Energetics and Composition in the Thermosphere

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Major Species Continuity Equations (O and O_2)

Molecular diffusion

$$\frac{\partial \tilde{\Psi}}{\partial t} = -\frac{e^Z}{\tau}\frac{\partial}{\partial Z}\left[\frac{\bar{m}}{m_{N_2}}\left(\frac{T_{00}}{T_n}\right)^{0.25}\tilde{\alpha}^{-1}L\tilde{\Psi}\right] + S - R +$$

$$e^Z\frac{\partial}{\partial Z}\left[K(Z)e^{-Z}\frac{\partial}{\partial Z}\left(1+\frac{1}{\bar{m}}\frac{\partial m}{\partial Z}\right)\tilde{\Psi}\right] - \left(\vec{V}\bullet\nabla\tilde{\Psi} + w\frac{\partial \tilde{\Psi}}{\partial Z}\right)$$

Horizontal advection

Vertical advection

$$\Psi_{N_2} = 1 - \Psi_O - \Psi_{O_2}$$

S is the loss of O_2 through photodissociation and the loss of O through three body recombination. Short term changes in O and O_2 are dominated by the transport processes (e.g., Rees, 1989), so only these will be discussed here.

Neutral Energy Equation

Downward heat conduction

Heat advection

$$\frac{\partial T}{\partial t} = \frac{ge^{Z}}{P_0 C_p}\frac{\partial}{\partial Z}\left\{\frac{K_T}{H}\frac{\partial T}{\partial Z} + K_E H^2 C_P \rho\left[\frac{g}{C_P} + \frac{1}{H}\frac{\partial T}{\partial Z}\right]\right\} - \mathbf{V}\bullet\nabla T - w\left(\frac{\partial T}{\partial Z} + \frac{RT}{C_P \overline{m}}\right) + \frac{(Q-L)}{C_P} + F_{DH}$$

Joule heating

Compressional heating and cooling by expansion

Thermospheric heating (*Q*) includes solar radiation heating, Joule heating, collisional heat transfer and heat release by chemical reactions. Energy loss (*L*) process is primarily radiation cooling (NO, $O(^3P)$ and CO_2)

Minor Species Continuity Equations (NO and N(^{4}S))

$$\frac{\partial\tilde{\Psi}}{\partial t} = -e^{Z}\frac{\partial}{\partial Z}\left[\tilde{A}\left(\frac{\partial}{\partial Z}-\tilde{E}\right)\tilde{\Psi}\right]+\tilde{S}-\tilde{R}+$$

$$e^{Z}\frac{\partial}{\partial Z}\left[e^{-Z}K_{E}(Z)\left(\frac{\partial}{\partial Z}+\frac{1}{\overline{m}}\frac{\partial\overline{m}}{\partial Z}\right)\tilde{\Psi}\right]-\left(\vec{V}\bullet\nabla\tilde{\Psi}+w\frac{\partial\tilde{\Psi}}{\partial Z}\right)$$

The NCAR-TIEGCM solves for NO, N(4S) and N(2D)

The NCAR-TIME-GCM additionally solves for H in the upper thermosphere and a multitude of species in the lower thermosphere and mesosphere (see Roble, 1995)

Boundary Conditions for Thermosphere Equations:

Upper boundary conditions:

Diffusive equilibrium for *U, V, W, T,* Ψ_{O2}, Ψ_O

$$\frac{\partial u}{\partial Z}=\frac{\partial v}{\partial Z}=\frac{\partial w}{\partial Z}=\frac{\partial T}{\partial Z}=0$$

$$[\frac{\partial}{\partial Z}-(1-\frac{m}{\overline{m}}-\frac{1}{\overline{m}}\frac{\partial \overline{m}}{\partial Z})]\Psi=0$$

$$T_b = T_{b0} + T_b'(\theta)\exp(i\omega t + is\lambda)$$

$$U_b = U_b'(\theta)\exp(i\omega t + is\lambda)$$

$$V_b = V_b'(\theta)\exp(i\omega t + is\lambda)$$

Chemical equilibrium for N(4S) and NO

Lower boundary conditions:

specified using the global scale wave model (GSWM)

U and V: specified by tides

T: 181 K + perturbations introduced by tides

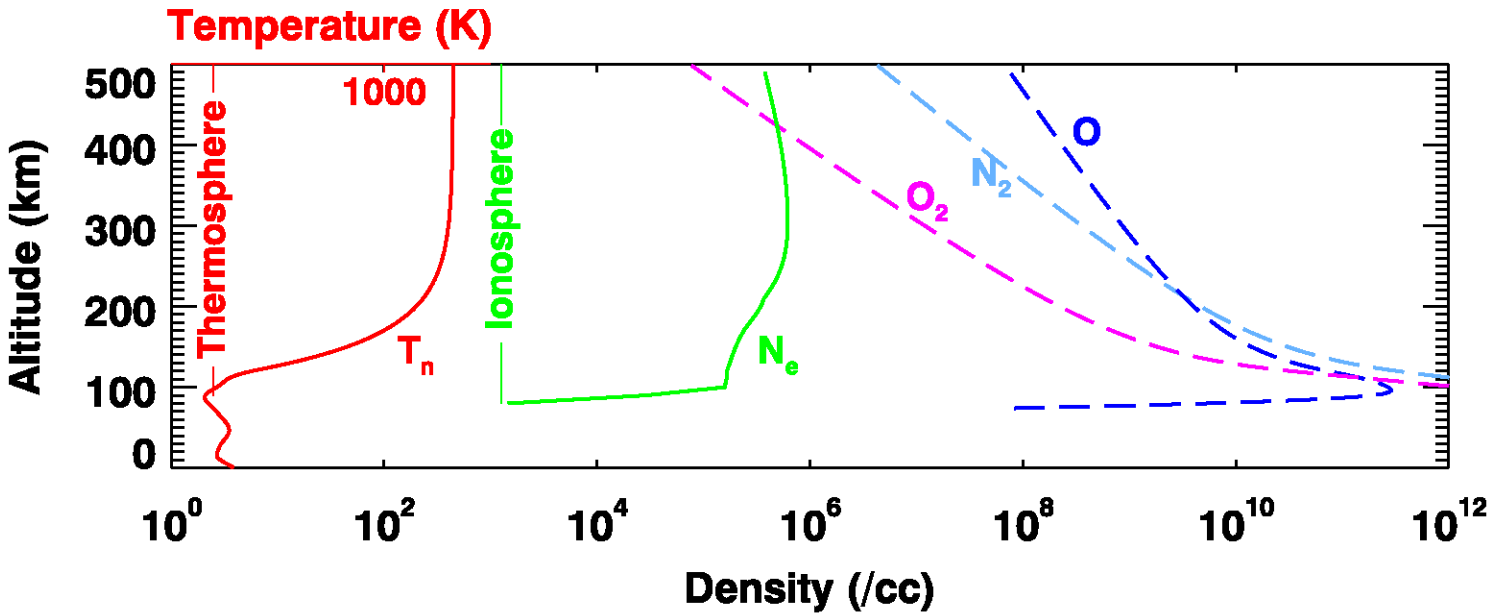
O_2: fixed mixing ratio of 0.22

O: gradient of the mixing ratio is zero

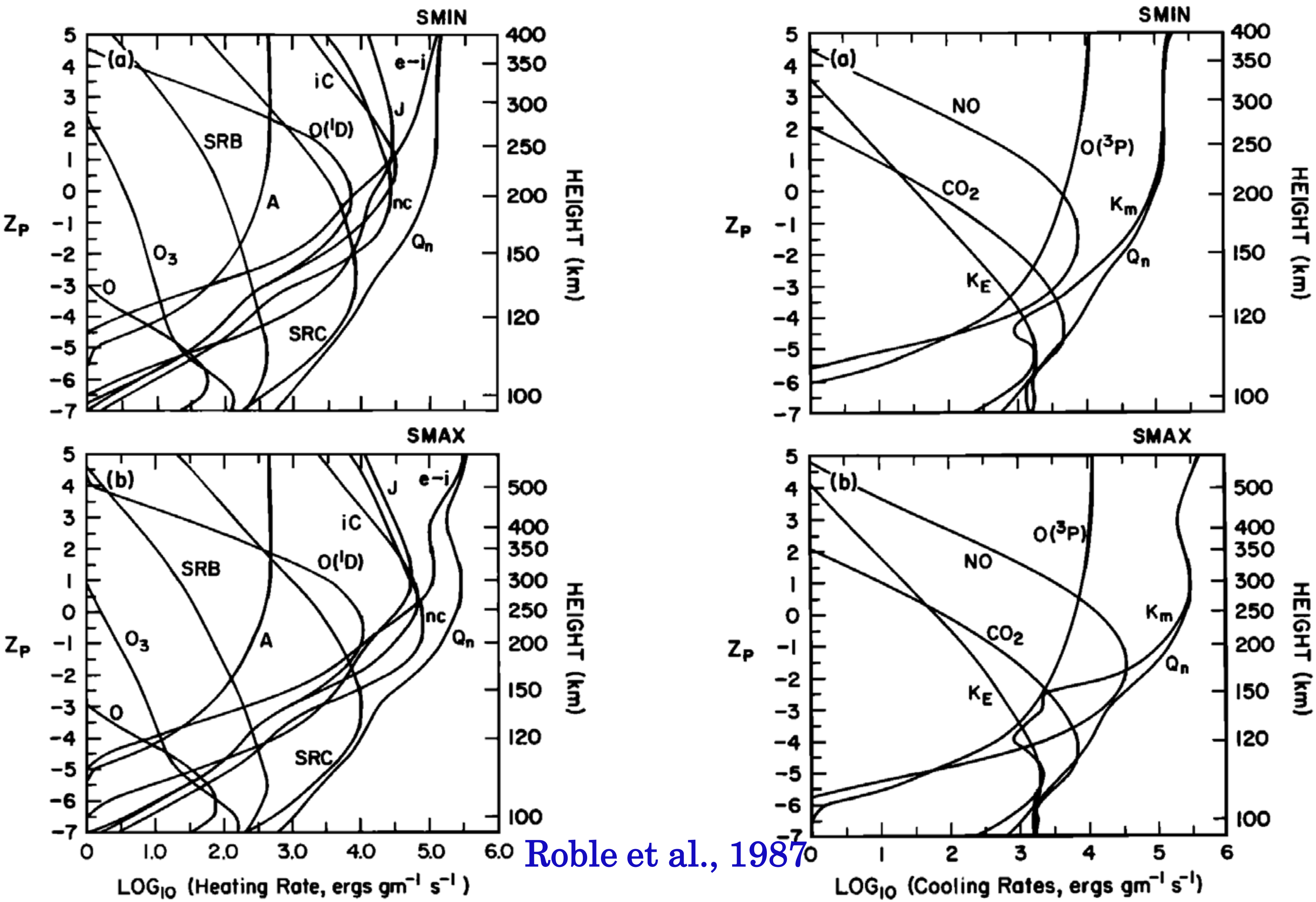
N(4S): chemical equilibrium

NO: constant density of $8\text{x}10^6$

The Thermosphere/ionosphere System

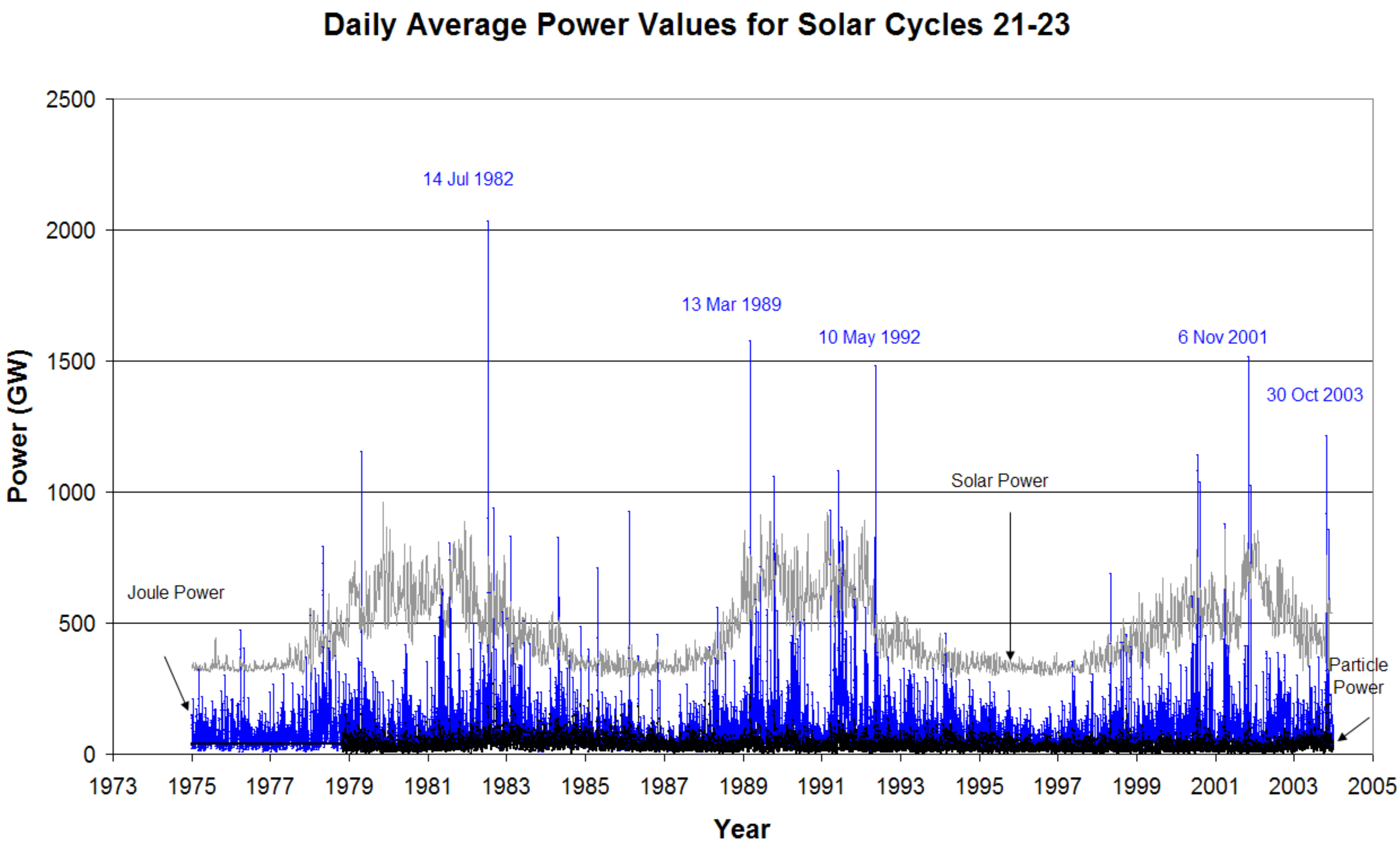


What Drives the Temperature Structure of the Thermosphere



Roble et al., 1987

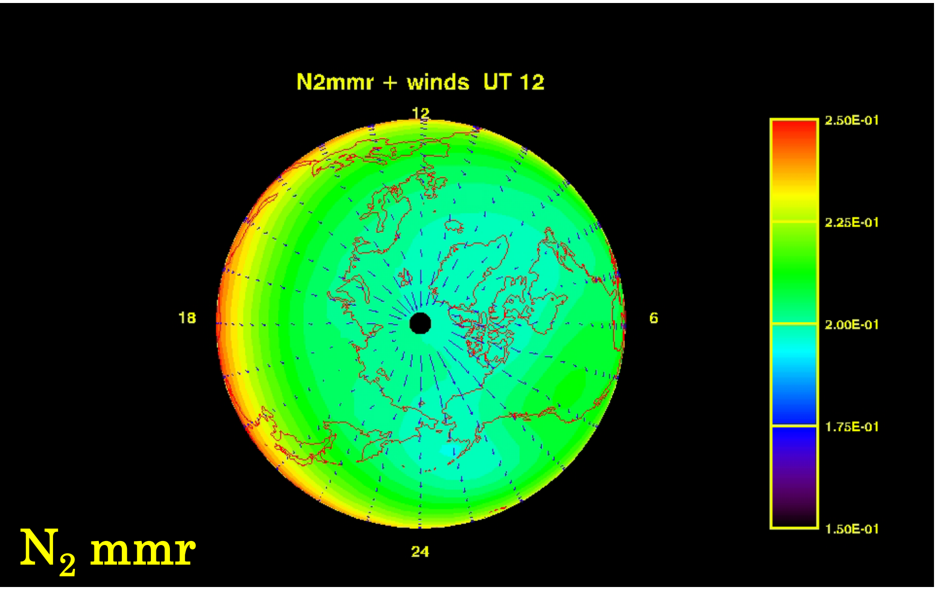
Forcing the Thermosphere

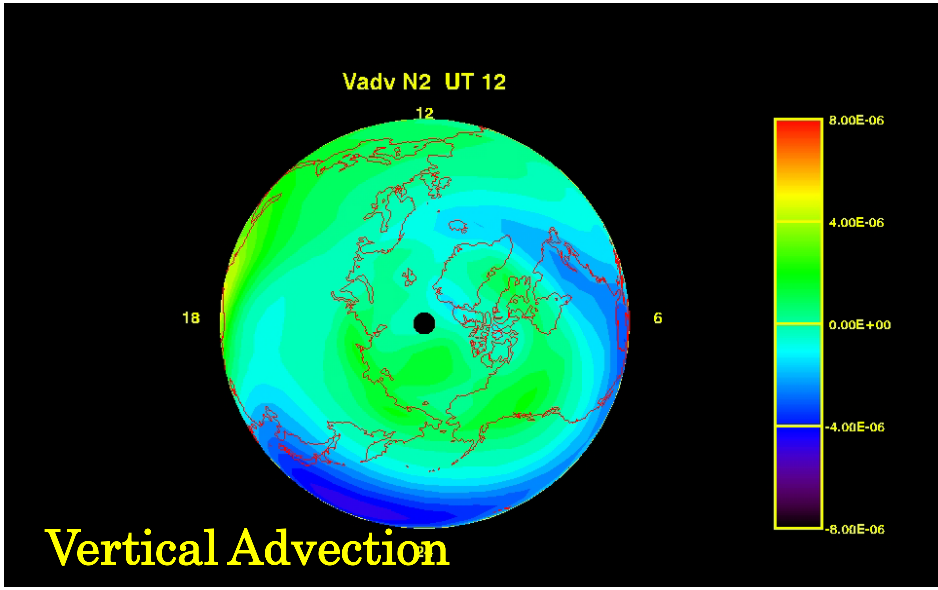


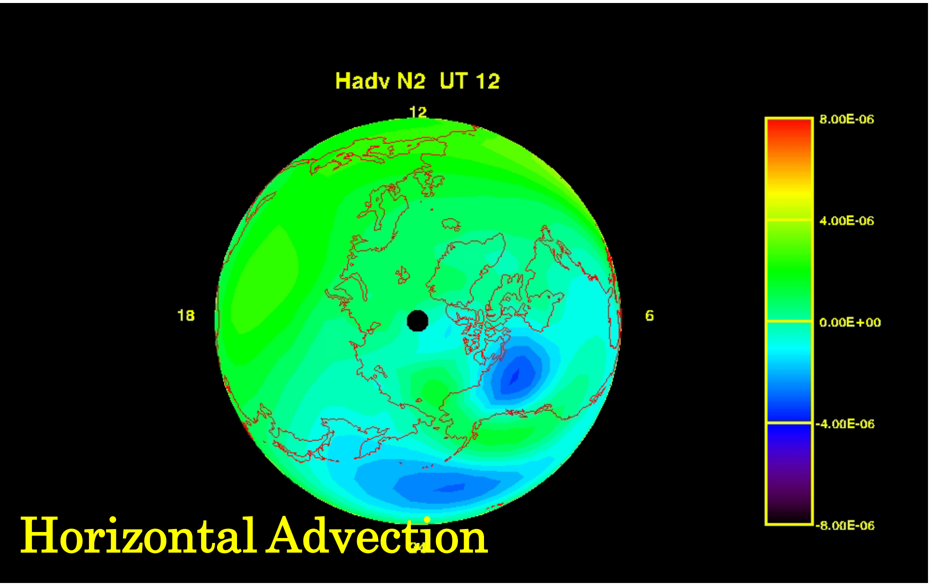
Knipp et al, 2004

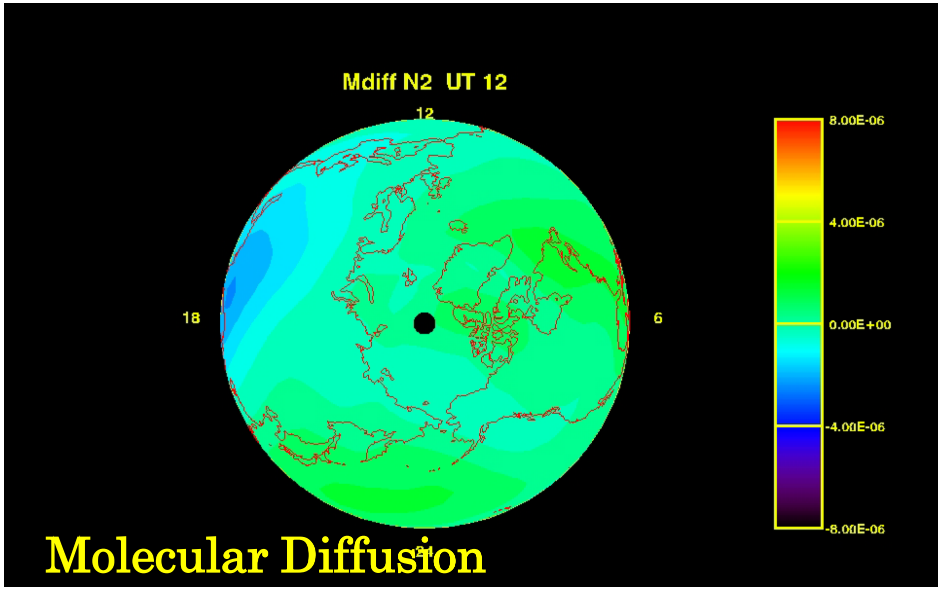
Changes in Major Species Neutral Composition

N_2 mmr and forcing in quiet time

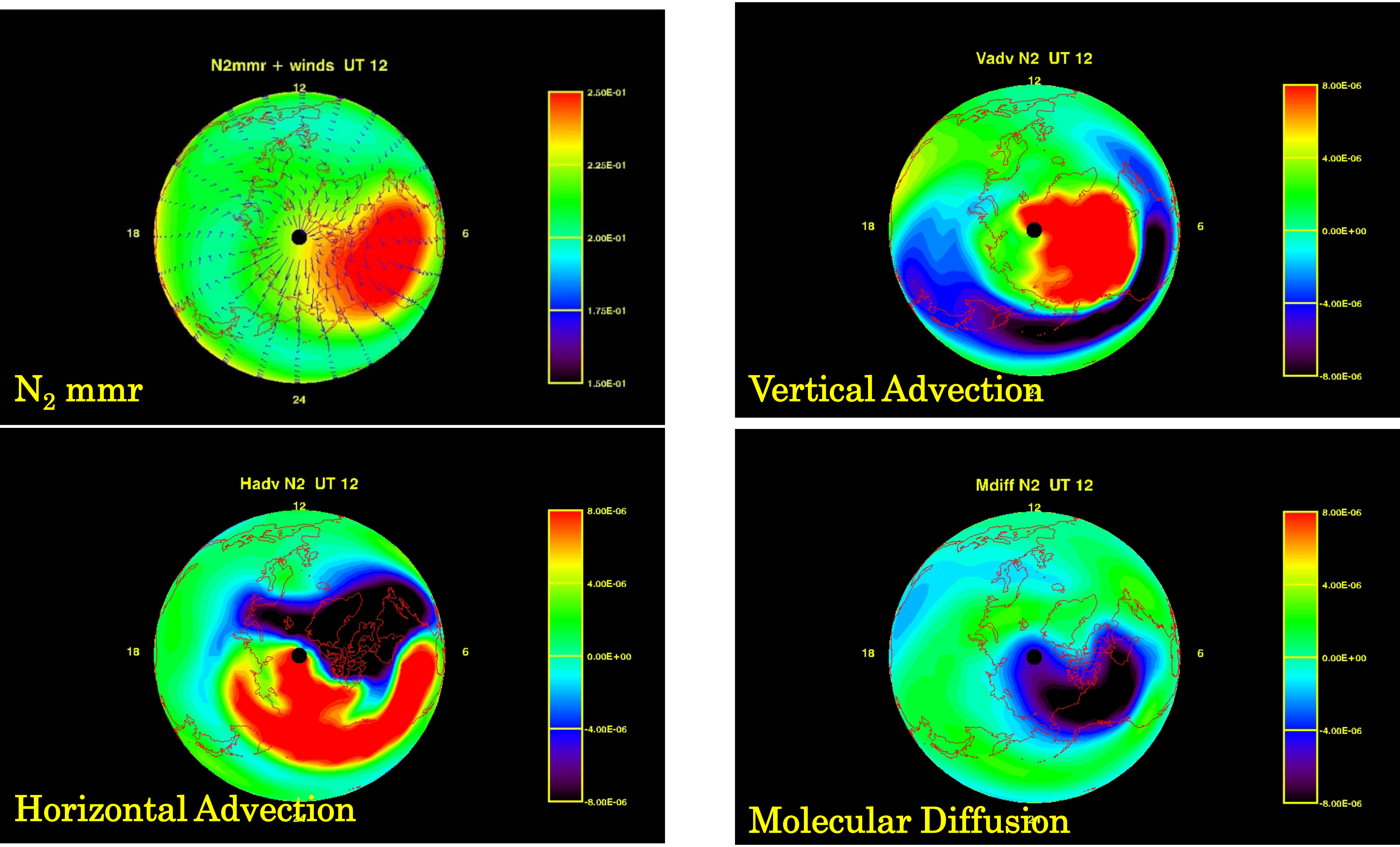




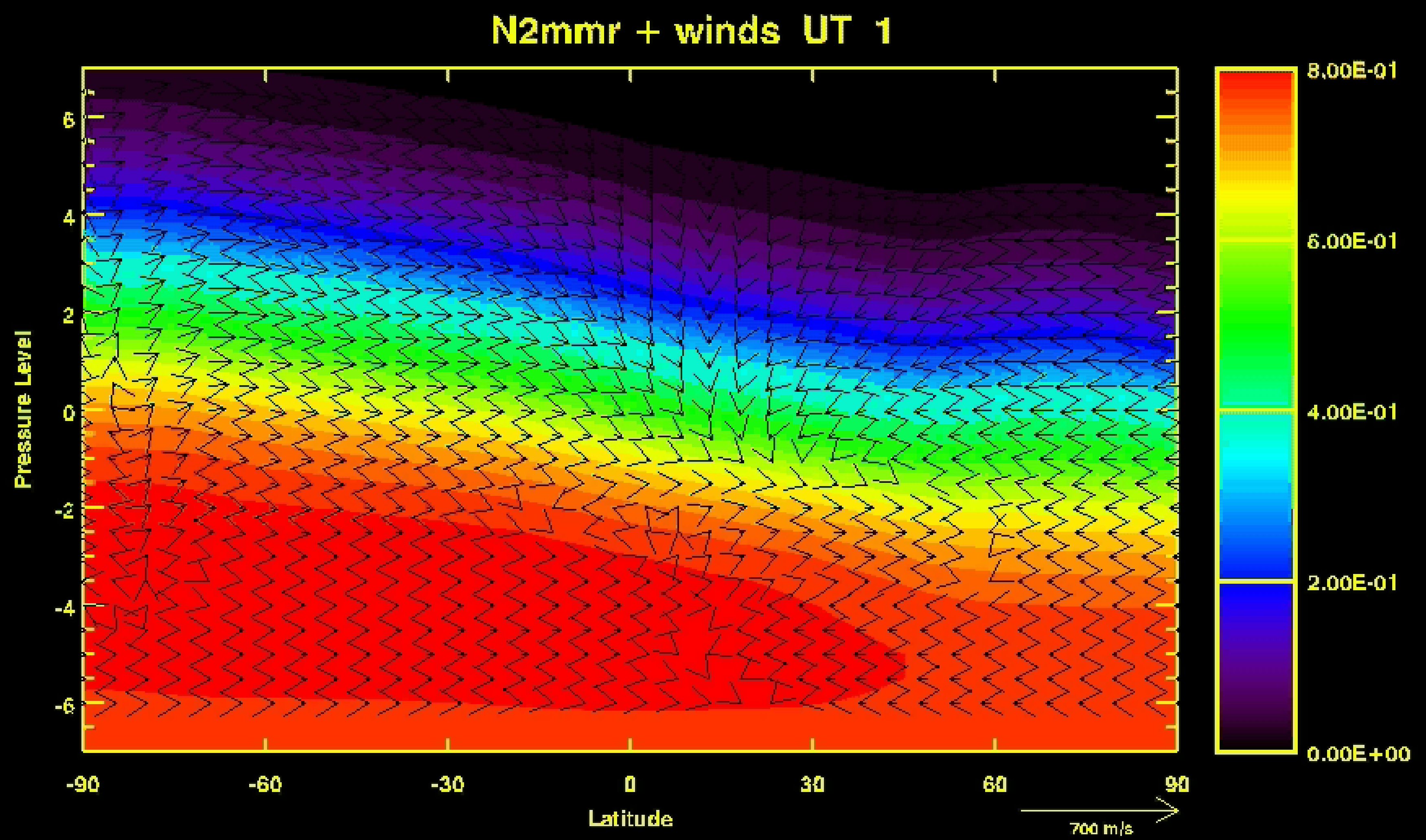




Compositional Forcing (storm)



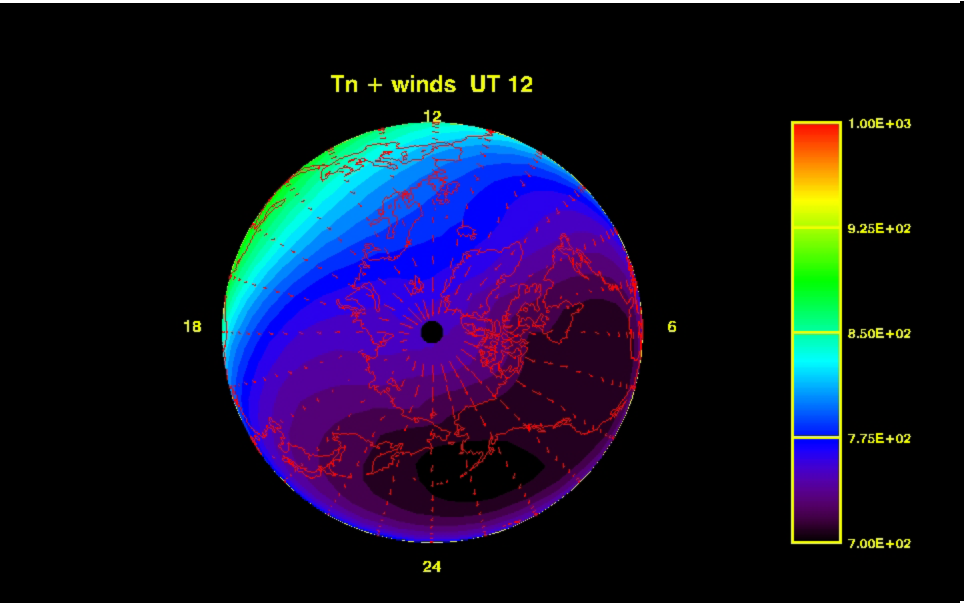
N2mmr movie for a storm



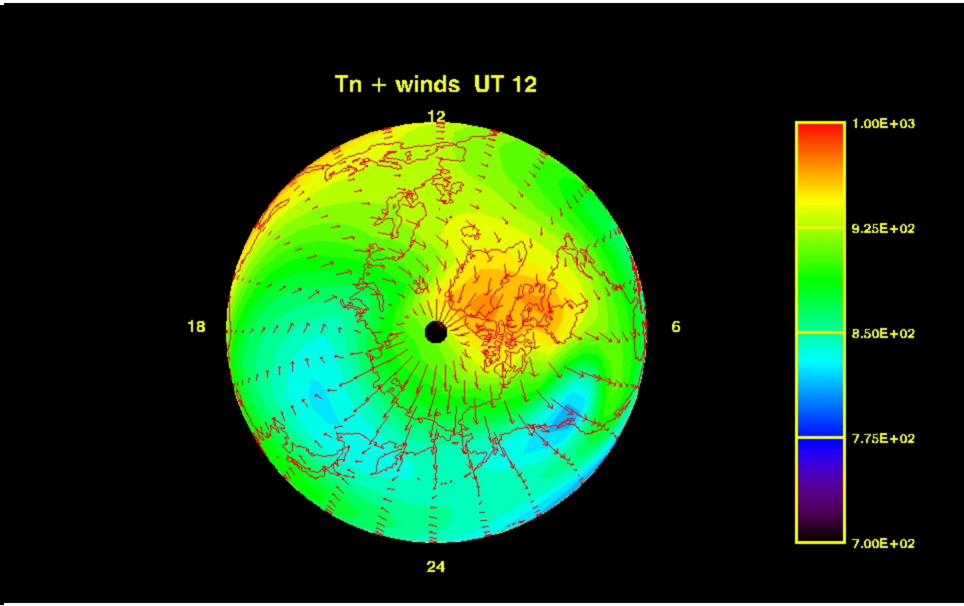
Changes in Neutral Temperatures

Temperature Changes in the Upper Thermosphere during Geomagnetic Storms

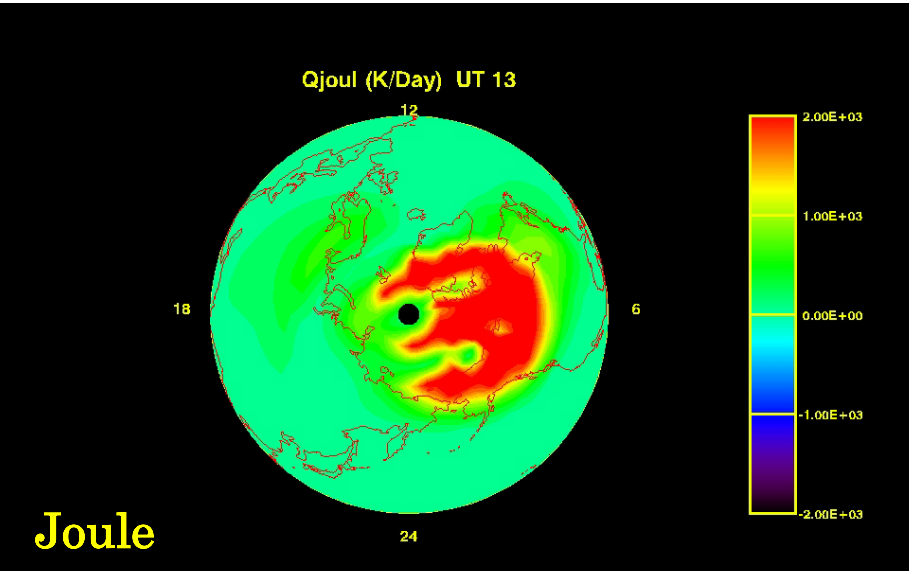
Quiet

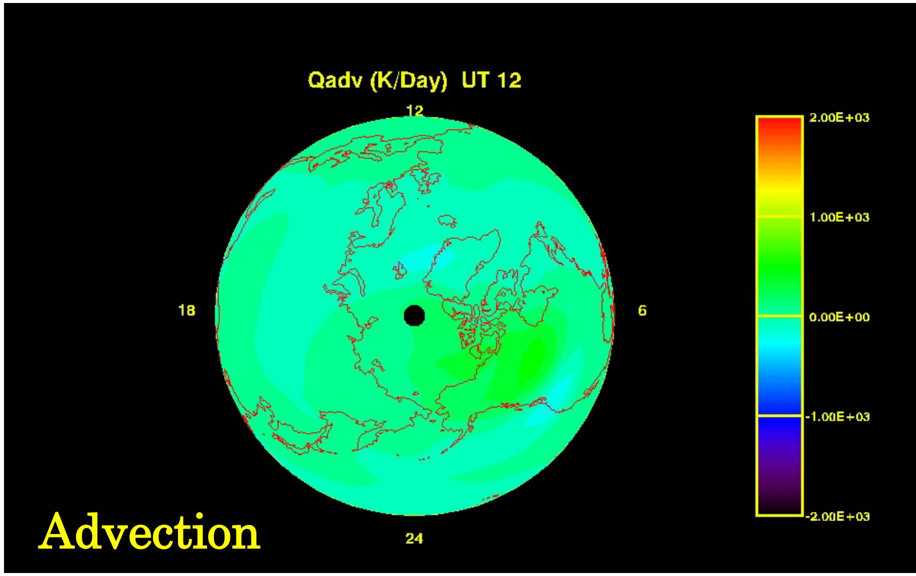


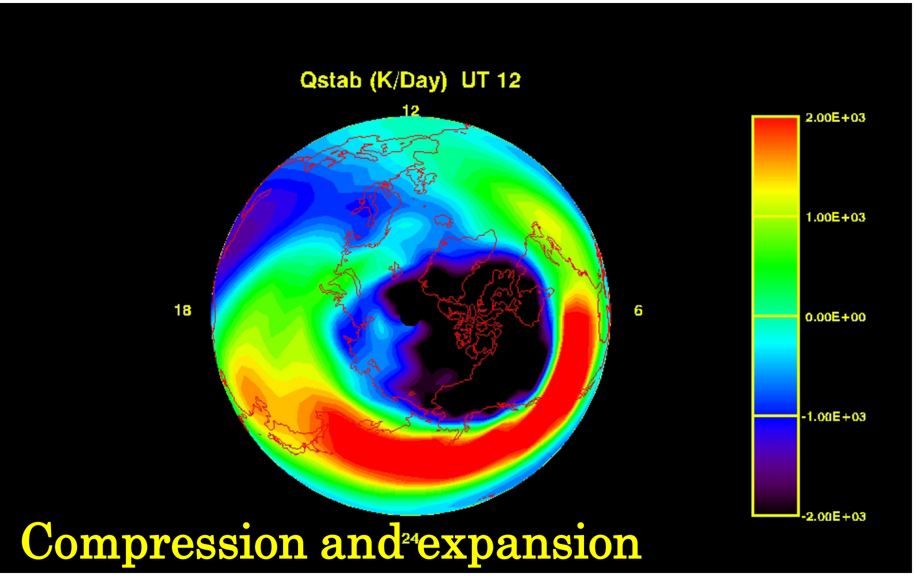
Storm

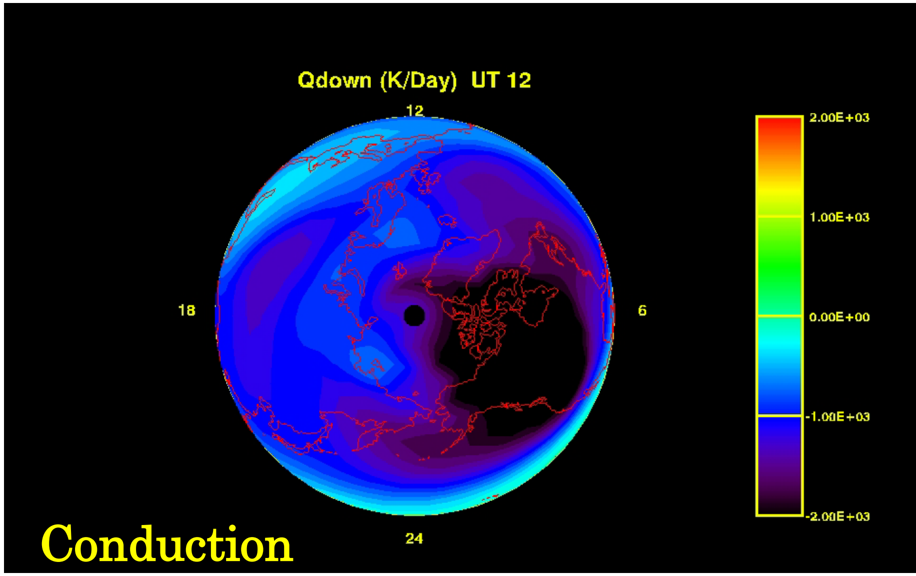


Thermal Storm Forcing (K/Day)

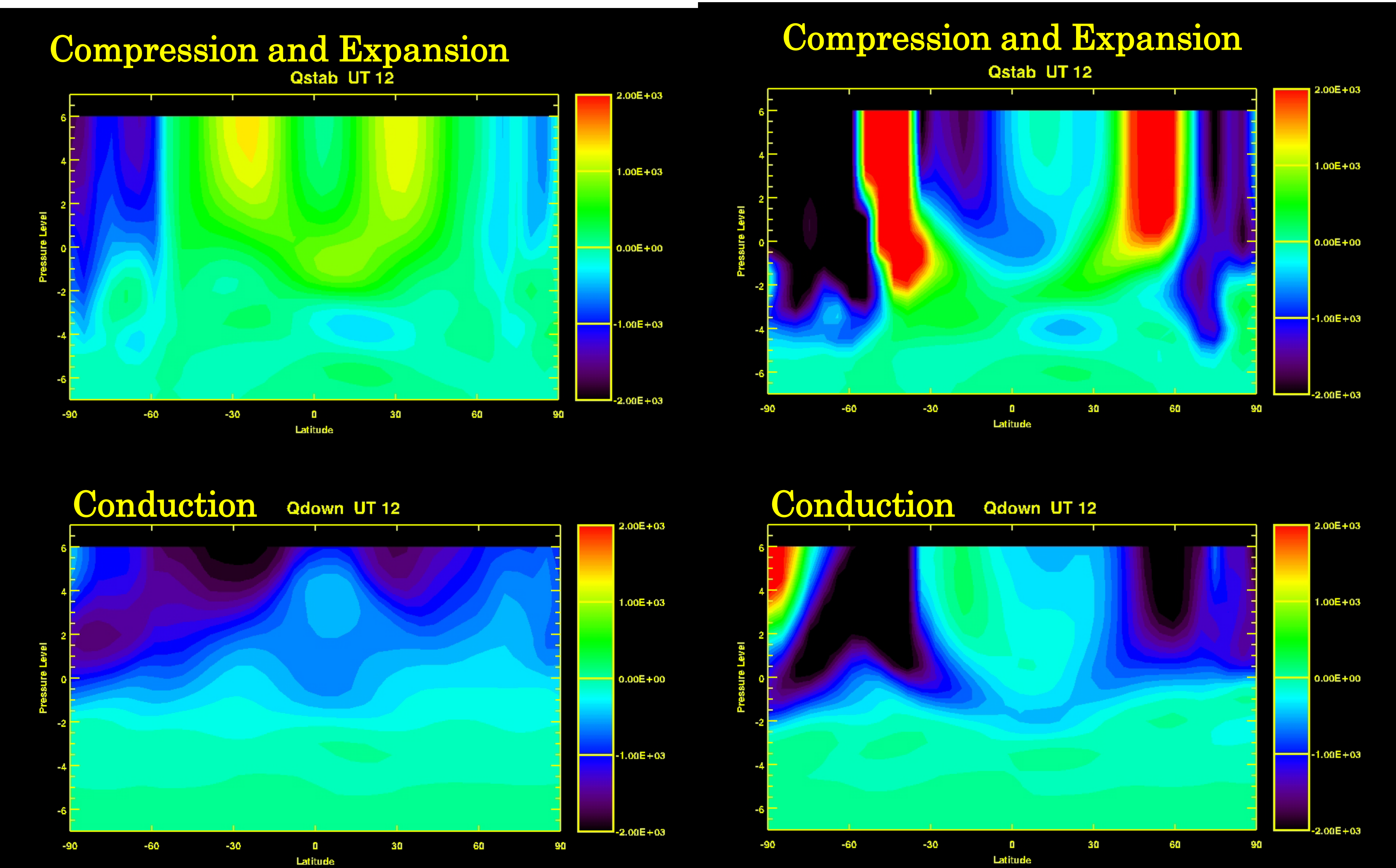






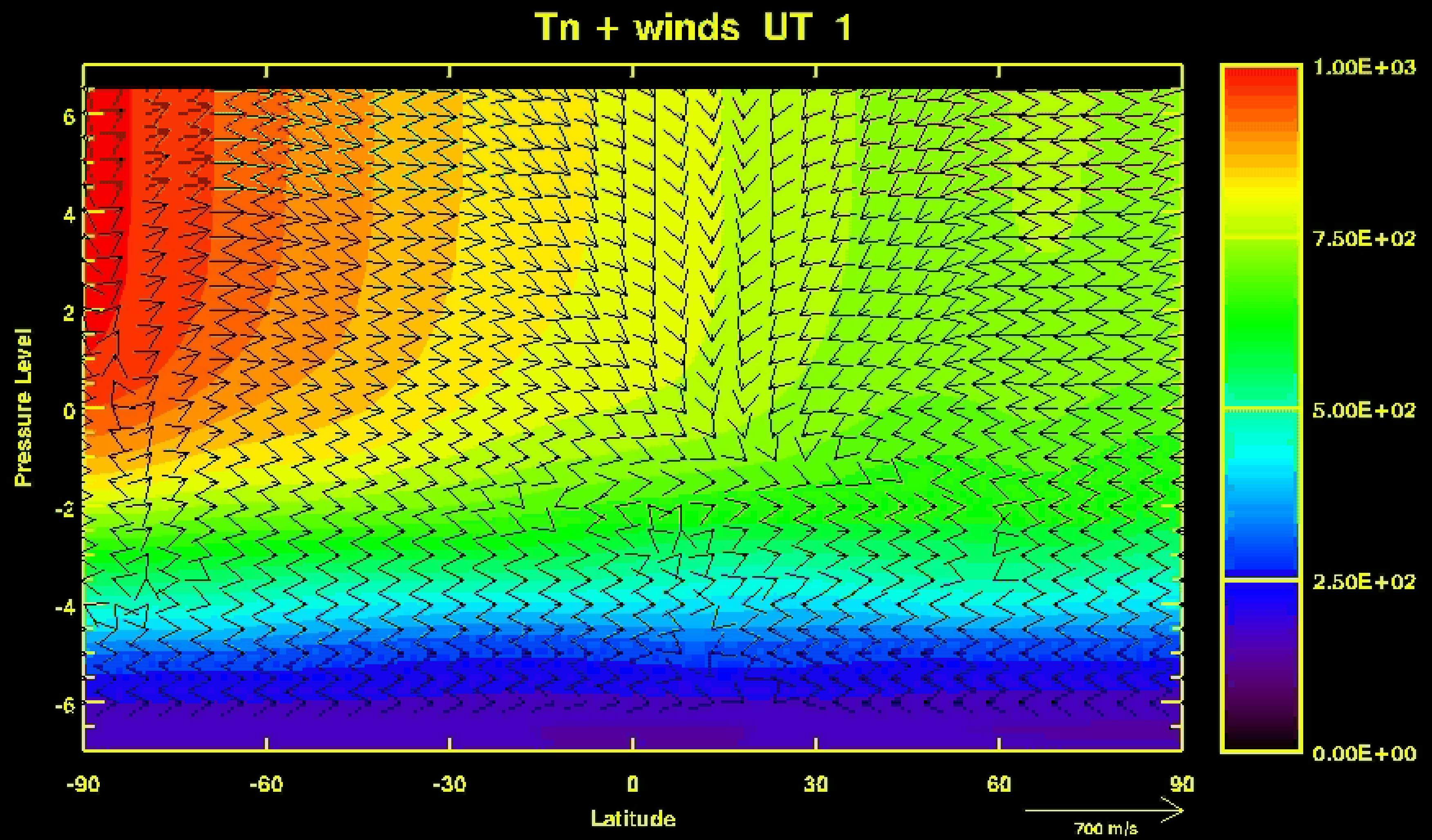


Changes in Low Latitude Thermal Forcing

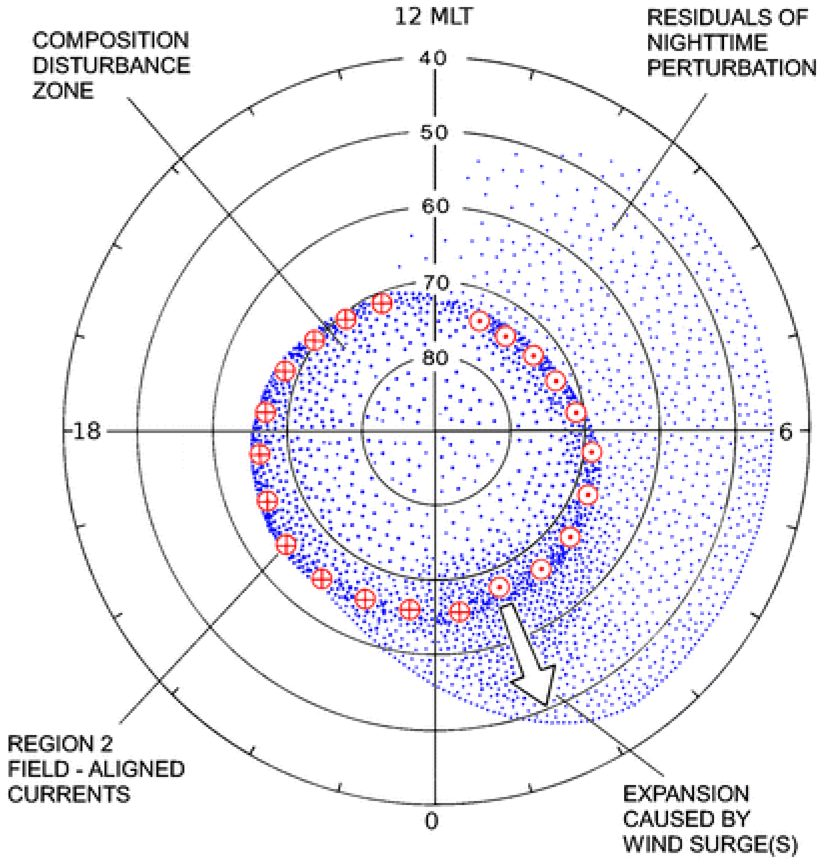


Quiet Storm

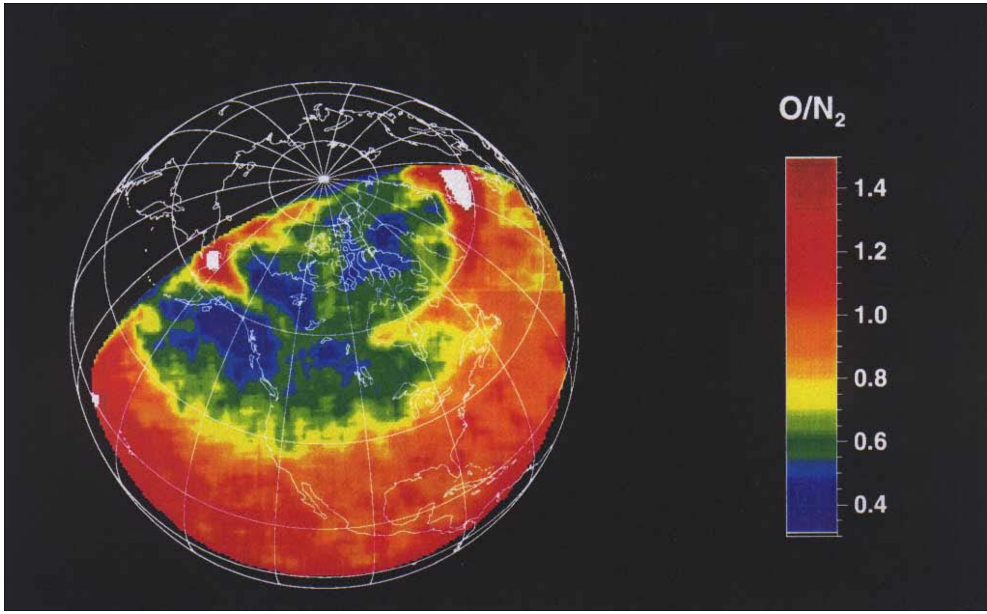
Temperature Evolution during the AGU Storm



Compositional Disturbances During Geomagnetic Storms

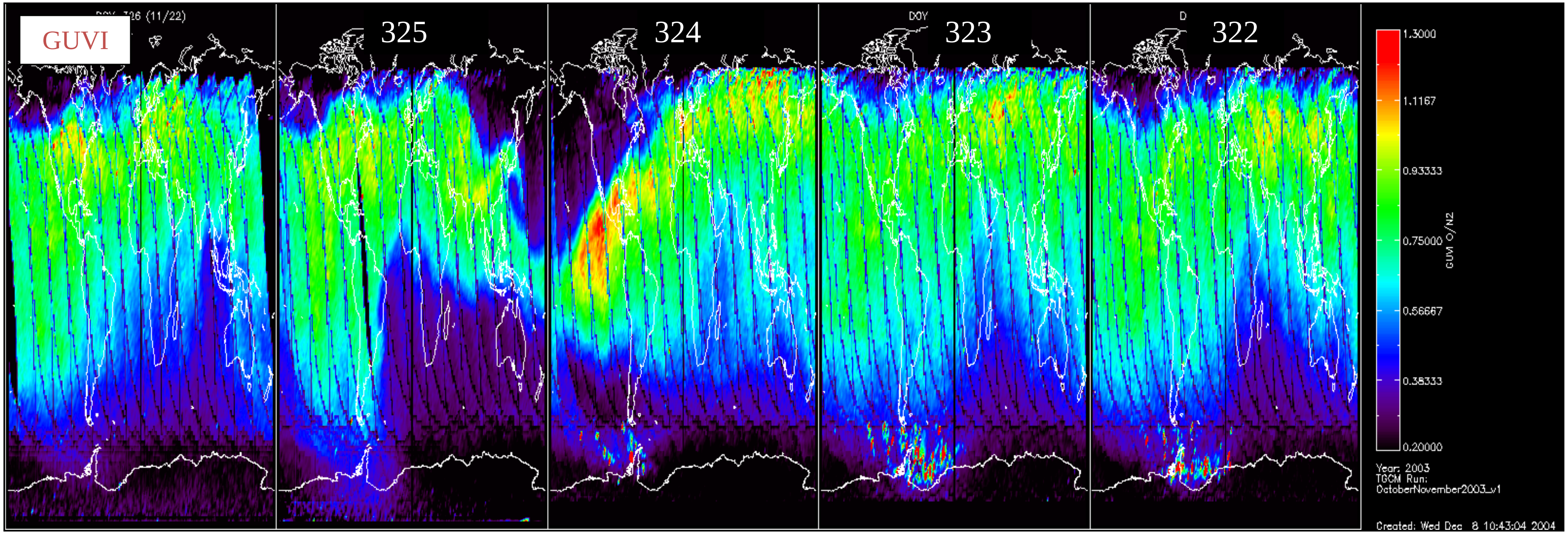


Prolss (1981, 2011)



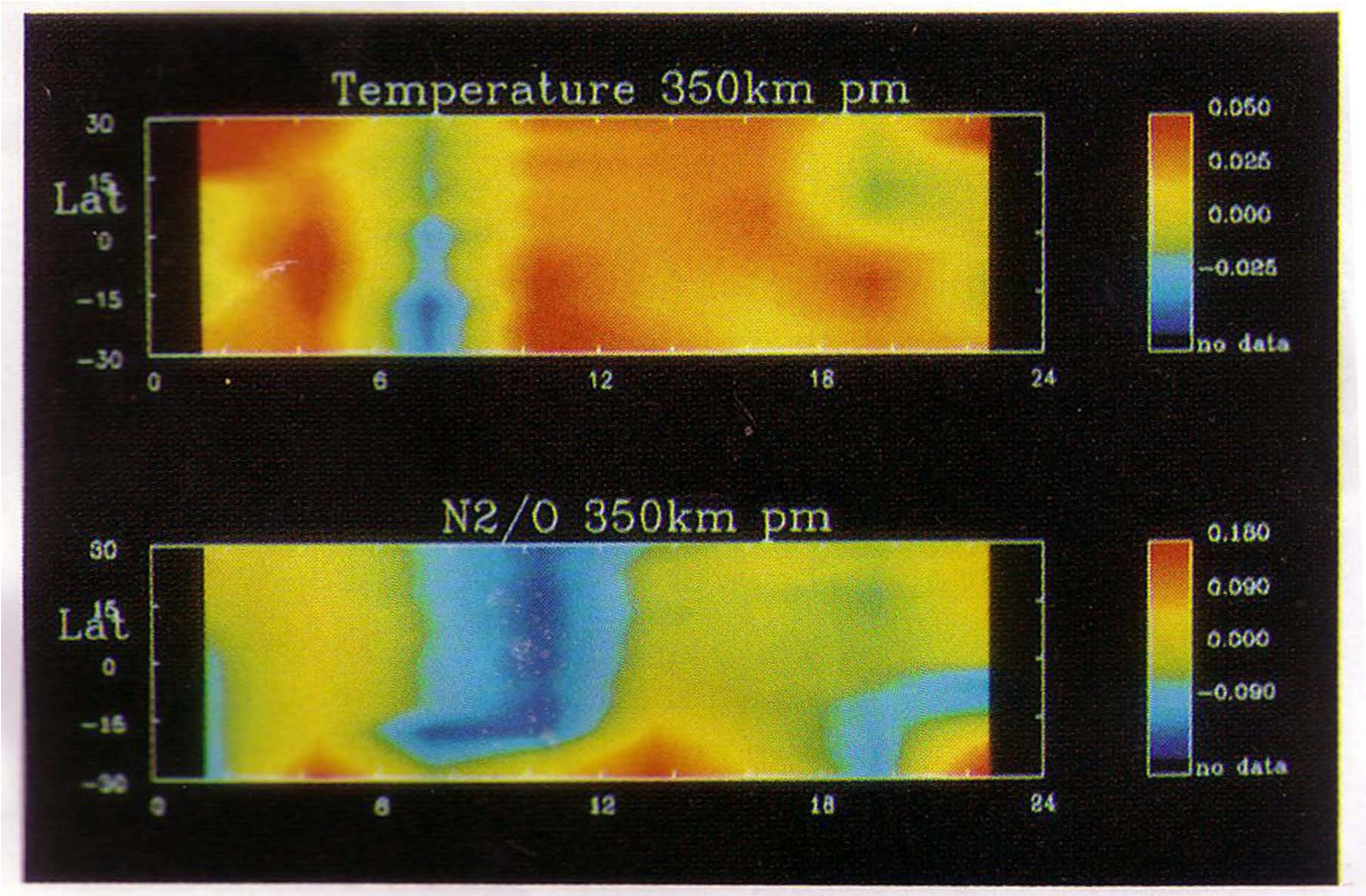
Strickland et al.

Compositional Changes Caused by Storms



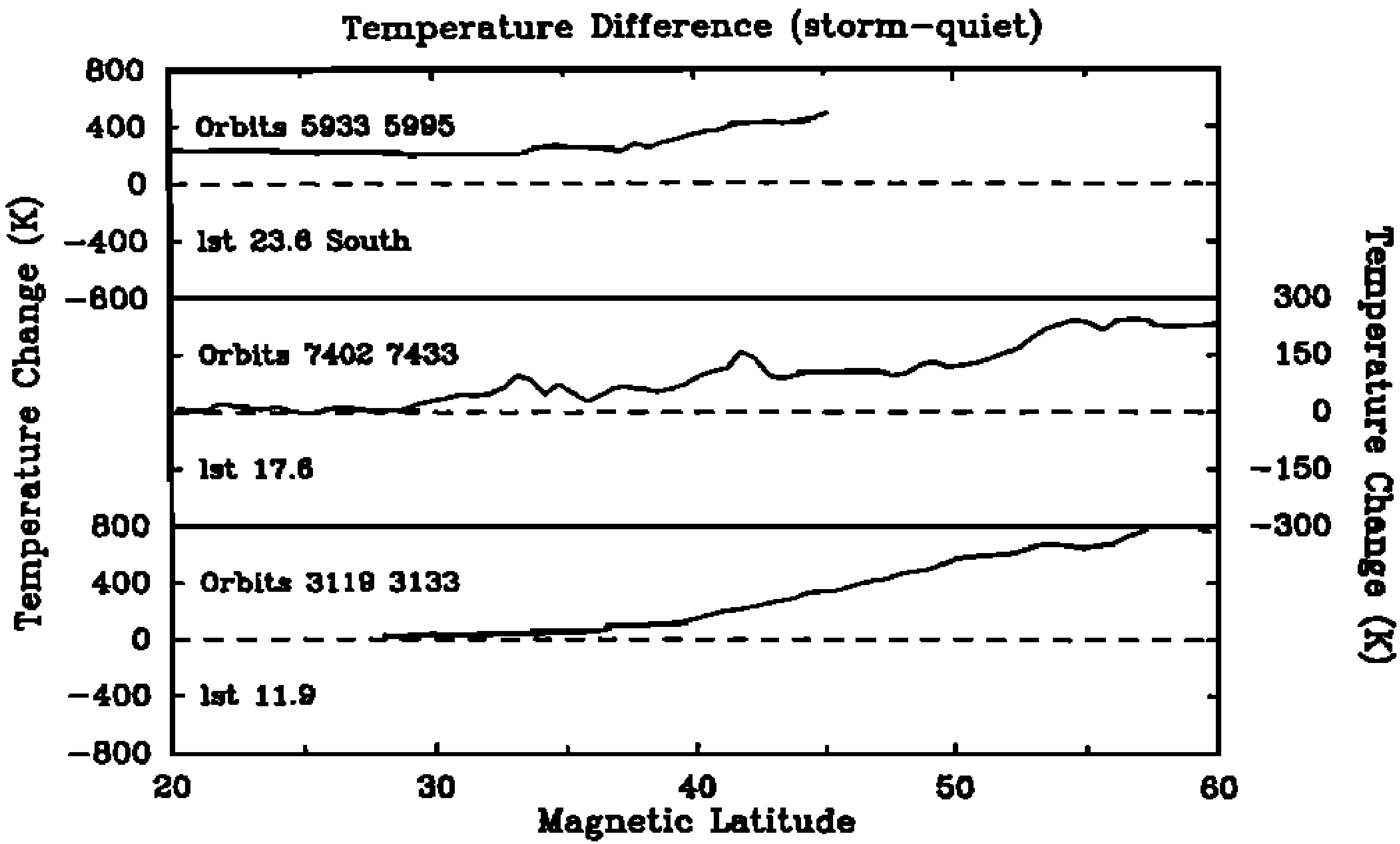
Crowley

Temperature and Composition Changes with Storm Time



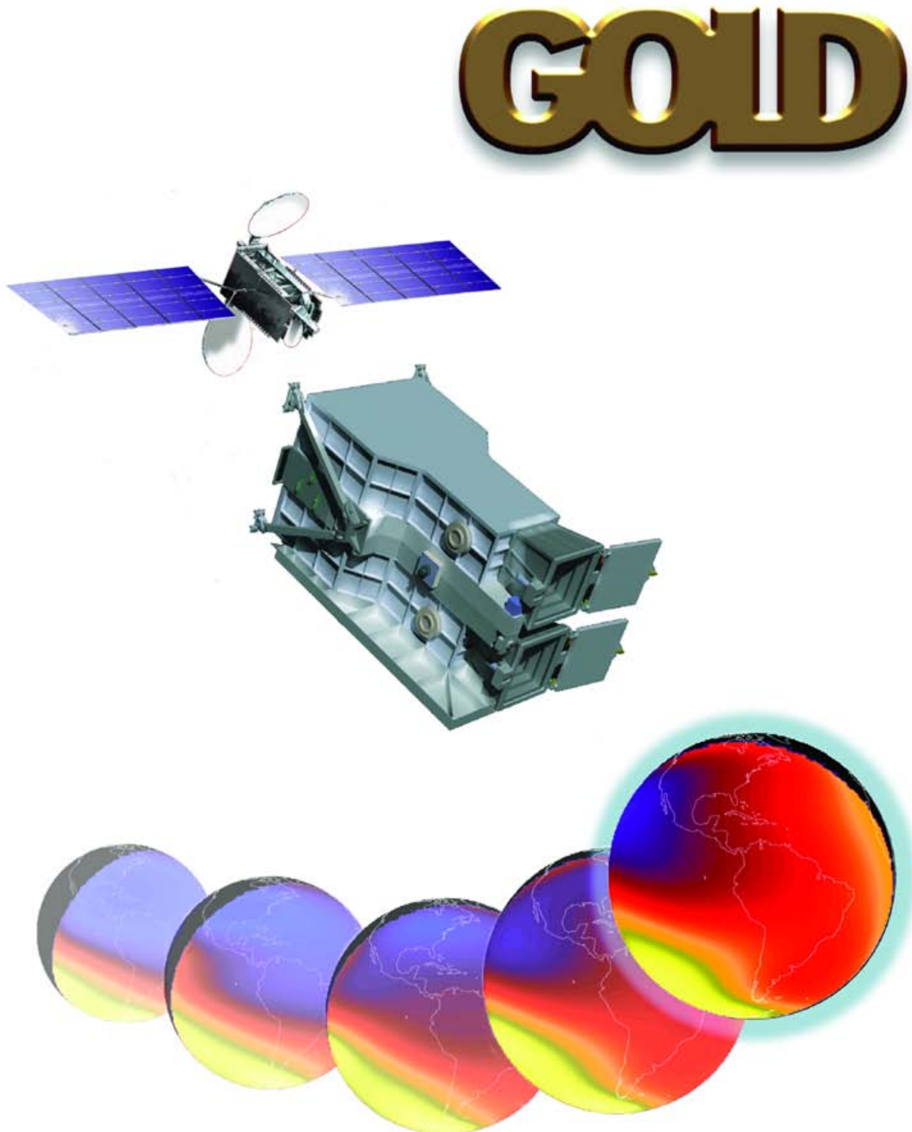
Burns and Killeen, 1992

Temperature Changes (Storm - Quiet)

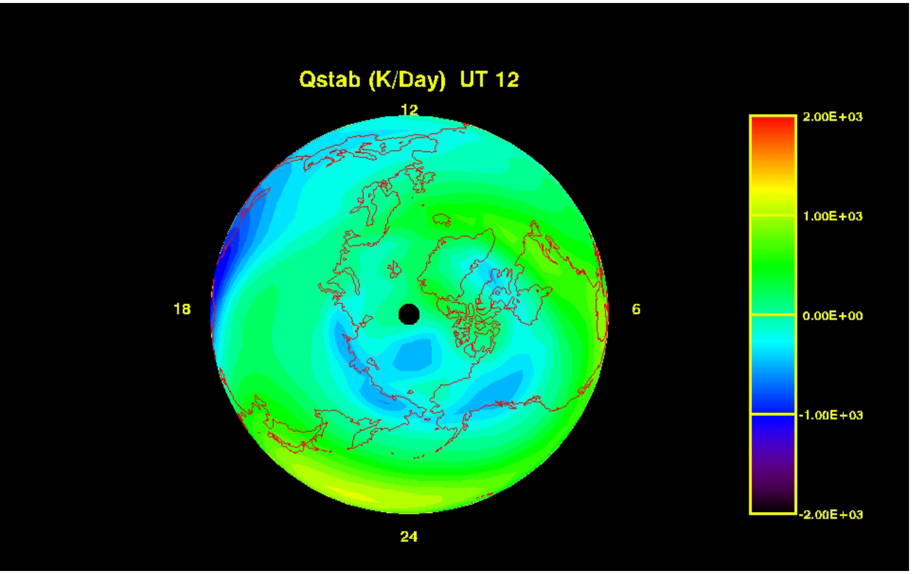


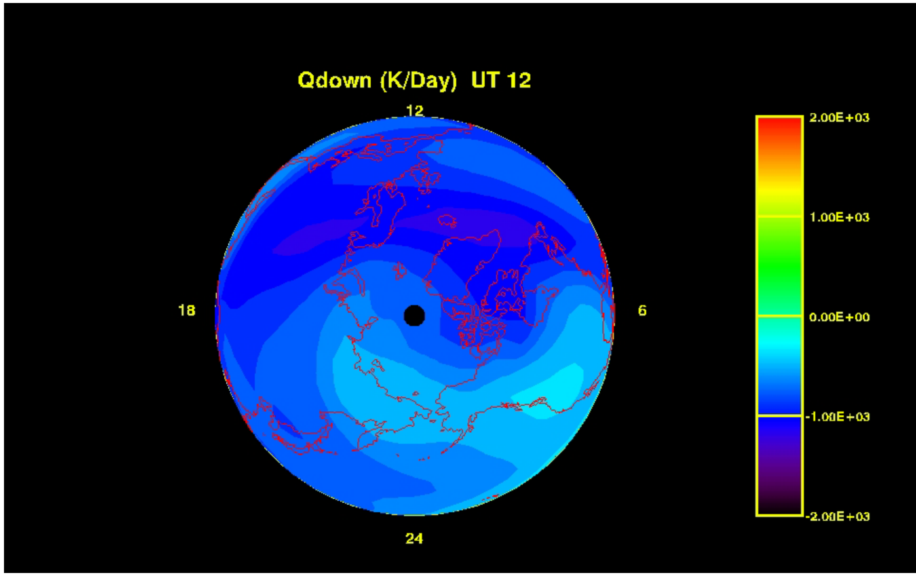
Burns et al., 1995

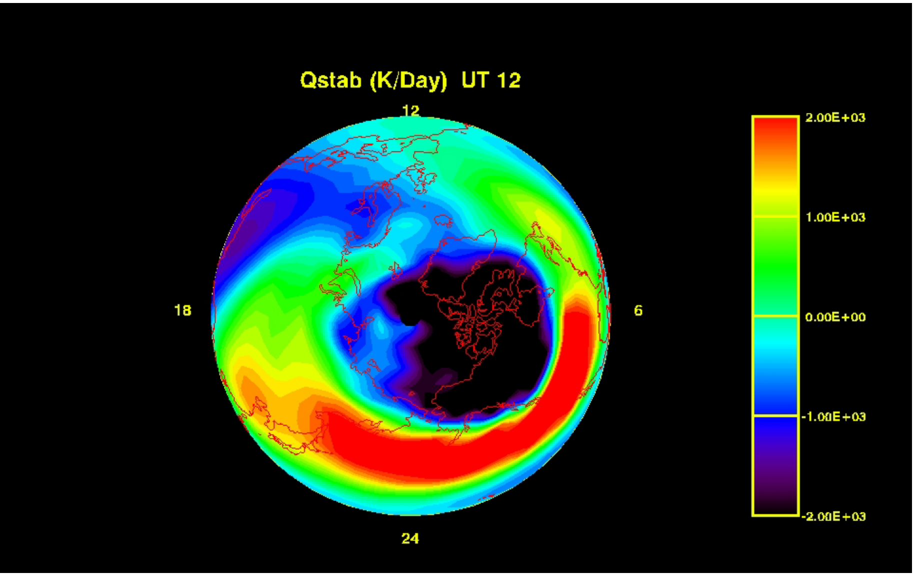
What Measurements do we need to Improve our Models?

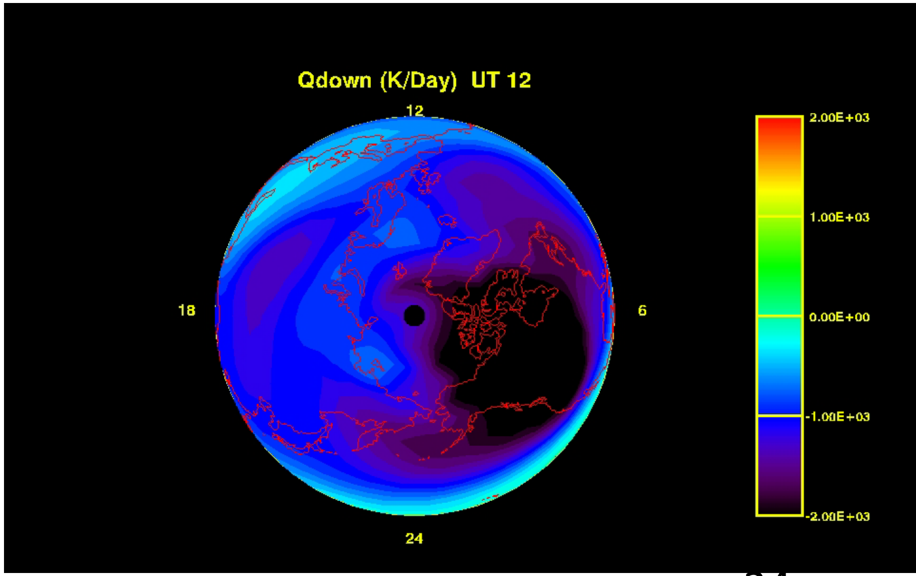


Treat the thermosphere and ionosphere as a global weather system

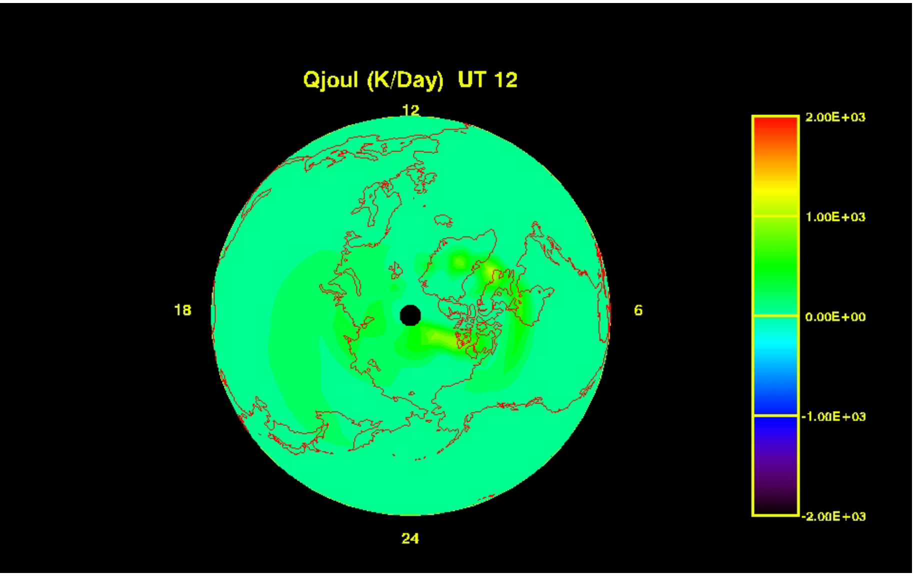

Qstab (K/Day) UT 12
12
18
6
24
2.00E+03
1.00E+03
0.00E+00
-1.00E+03
-2.00E+03

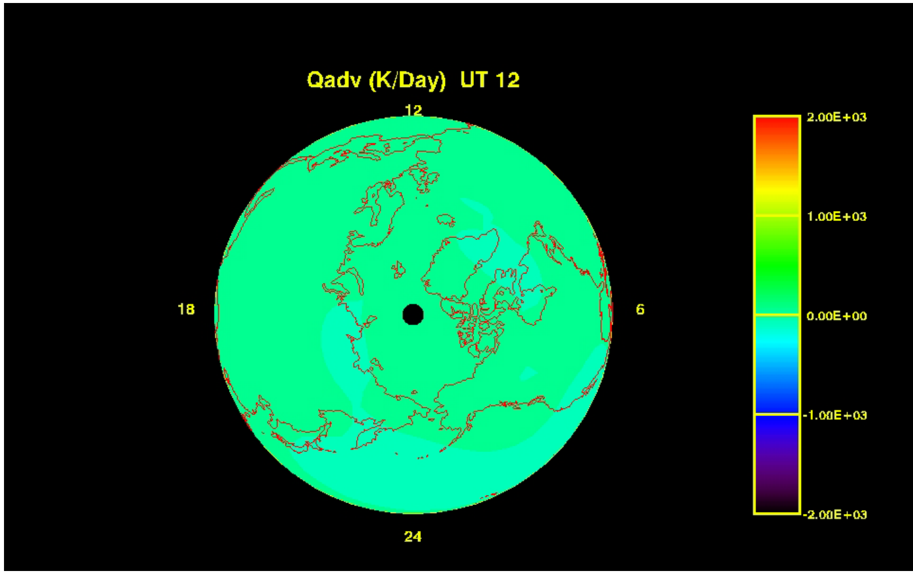

Qdown (K/Day) UT 12
12
18
6
24
2.00E+03
1.00E+03
0.00E+00
-1.00E+03
-2.00E+03

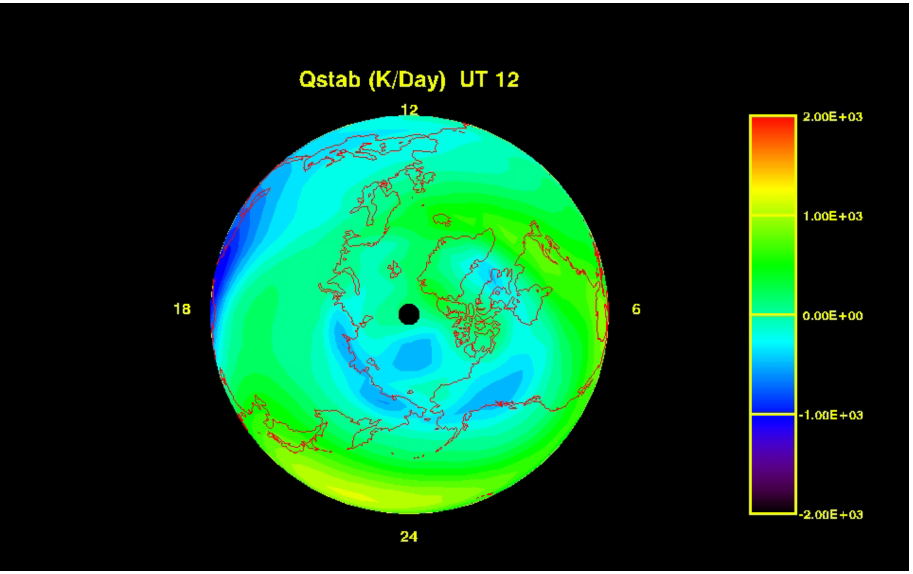

Qstab (K/Day) UT 12
12
18
6
24
2.00E+03
1.00E+03
0.00E+00
-1.00E+03
-2.00E+03

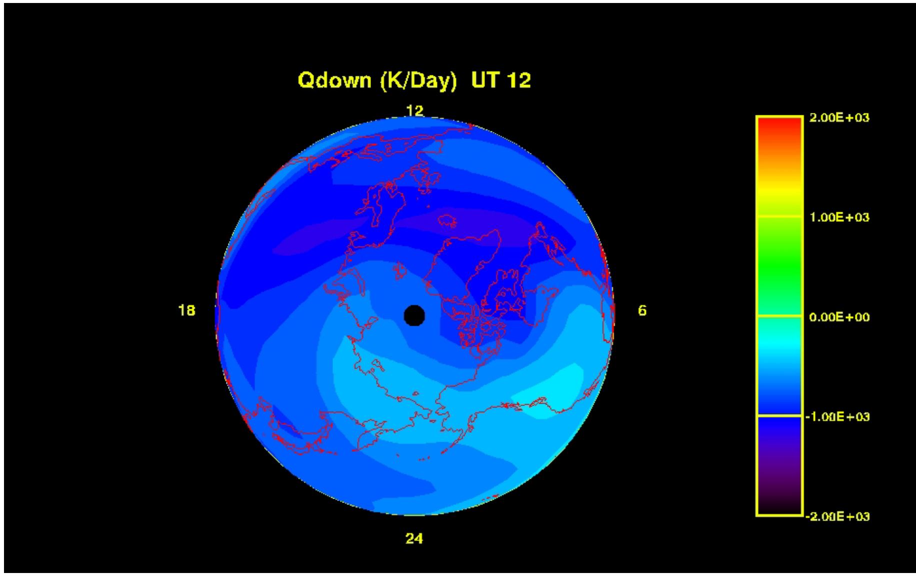

Qdown (K/Day) UT 12
12
18
6
24
2.00E+03
1.00E+03
0.00E+00
-1.00E+03
-2.00E+03

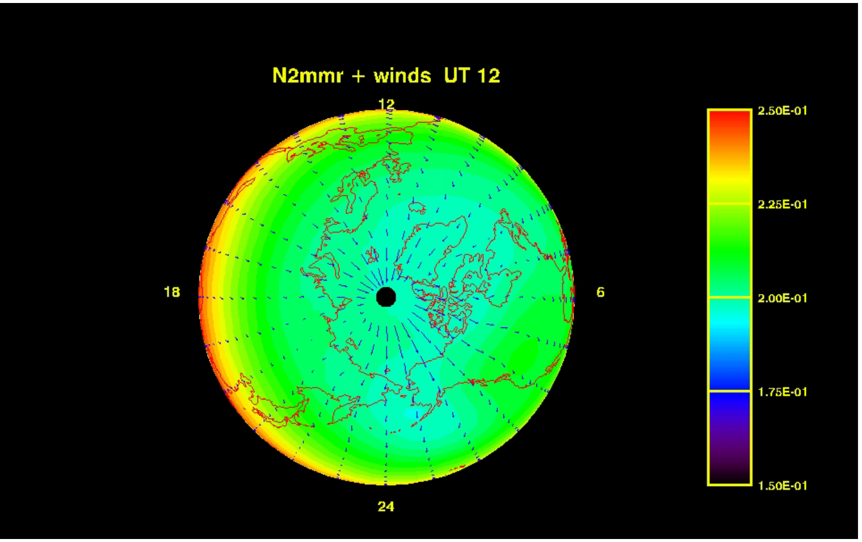
Causes of Temperature Changes

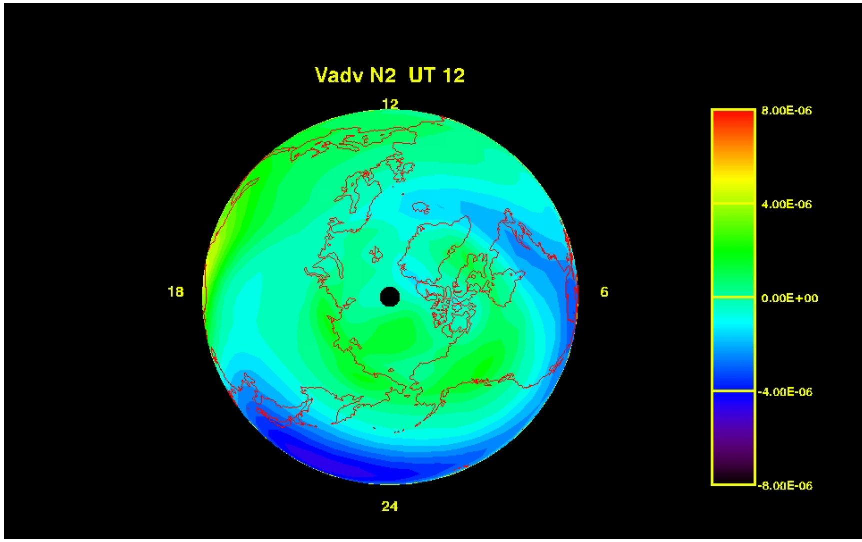


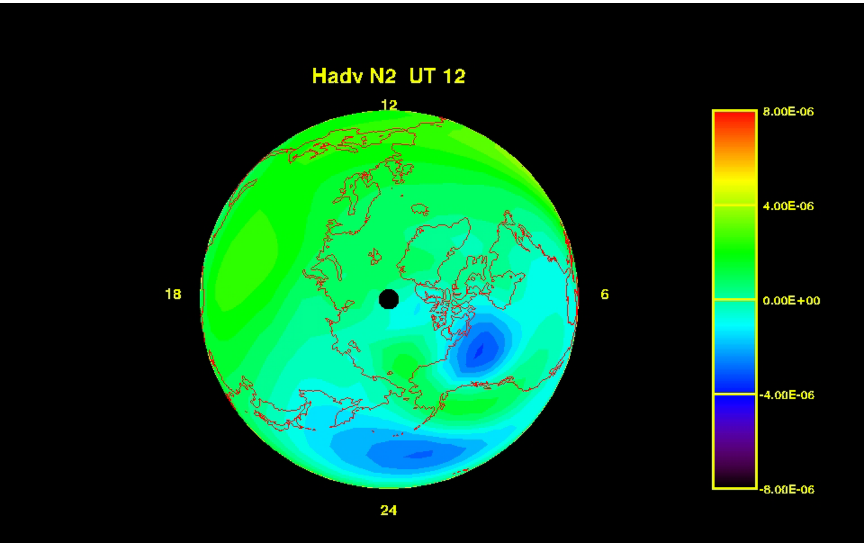


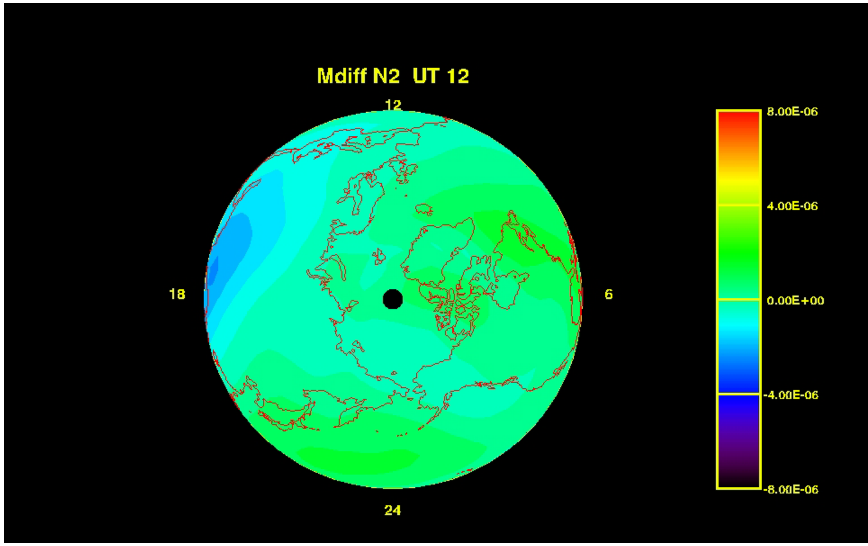


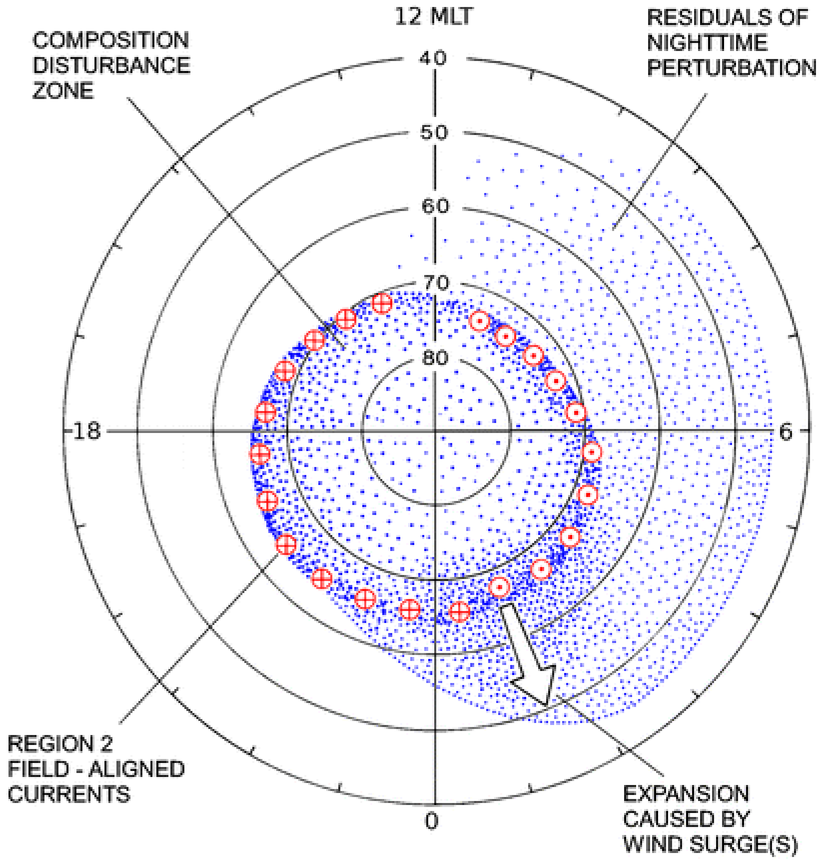


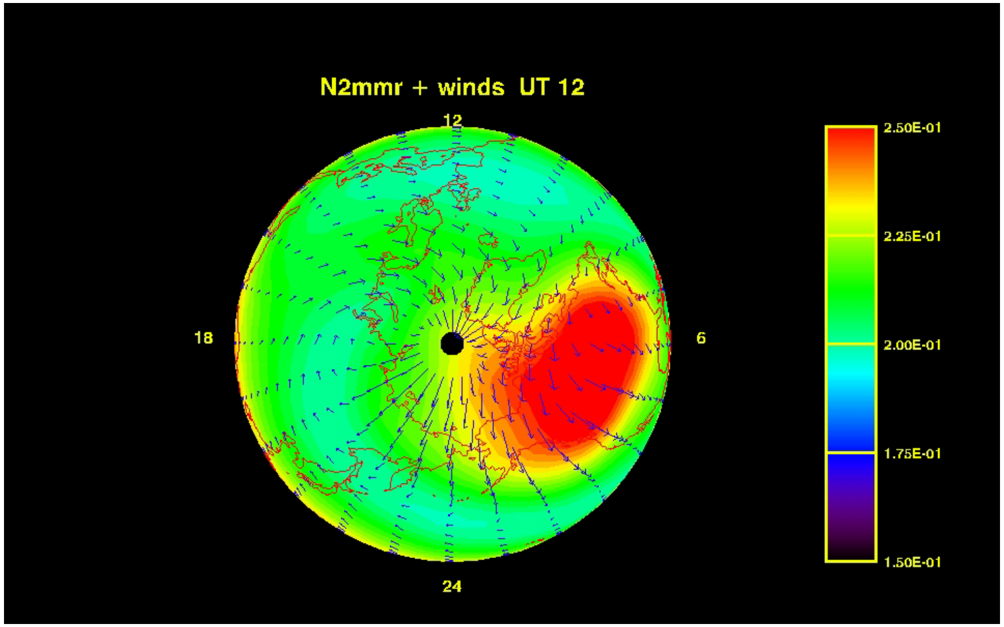

N2mmr + winds UT 12
12
18
6
24
2.50E-01
2.25E-01
2.00E-01
1.75E-01
1.50E-01


Vadv N2 UT 12
12
18
6
24
8.00E-06
4.00E-06
0.00E+00
-4.00E-06
-8.00E-06


Hadv N2 UT 12
12
18
6
24
8.00E-06
4.00E-06
0.00E+00
-4.00E-06
-8.00E-06


Mdiff N2 UT 12
12
18
6
24
8.00E-06
4.00E-06
0.00E+00
-4.00E-06
-8.00E-06





Prolss (1981, 2011)