12,340 GW
1997 JAN 10 02:55+/-003
Bx,y= -3.5, 8.3
Bz= 0.8
MH I 6
HPI = 6
ELECTRIC
POTENTIAL
62± 4.4 kV
1997 JAN 10 11:05+/-003
Bx,y= -4.3, -9.5
Bz= -9.7
MH I 10
HPI =10
ELECTRIC
POTENTIAL
111± 9.2 kV
1997 JAN 10 02:55+/-003
Bx,y= -3.5, 8.3
Bz= 0.8
MH I 6
SIMPLE JOULE
HEATING
29.5 GW
1997 JAN 10 11:05+/-003
Bx,y= -4.3, -9.5
Bz= -9.7
MH I 10
SIMPLE JOULE
HEATING
365.9 GW
12
18
06
00
50°

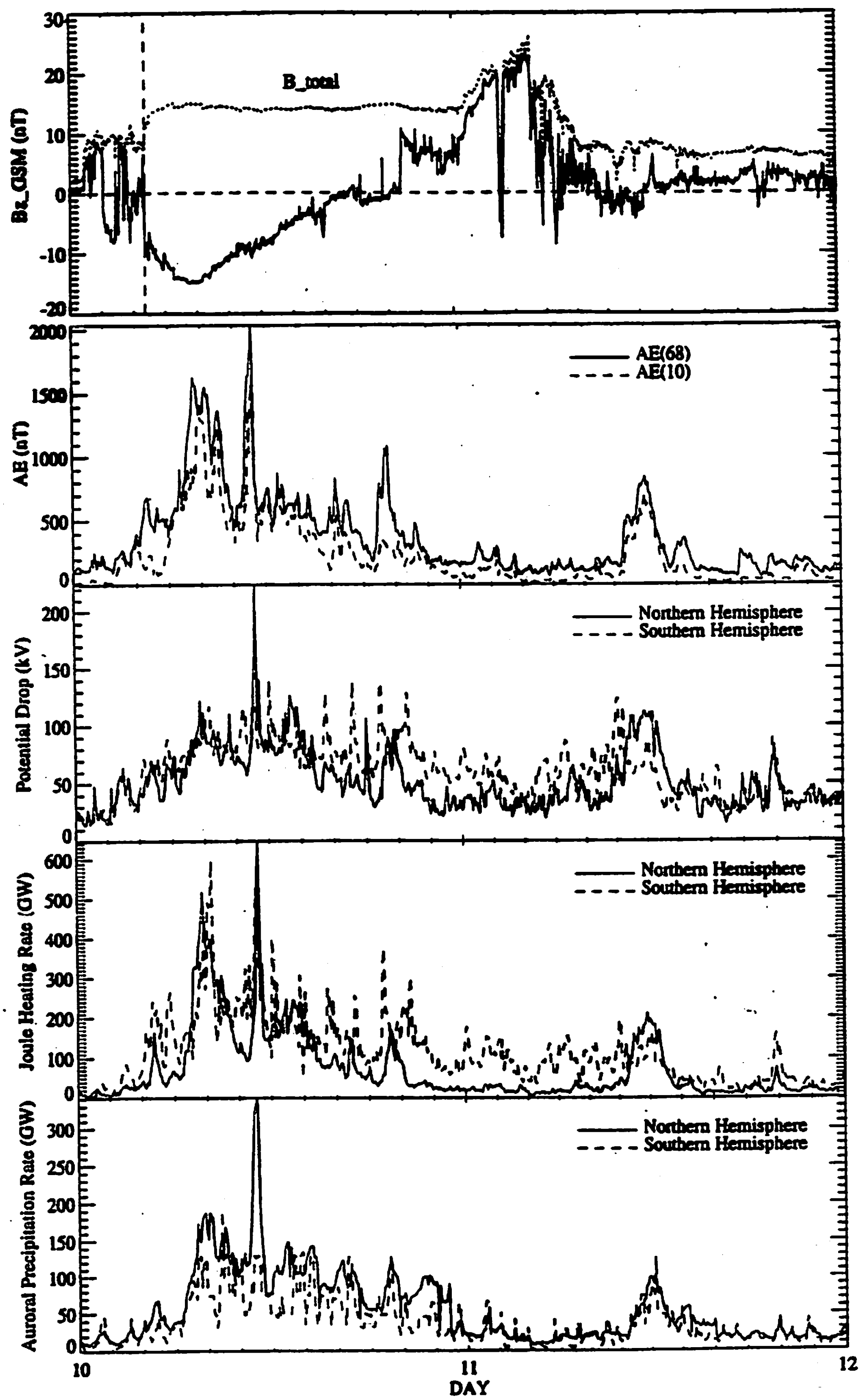
O. Brinkman

STORM-TIME WINDS 12 HR AVE

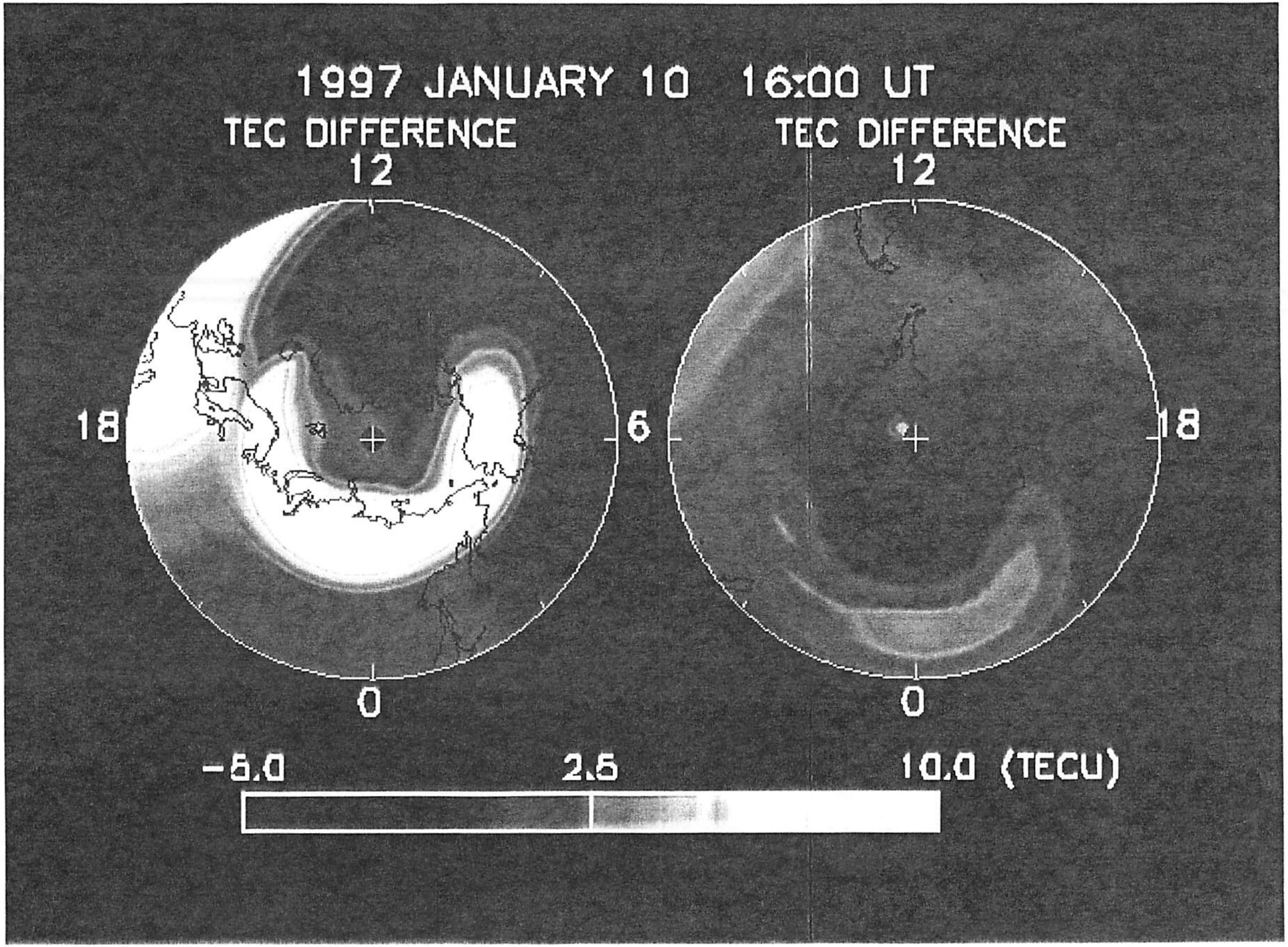


G. Prölss

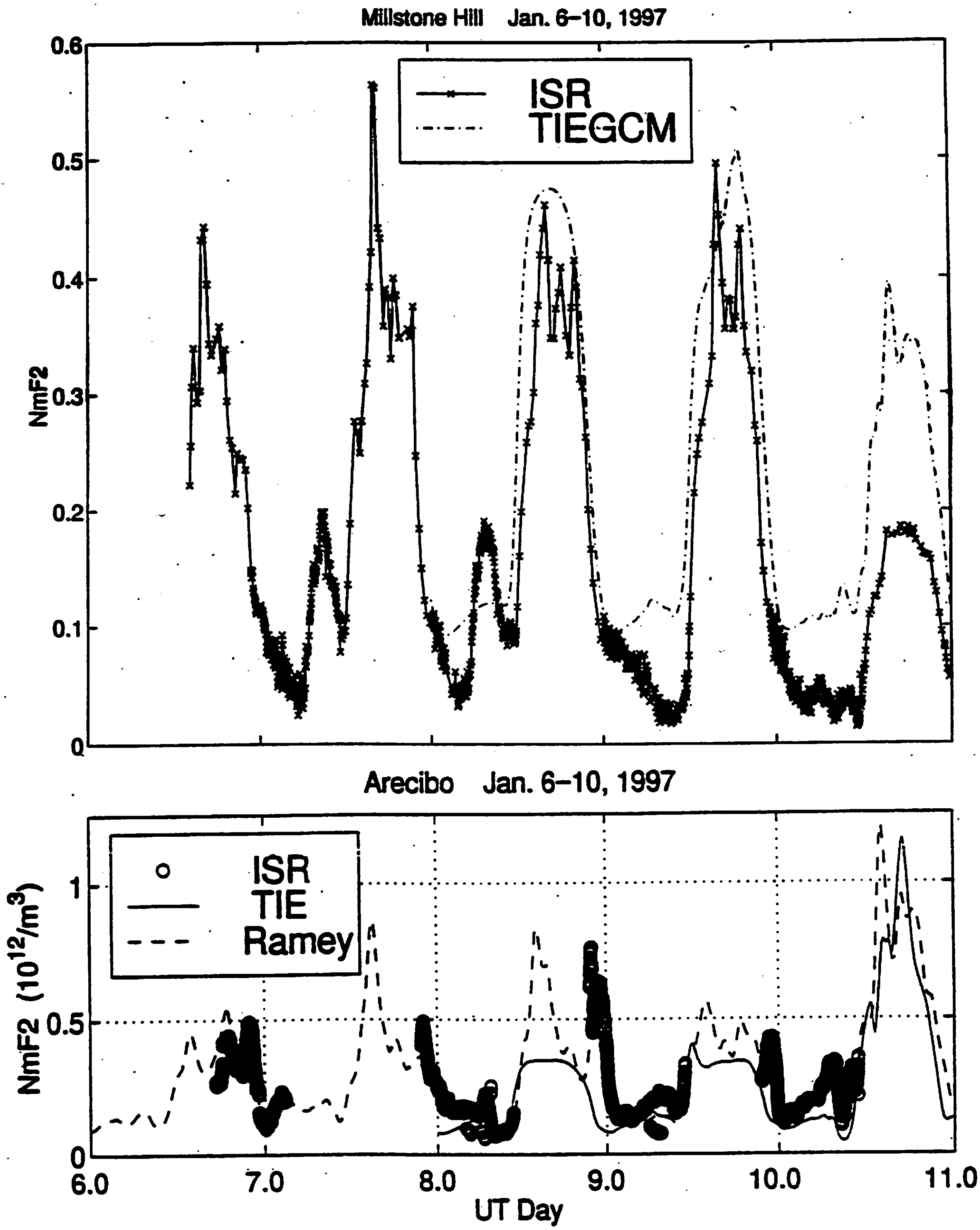

12 MLT
COMPOSITION DISTURBANCE ZONE
RESIDUALS OF NIGHTTIME PURTURBATION
40
50
60
70
80
18
6
0
REGION 2 FIELD-ALIGNED CURRENTS
EXPANSION CAUSED BY WIND SURGE(S)

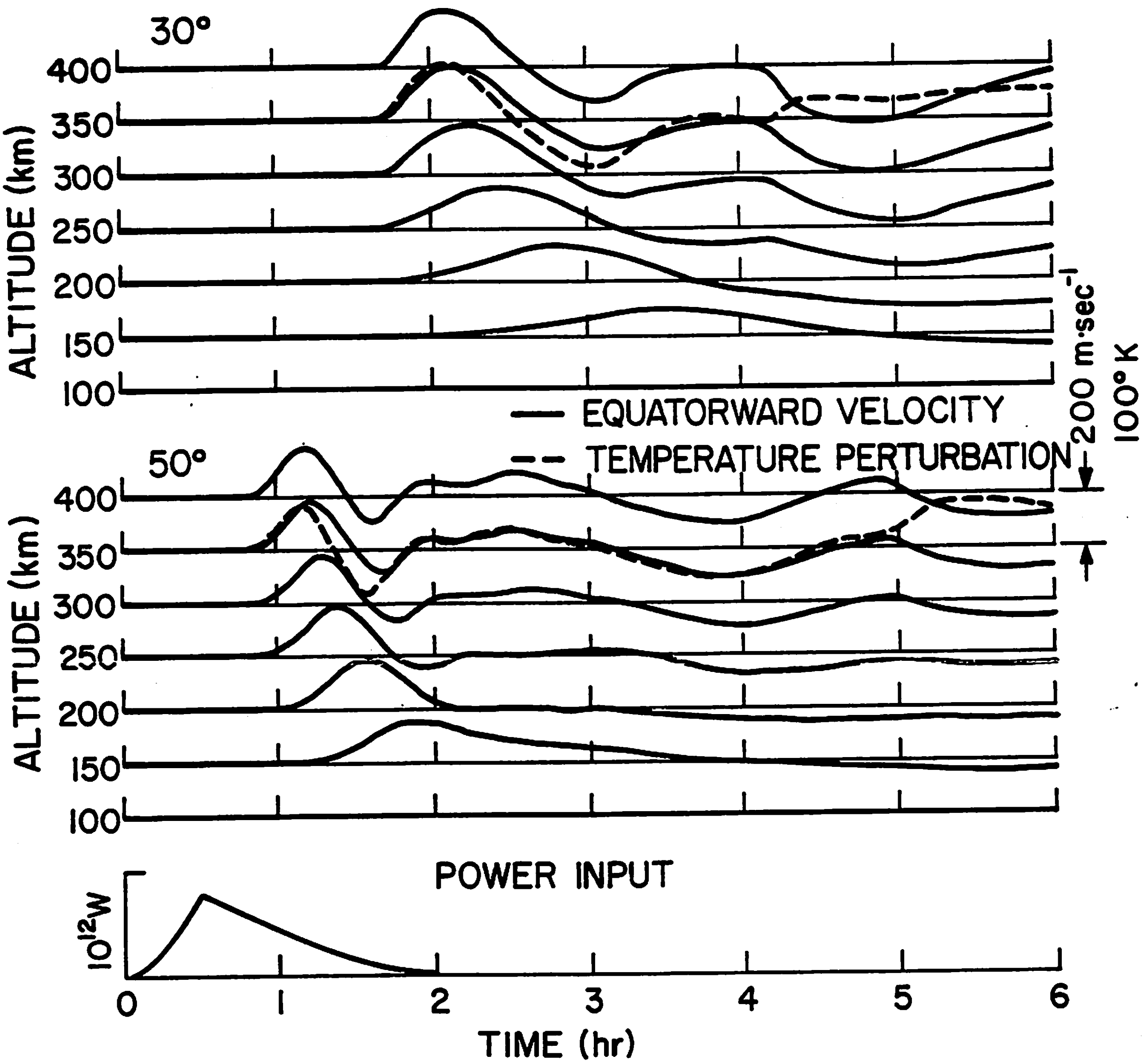


January, 1997


1997 JANUARY 10 16:00 UT
TEC DIFFERENCE
12
18
6
0
TEC DIFFERENCE
12
18
0
-5.0
2.5
10.0 (TECU)

M. Buonsanto


Millstone Hill Jan. 6–10, 1997
ISR
TIEGCM
NmF2
0
0.1
0.2
0.3
0.4
0.5
0.6
Arecibo Jan. 6–10, 1997
ISR
TIE
Ramey
NmF2 (10^12/m^3)
0
0.5
1
6.0
7.0
8.0
9.0
10.0
11.0
UT Day



30°
50°
400
350
300
250
200
150
100
ALTITUDE (km)
EQUATORWARD VELOCITY
TEMPERATURE PERTURBATION
200 m·sec⁻¹
100° K
POWER INPUT
10¹²W
0
1
2
3
4
5
6
TIME (hr)

M. Buonsanto

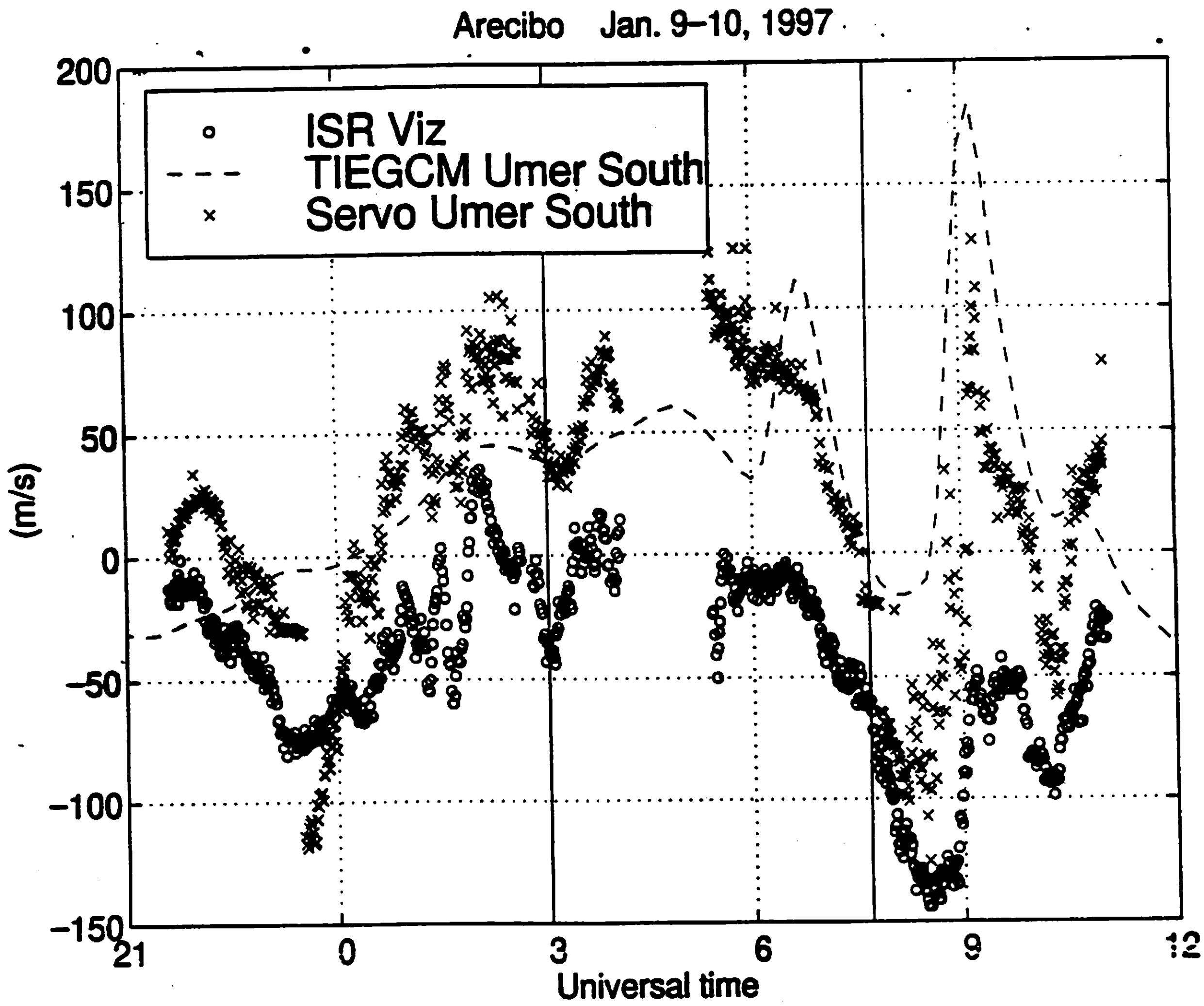
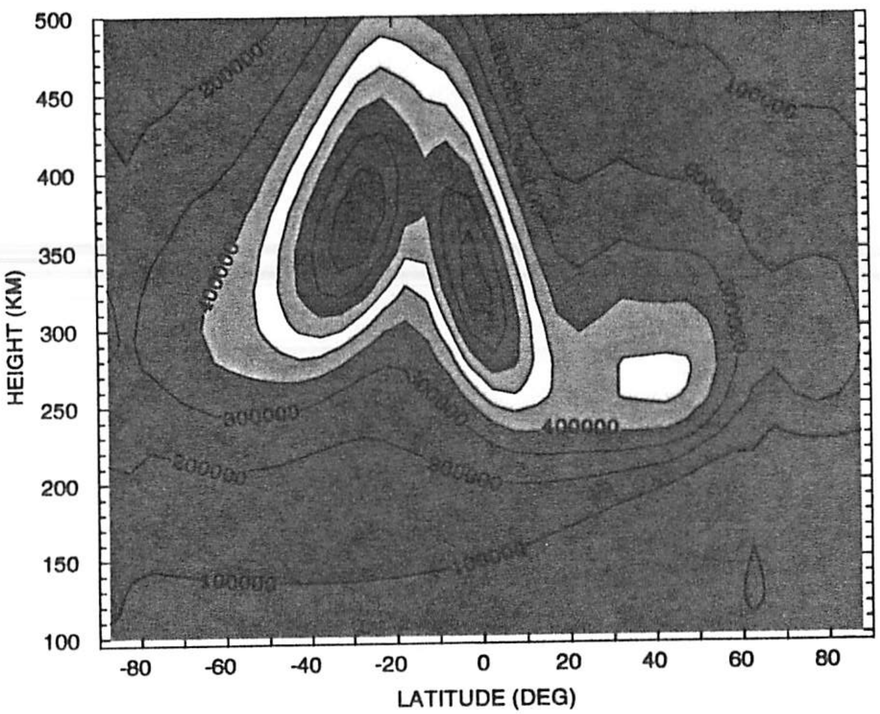


Figure 13. Vertical ion velocity observed by the ISR compared with the meridional wind from the TIEGCM and the servo model (positive southward) at Arecibo on the night of January 9–10, 1997. The vertical lines indicate times of possible electric field penetration events (see text).

1997 January 9

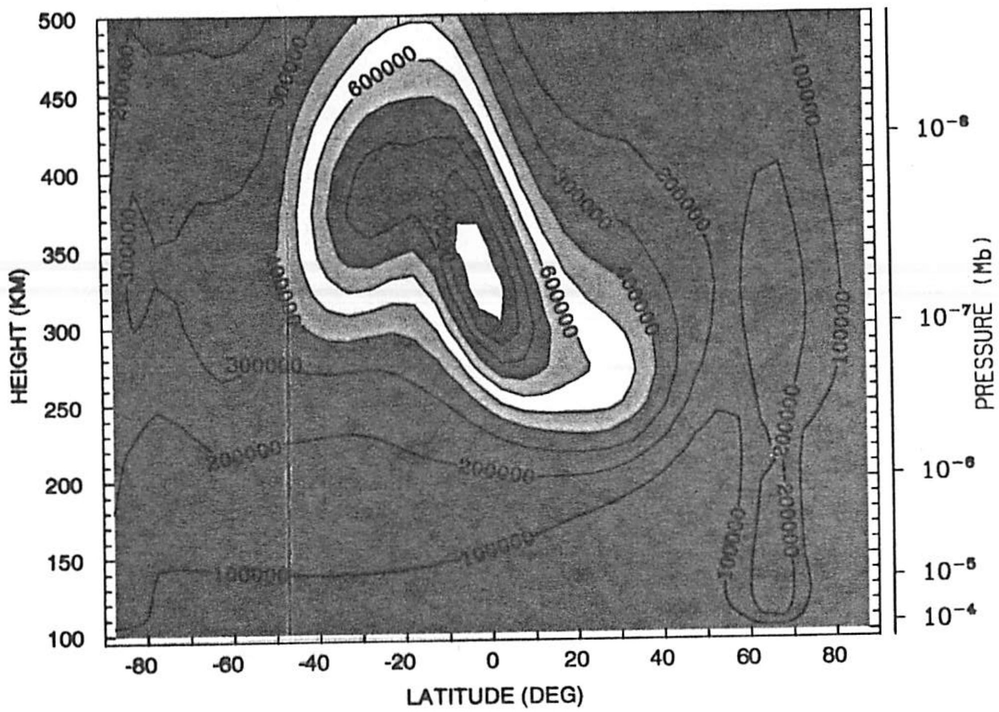
ELECTRON DENSITY (CM3)
UT=21.00 LON= -70.00 (DEG) SLT=16.33 (HRS)



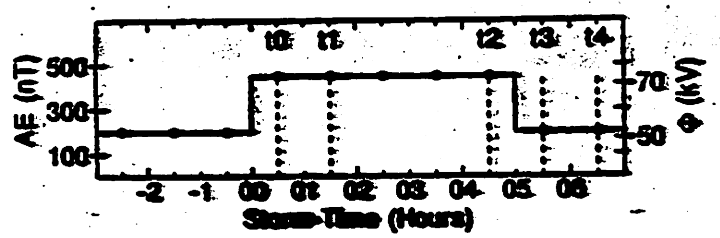
MIN,MAX= 0.0000E+00 1.0000E+06 INTERVAL= 1.0000E+05
TGCM13 /GANGLU/TGCM13/J97B10 (DAY,HR,MIN= 9,21, 0)

1997 January 10

ELECTRON DENSITY (CM3)
UT=21.00 LON= -70.00 (DEG) SLT=16.33 (HRS)



MIN,MAX= 0.0000E+00 1.0000E+06 INTERVAL= 1.0000E+05
TGCM13 /GANGLU/TGCM13/J97B22 (DAY,HR,MIN= 10,21, 0)



igure 1. Idealized time variations of the AE index and polar ip potential drop used in this work.

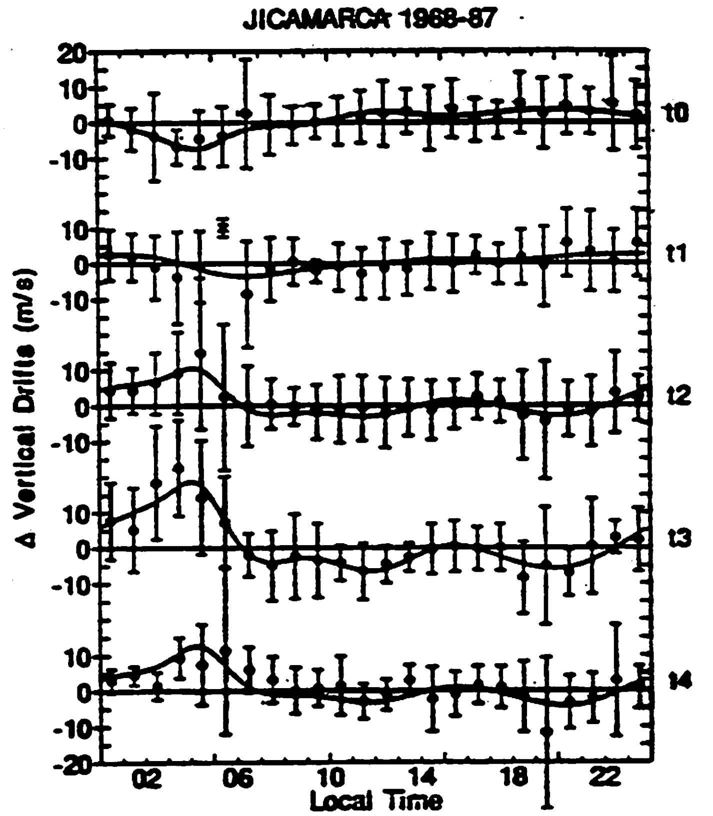


Figure 2. Equatorial vertical drift perturbations for the conditions and at the five storm times shown in Figure 1. The dots indicate the average perturbation velocities obtained by binning the data; the X denotes an average from less than 5 samples, and the vertical bars are the standard deviations. The solid curves indicate the velocity patterns determined from an analytical model.

Sensitivities of Ionosphere/Thermosphere Response

- Polar ionospheric plasma distribution depends sensitively on space-time distributions of auroral precipitation and electric fields
- Midlatitude boundary between increases and decreases of N_2/O ratio depends sensitively on space-time distribution of high-latitude electric fields and currents
- Amplitude and timing of traveling atmospheric disturbances depends sensitively on temporal variations of high-latitude Joule heating
- Sign and amplitude of low-latitude disturbance electric fields depends sensitively on space-time distribution of high-latitude electric fields and Joule heating

Critical Need for Progress in Predicting Storm Effects in the Ionosphere/Thermosphere:

- Accurate determination of space-time distributions of high-latitude electric fields, currents, and particle precipitation

Some References

Buonsanto, M.J., Ionospheric storms - a review, *Space Sci. Rev.*, in press.

Buonsanto, M.J., S.A. González, G. Lu, and J.P. Thayer, Coordinated incoherent scatter radar study of the January, 1997 storm, *J. Geophys. Res.*, submitted.

Fuller-Rowell, T.J., M.V. Codrescu, R.G. Roble, and A.D. Richmond, How does the thermosphere and ionosphere react to a geomagnetic storm? in *Magnetic Storms*, pp. 203-225, AGU Geophysical Monograph 98, 1997.

Lu, G., D.N. Baker, C.J. Farrugia, D. Lummerzheim, J.M. Ruohoniemi, F.J. Rich, D.S. Evans, R.P. Lepping, M. Brittnacher, X. Li, R. Greenwald, G. Sofko, J. Villain, M. Lester, J. Thayer, T. Moretto, D. Milling, O. Troshichev, A. Zaitzev, G. Makarov, and K. Hayashi, Global energy deposition during the January 1997 magnetic cloud event, *J. Geophys. Res., 103*, 11,685-11,694, 1998.

Prölss, G.W., Ionospheric F-region storms, in *Handbook of Atmospheric Electrodynamics, Volume II*, edited by H. Volland, pp. 195-248, CRC Press, Boca Raton, Florida, 1995.

Prölss, G.W., Magnetic storm associated perturbations of the upper atmosphere, in *Magnetic Storms*, AGU Geophysical Monograph 98, 1997.

1997 January 10 AMIE results

http://www.hao.ucar.edu/public/research/tiso/cedar/jan97.html

1997 January 10 TIE-GCM results

http://www.hao.ucar.edu/public/research/tiso/tgcm/tgcm.html