THE NCAR TGCM'S: PAST, PRESENT, AND FUTURE

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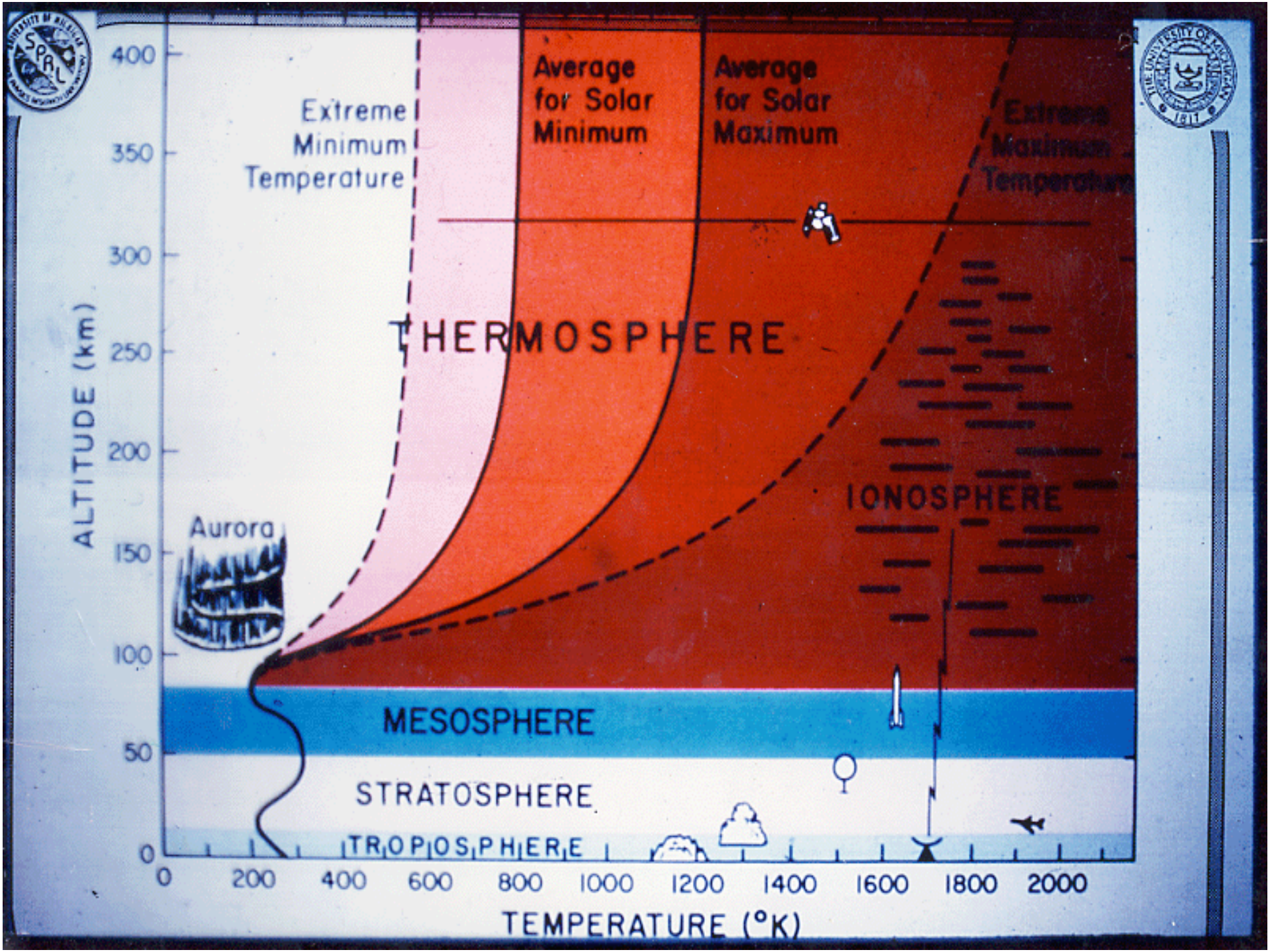
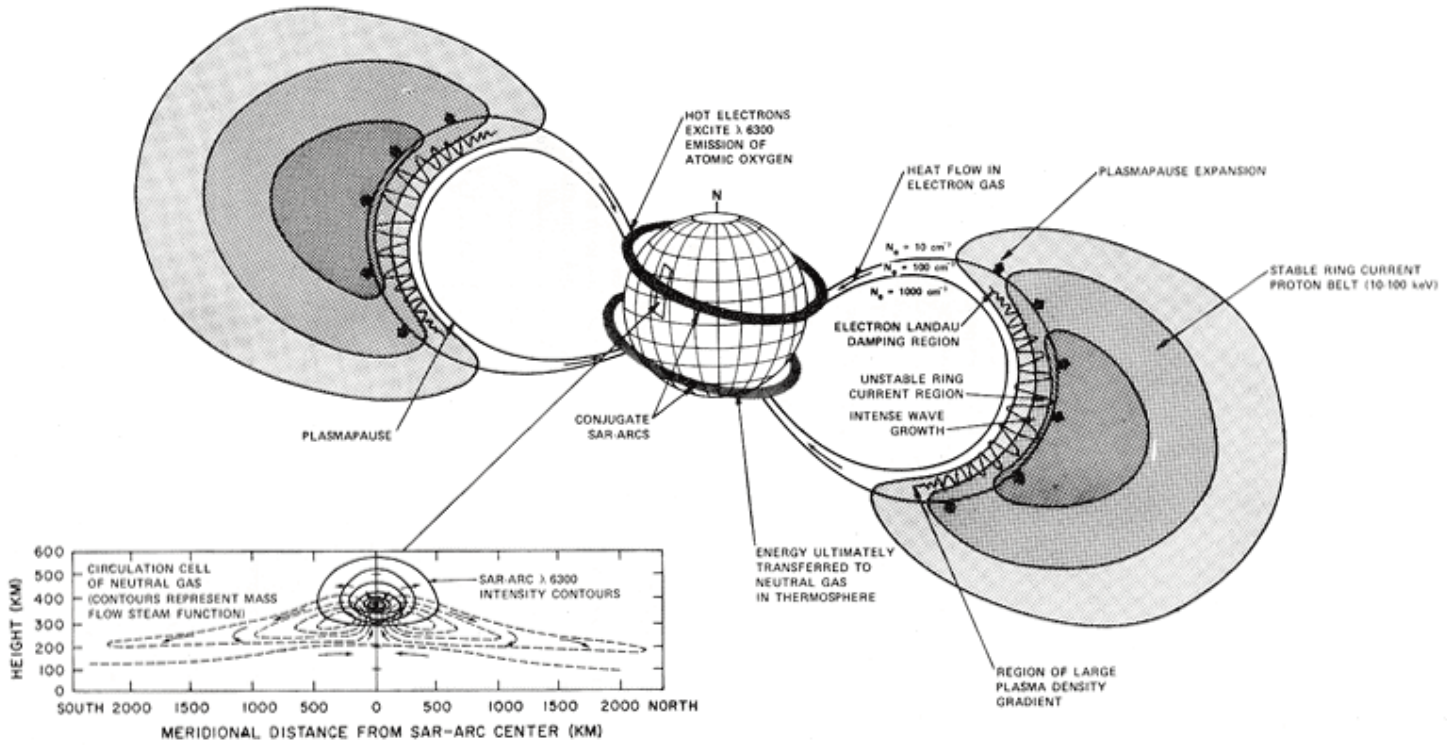
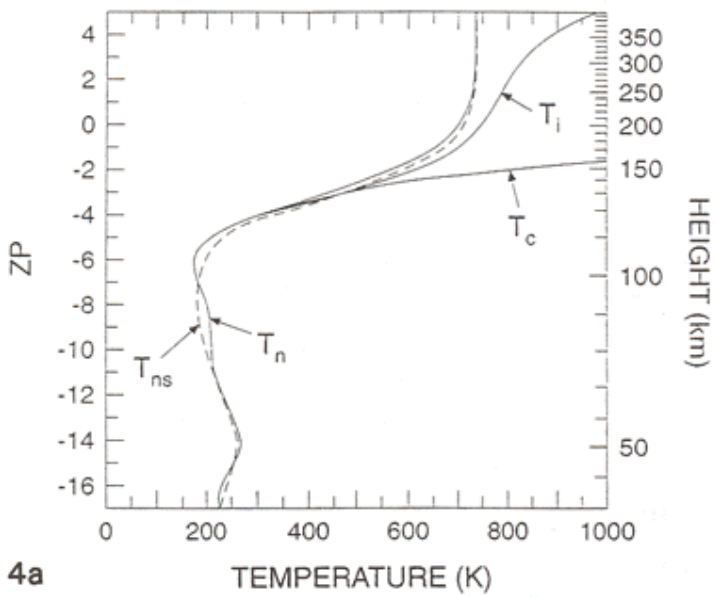

Extreme
Minimum
Temperature
Average
for Solar
Minimum
Average
for Solar
Maximum
Extreme
Maximum
Temperature
THERMOSPHERE
IONOSPHERE
Aurora
MESOSPHERE
STRATOSPHERE
TROPOSPHERE
ALTITUDE (km)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
TEMPERATURE (°K)

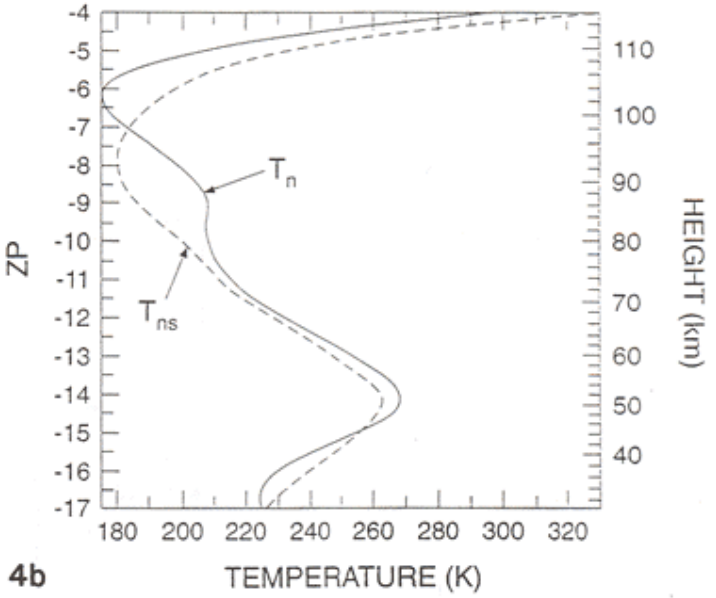
Talk outline

- How and why the TGCM's were developed
  at NCAR.
- Their present day capability and how they
  are being used in CEDAR.
- The future modeling efforts in a changing
  Climate.

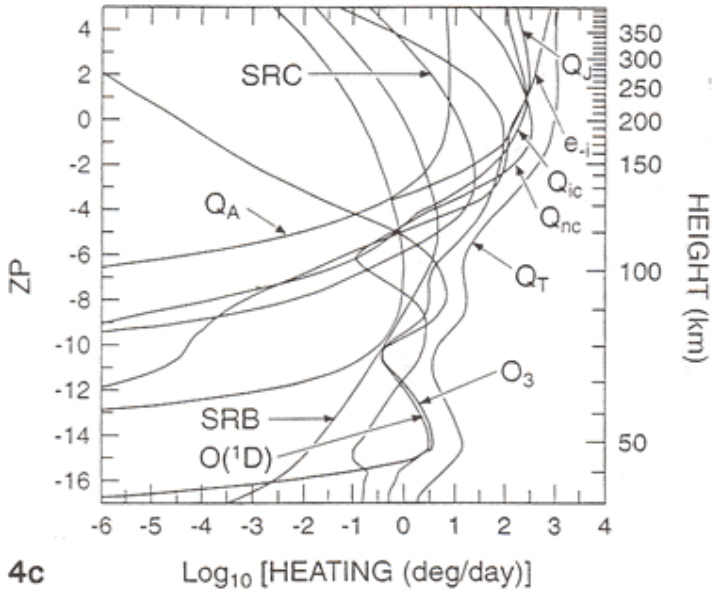

HOT ELECTRONS EXCITE λ 6300 EMISSION OF ATOMIC OXYGEN
HEAT FLOW IN ELECTRON GAS
PLASMAPAUSE EXPANSION
N
N_e = 10 cm^{-3}
N_e = 100 cm^{-3}
N_e = 1000 cm^{-3}
STABLE RING CURRENT PROTON BELT (10-100 keV)
ELECTRON LANDAU DAMPING REGION
UNSTABLE RING CURRENT REGION
INTENSE WAVE GROWTH
PLASMAPAUSE
CONJUGATE SAR-ARCS
ENERGY ULTIMATELY TRANSFERRED TO NEUTRAL GAS IN THERMOSPHERE
REGION OF LARGE PLASMA DENSITY GRADIENT
CIRCULATION CELL OF NEUTRAL GAS (CONTOURS REPRESENT MASS FLOW STEAM FUNCTION)
SAR-ARC λ 6300 INTENSITY CONTOURS
HEIGHT (KM)
600
500
400
300
200
100
0
SOUTH 2000 1500 1000 500 0 500 1000 1500 2000 NORTH
MERIDIONAL DISTANCE FROM SAR-ARC CENTER (KM)


ZP
HEIGHT (km)
TEMPERATURE (K)
T_i
T_c
T_n
T_{ns}

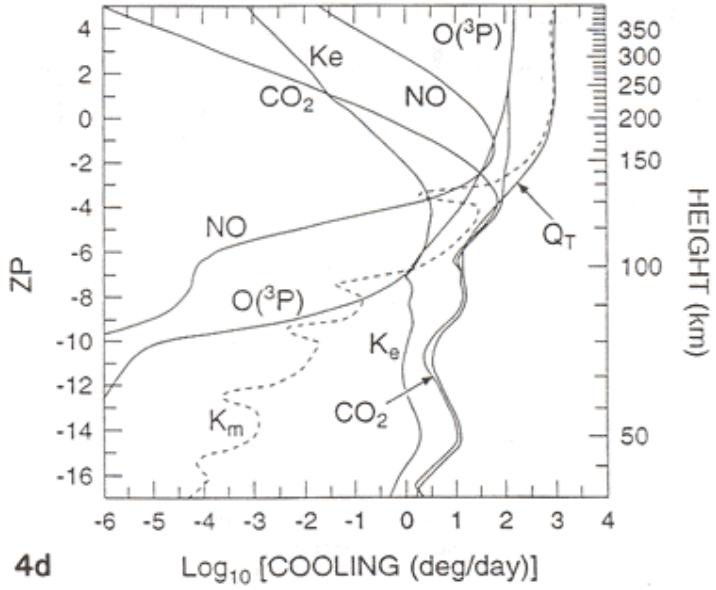
4a


ZP
HEIGHT (km)
TEMPERATURE (K)
T_n
T_{ns}

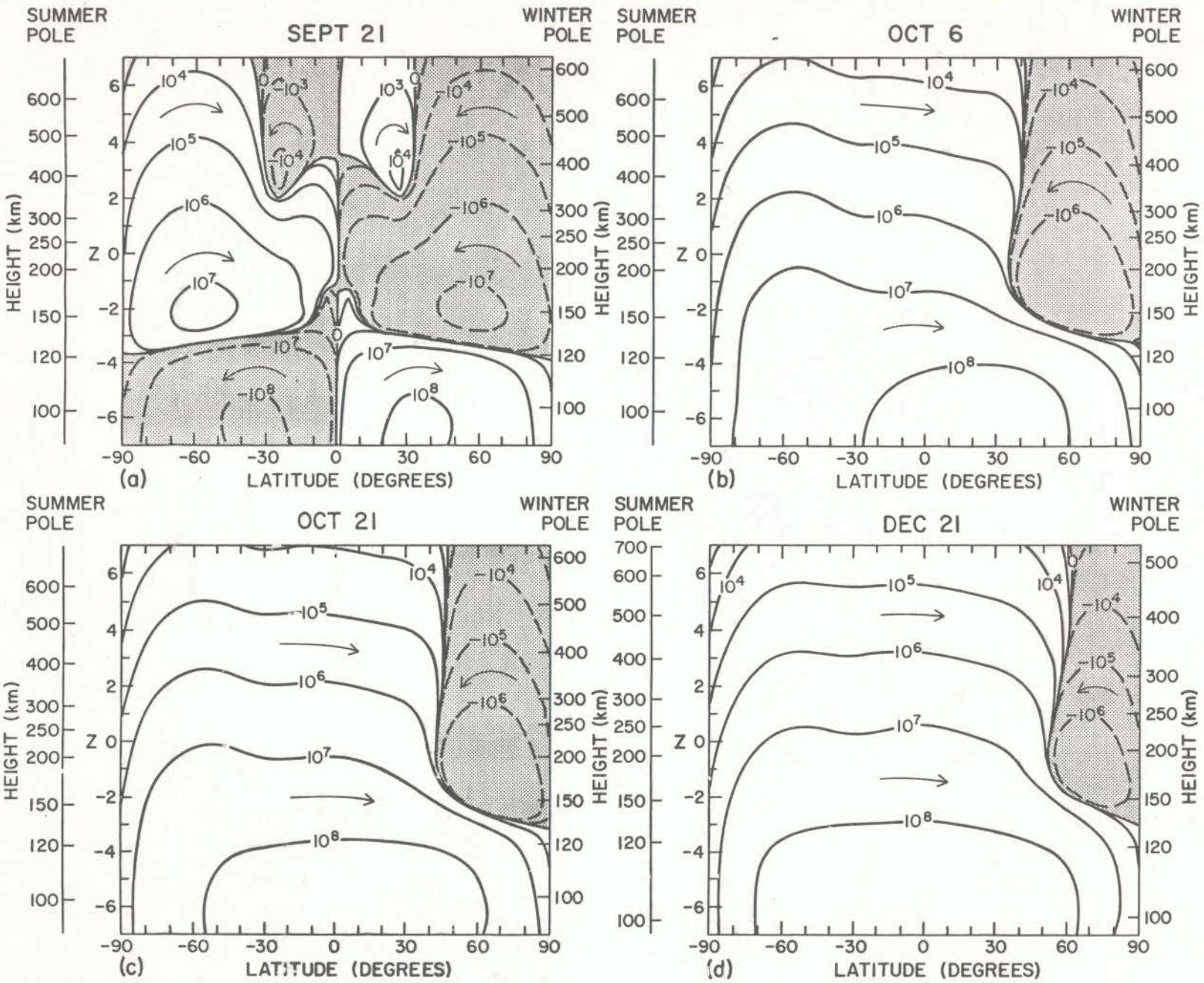
4b

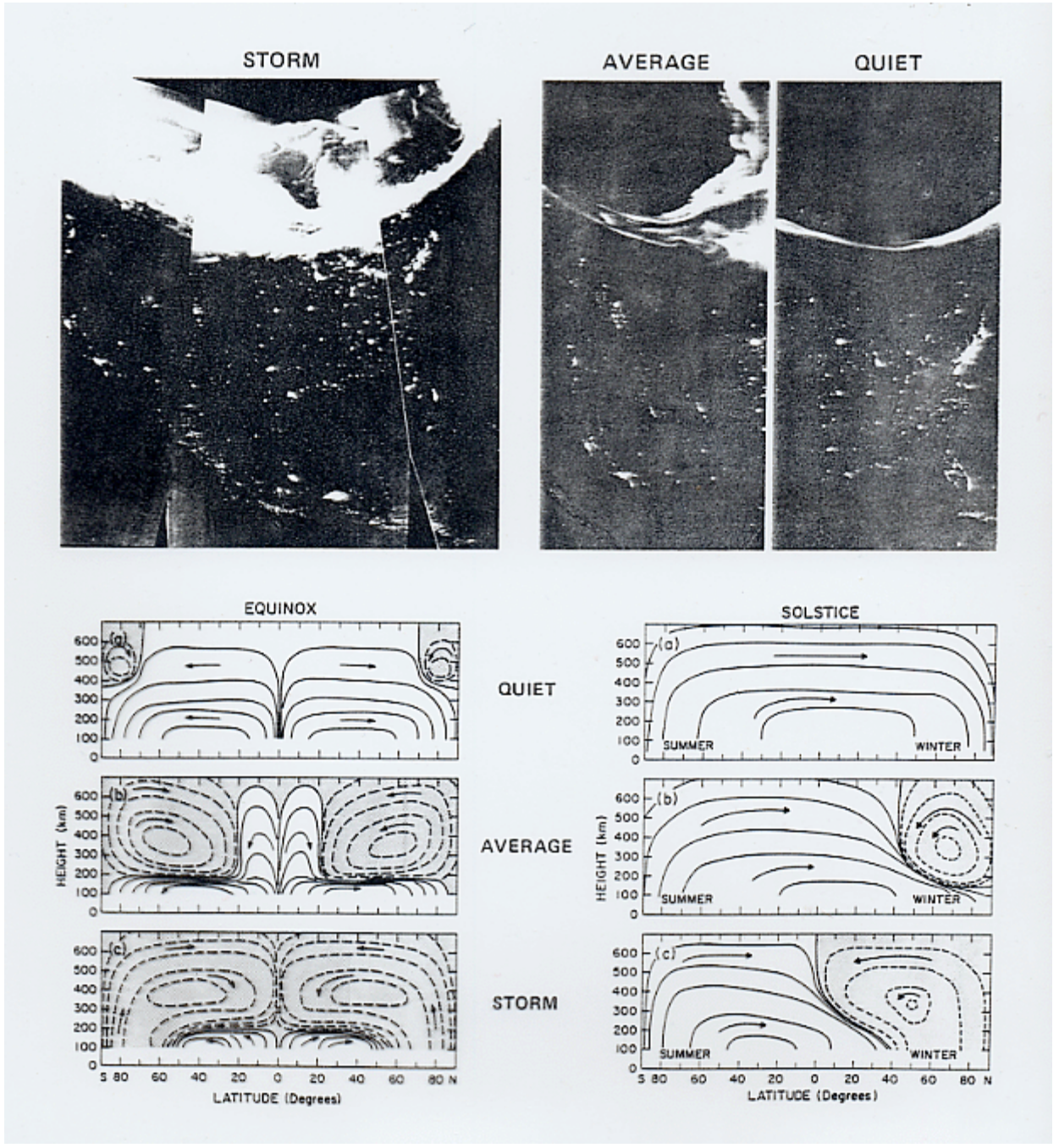

ZP
HEIGHT (km)
Log_{10} [HEATING (deg/day)]
SRC
Q_J
e_{-i}
Q_{ic}
Q_{nc}
Q_A
Q_T
O_3
SRB
$O(^1D)$

4c

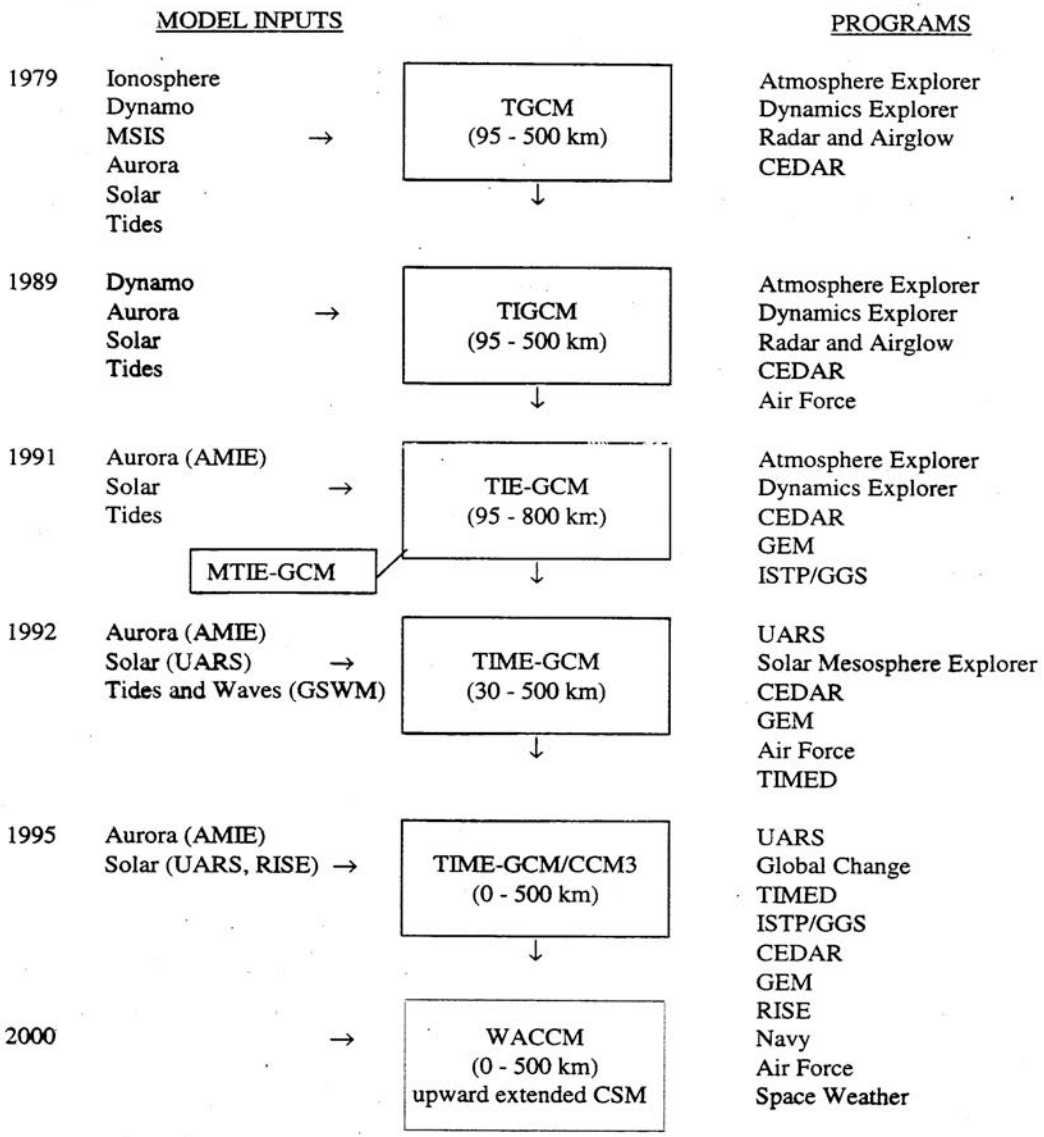

ZP
HEIGHT (km)
Log_{10} [COOLING (deg/day)]
$O(^3P)$
Ke
CO_2
NO
Q_T
NO
$O(^3P)$
K_e
K_m
CO_2

4d


SUMMER POLE
SEPT 21
WINTER POLE
HEIGHT (km)
Z
LATITUDE (DEGREES)
(a)
SUMMER POLE
OCT 6
WINTER POLE
HEIGHT (km)
LATITUDE (DEGREES)
(b)
SUMMER POLE
OCT 21
WINTER POLE
HEIGHT (km)
LATITUDE (DEGREES)
(c)
SUMMER POLE
DEC 21
WINTER POLE
HEIGHT (km)
LATITUDE (DEGREES)
(d)

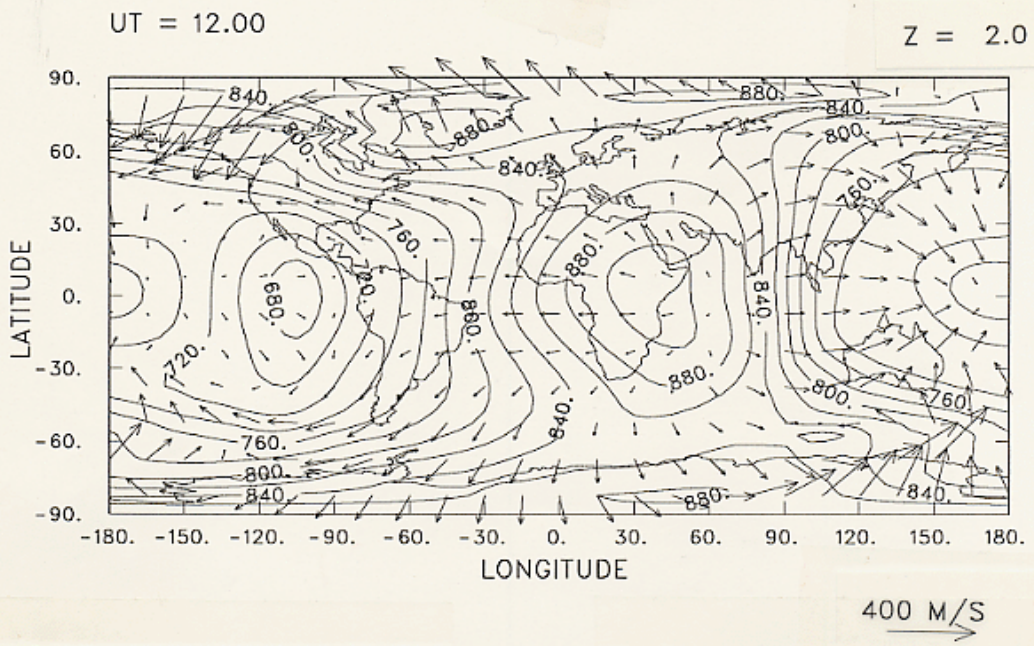

STORM
AVERAGE
QUIET
EQUINOX
SOLSTICE
QUIET
AVERAGE
STORM
(a)
(b)
(c)
SUMMER
WINTER
HEIGHT (km)
LATITUDE (Degrees)
0
100
200
300
400
500
600
S 80 60 40 20 0 20 40 60 80 N

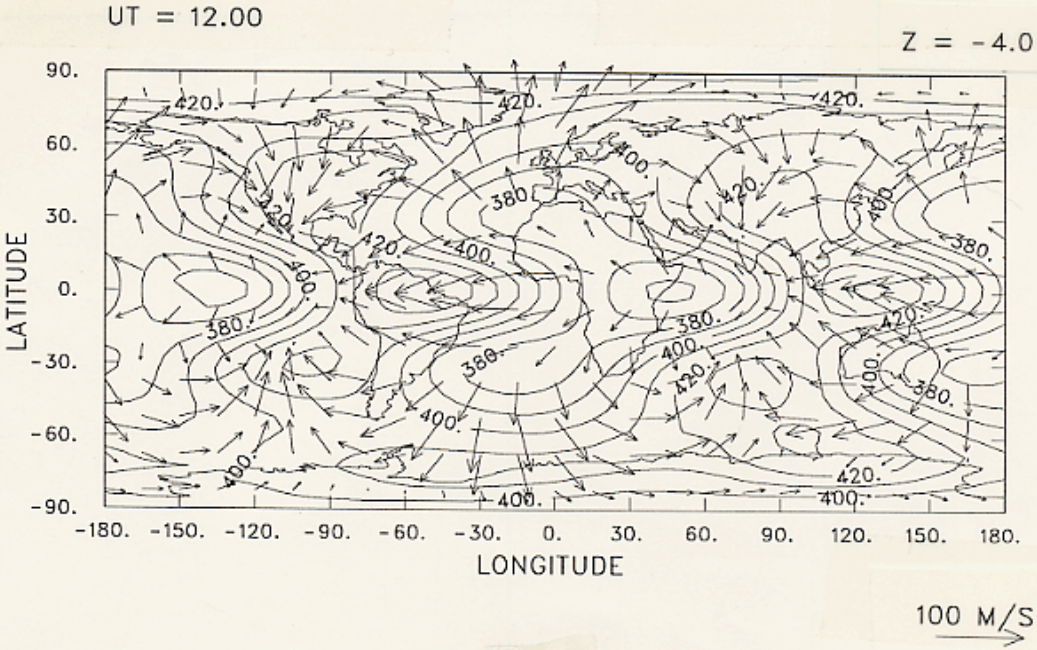
LONG RANGE TGCM MODEL DEVELOPMENT

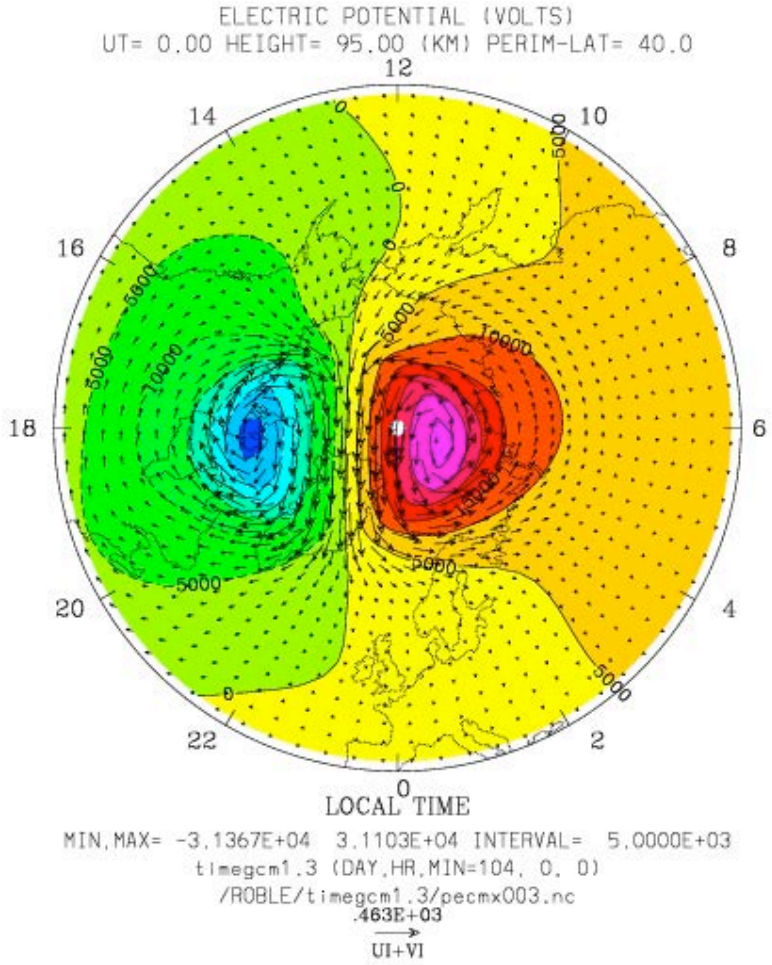


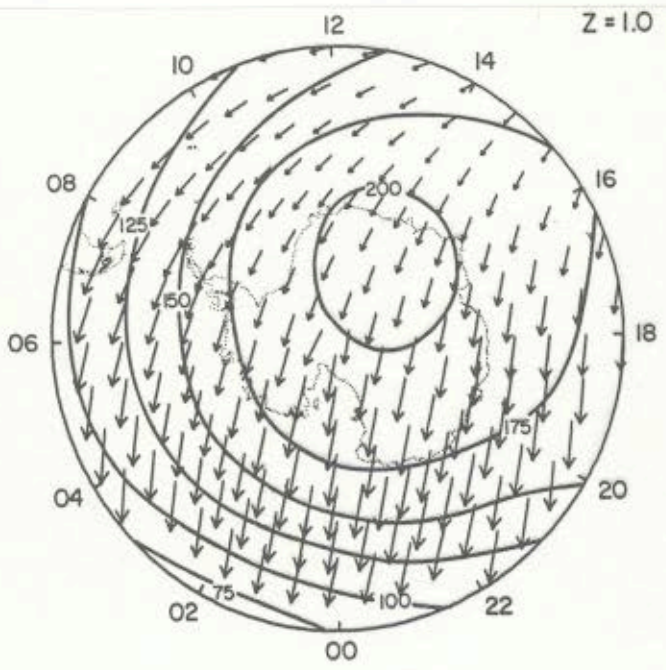
Schematic illustrating past and future TGCM development. The year of model development and diminishing dependence on empirical specification is given on the left of the boxes and the programs and data sources used for GCM validation and scientific studies is given on the right. CCM refers to the NCAR Community Climate Model.

EARTH

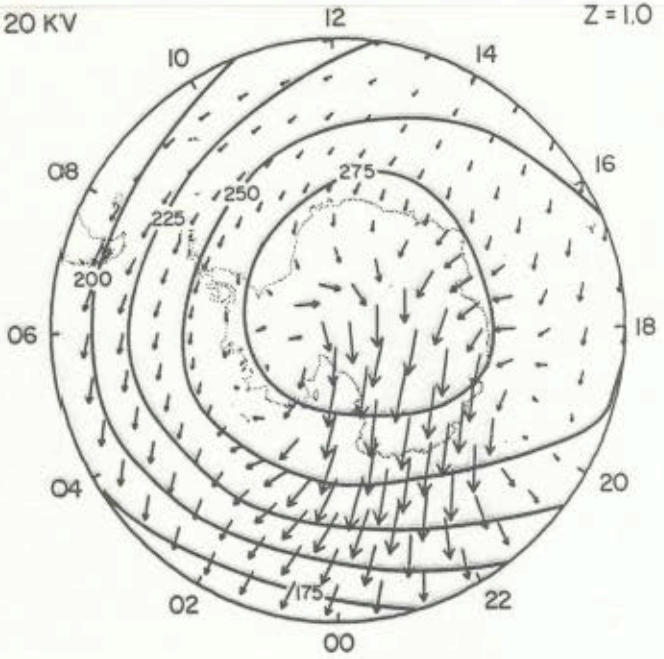

UT = 12.00
Z = 2.0
LATITUDE
LONGITUDE
90.
60.
30.
0.
-30.
-60.
-90.
-180. -150. -120. -90. -60. -30. 0. 30. 60. 90. 120. 150. 180.
840.
800.
880.
760.
720.
680.
400 M/S


UT = 12.00
Z = -4.0
LATITUDE
LONGITUDE
90.
60.
30.
0.
-30.
-60.
-90.
-180. -150. -120. -90. -60. -30. 0. 30. 60. 90. 120. 150. 180.
420.
400.
380.
460.
100 M/S

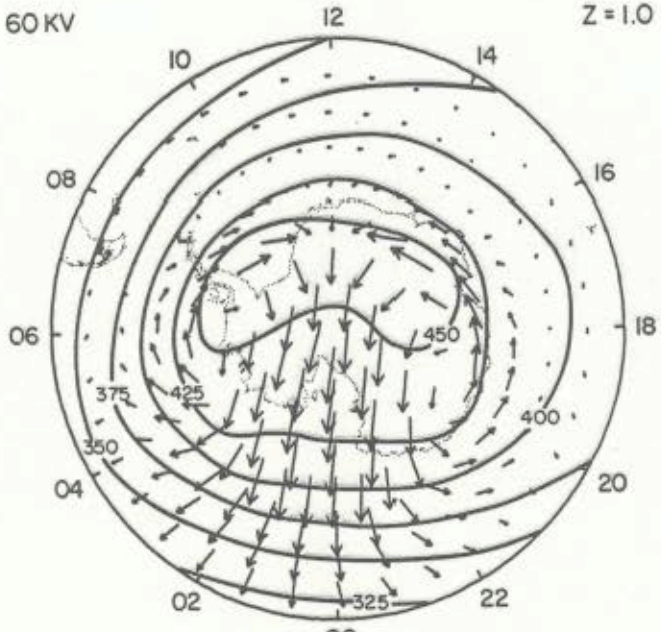

ELECTRIC POTENTIAL (VOLTS)
UT= 0.00 HEIGHT= 95.00 (KM) PERIM-LAT= 40.0
12
14
10
16
8
18
6
20
4
22
2
0
LOCAL TIME
MIN,MAX= -3.1367E+04 3.1103E+04 INTERVAL= 5.0000E+03
timegcm1.3 (DAY,HR,MIN=104, 0, 0)
/ROBLE/timegcm1.3/pecmx003.nc
.463E+03
UI+VI

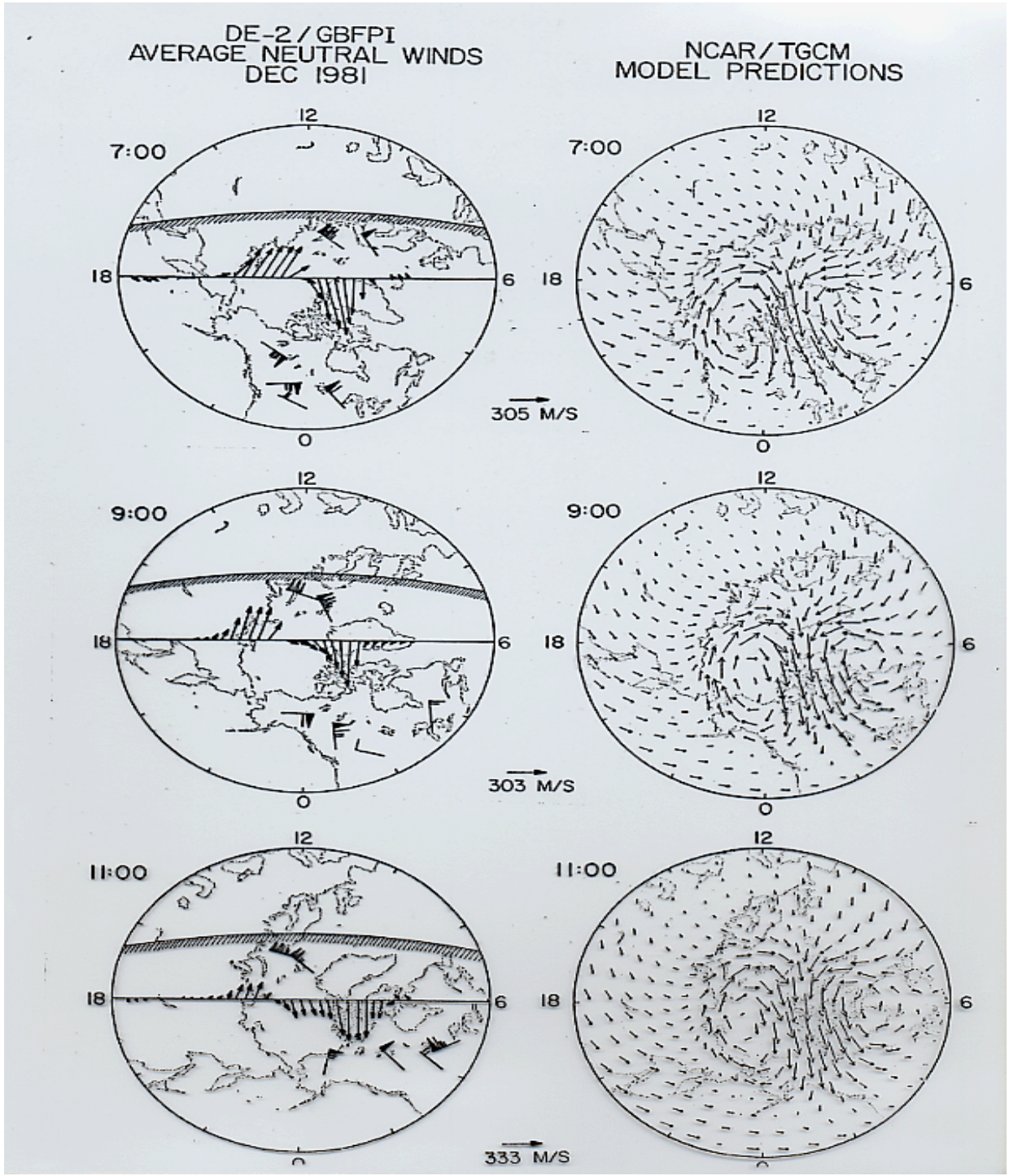


(a) LOCAL TIME

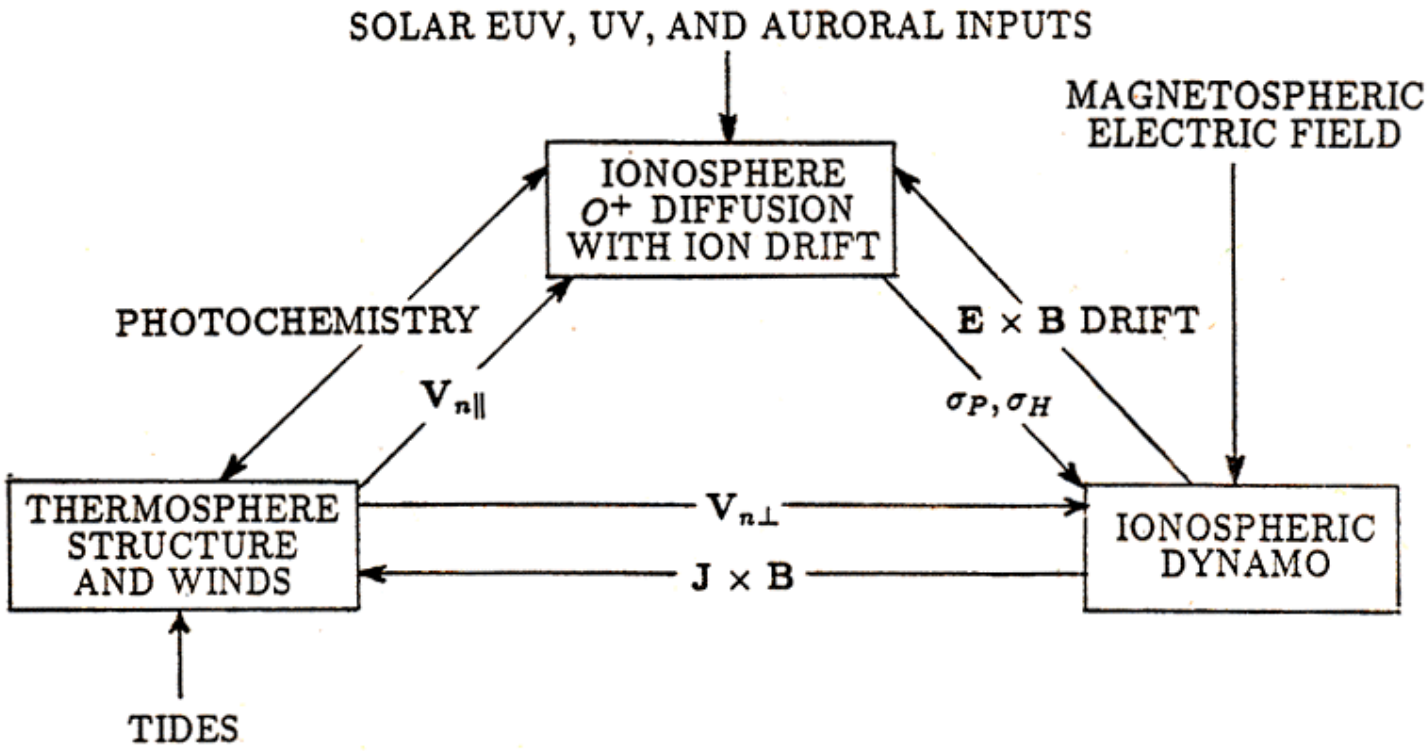


(b) LOCAL TIME




DE-2 / GBFPI
AVERAGE NEUTRAL WINDS
DEC 1981
NCAR / TGCM
MODEL PREDICTIONS
7:00
9:00
11:00
12
18
6
0
305 M/S
303 M/S
333 M/S

TIE-GCM


SOLAR EUV, UV, AND AURORAL INPUTS
MAGNETOSPHERIC ELECTRIC FIELD
IONOSPHERE O^+ DIFFUSION WITH ION DRIFT
PHOTOCHEMISTRY
$\mathbf{V}_{n\parallel}$
$\mathbf{E} \times \mathbf{B}$ DRIFT
σ_P, σ_H
THERMOSPHERE STRUCTURE AND WINDS
$\mathbf{V}_{n\perp}$
$\mathbf{J} \times \mathbf{B}$
IONOSPHERIC DYNAMO
TIDES

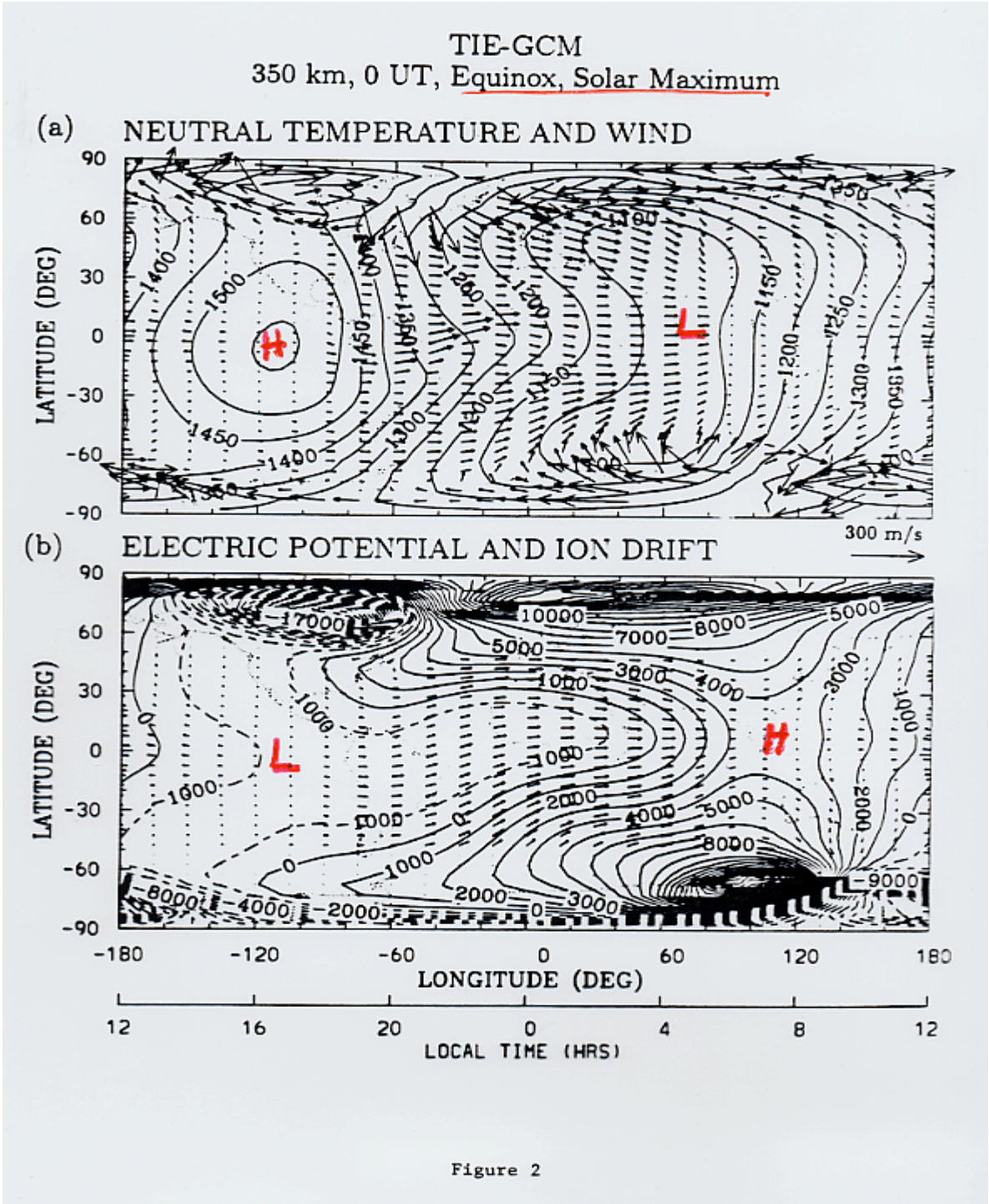
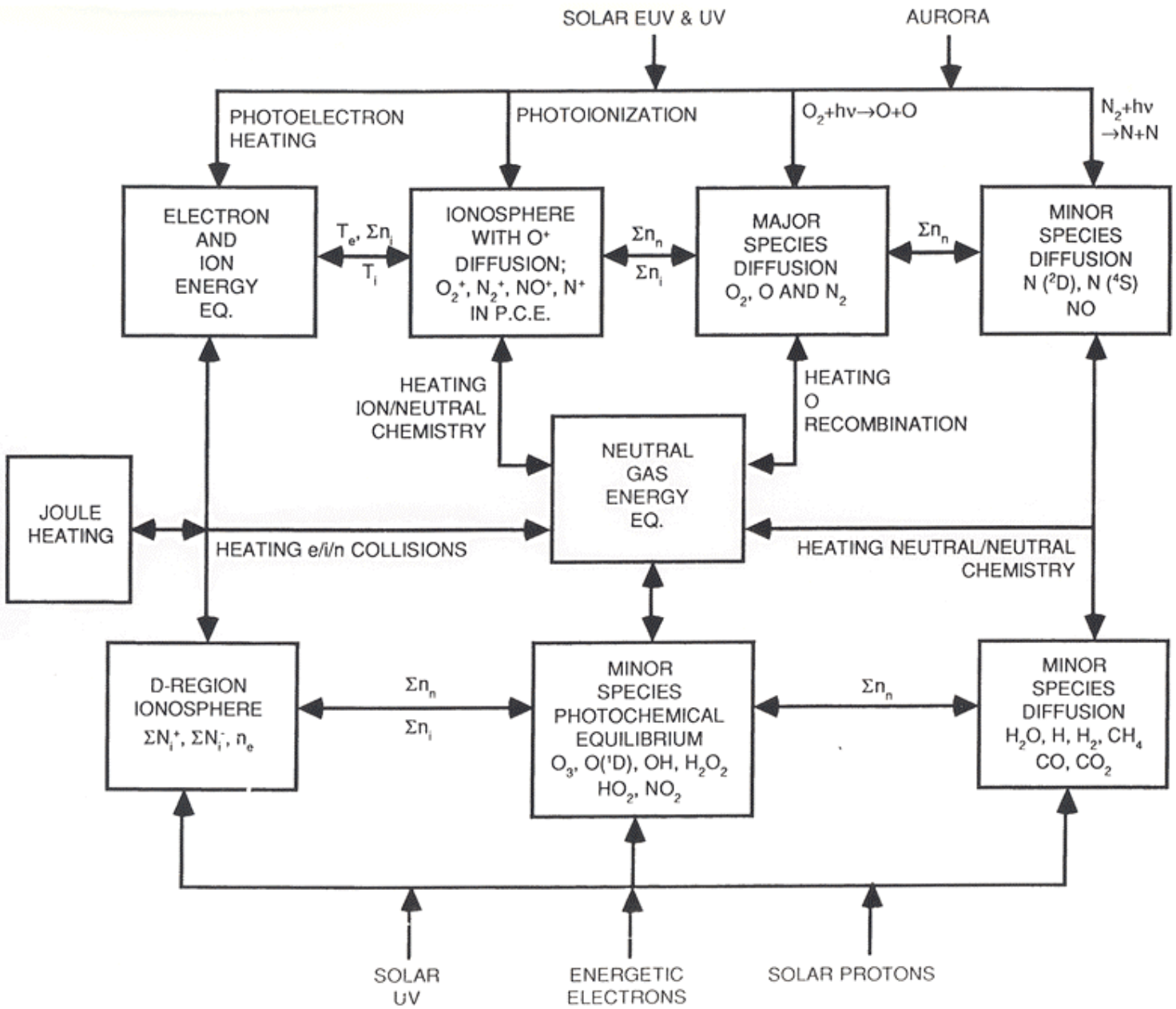
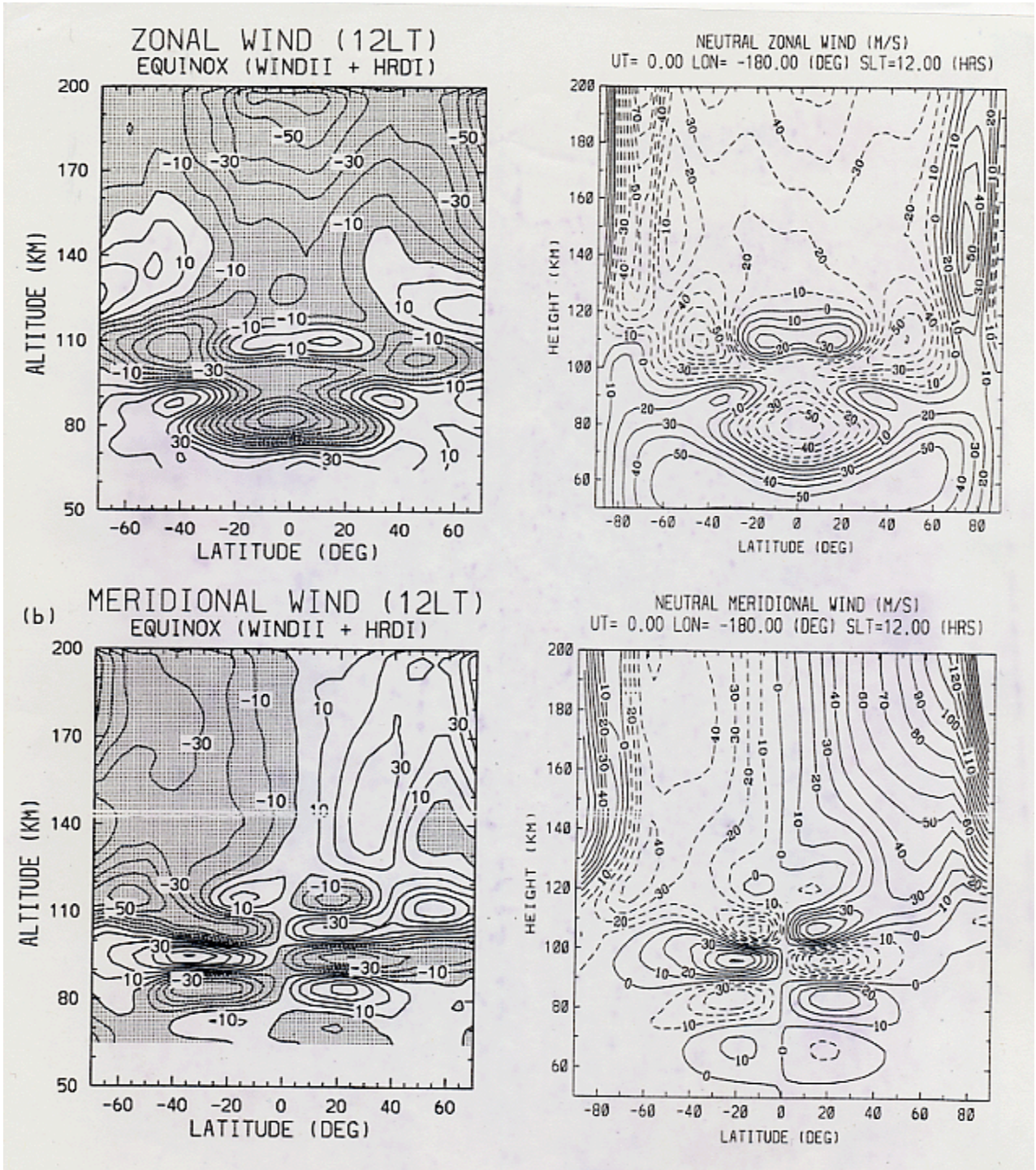
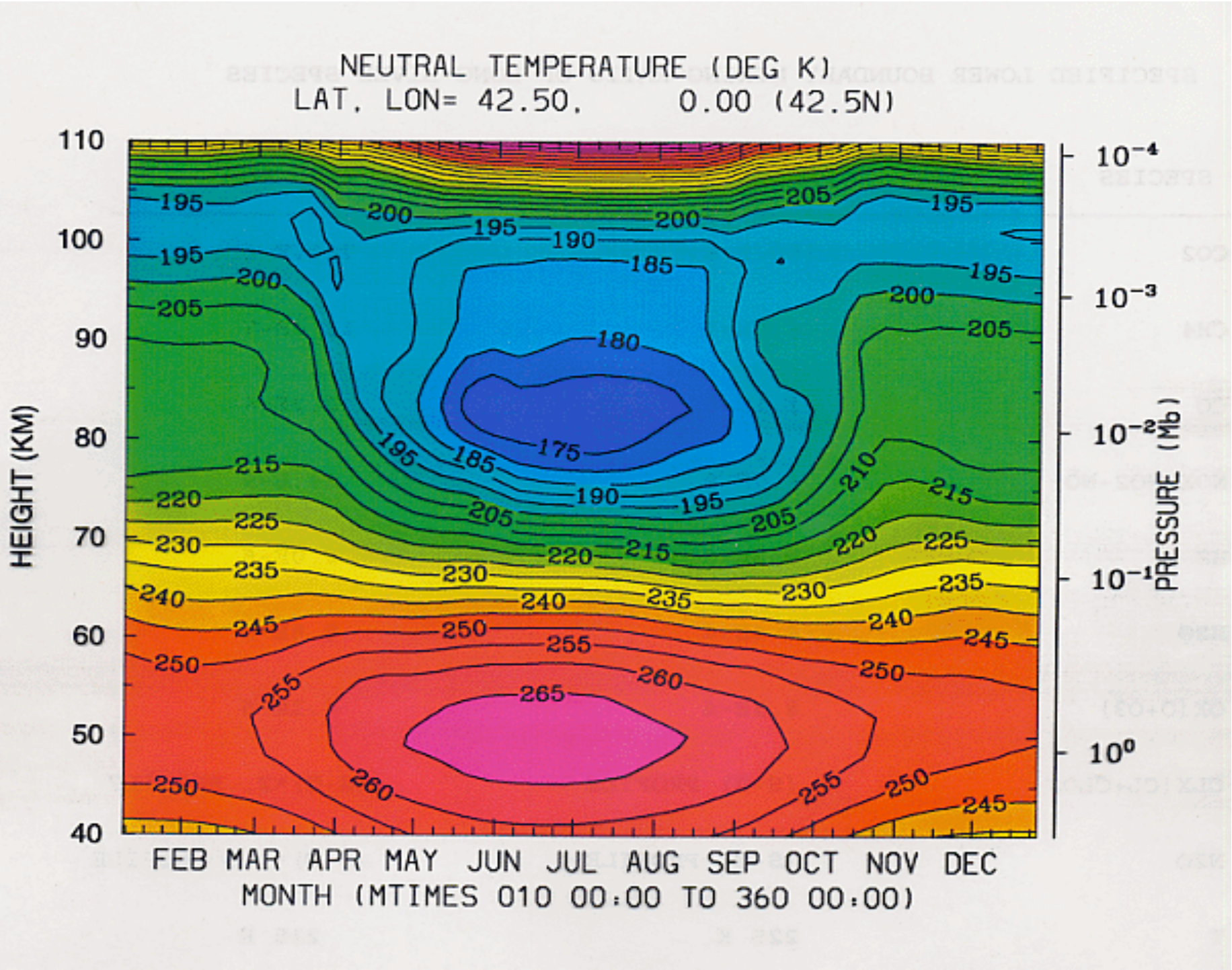
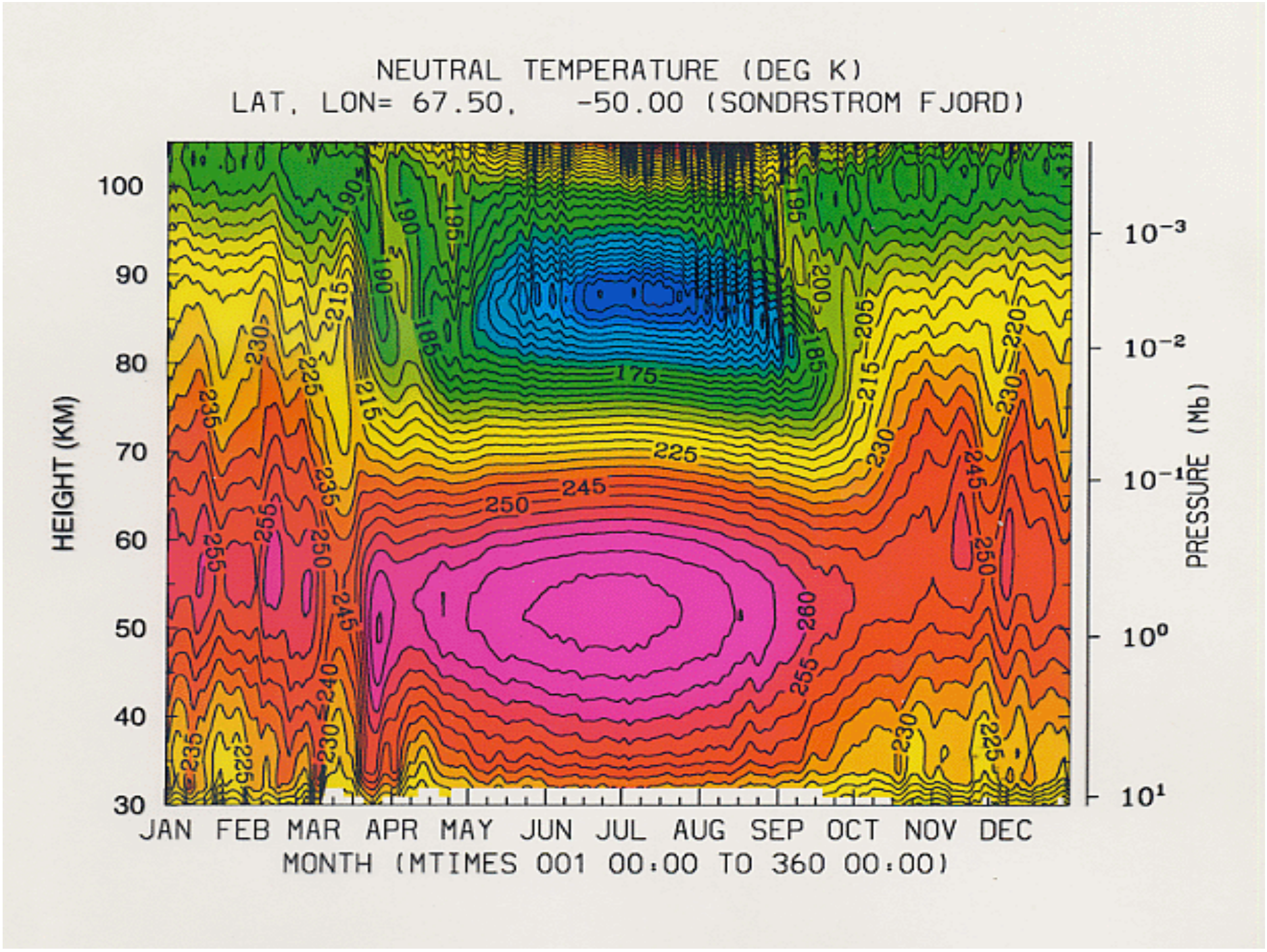

TIE-GCM
350 km, 0 UT, Equinox, Solar Maximum
(a) NEUTRAL TEMPERATURE AND WIND
LATITUDE (DEG)
90
60
30
0
-30
-60
-90
300 m/s
(b) ELECTRIC POTENTIAL AND ION DRIFT
LATITUDE (DEG)
-180
-120
-60
0
60
120
180
LONGITUDE (DEG)
12
16
20
0
4
8
12
LOCAL TIME (HRS)

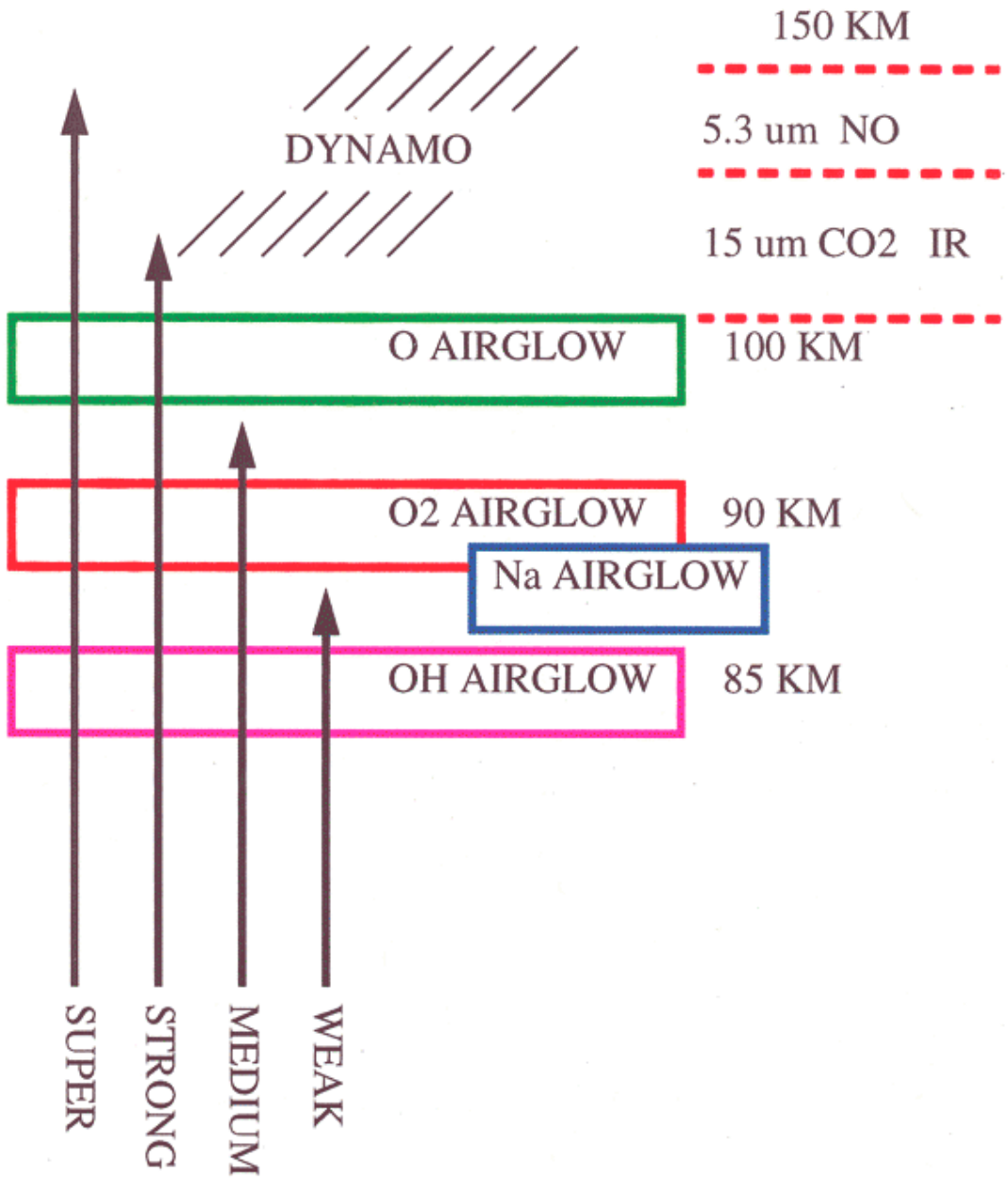
Figure 2


SOLAR EUV & UV
AURORA
PHOTOELECTRON HEATING
PHOTOIONIZATION
$O_2+h\nu \rightarrow O+O$
$N_2+h\nu \rightarrow N+N$
ELECTRON AND ION ENERGY EQ.
T_e, Σn_i
T_i
IONOSPHERE WITH O^+ DIFFUSION; O_2^+, N_2^+, NO^+, N^+ IN P.C.E.
Σn_n
Σn_i
MAJOR SPECIES DIFFUSION O_2, O AND N_2
Σn_n
MINOR SPECIES DIFFUSION N (^{2}D), N (^{4}S) NO
HEATING ION/NEUTRAL CHEMISTRY
HEATING O RECOMBINATION
NEUTRAL GAS ENERGY EQ.
JOULE HEATING
HEATING e/i/n COLLISIONS
HEATING NEUTRAL/NEUTRAL CHEMISTRY
D-REGION IONOSPHERE ΣN_i^+, ΣN_i^-, n_e
Σn_n
Σn_i
MINOR SPECIES PHOTOCHEMICAL EQUILIBRIUM O_3, O(^{1}D), OH, H_2O_2 HO_2, NO_2
Σn_n
MINOR SPECIES DIFFUSION H_2O, H, H_2, CH_4 CO, CO_2
SOLAR UV
ENERGETIC ELECTRONS
SOLAR PROTONS

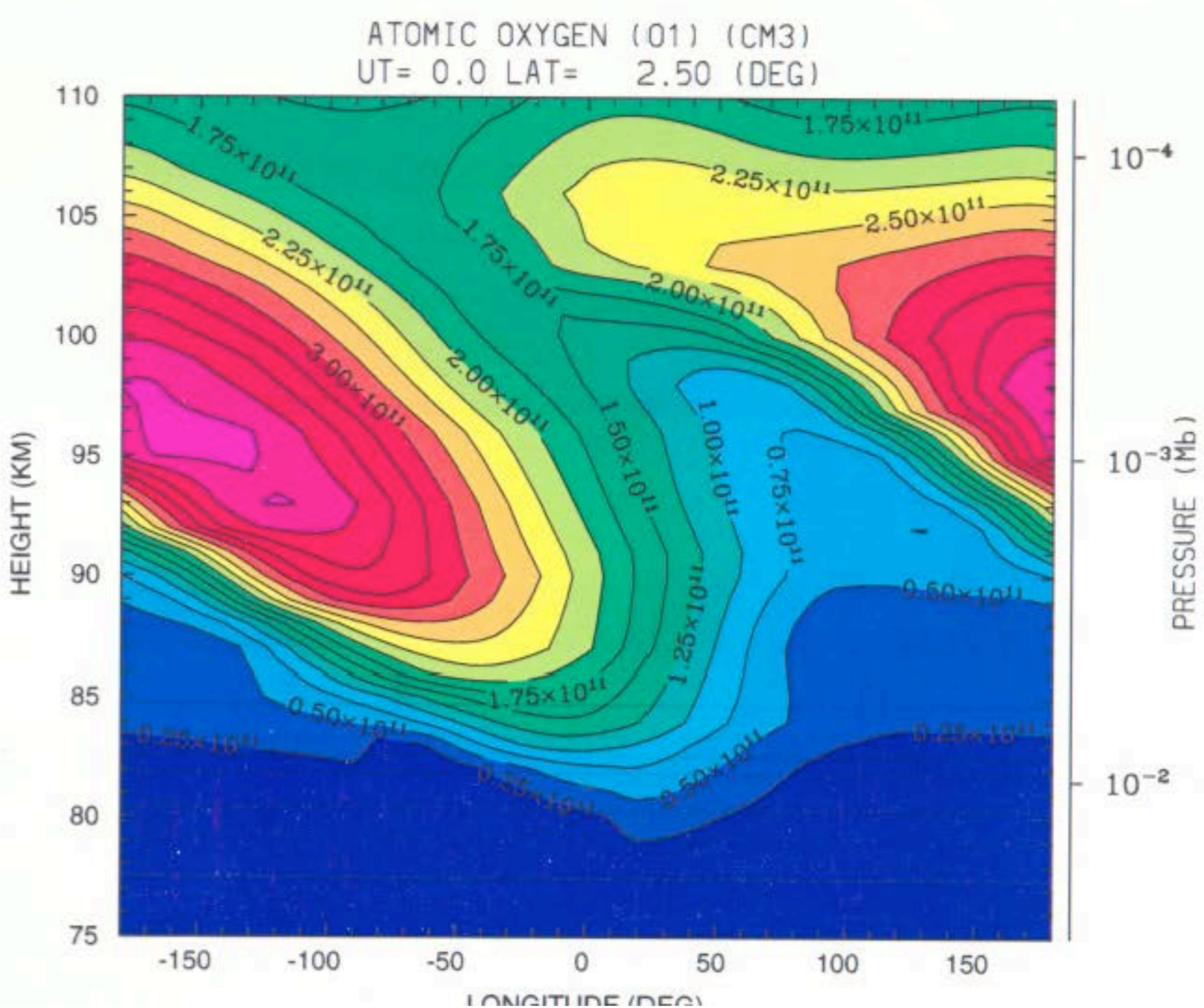

ZONAL WIND (12LT)
EQUINOX (WINDII + HRDI)
ALTITUDE (KM)
LATITUDE (DEG)
NEUTRAL ZONAL WIND (M/S)
UT= 0.00 LON= -180.00 (DEG) SLT=12.00 (HRS)
HEIGHT (KM)
LATITUDE (DEG)
(b)
MERIDIONAL WIND (12LT)
EQUINOX (WINDII + HRDI)
ALTITUDE (KM)
LATITUDE (DEG)
NEUTRAL MERIDIONAL WIND (M/S)
UT= 0.00 LON= -180.00 (DEG) SLT=12.00 (HRS)
HEIGHT (KM)
LATITUDE (DEG)

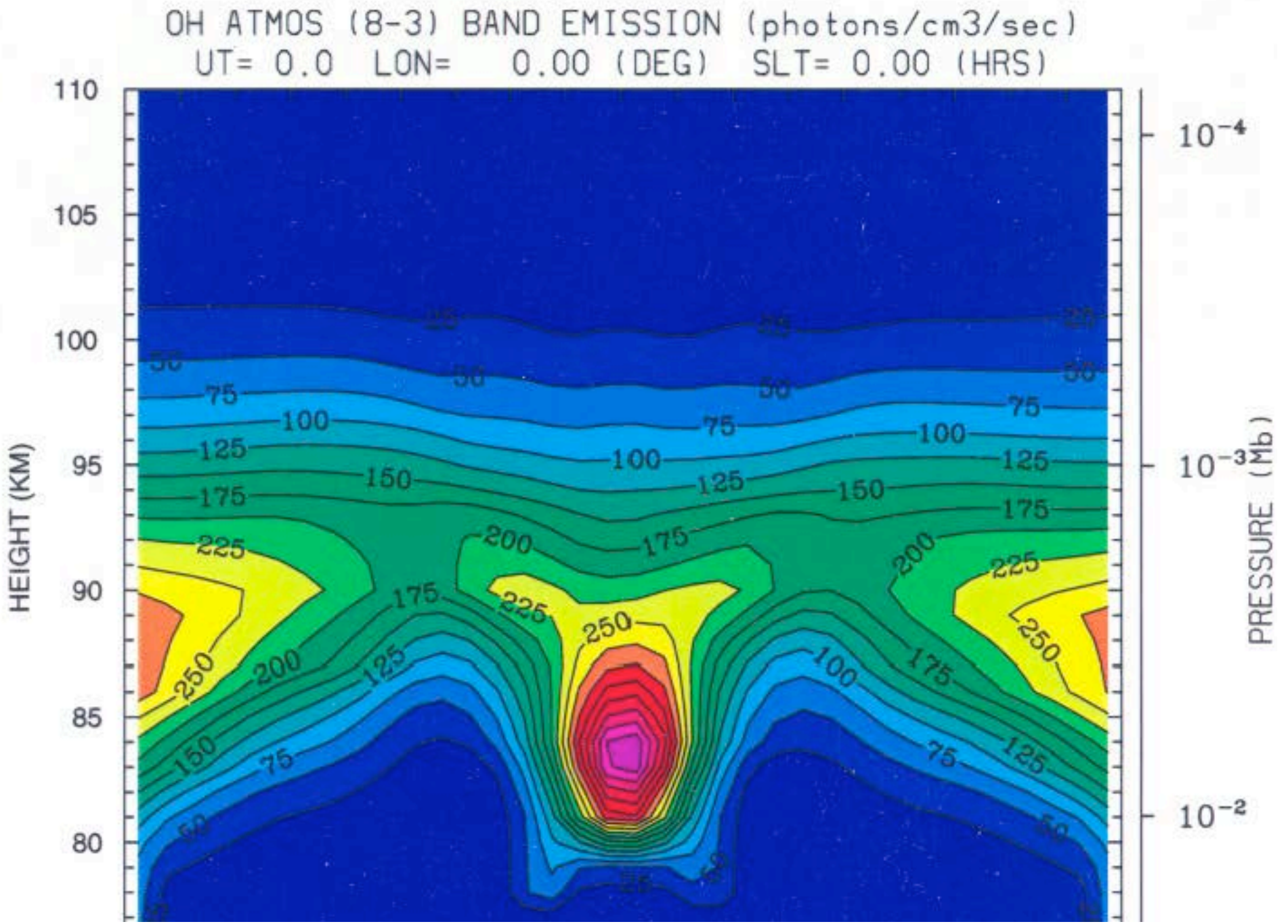

NEUTRAL TEMPERATURE (DEG K)
LAT, LON= 42.50, 0.00 (42.5N)
HEIGHT (KM)
110
100
90
80
70
60
50
40
PRESSURE (Mb)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH (MTIMES 010 00:00 TO 360 00:00)


NEUTRAL TEMPERATURE (DEG K)
LAT, LON= 67.50, -50.00 (SONDRSTROM FJORD)
HEIGHT (KM)
100
90
80
70
60
50
40
30
PRESSURE (Mb)
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH (MTIMES 001 00:00 TO 360 00:00)

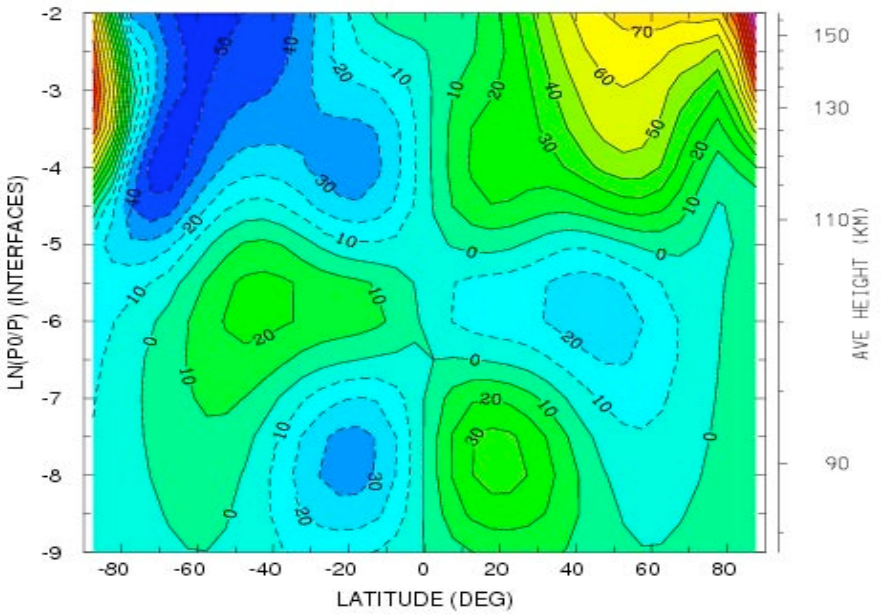


DIURNAL TIDE

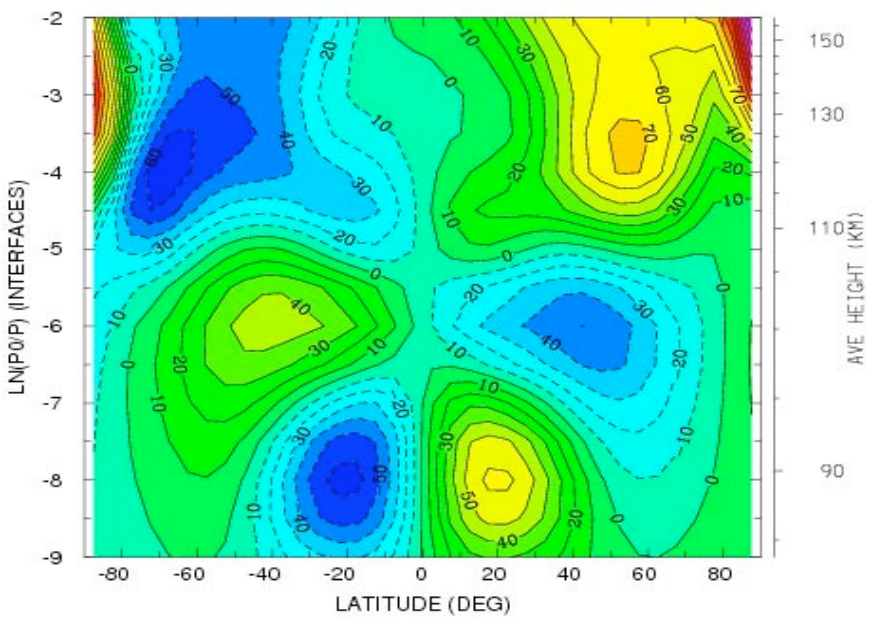

ATOMIC OXYGEN (O1) (CM3)
UT= 0.0 LAT= 2.50 (DEG)
HEIGHT (KM)
110
105
100
95
90
85
80
75
-150
-100
-50
0
50
100
150
LONGITUDE (DEG)
PRESSURE (Mb)
10^{-4}
10^{-3}
10^{-2}
1.75×10¹¹
2.25×10¹¹
2.50×10¹¹
2.00×10¹¹
3.00×10¹¹
1.50×10¹¹
1.00×10¹¹
0.75×10¹¹
1.25×10¹¹
0.50×10¹¹


OH ATMOS (8-3) BAND EMISSION (photons/cm3/sec)
UT= 0.0 LON= 0.00 (DEG) SLT= 0.00 (HRS)
HEIGHT (KM)
110
105
100
95
90
85
80
PRESSURE (Mb)
10^{-4}
10^{-3}
10^{-2}
25
50
75
100
125
150
175
200
225
250

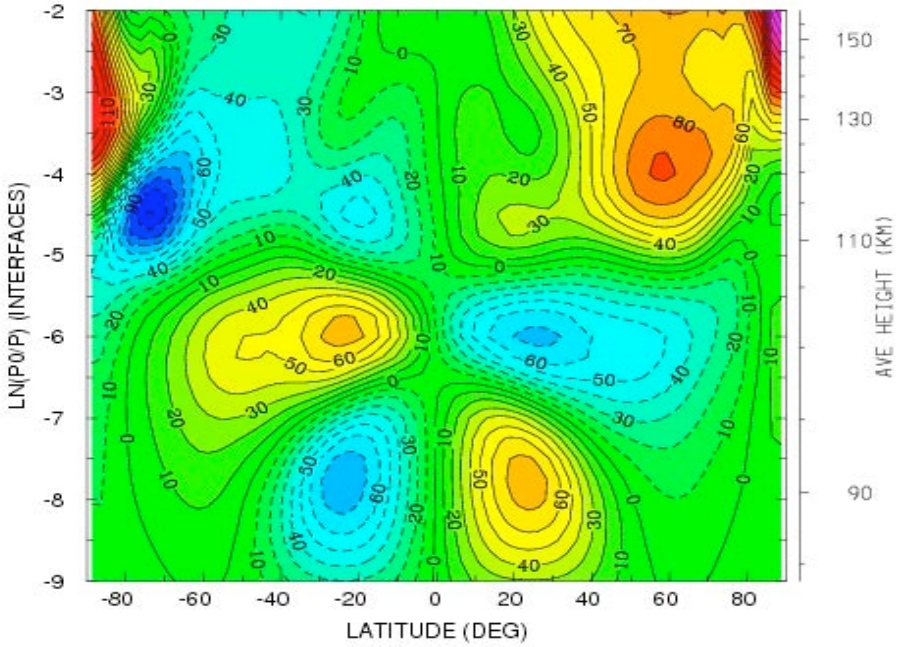
VN SLT=12 AMPLITUDE*1



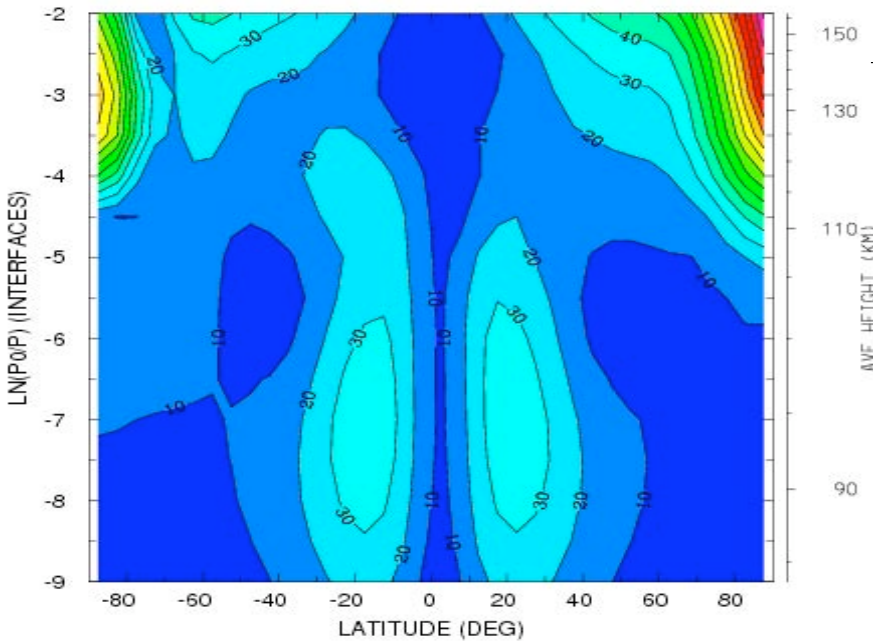
VN SLT=12 AMPLITUDE*2



VN SLT=12 2.5 deg

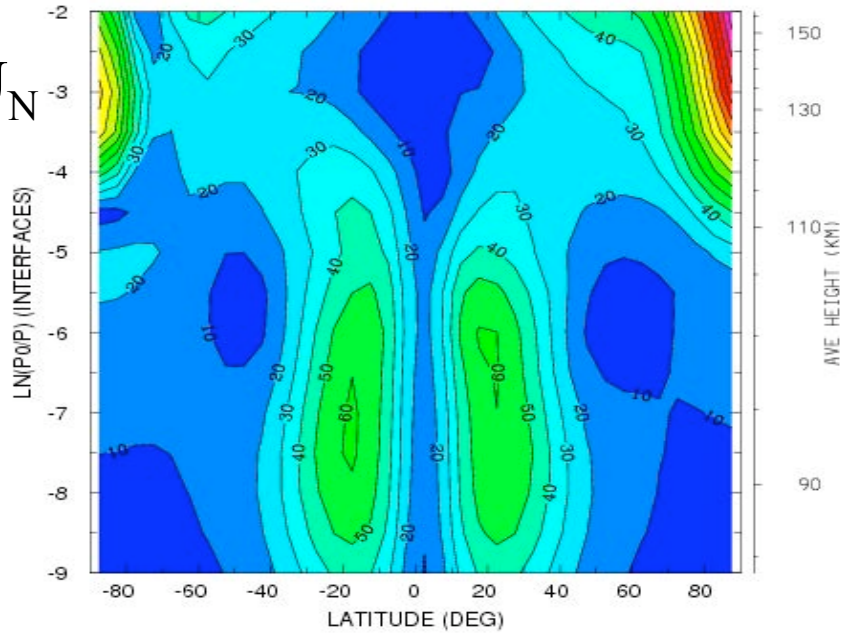


VN WAVE 1 AMPLITUDE*1

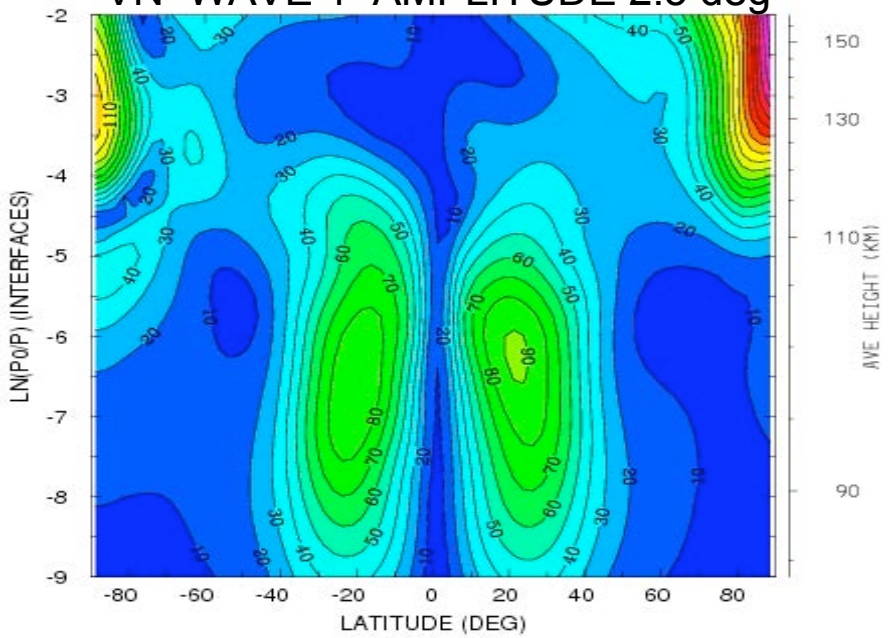


U_N

VN WAVE 1 AMPLITUDE*2

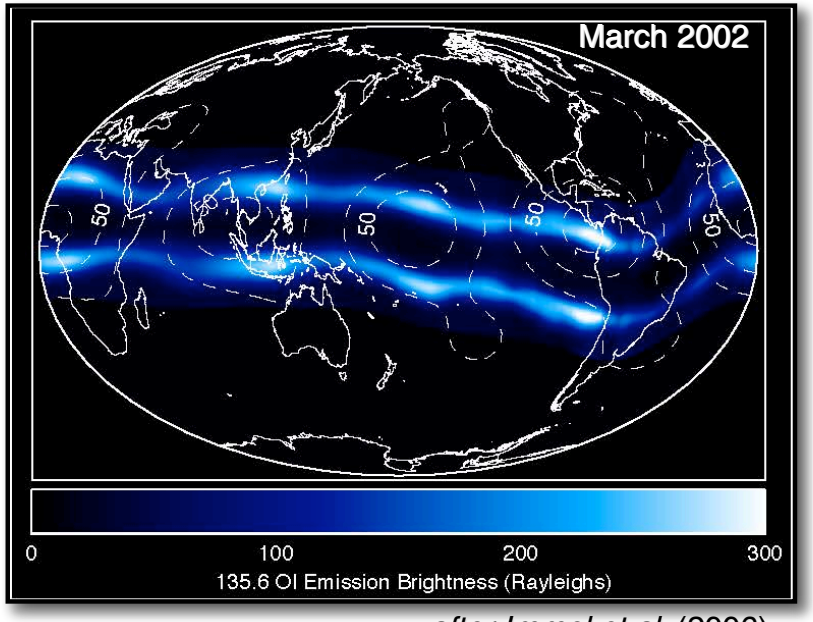


VN WAVE 1 AMPLITUDE 2.5 deg



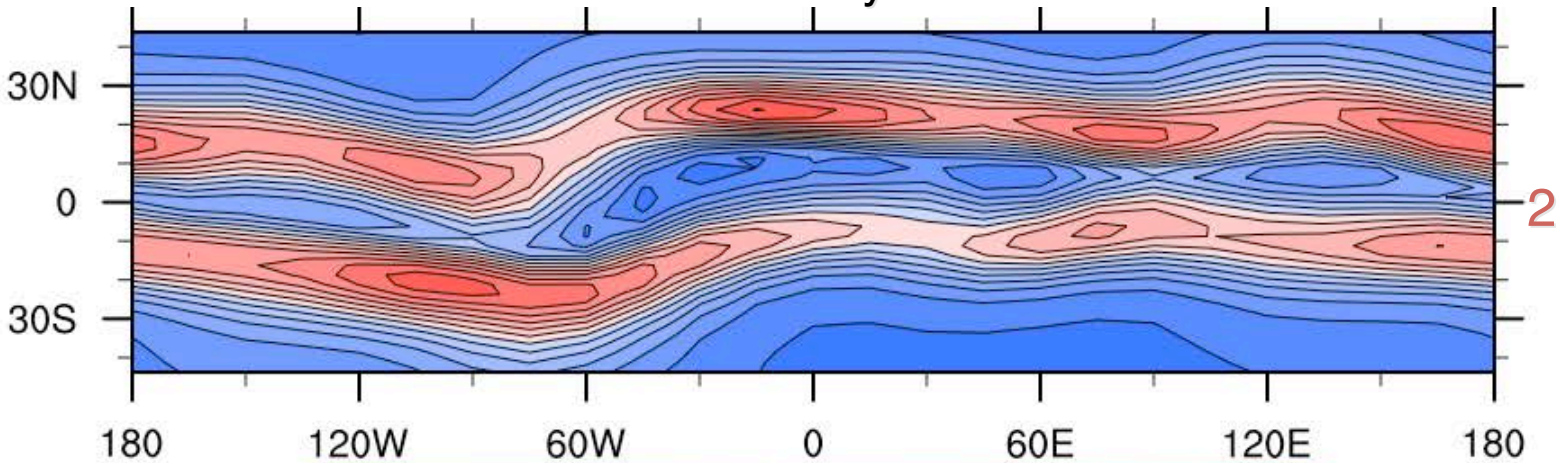
Tropospheric Tidal Effects in the Earth's Ionosphere

IMAGE FUV Ionospheric Emission



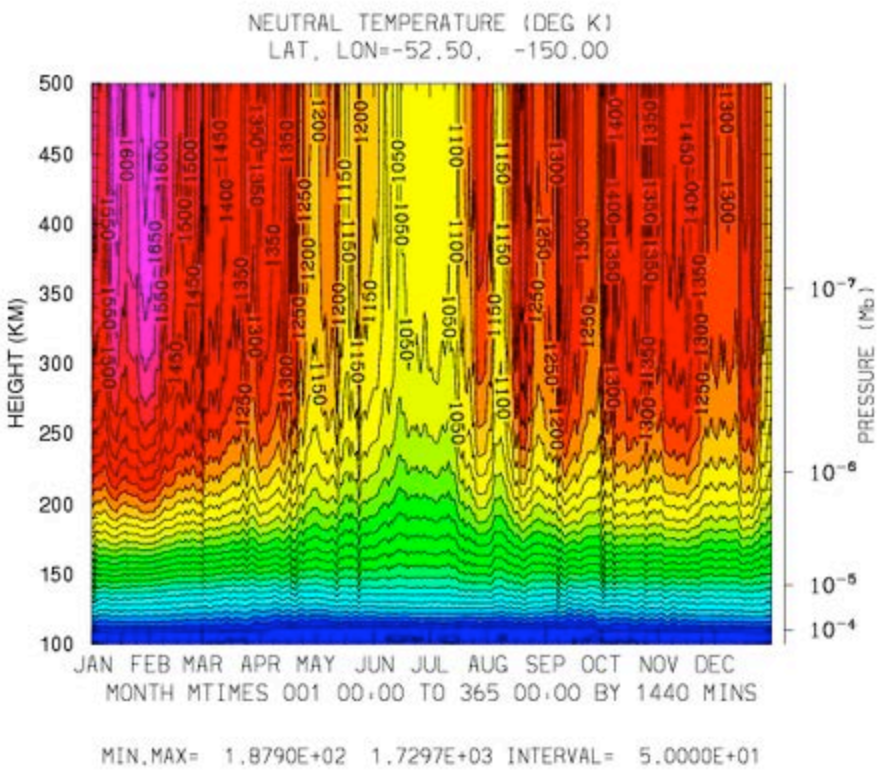
after Immel et al. (2006)

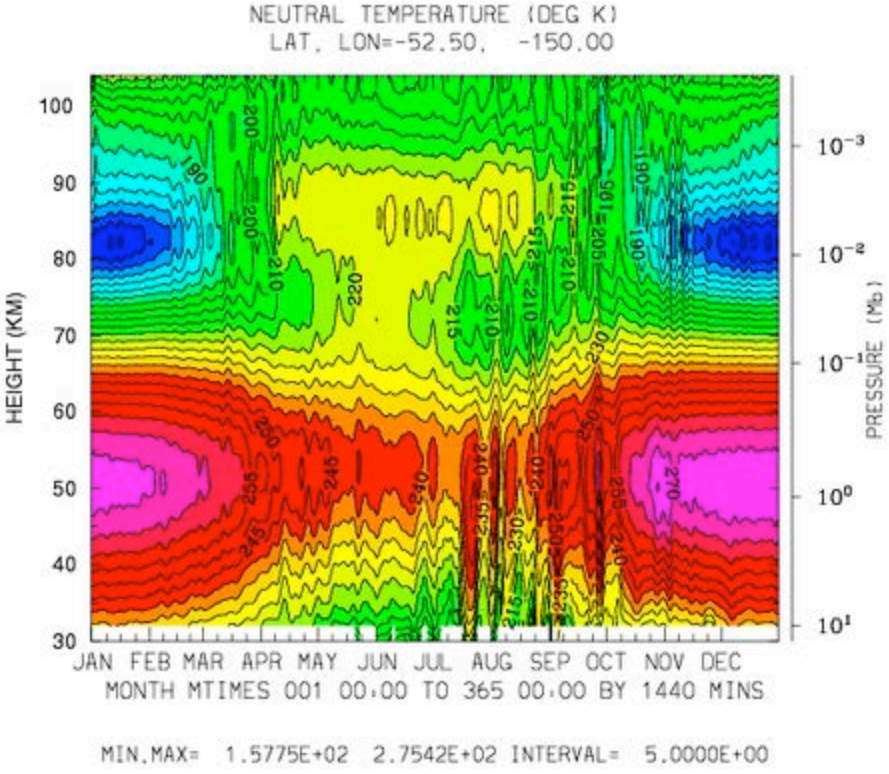
TIME-GCM Electron Density at 450 km - March

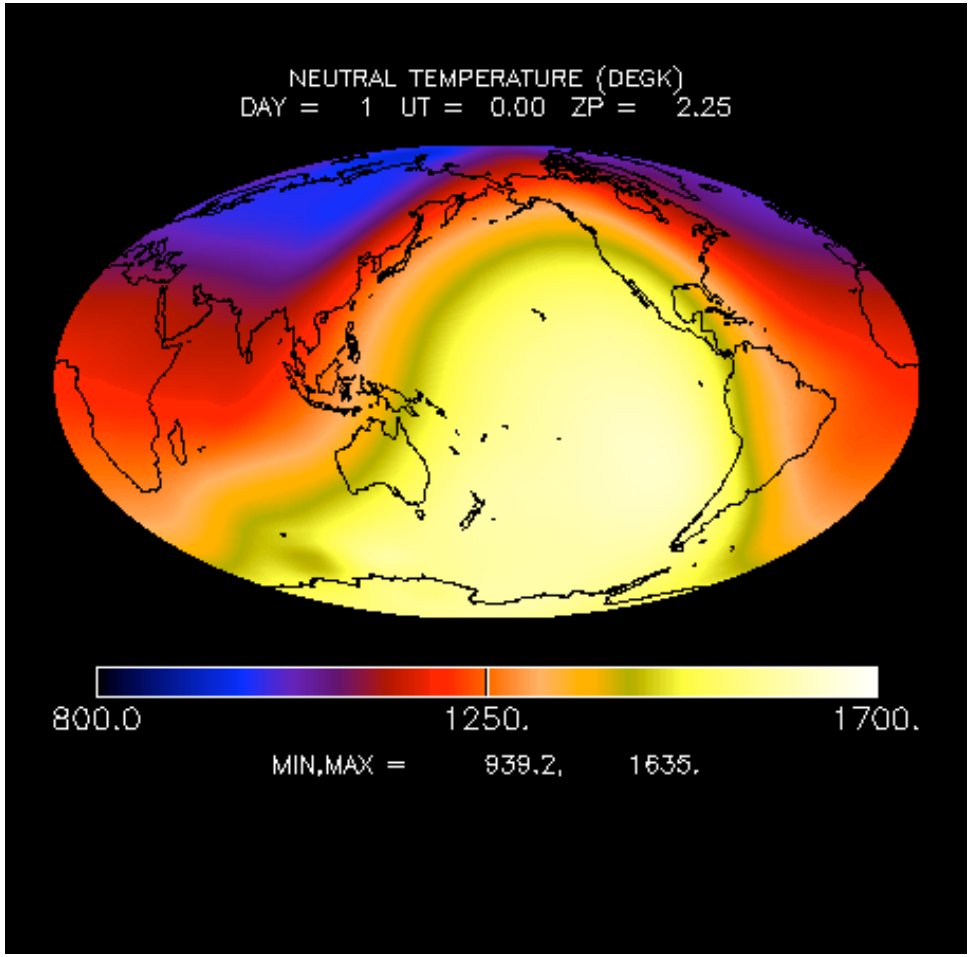


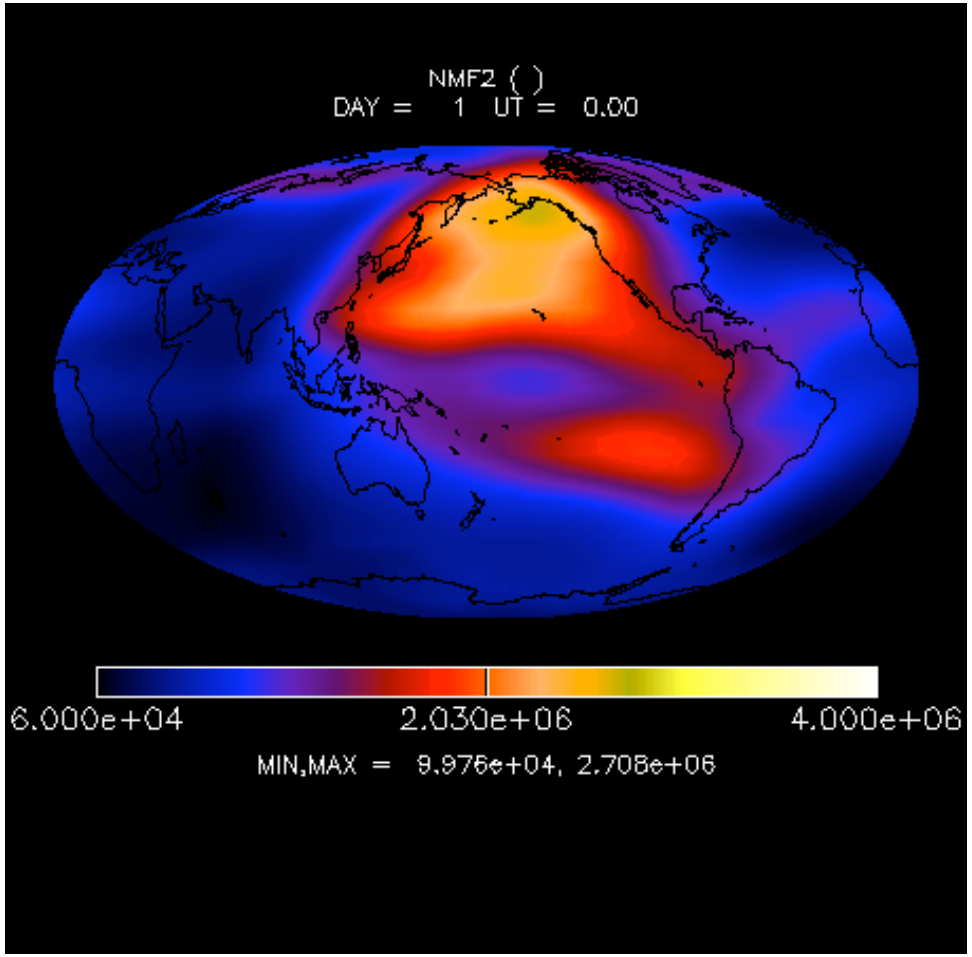
20 LST

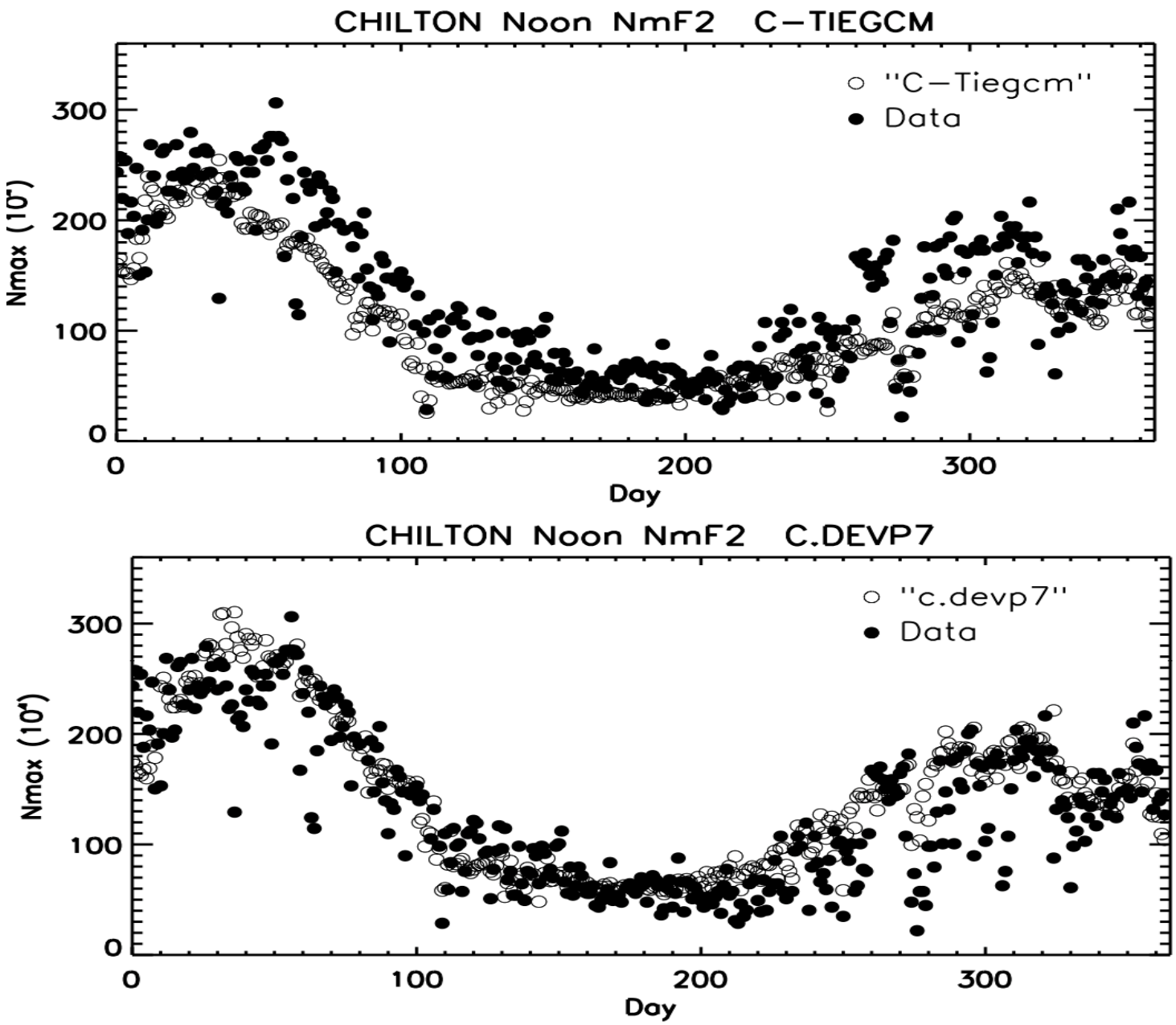
after *Hagan et al.* [2007]


NEUTRAL TEMPERATURE (DEG K)
LAT, LON=-52.50, -150.00
HEIGHT (KM)
PRESSURE (Mb)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH MTIMES 001 00:00 TO 365 00:00 BY 1440 MINS
MIN,MAX= 1.8790E+02 1.7297E+03 INTERVAL= 5.0000E+01

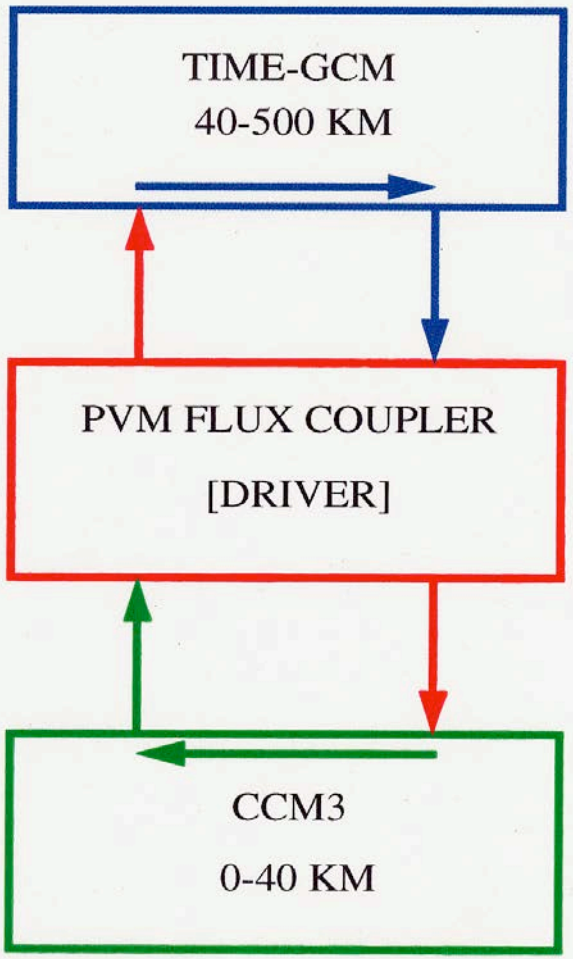

NEUTRAL TEMPERATURE (DEG K)
LAT, LON=-52.50, -150.00
HEIGHT (KM)
PRESSURE (Mb)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH MTIMES 001 00:00 TO 365 00:00 BY 1440 MINS
MIN,MAX= 1.5775E+02 2.7542E+02 INTERVAL= 5.0000E+00


NEUTRAL TEMPERATURE (DEGK)
DAY = 1 UT = 0.00 ZP = 2.25
800.0
1250.
1700.
MIN,MAX = 939.2, 1635.


NMF2 ( )
DAY = 1 UT = 0.00
6.000e+04
2.030e+06
4.000e+06
MIN,MAX = 9.976e+04, 2.708e+06


CHILTON Noon NmF2 C−TIEGCM
"C−Tiegcm"
Data
Nmax (10⁴)
Day
0
100
200
300
CHILTON Noon NmF2 C.DEVP7
"c.devp7"
Data
Nmax (10⁴)
Day

TIME-GCM / CCM3 (0-500 KM)



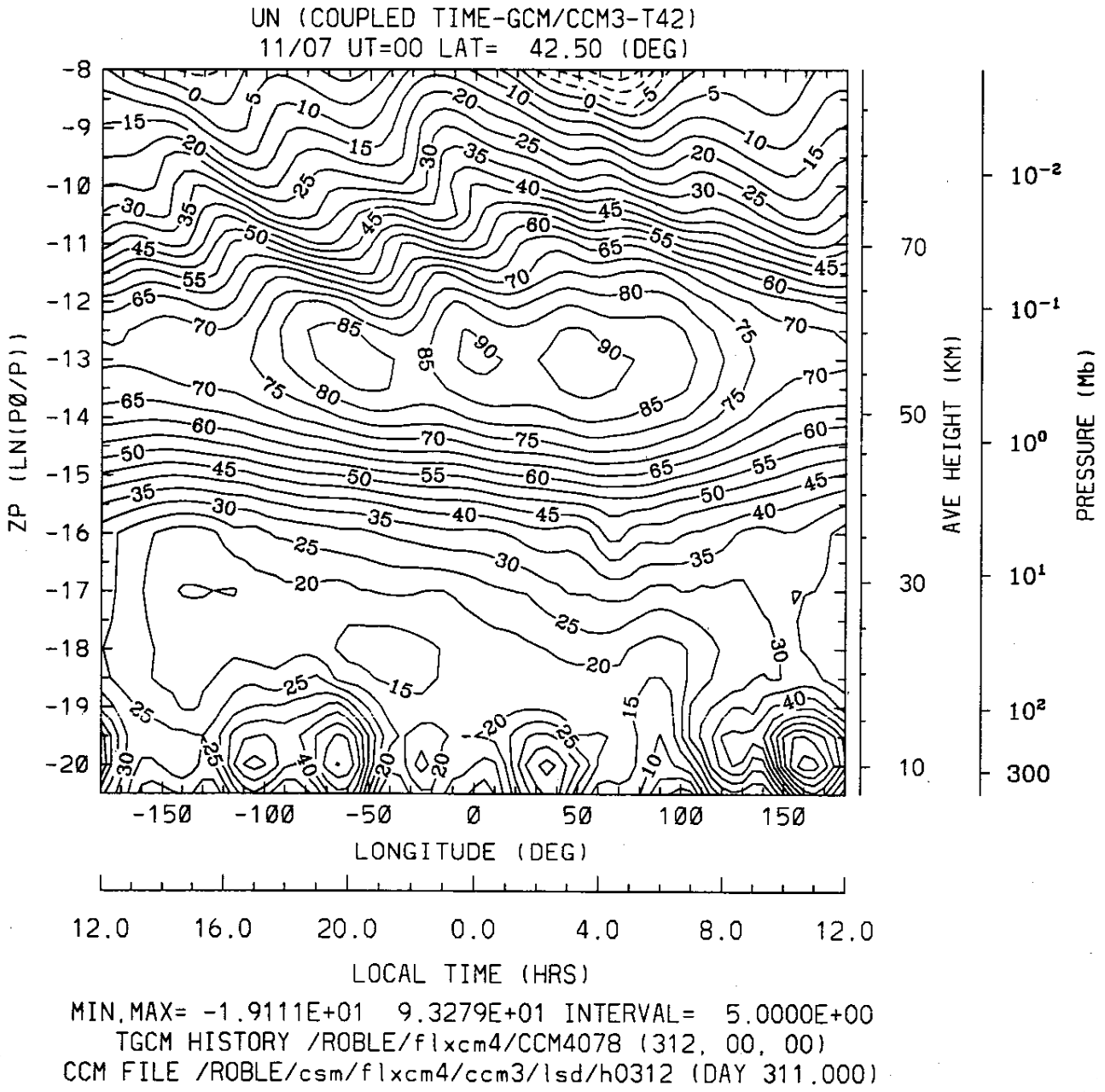
5 x 5 deg lat,lon

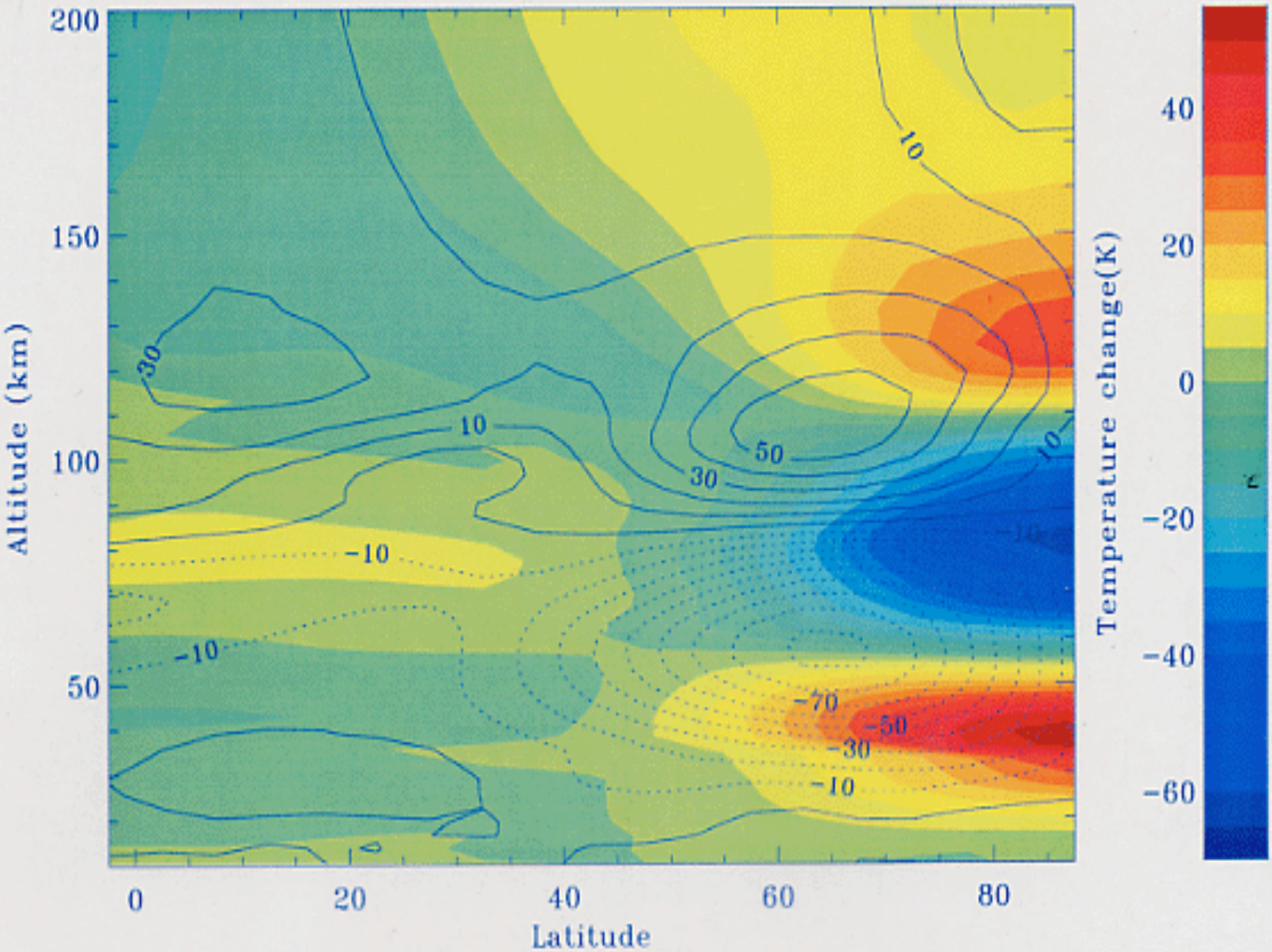
step = 5 min

T42 resolution

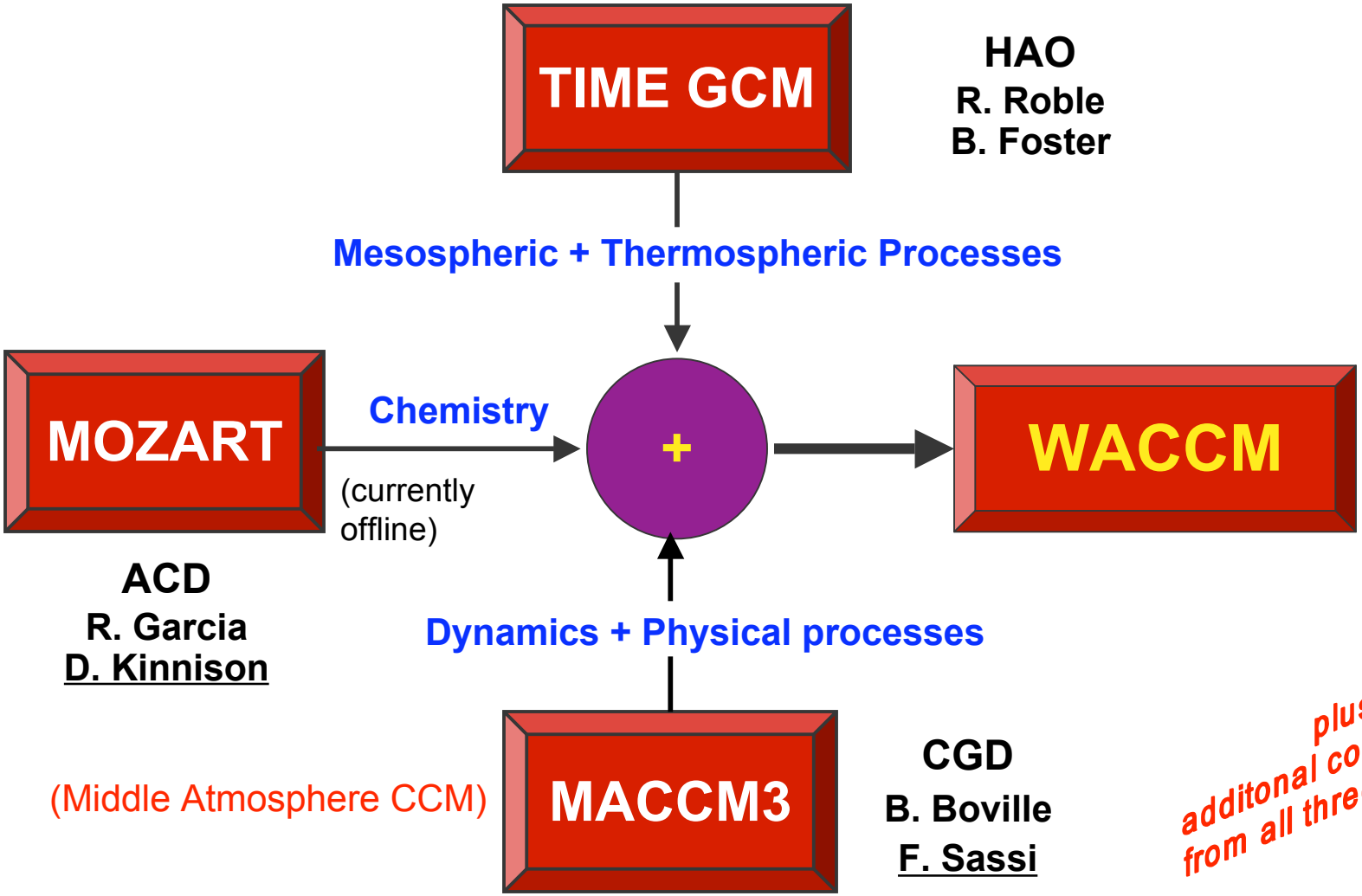
step = 20 min

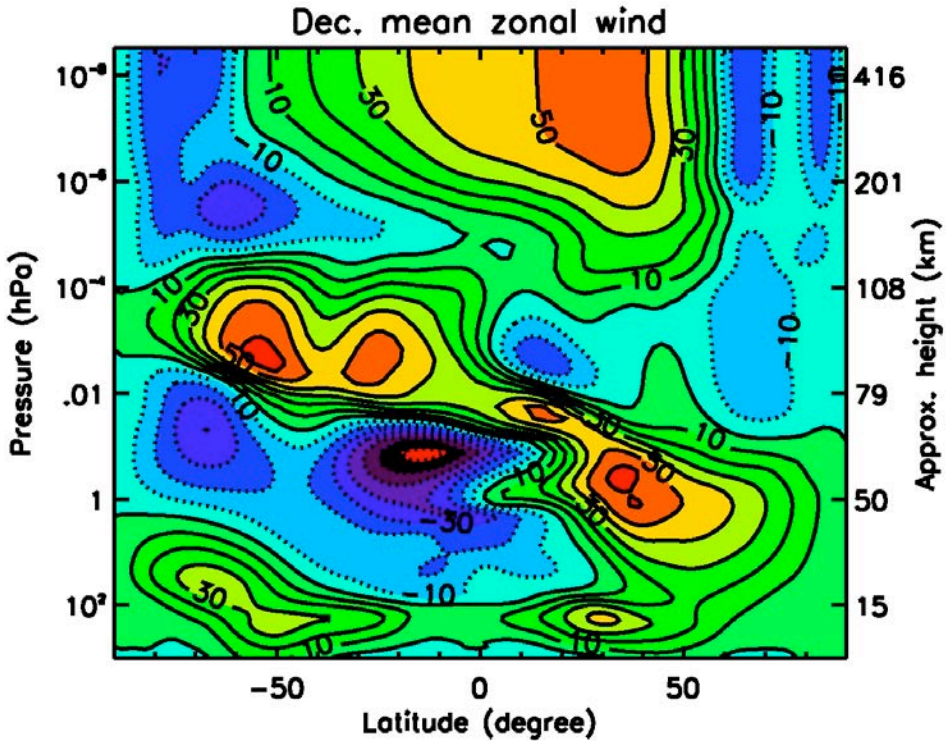
Fields exchanged: T, U, V, H, W, H_2O, CH_4

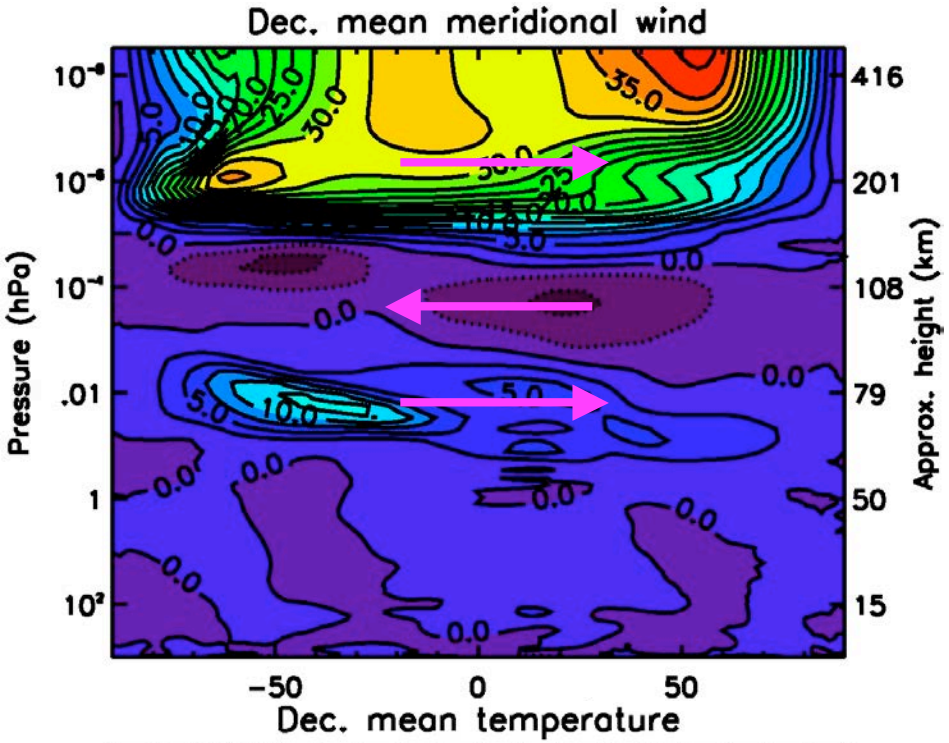

UN (COUPLED TIME-GCM/CCM3-T42)
11/07 UT=00 LAT= 42.50 (DEG)
ZP (LN(PØ/P))
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
AVE HEIGHT (KM)
70
50
30
10
PRESSURE (Mb)
10⁻²
10⁻¹
10⁰
10¹
10²
300
-150 -100 -50 0 50 100 150
LONGITUDE (DEG)
12.0 16.0 20.0 0.0 4.0 8.0 12.0
LOCAL TIME (HRS)
MIN,MAX= -1.9111E+01 9.3279E+01 INTERVAL= 5.0000E+00
TGCM HISTORY /ROBLE/flxcm4/CCM4078 (312, 00, 00)
CCM FILE /ROBLE/csm/flxcm4/ccm3/lsd/h0312 (DAY 311.000)


200
150
100
50
Altitude (km)
0
20
40
60
80
Latitude
10
30
50
10
10
−10
−10
−70
−50
−30
−10
Temperature change(K)
40
20
0
−20
−40
−60

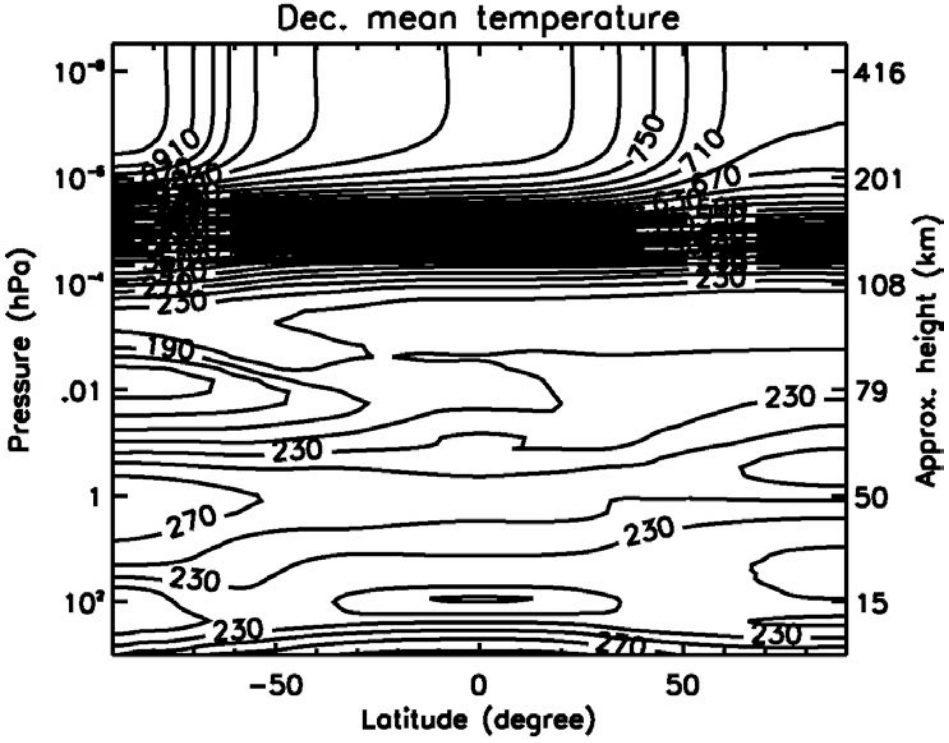
WACCM Components:
A collaboration among 3 NCAR Divisions

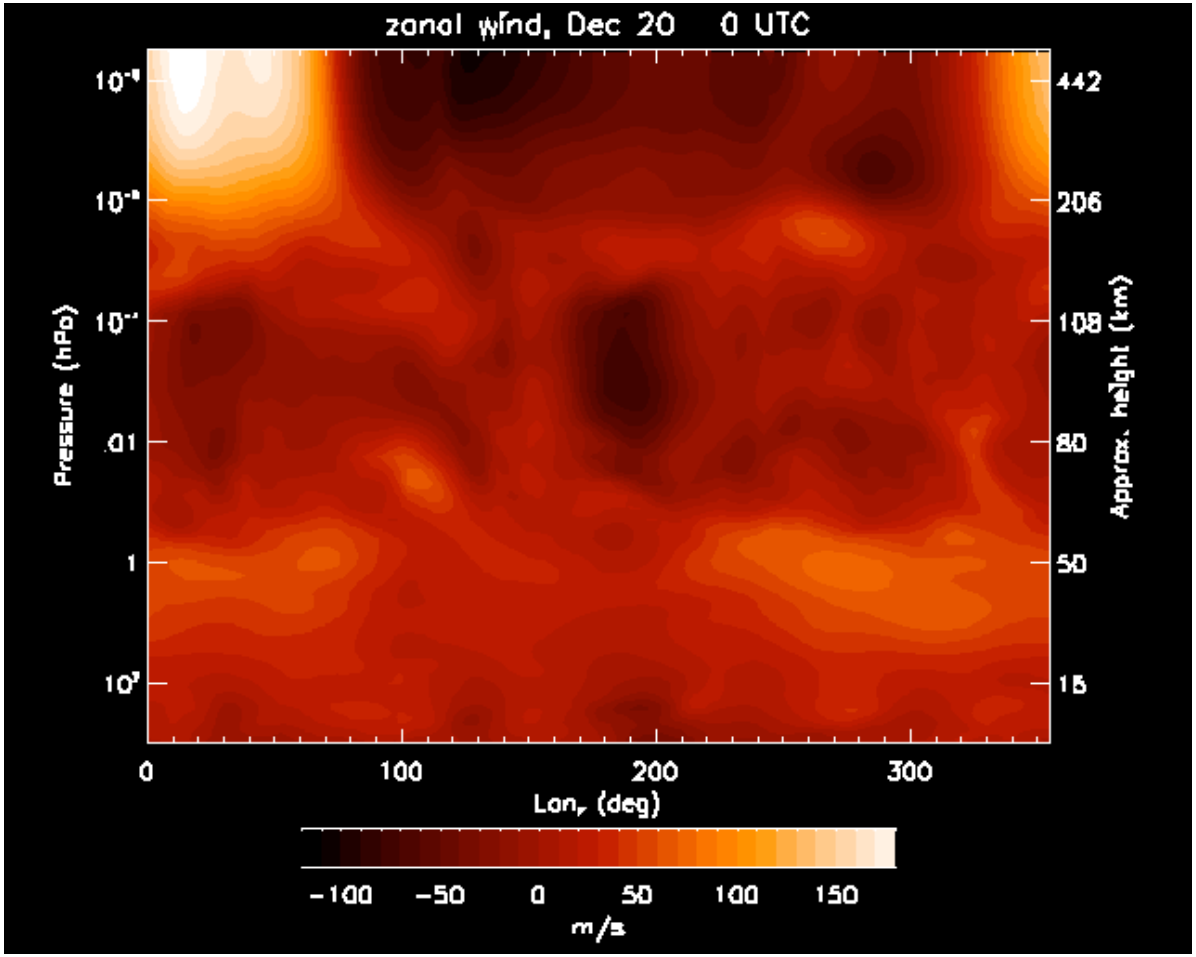






WACCM: Winds and Temperature (December)




zonal wind, Dec 20 0 UTC
Pressure (hPa)
Approx. height (km)
442
206
108
80
50
15
0
100
200
300
Lon, (deg)
-100
-50
0
50
100
150
m/s

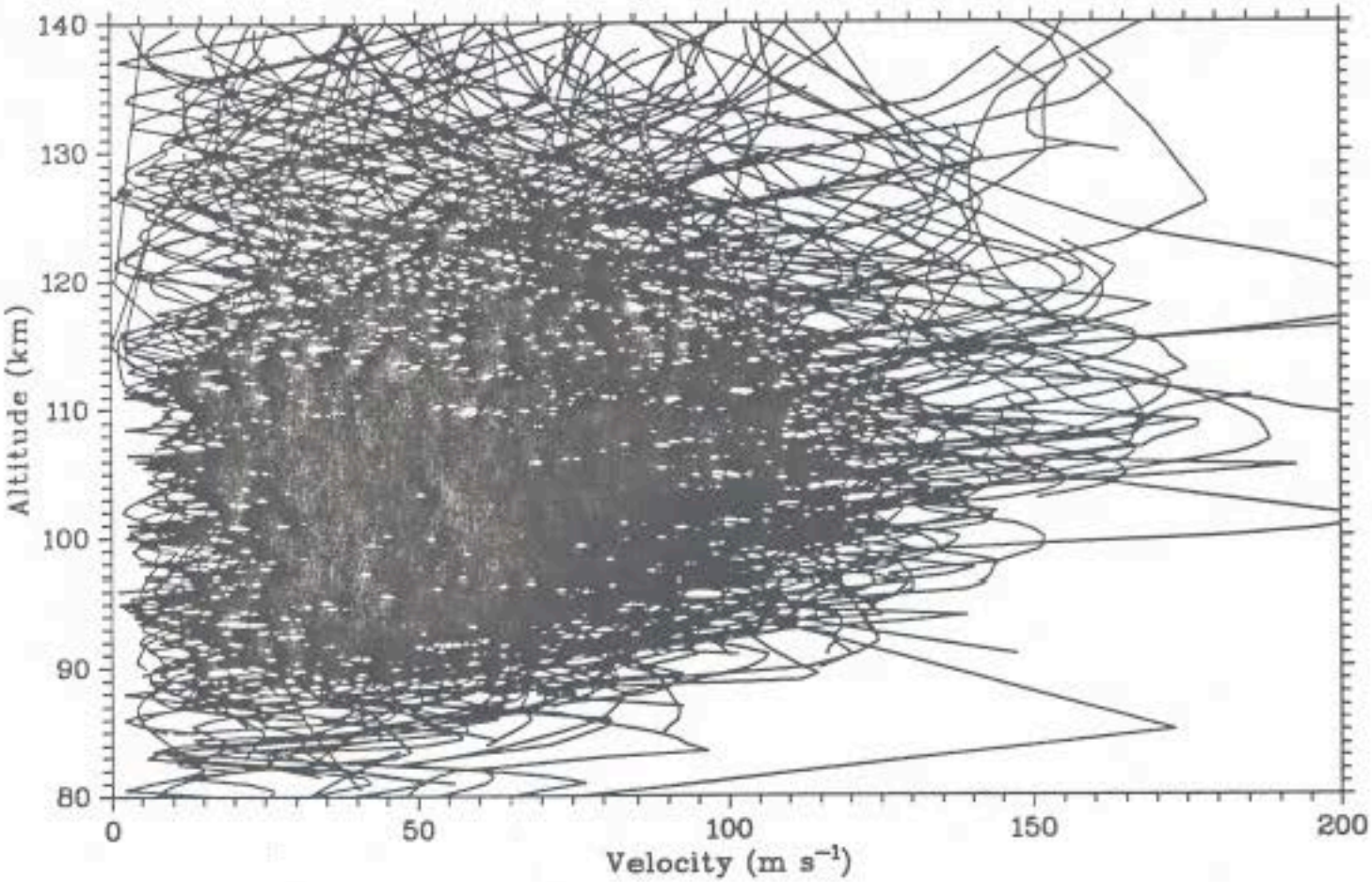
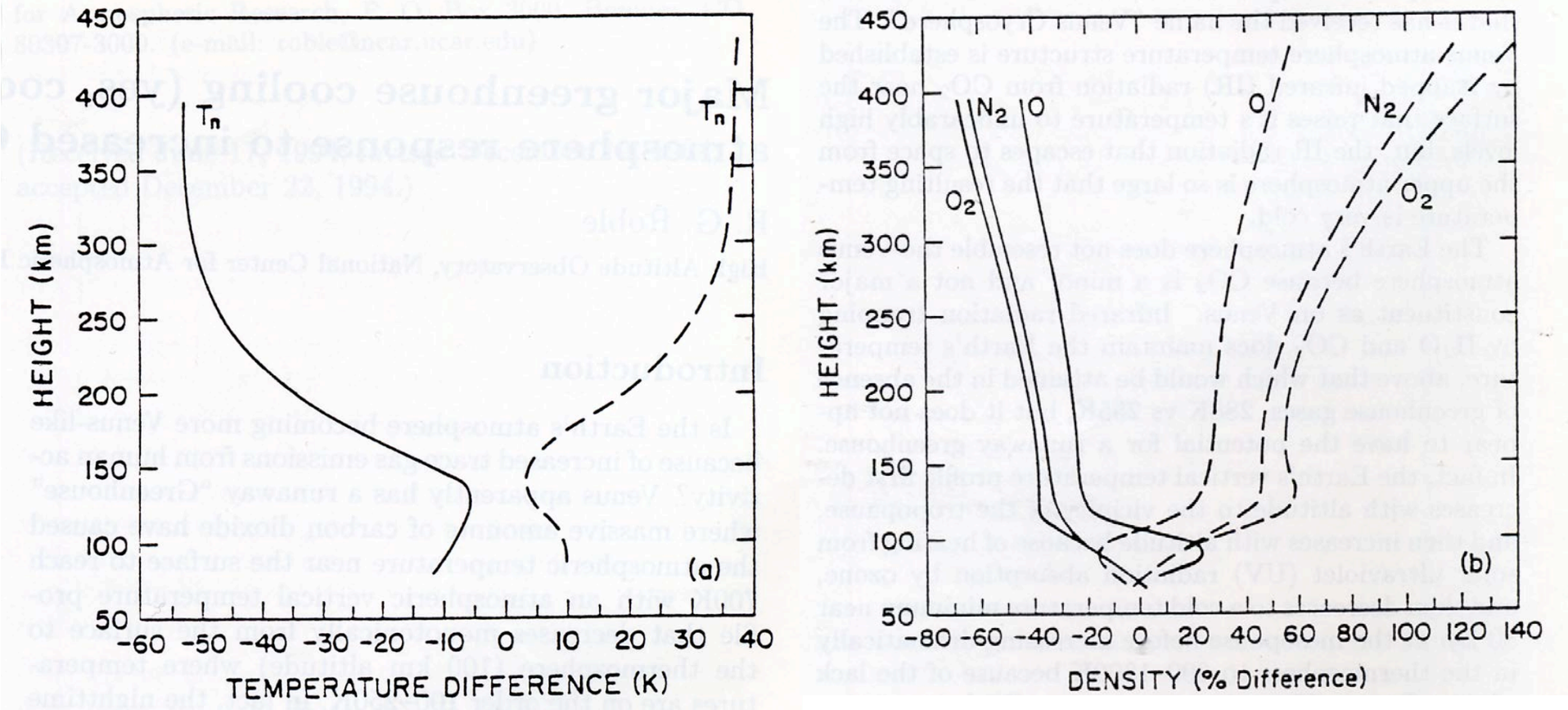
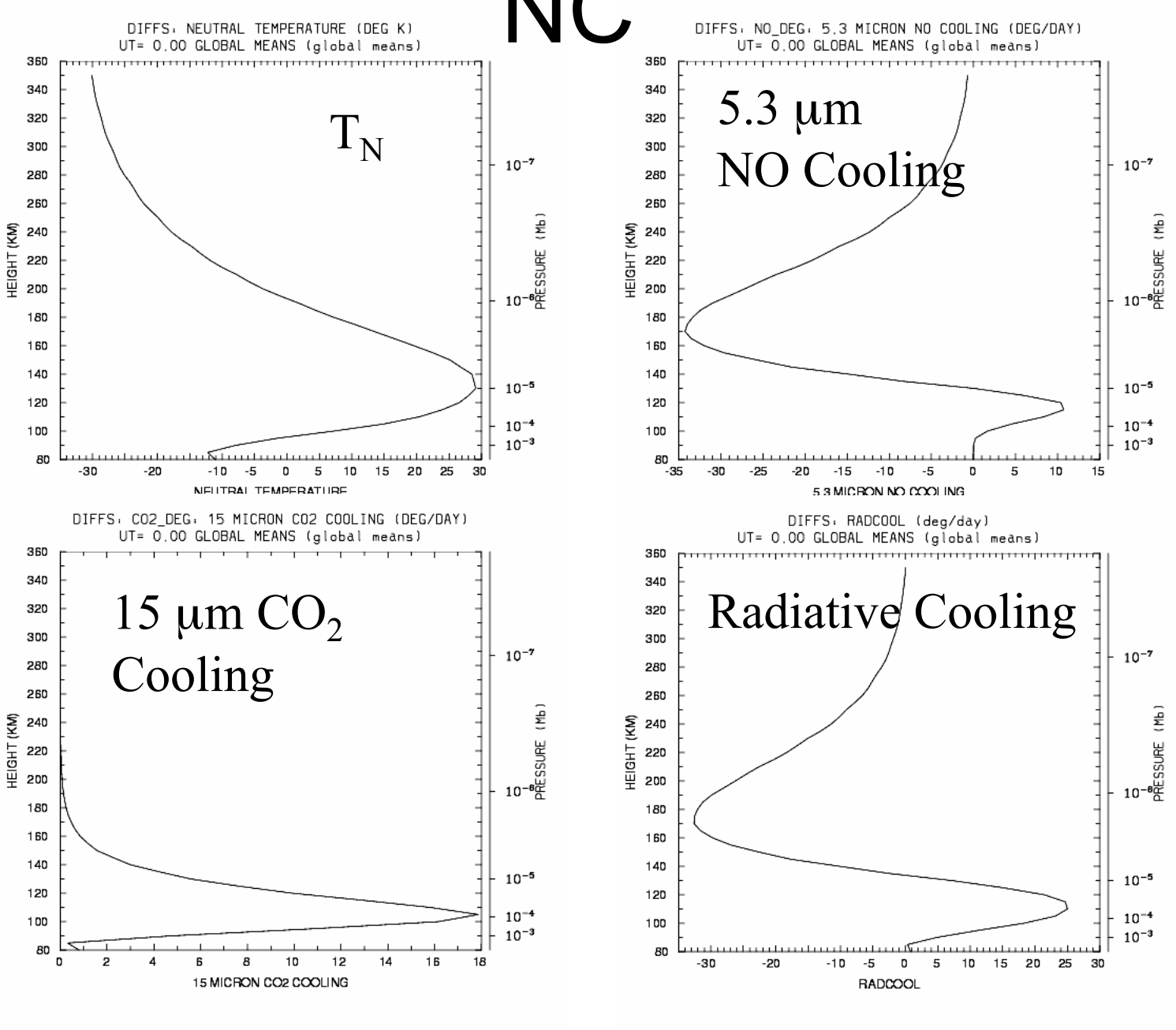


Figure 2. Superposition of the wind speed profiles for all the mid- and low-latitude chemical release wind profile data.

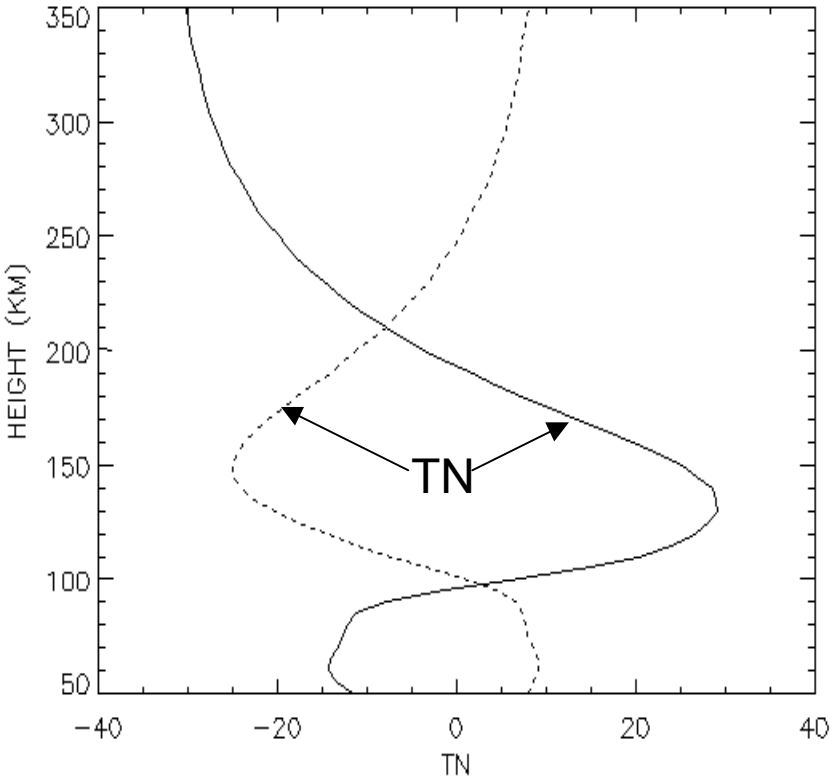
Roble and Dickinson (1989)



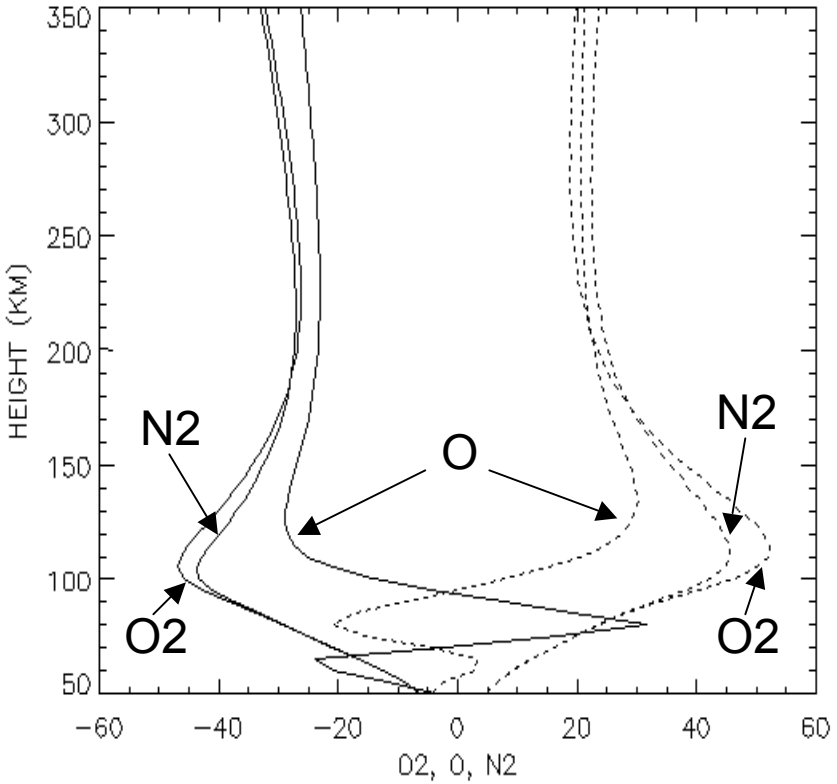
Solar Medium Conditions, GC-NC



Difference: Neutral temperature (



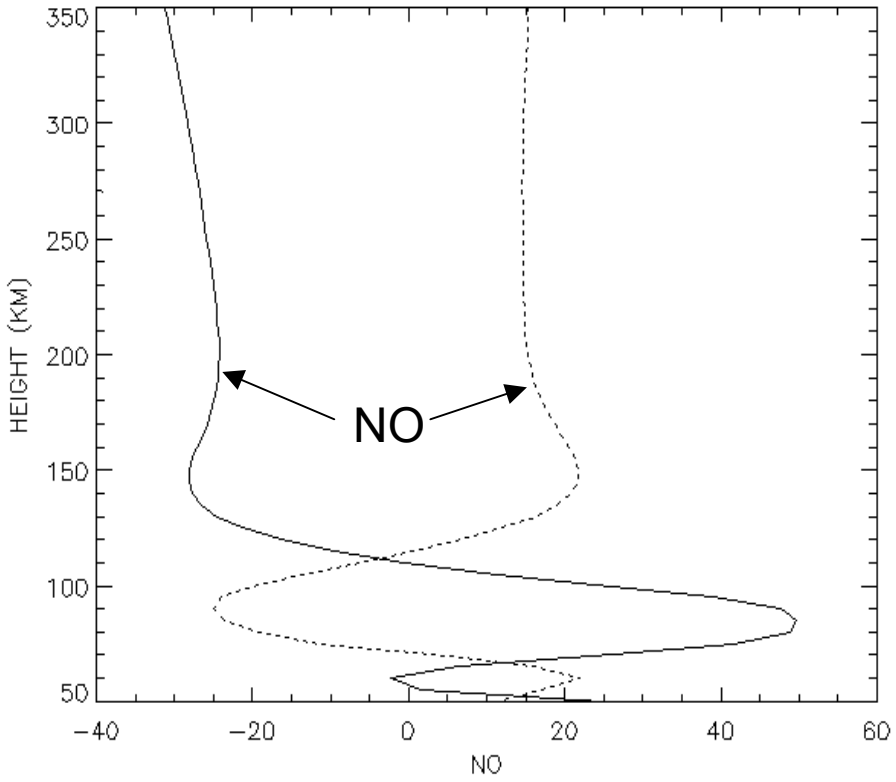
Percent difference: O2, O, N2



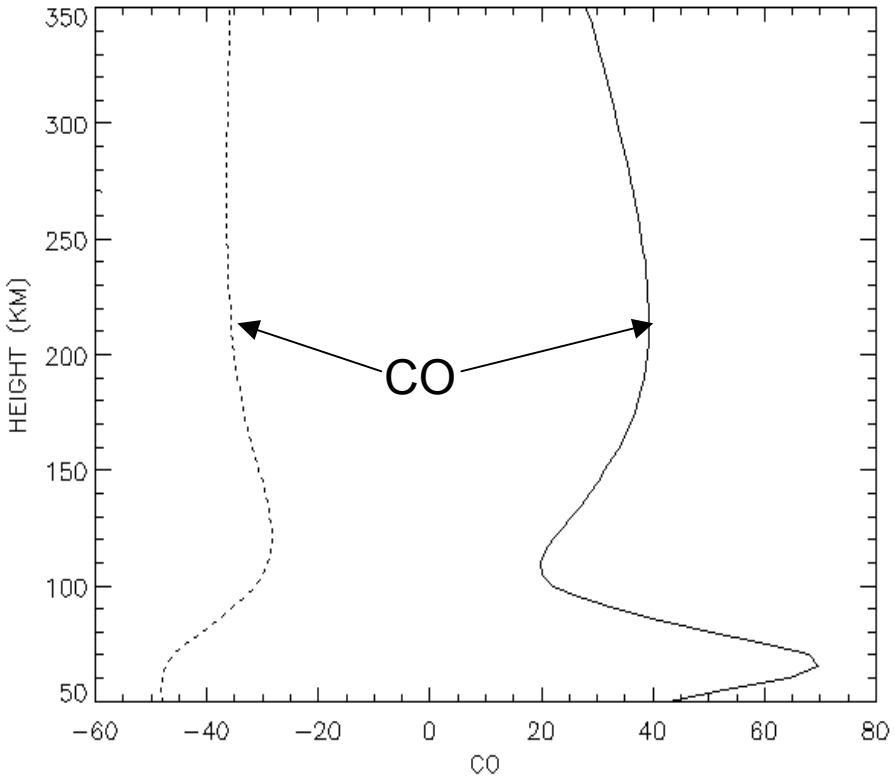
Global change minus no change

Ice Age minus no change

Percent change: NO (cm3)



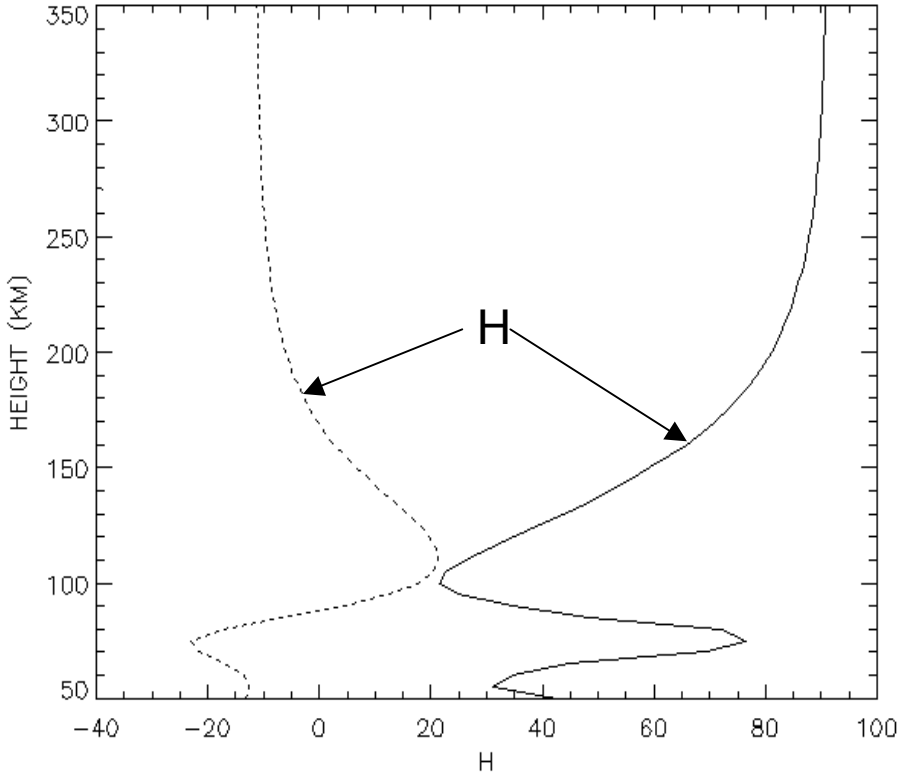
Percent change: CO (cm3)



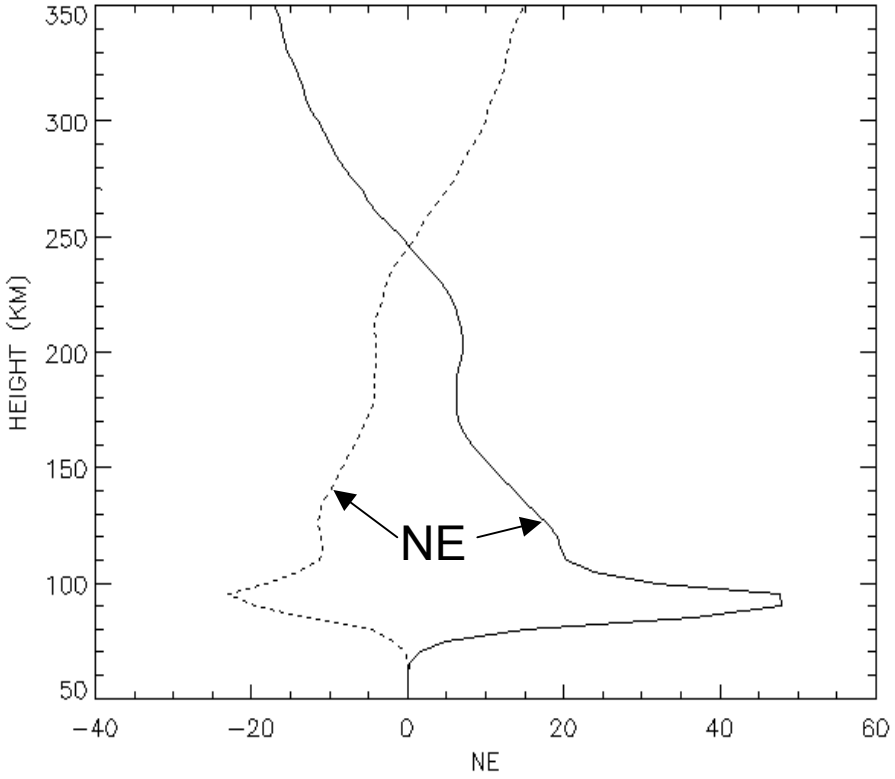
Global change minus no change

Ice Age minus no change

Percent change: H (cm3)



Percent change: NE (cm3)

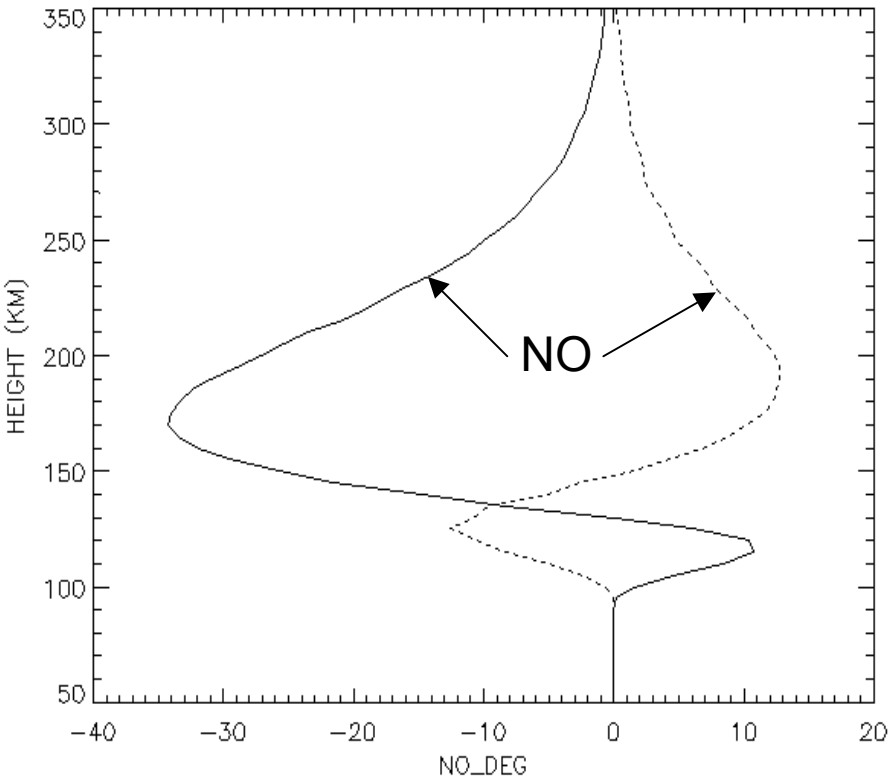


Global change minus no change

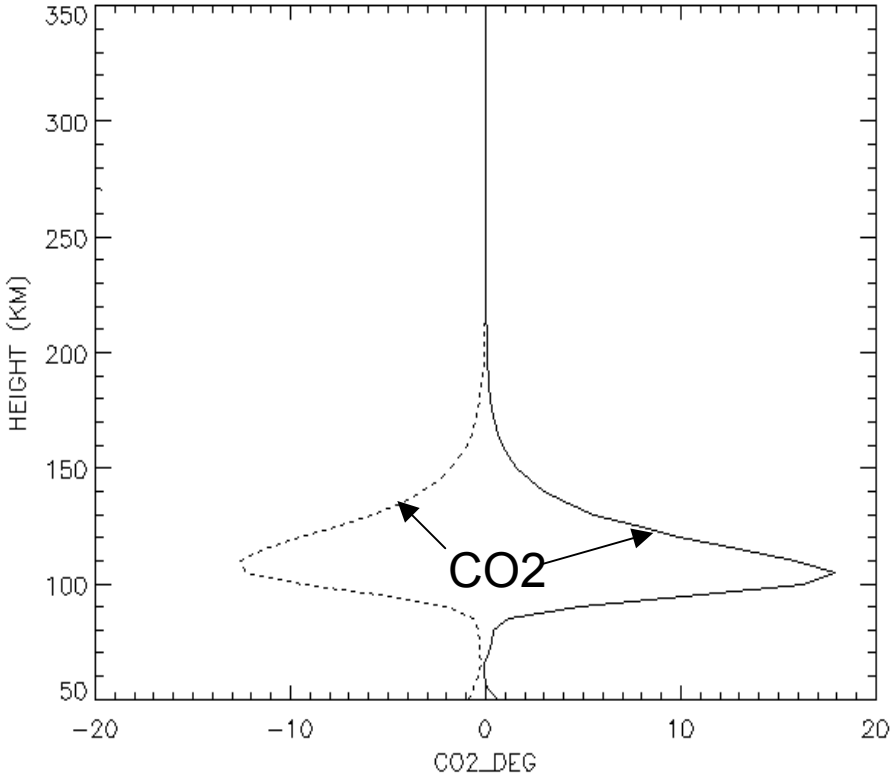
Ice Age minus no change

Change in NO and CO2 cooling

5.3 micron NO cooling (deg/day)



15 micron CO2 cooling (deg/day)



——— Global change minus no change

- - - - - - - - - - Ice Age minus no change

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